2010-09

A systems engineering analysis of energy economy options for the DDG-51 class of U.S. Naval ships

Cannon, Joseph

Monterey, California. Naval Postgraduate School

NPS-SE-10-004

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships:

Joseph Cannon
Vesmiene Ceasor
Fernando Escobar
Gloria Huapaya
William Jones
Deepak Kumar
Eric Lavetti
Stephen Lucero
Anthony Nguyen
Vinnie Picicci
Shirlean Todd
David Toth

September 2010

Approved for public release; distribution is unlimited

Prepared for: Naval Postgraduate School

THIS PAGE INTENTIONALLY LEFT BLANK

NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943-5000

Daniel T. Oliver
President

Leonard A. Ferrari
Provost

This report was prepared for the Chairman of the Systems Engineering Department in partial fulfillment of the requirements for the degree of Master of Science in Systems Engineering.

This report was prepared by the Master of Science in Systems Engineering (MSSE) Cohort 311-912 under the direction of the Naval Postgraduate School, Department of Systems Engineering, Monterey, CA.

Submitted by:

Joseph Cannon
Vesmiene Ceasor
Fernando Escobar
Gloria Huapaya
William Jones
Deepak Kumar
Eric Lavetti
Stephen Lucero
Anthony Nguyen
Vinnie Picicci
Shirlean Todd
David Toth

Reviewed by:

____
DAVID H. OLWELL
311-912 Capstone Project Advisor

____
KRISTIN M. GIAMMARCO
311-912 Capstone Project Advisor

Accepted by:

____
CLIFFORD A. WHITCOMB
Systems Engineering Department Chair

Released by:

____
KARL A. VAN BIBBER
Vice President & Dean of Research

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
September 2010	Technical Report	

4. TITLE AND SUBTITLE
A Systems Engineering Analysis of Energy Economy Options for DDG-51 Class of U.S. Naval Ships

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Cannon, J., Ceasor, V., Escobar, F., Huapaya, G., Jones, W., Kumar, D., Lavetti, E., Lucero, S., Nguyen, A., Picicci, V., Todd, S., Toth, D.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

NPS-SE-10-004

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

N/A

10. SPONSOR/MONITOR'S ACRONYM(S)

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

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
The view expressed in this report are those of the authors and do not reflect the official policy or position of the Department of Defense of the U.S. Government.

14. ABSTRACT
The Secretary of the Navy (SECNAV) has identified an ambitious set of goals for the Navy's energy programs. The authors addressed Department of the Navy (DoN) energy surety, economy, and ecology goals, scoped the problem to focus on the economy aspect of the DoN's energy goal, and further bounded the analysis to energy economy of the DDG-51 class of surface combatants which appeared to be an area with potentially high return on investment. We determined that if energy was conserved or better utilized then the triad of SECNAV goals for energy surety, economy and ecology was positively addressed. This report documents a method to assess energy consumption that could be used to make trade-offs for current and future ships. Eight subsystems, along with fuel type, were researched for alternative solutions, with eight of nine subsystem alternatives resulting as "more cost effective." By implementing the optimal recommendations from our team findings and using the fully burdened cost of fuel, we estimate that the DDG-51 program could save $1.9M per year per ship. For a fleet of 50 ships, this translates to a savings of $950M over ten years.

15. SUBJECT TERMS
Energy Conservation, Housekeeping Loads, Green Fleet, Energy Systems Analysis.

16. SECURITY CLASSIFICATION OF: Unclassified			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
Unclassified	Unclassified	Unclassified	UU	290	

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

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The SECNAV has identified an ambitious set of goals for the Navy's energy programs. The authors addressed DoN energy surety, economy, and ecology goals, scoped the problem to focus on the economy aspect of the DoN's energy goal, and further bounded the analysis to energy economy of the DDG-51 class of surface combatants which appeared to be an area with potentially high return on investment. The team determined that if energy was conserved or better utilized then the triad of SECNAV goals for energy surety, economy and ecology was positively addressed. This report documents a method to assess energy consumption that could be used to make trade-offs for current and future ships. Eight subsystems, along with fuel type, were researched for alternative solutions, with eight of nine subsystem alternatives resulting as "more cost effective." By implementing the optimal recommendations from our team findings and using the fully burdened cost of fuel, we estimate that the DDG-51 program could save \$1.9M per year per ship. For a fleet of 50 ships, this translates to a savings of \$950M over ten years.

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGEMENT

The proponents would like to extend their gratitude and acknowledge the help received from the following individuals that enabled the success of this thesis.

First of all, thanks to all of the students' families, who through their full support, patience and encouragement, provided the students inspiration to continue working diligently each and every quarter of this program.

Thanks to our advisors, Dr. David Olwell and Professor Kristin Giammarco, and our Capstone Proofreader, Professor Mary Vizzini, for their guidance and perseverance in ensuring that the Capstone team provided a quality product. They saw to it that our product was reflective of the Naval Postgraduate School mission: high quality, relevant and unique advanced education and research programs that increase the combat effectiveness of the Naval Services, other Armed Forces of the U.S. and our partners, to enhance our national security.

Also, thanks to all the individuals from NAVFAC with special thanks to Captain Ricky Williamson, USN Commanding Officer, Naval Base San Diego, Commander Vincent Garcia, USN Executive Officer, Naval Base San Diego, Commander Jordy Harrison, Commanding Officer, USS HALSEY DDG-97, Lieutenant Bryan Schneider, USN Engineering Officer, USS HALSEY DDG-97, Mr. Stanley A. Walker, CEM Shipboard Resource Efficiency Manager, Tetra Tech EM Inc., Mr. Charles Crossan, CEM Lead Shipboard Resource Efficiency Manager-Tetra Tech EM Inc., Mrs. Whinny Smith of Smitty's Laundromat Service (Ferriday, La), Mr. Jerry Johnson of Jerry's Plumbing Service, Pascagoula MS, and Mr. Chuck Rozanski, DDG-1000 Principal for Safety at Naval Surface Warfare Center, Division Carderock, who dedicated a significant amount of their time and support for the research team allowing us the opportunity to collect all the data necessary to baseline our research. Without their support our Capstone team would not have been able to move forward with confidence based on hard data and expert opinion.

Last but not least, thanks to our stakeholders who responded to our survey and provided advice at interim reviews, Richard Griggel, NSWC Carderock, Dave Gilbert, Surface Warfare Development Group, and Fred Tsao, NAVSEA 05, their inputs and willingness to share their years of knowledge in support of the different phases for this research was tremendous.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

The U.S. Navy is taking significant steps to insure that Fleet and land-based Maritime Operations Centers (MOC) have the adequate, clean, and affordable energy necessary to carry out their missions. The Department of the Navy (DoN), as stated in the SECNAV 2009 DoN Energy Strategy,[1] has aggressive goals to increase combat effectiveness by seeking energy programs that increase tactical and shore energy security while reducing the Navy's carbon footprint. The strategic plan suggests that these goals will be achieved in the near to long term by establishing energy conservation best practices, by optimizing energy usage in existing platforms, by leveraging new technologies, and by the increasing utilization of reliable and renewable energy sources.

These programs have become priorities under the leadership of SECNAV, Hon. Ray Mabus, who has targeted fielding a green strike group by 2012 and deploying one by 2016. The reduction in energy consumption for Naval Operations will play a major role in restructuring the Naval ship inventory, retrofitting, and producing alternative energy sources for a more fuel efficient fleet. To add to this complex problem, the SECNAV has mandated the reduction of the Navy's carbon footprint and a balance must be achieved between a triad (surety, economy, and ecology) of competing concerns.

The Naval community has made initial efforts to reduce energy usage through the Incentivized Energy Conservation Program. Retrofitting existing ships with more energy efficient technologies will require considerable further investment in research and implementation. The Navy has already deployed an efficient auxiliary propulsion system on the USS MAKIN ISLAND and is making additional strategic investments for DDG-51 Class ships.

Students at the Naval Postgraduate School (NPS) chose an energy research topic resulting in the development of this Capstone Project entitled "*A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships.*" Students approached this as a systems engineering problem that could be broken down into several distinct subsystems each capable of contributing to the conservation of energy issue.

[1] Mabus, R., "*Briefing:Naval Energy, A Strategic Approach,*" SECNAV, Washington, DC, October 2009 downloaded on 24 August 2010 from http://www.onr.Navy.mil/naval-energy-forum/~/media/5EFD428CFEB0412391CC321DCAF67138.ashx

Stakeholders were identified and recruited as a first order of business, based on the team's perception of likely interest and the roles of various organizations within the Navy. A survey was sent to each Stakeholder requesting feedback on the relevancy of this Capstone Project. The stakeholders' survey results indicated that preserving mission effectiveness by increasing tactical and shore energy security is the primary concern for the Navy, although assured delivery of fuel cannot be overlooked. Understandably mission assurance is the key concern for our stakeholders, and energy ecology effects were rated as the lowest concern. The priorities identified by stakeholders were not well aligned with those of the SECNAV, indicating that additional leadership coordination effort may be required to align the workforce based off the small sample-size result in our research.

There are significant risks associated with energy security. Energy risks include volatile petroleum prices along with non-secure supplies of petroleum. Petroleum is the primary source of energy for the Navy and in an effort to mitigate these risks near-term, the Navy is looking at several alternatives to petroleum-based energy. In terms of conservation, for example, the Navy is looking at ways to reduce the overall consumption of petroleum. The Navy is also looking at ways to increase the use of alternate and renewable energy sources while ensuring energy reliability to maintain critical infrastructure.

In terms of energy efficiencies, the Navy is increasing energy awareness and encouraging conservation practices with mid-term technology modification, long-term acquisition decisions, and by adapting operational policy and doctrine that recognizes the role of energy as a strategic and tactical asset, but deeming imperative that these energy efficiency considerations be achieved without any degradation to mission effectiveness. At any rate, aggressive steps are being taken and dollars are being spent to develop, adopt, and rapidly procure and replace more efficient technologies within the Navy and other armed forces.

As far as the environment, the Navy is recognized as a leader in environmental stewardship as it plays an active role in pursuing ways to protect the environment. Reducing energy consumption has the dual benefit of addressing the pressure imposed by growing environmental concerns while increasing energy efficiency has the benefit of reducing greenhouse gas emissions. Thinking about energy security, energy efficiency and environmental stewardship, in a unified way so as to make sure one area is not being overlooked, is the key to coming up with a solution that will benefit the U.S. Navy, our country and potentially, the entire world.

On January 10, 2010 Cohort 311-912 students received the following problem statement provided by their NPS Capstone Project advisors: "*Develop a technically feasible, cost effective approach to address and balance the Department of the Navy (DoN) energy surety, economy, and ecology goals.*" To reduce the broad scope of this statement, the student team proceeded to review background information and rapidly framed a workable subset of the problem with achievable solutions within a nine month schedule constraint. Two briefings in particular were influential in the discussion process of selecting a reduced scope. First was the briefing on Navy energy initiatives by CAPT Clayton Mitchell indicating the efforts to reduce DoN Energy consumption at shore-based facilities and second, the SECNAV Energy Strategy and Vision for energy security with plans of deploying a "green" fleet with reduced reliance on fossil fuels by 2016.[2] The initial research conducted by the team also revealed two existing reports that provided the baseline for the Capstone Project. A report written by Cusanelli & Karafiath, entitled *"U.S. Navy Surface Ship Fleet: Propulsion Energy Evaluation, and Identification of Cost Effective Energy Enhancements Devices,"* from the NSWC, Division Carderock, December 2006, provided evidence of the return on investment for a 5% reduction in fuel usage over the remaining life cycle of eleven surface combatant ship classes.[3] The DDG-51 (Arleigh-Burke) class was projected to have a $283M fuel savings and the CG 47 (Ticonderoga) class was projected to have a $129M fuel savings based on a nominal spot price of $55 per barrel of F76 diesel fuel or $1.31/gal; the Carderock report did not consider the fully burdened cost of fuel. None of the other classes examined had triple digit projected savings. Another report written by Amory B. Lovins, et. al, from the Rocky Mountain Institute, entitled "Energy Efficiency Survey Aboard USS PRINCETON CG-59," provided a set of recommendations for further study and concluded that "energy efficiency seeks to deliver the same service with less fuel and uncompromised or improved war-fighting capability via improved technologies or operational practices."[4] Taken together, these reports provided important background information, which

---

[2] Mitchell, C., *"Navy Energy Initiative,"* MORS Energy Meeting, Reston, VA, December 2009.

[3] Cusanelli, D. & Karafiath, G., *"U.S. Navy Surface Ship Fleet: Propulsion Energy Evaluation, and Identification of Cost Effective Energy Enhancements Devices,"* NSWC, Division Carderock, December 2006.

[4] Lovins, A.B., *"Energy Efficiency Survey Aboard USS Princeton CG-59,"* Rocky Mountain Institute, Snowmass, CO, June 2001.

allowed the Capstone Project to be narrowed to the study of the energy economy options for the DDG-51 Class of U.S. Naval Ships.

Eight subsystems aboard the DDG-51 that consume substantial energy, along with the fuel type, were identified and investigated as potential sources for energy reduction. The eight subsystems were selected in a Pareto analysis of power consumption of all ship subsystems and then limited to the top consumers that were not critical to mission effectiveness of the ship as a weapon system. The team decided that systems related to command and surveillance, propulsion, or armaments would not be included in this research since any modifications to subsystems in these areas may, in some way, compromise the mission capability of the ship. The investigation focus areas include: 1) fire pumps; 2) HVAC pre-heaters; 3) fuel transfer heaters; 4) hot water heaters; 5) AC chill-water pumps; 6) ovens; 7) dryers; 8) lighting fixtures; and 9) fuel type.

The system engineering approach selected for this study (and outlined in more detail in Section I) utilized an adaptation of a generic analysis process model provided by Blanchard & Fabrycky.[5] The process basically consisted of a systematic analysis and evaluation method for each of the eight subsystems, along with fuel type, to determine alternate and more cost effective ways for energy consumption, energy reduction, and energy conservation by these subsystems. The process proved to be appropriate for problem scoping and resolution, for source data collection, and ultimately for the evaluation of the best alternatives for each of the eight subsystems of interest for the DDG-51 class. Virtually no compatibility issues were associated among any of the recommended alternatives since the subsystems are independent of each other. However, potential integration issues could result between the subsystems and the ship, but these integration issues are viewed to be a one-time cost.

Several analysis goals addressing the energy conservation problem were achieved by the team including a) an accurate representation of the DDG-51 energy usage profile for the eight subsystems of interest, b) an analysis of Key Performance Parameters (KPPs) and cost utilizing a Quality Function Deployment , c) identification of critical areas of energy inefficiency with potential commercially available technology solutions to solve these inefficiencies, and d) recommendations of cost saving alternatives with impacts on energy usage. KPPs were ranked

[5] Blanchard, B.S., Fabrycky, W.J., "*Systems Engineering and Analysis,*" Prentice Hall, Upper Saddle River, NJ, 2006, 4th Edition.

with help of both stakeholder input and a weighting process to produce a hierarchy in terms of the importance of each KPP. All stakeholders responding (three in total) consistently rated "Effectiveness" as the parameter scored the highest. A more detailed discussion on the KPPs ranking process is offered in Section III of this report.

For the subsystem data collection the focus was on the electrical loads generated by the DDG-51 subsystems requiring power on the ship. A well organized ship work breakdown structure (SWBS) detailing the operating electrical load requirements for this subset of systems while the ship is at shore, anchored, or cruise operating condition was made available (courtesy of Northrop Grumman) for the DDG-51. A down-select using the Pareto analysis to refine the data scope of the SWBS was performed on HVAC systems, Auxiliary Systems, Outfitting and Furnishing, and the lighting portion of the electric plant. Section V of this report provides more detailed explanations on the scoping of the problem for every SWBS and more detailed explanation of the specifications and tables of values associated with electrical load requirements for each subsystem under winter and other operating conditions for every SWBS.

To complement the data collection efforts, field data was also obtained by the team during a visit to the US Naval Facilities Engineering Command Southwest (NAVFAC) in San Diego held the week of the 24-28 May 2010.

Figure 1 - Five of the Twelve Team Members with Commander Jordy Harrison, USS HALSEY Commanding Officer

During the site visit to NAVFAC, San Diego, the team was provided a ship study of energy consumed onboard the USS HALSEY DDG-97 which also included the class average over 14 ships that NAVFAC collected data for over the period 1 October 2009 to 30 April 2010. The team learned that ship class average daily energy cost is $4,891 (pier-side) with an average daily consumption of 34,454 kWh at a pier-side energy rate of approximately $0.14/kWh.

When the ship is generating its own power in the anchor and cruise conditions, the electricity is provided from the gas turbine generators. The manufacturer's specified fuel consumption rate is 15,375 BTU/kWh. The converted fuel consumption rate is approximately 0.11782 gal/kWh. The unburdened price of F76 diesel fuel, which is currently used for the gas turbine generators, is about $2.63/gal for the Defense Energy Support Center (DESC) price on 1 January 2010 which results in a ship-generated energy rate of approximately $0.33/kWh using a single Gas Turbine Generator (GTG) at 2500 kW. However, the typical operational mode is to run two GTGs at 1250 kW which incurs about a 34% penalty in specific fuel consumption, which increases the cost to approximately $0.44/kWh.

Enclosure 7 of DoD Instruction 5000.02 states *"The fully burdened cost of delivered energy shall be used in trade-off analyses conducted for all DoD tactical systems with end items that create a demand for energy."* The Fully Burdened Cost of Fuel Calculator version 7.1 provided by the Defense Acquisition University, estimates that for a commodity spot price of $2.63/gal, the resultant Fully Burdened Cost of Fuel (FBCF) is $13.02/gal which adjusts the ship-generated energy rate to approximately $2.06/kWh. The use of fully burdened fuel costs allows the true magnitude of energy savings and returns on investment to be calculated.

The team found other additional important information during the visit to NAVFAC. Ships are in port two thirds of the time and while in port ships use shore power. Energy loading is typically high during breakfast, lunch and dinner time. Loads are reduced after dinner until 0500 the next morning. The shore based facility uses a Supervisory Control and Data Acquisition System (SCADA) to track energy usage and provide billing read outs. The USS HALSEY is estimated to use about 35,556 kWh daily at a cost of $4,991 while pier-side. While underway, the ship is estimated to carry about 440,000 gallons of fuel onboard. It consumes about 5.75% of fuel per day, or about 25,300 gallons worth of fuel per day, which is about $66,539.00 per day at a quoted commodity spot cost from the ship captain of $2.63 per/gal. The team also looked at ecological information such as Freon, which is recycled on the USS

HALSEY, but the synthetic lube oil for some systems is highly toxic. Section V-D of the report outlines additional important facts found during the site visit which provided a solid foundation for the development and analysis of alternatives.

For each of the eight subsystems, along with fuel type, the current subsystem aboard the DDG-51 was used as a baseline and as many as three alternatives were researched and compared to the baseline. For seven of the eight subsystems, a more cost effective alternative was revealed (hot water heaters are already most efficient with the baseline configuration). The alternatives for ovens were more energy efficient, but used more manpower and are not recommended for further investigation.

The results of the analysis of alternatives are summarized as recommendations and potential trade-offs for the eight subsystems that were the focus of the present work. The summary of results from the common analysis of the eight subsystems analyzed, along with fuel type, is given in Table 1 below with the alternatives ranked by the projected ten-year net savings per ship. The five-year return on investment (ROI) is also included in Table 1 and is used in later sections of this report as the chosen ranking mechanism.

Subsystem	Subsystem Analysis Notation	Best Alternative	Five-Year ROI ($ Saved/$ Invested)	Ten-Year Net Savings($M)/per Ship
1. Pre-Heaters	A1	Chromolax	23	5.65
2. Fire Pumps	A9	Vertical InLine	72	4.37
3. Fuel Type	A18	Biodiesel B20	Infinite	2.27
4. Dryers	A13	Gas Conversion	29	2.00
5. AC Chill-Water Pumps	A2	Variable Frequency Drive	40	1.78
6. Lighting Fixtures	A15	CFB Distribution	37	1.61
7. Fuel Transfer Heater	A8	20% Efficiency	6	1.13
8. Ovens	A12	Halogen Microwave	29	0.54
9. Hot Water Heaters	A0	Baseline	0	0.00

[This table shows the subsystems researched and analyzed (including fuel alternatives) along with their five-year return on investment and projected ten-year savings per ship. The subsystem analysis notation helps with the notation used in the recommendations and conclusions section of this executive summary.]

Table 1 - Common Analysis Summary Results 10-year savings

The alternatives for pre-heaters and fire pumps clearly provide the highest net savings over the ten-year period, but significant savings can be accomplished by implementing all other alternatives with one exception. The hot water heater alternatives investigated did not indicate a better option than the existing baseline. Also, the significant cost incurred for fuel type option A (corn ethanol E85) and option B (cellulosic ethanol) is adverse enough that those two options were dropped from the trade-off analysis and only biodiesel B20 was included in the end results.

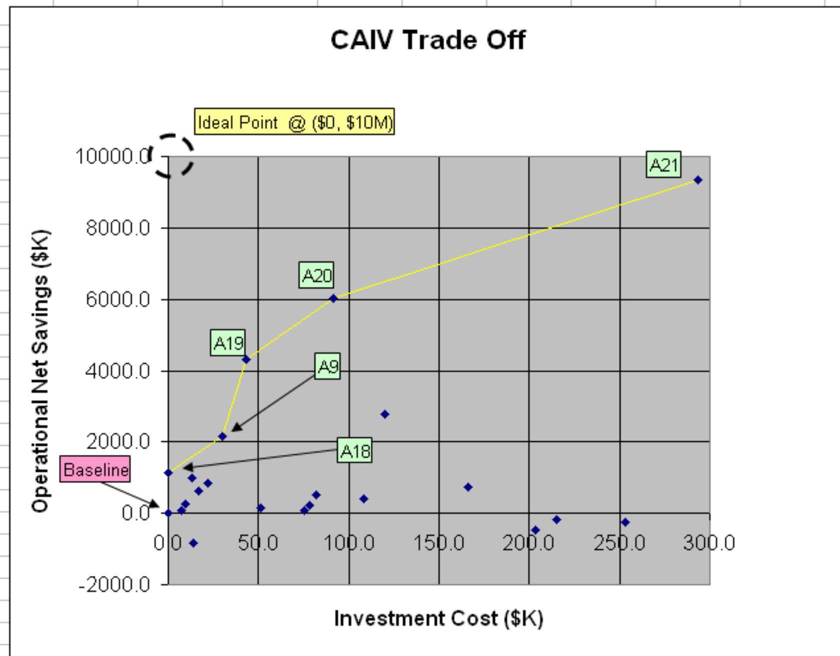
The team performed trade-off analyses of investment versus net savings over five years. Combinations of the basic alternative for each subsystem were synthesized including the baseline subsystem. Also included in the analysis is the normalized investment cost incurred in the first year. This investment cost was established and helped to derive break-even points for each investment. In other words, the break-even point is the point where the initial investment cost can be recouped, or the length of time for a specific alternative to reach a zero net savings given the initial investment cost. Pareto boundaries were developed to illustrate the solutions on the efficient frontier. All the non-dominated solutions identified on the Pareto boundary had a break-even time that was less than six months, suggesting a near-immediate return on investment.

An example of this Pareto analysis is shown in Figure 2. In this Figure it is seen that alternative 9 (A9) along with A18, A19, A20 and A21 lie on the Pareto boundary of non-dominated solutions. A18 is the biodiesel fuel type alternative, A9 is the inline vertical augmentation technology for fire pump number four, A19 consists of the top three single-option alternatives ranked by return on investment which include A18, A13 (dryers, gas), and A9. A20 adds A2 (chill water pump, variable frequency drive), A15 (Compact Fluorescent Bulb (CFB) lighting), and A12 (ovens, halogen microwave), and A21 adds the remaining two on the list which includes A1 (AC pre-heaters, Chromolax) and A8 (fuel transfer heater with +20% efficiency).

Savings-5

Alternative	Cost	Sav-5	L_1 Norm
A0	0	0	12,600
A1	120	2766	9,714
A2	22	842	11,736
A3	215	-181	12,566
A4	203	-478	12,875
A5	253	-244	12,590
A6	75	94	12,431
A7	78	226	12,296
A8	82	526	11,992
A9	30	2168	10,402
A10	7	78	12,515
A11	51	168	12,381
A12	9	268	12,323
A13	14	993	11,594
A14	14	-824	13,410
A15	17	633	11,950
A16	166	723	11,711
A17	108	412	12,079
A18	0	1134	11,466
A19	44	4295	8,262
A20	92	6037	6,471
A21	294	9329	2,977

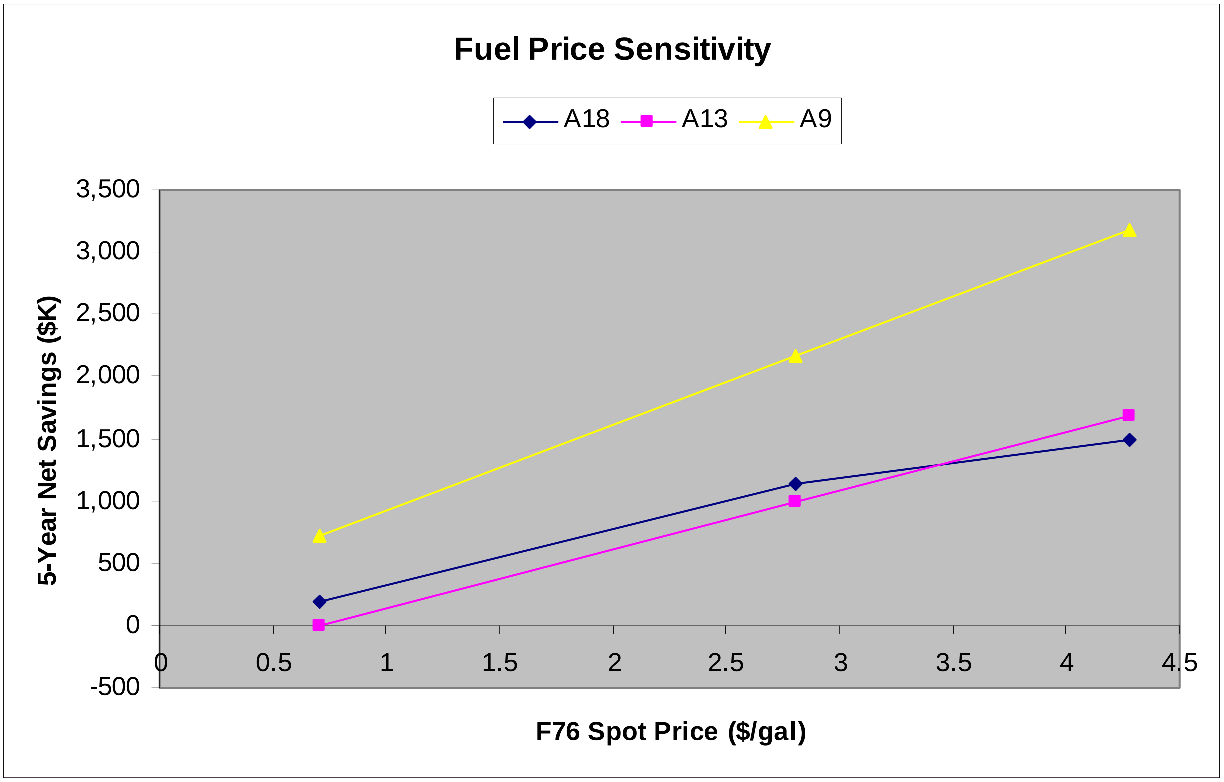
	Pareto Points	
A20	0	1134
A11	30	2168
A21	44	4295
A22	92	6037
A23	294	9329



[This Figure shows that numbered alternatives A9 and A18 through A21 lie on the Pareto boundary of efficient solutions. Note that the scale of the vertical axis (savings) is ten times the scale of the horizontal axis (cost).]

Figure 2 - Investment Cost versus Five-Year Net Savings

The assessment of the sensitivity of the resultant solution rankings for changes in input parameters is limited to variations on the global inputs of the spot price of diesel F76 and biodiesel B20, as well as the operational tempo for pier-side versus anchor/cruise. The reason for assessing B20 is due to the fact that the top-ranked single-option alternative A18 (fuel type) has a significant influence on the ranking of all the combination options that also lie on the Pareto boundary including alternatives A19 through A21.



[This Figure shows a cross-over among A18 (biodiesel) and A13 (gas dryers) at around $3.50/gal spot price showing that biodiesel has a diminishing return with rising fuel price.]

Figure 3 - Fuel Price Sensitivity

The DESC price sheets showed that it is not realistic to vary the price of F76 and leave the price of B20 fixed, since price movements are highly correlated. Additionally, for all ten price sheets that were examined, B20 is always lower in price than F76 which suggests that the savings estimated for alternative A18 has higher confidence than if the pricing had shown cross-over points among F76 and B20. When the input spot price of F76 and B20 are both raised to $4.28/gal and $4.14/gal respectively, the ranking of top three single-option solutions (A18 fuel type biodiesel B20, A13 dryers gas, and A9 fire pump number four vertical inline) is unchanged, although the net savings over five years is magnified. Similarly when the spot price of F76 and B20 are both lowered to $0.71/gal and $0.69/gal respectively, the rankings are again unchanged, but as expected the savings over five years are reduced. There is a cross-over in rankings among A20 and A15 suggesting a diminishing return on investment as the price of fuel increases for B20 biodiesel as shown in Figure 3.

The sensitivity to operational tempo (OPTEMPO) was also assessed with the time spent pier-side nominally at 67%, but when this parameter was reduced to 50% and 33%, there were no identified cross-over points among top three single-option solutions indicating the results are not sensitive to variations in OPTEMPO.

RECOMMENDATIONS AND CONCLUSIONS

For the given set of inputs for this analysis, the resultant recommendation clearly flows from Figure 2 above. Alternatives A18, A9, A19, A20, and A21 all lie on the Pareto boundary and represent a set of non-dominated solutions. Any particular solution from this set can be selected by stakeholder preference or by budgetary constraints. The first-year investment cost for A20 is about $92K with a net savings in one year of $1.1M, in five years of $6.0M, and in ten years of $12M. Other solutions on the Pareto boundary include A21 which offers the highest net savings in year ten of $19M for a higher investment cost of $294K, as well as A19 which offers both the lowest net savings in year ten of $2.3M for the lowest investment cost of $0. As a reminder, the notations for A0 through A20 are given in Table 1. A19, A20, and A21 are simply combinations of the top three, top six, and top eight solutions ranked by five-year return on investment. Caveats to the top three single-option solutions include: Biodiesel may not be suitable for use on surface ships; storing natural gas on-board ships for dryers may encounter cultural resistance; and the reduced flow capacity of inline vertical fire pumps may not be adequate for backup cooling.

The ranking of solutions is largely insensitive to changes in the spot price of fuel, assuming that F76 and B20 continue to move in lock-step, as well as to changes in the operational tempo driving the percentage of time ships spend pier-side versus at-anchor/at-sea. There is a point of diminishing returns for B20 as the spot price of fuel moves into very high values. Reducing power consumption for all of these subsystems contributes significantly to meeting the SECNAV's energy vision. Reduced power consumption results in improved fuel economy and indirectly adds to improved fuel surety as the need for petroleum fuel is reduced, and improved fuel ecology as less fuel is burned producing fewer pollutants. Given that DESC's pricing for biodiesel B20 is comparable to diesel F76, the surety and ecology pillars of the

SECNAV's energy vision can be partially addressed by further studying the feasibility of switching ships over to this existing alternative fuel.

It is the team's conclusion that the Navy should prioritize efforts to refine the analysis of the recommended solutions above by funding a feasibility study sponsored by OPNAV to pursue an acquisition strategy to implement some or all of the recommendations, as well as to consider reapplication of this approach to other ship classes. The results indicate that appreciable net savings on the order of $1.9M per ship can be achieved within a year for an investment cost of less than $300K, and that over a ten-year period the net savings can be on the order of $19M. If this savings per ship is realized over the 50 ships in the class, the total savings over ten years could reach $950M. Savings of that magnitude are equivalent to a significant portion of the acquisition cost of an entire ship. It is also noted that, given the consistently low stakeholder rankings for fuel economy, surety (with the exception of one out of three responses), and ecology, that the Office of the SECNAV needs to develop a strategy that includes measurable, objective metrics for adoption that will ensure that the energy vision is taken on with full force by those who execute the acquisition of petroleum-consuming Navy systems.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

ACRONYM	TERM
AC	Air Conditioning
AHP	Analytical Hierarchy Process
AoA	Analysis of Alternatives
ASEO	Army Systems Engineering Office
ASN(I&)	Asst. Sec. of the Navy (Installations & Environment)
BTU	British Thermal Units
C3I	Command, Control, Communications & Intelligence
CAIV	Cost as an Independent Variable
CAPT	Captain
CARE	Combustion Auto Response Equipped System
CDD	Capability Development Document
CDR	Commander
CFM	Cubic Feet per minute
CG	Guided missile cruiser
CID	Commercial Item Description
CO	Commanding Officer
CO2	Carbon Dioxide
COMSURFOR	Commander Naval Surface Force
CONOPS	Concept of operations
COSYSMO	Constructive Systems Engineering Cost Model
CRM	Composite Risk Management
CWP	Chilled Water Pumps
DASA	Deputy Assistant Secretary of the Army
DASN	Deputy Assistant Secretary of the Navy
DAWIA	Defense Acquisition Workforce Improvement Act
dB	decibels
DDG	Guided missile destroyer
DESC	Defense Energy Support Center
DoD	Department of Defense
DoE	Department of Energy
DoN	Department of the Navy
DT&E	Developmental Test and Evaluation
ECN	Engineering change notice
ECON	Energy Conservation
ECPs	Engineering Change Proposals
EMI	ElectroMagnetic Interference

ESOH	Environmental, Safety and Occupational Health
FBCF	Fully Burdened Cost of Fuel
FMEA	Failure Mode and Effects Analysis
FSTC	Food Service Technology Center
FY	Fiscal Year
gal	Gallons
GPM	Gallons per minute
GTG	Gas Turbine Generators
HOQ	House of Quality
HP	Horsepower
HIS	Human Systems Integration
HV	High voltage
IPR	In Progress Review
IRT	Item Response-Option
KPP	Key Performance Parameters
kW	kilowatt
kWh	Kilowatt hours
Lb	Pounds
LED	Light Emitting Diode
LF	Load Factor
MIL-STD	Military Standard
MOC	Major Maritime Operating Centers
MRL	Manufacturing Readiness Level
MSSE	Masters of Science Systems Engineering
MWH	Megawatt Hours
NAVFAC	Naval Facilities Engineering Command
NAVFAC SD	Naval Facilities Engineering Command San Diego
NAVOCEANO	Naval Oceanographic Office
NAVSEA	Naval Sea Systems Command
NAVSUP	Naval Supply Systems Command
NEST	NPS Energy Security Team
NGSB	Northrop Grumman Shipbuilding
NPS	Naval Postgraduate School
NRE	Non-recurring Engineering
nSAV	Net Savings
NSWC	Naval Surface Warfare Center
NSWCCD	Naval Surface Warfare Center Carderock Division
O&F	Outfitting and Furnishing
OMOE	Overall Measure of Effectiveness
ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations

OPTEMPO	Operational tempo
ORD	Operational Requirements Document
ORNL	Oak Ridge National Laboratory
OT&E	Operational Test and Evaluation
PEO S&T	Program Executive Office for Science & Technology
PEO-SHIPS	Program Executive Office for Ships
PM	Preventative Maintenance
PMP	Project Management Plan
PMS	Planned Maintenance Subsystem
PMS400	NAVSEA Program Manager
POC	Points of Contact
POM	Program Objectives Memorandum
PSI	Pounds Per Square Inch
QFD	Quality Function Deployment
R&D	Research and Development
RMI	Rocky Mountain Institute
RMP	Risk Management Plan
RMR	Risk Management Review
ROI	Return on Investment
RPM	Revolutions per minute
RTUs	Remote Transmitter Units
SBIR	Small Business Innovation Research
SCADA	Supervisory Control and Data Acquisition System (SCADA)
SECNAV	Secretary of the Navy
SEMP	Systems Engineering Management Plan
SME	Subject Matter Experts
SRVS	Solid-State Reduced Voltage Starter
SWBS	Ship Work Breakdown Structure
SWDG	Surface Warfare Development Group
SYSCOM MIP	System Command Maintenance Index Pages
TBD	To be determined
TRL	Technology Readiness Level
TYCOM	Surface Type Commander
USN	United States Navy
USS	United States Ship
VFD	Variable Frequency Drive
W	Watts
XO	Executive Officer

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. BACKGROUND

The NPS Energy Security Team (NEST), a group of twelve students at the Naval Post Graduate School working towards the Masters Degrees in Systems Engineering, culminated two years of study with this Capstone Project to look at energy surety, economy, and ecology from the perspective of a single ship class, the DDG-51, illustrated in Figure 4.

Figure 4 - DDG-51 Arleigh Burke Class[6]

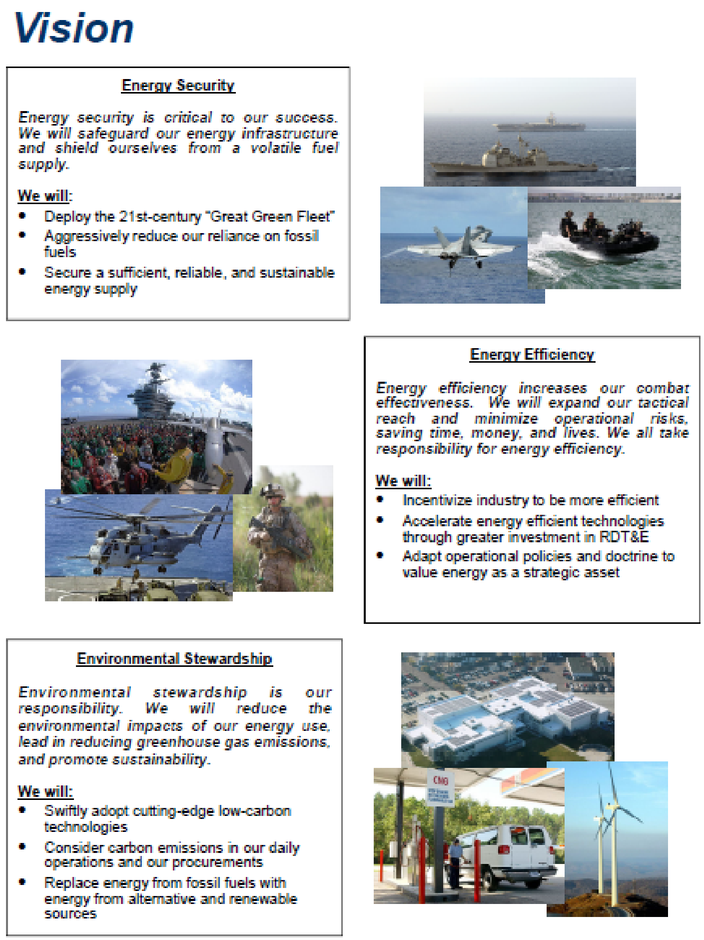
These energy goals are to ensure that the U.S. armed forces have the required energy to perform and carryout the missions set forth for them. The emphasis of this Capstone Project was aimed towards a subset of this broad problem and focused mainly on the economy and surety aspects but also documented findings on the ecology aspect. The objectives of this Capstone were to apply the systems engineering knowledge and skills acquired over the course of the NPS MSSE program in an integrated project to solve an applicable "UNCLASSIFIED" problem and to develop a technically feasible, cost effective approach to address and balance the DoN energy surety, economy, and ecology goals. The problem was down scoped to a solvable subset of the original energy surety, economy, and ecology problem statement so the team could formulate alternative solutions, develop scoring criteria, analyze and rank these solutions, and develop achievable recommendations. This included developing an implementation approach for those

[6] Beida, G., "*Arleigh Burke Class Destroyer Profile Drawings*," downloaded 22 August 2010 from http://www.usmilitaryart.com/DDG51_07_18349-1200.jpg

recommendations that can be implemented to help the DoN achieve its energy goals for 2020, by analyzing the energy usage of the DDG-51 class ship and methods by which a reduction in overall usage and thus cost could be achieved. The recommendations the cohort ultimately came up with included a subset of systems aboard the ship class and specific methods or alternatives by which to reduce cost within those systems.

Energy security is a major concern, not only within the Navy, but within the entire DoD. Concerns about energy are far-reaching within our country and beyond our national borders. Currently the Navy is very reliant on petroleum as the primary source of fuel. Petroleum is not limitless and price increases recently are a major cause for concern. As a result, solutions involving alternative energy sources are receiving more attention than ever. A greener force is another goal with the Navy, filling a role in providing environmental stewardship.

Figure 5 below shows the Secretary of the Navy's vision from a very top level view. The Figures display the vision and strategic approach to energy security, energy efficiency, and environmental stewardship citing a set of aggressive goals and methods by which to reach those goals.



[This Figure depicts the Secretary of the Navy's energy vision for the future which includes Energy Security, Energy Efficiency, and Environmental Stewardship.]

Figure 5 - SECNAV Energy Vision

The Secretary of the Navy's vision and strategic approach from a very top level view is to increase tactical and shore energy security and reduce Navy's carbon footprint thus upholding its role in providing environmental stewardship. The focus is on the process of conservation, efficiency, and alternatives.

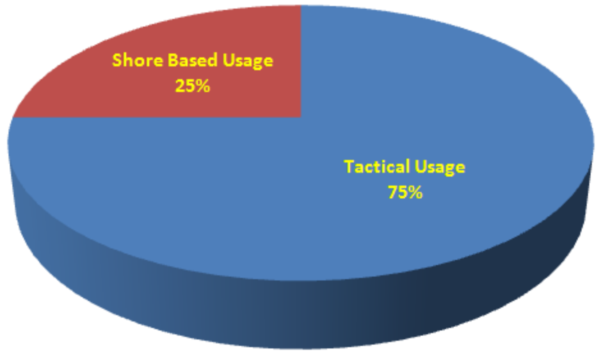
Conservation entails reducing fuel consumption and demonstrating energy awareness. Efficiency uses the approach to increase tactical and shore efficiency in order to optimize existing platforms and leverage new technologies. This results in an increase in combat effectiveness while minimizing operational risk. Fuel alternatives are implemented to replace petroleum and ensure a sustainable domestic fuel supply and help secure critical infrastructure. This contributes to the energy security of the country by protecting ourselves from a volatile fuel supply controlled by foreign nations. The production of fuel from alternative and renewable sources also reduces greenhouse gas emissions and the Navy's carbon footprint.

This vision is the reason our Capstone team chose one aspect of this seemingly boundless problem. Although the team down scoped to a single ship class, the DDG-51, results, recommendations, analysis of alternatives (AOA), and other general findings in this capstone report can be generalized and should provide value to any other class of ship.

The results of this Capstone Project parallel previous work performed by Amory Lovins, of the Rocky Mountain Institute (RMI), which is detailed in his report entitled, "Energy Efficiency Survey Aboard USS PRINCETON, CG-59,"[4] Figure 6 below. The Secretary of the Navy's vision and strategic approach from a very top level view are to increase tactical and shore energy security and to reduce Navy's carbon footprint thus upholding its role in providing environmental stewardship. The focus is on the process of conservation, efficiency, and alternatives.

Conservation entails reducing fuel consumption and demonstrating energy awareness. Efficiency uses the approach to increase tactical and shore efficiency in order to optimize existing platforms and leverage new technologies. This results in an increase in combat effectiveness while minimizing operational risk. Fuel alternatives are implemented to replace petroleum and ensure a sustainable domestic fuel supply and help secure critical infrastructure. This contributes to the energy security of the country by protecting ourselves from a volatile fuel supply controlled by foreign nations. The production of fuel from alternative and renewable sources also reduces greenhouse gas emissions and the Navy's carbon footprint.

This vision is the reason our capstone team chose one aspect of this seemingly boundless problem. Although the team down scoped to a single ship class, the DDG-51, results, recommendations, alternatives of analysis, and other general findings in this capstone report can be generalized and should provide value to any other class of ship.



[This Figure shows the distribution of energy usage for shore based versus tactical, with 25% of the total Navy's energy usage being shore based and 75% being tactical.]

Figure 6 - Energy Usage Distribution for the USN[2]

As seen in Figure 6 above, the overall energy consumption of the Navy has 75% attributed to tactical usage while only 25% is attributed to shore-based usage. Additionally, 57% of DoN's energy consumption is petroleum, while only 26% is electricity, natural gas, and other sources, besides nuclear and renewable.[2] Also, evidence indicated that energy consumption of ships is a significant proportion of the total DoN energy consumption and that within ships, surface combatants represent a majority of the usage.[2]

Figure 7 indicates that a 5% reduction in fuel consumption will result in the largest cost savings for the Arleigh Burke class of ships.

SELECTED CANDIDATE SHIP CLASSES FOR ENERGY DEVICE RETROFIT		
US Navy Surface Ship Class	Number of Ships in Class *	Potential Class Life Cycle Fuel Savings from 5% Device
(A) Surface Combatants		
Ticonderoga, CG 47	27	$ 129 M
Spruance / Kidd, DD 963 / DD 993	35	$ 84 M
Arleigh Burke, DDG 51	50	$ 283 M
Oliver Hazard Perry, FFG 7	35	$ 55 M
(B) Amphibious Warfare Ships		
San Antonio, LPD 17	12	$ 49 M
Wasp, LHD 1	6	$ 45 M
Tarawa, LHA 1	5	$ 18 M
Whidbey Island / Harpers Ferry, LSD 41 / LSD 49	12	$ 24 M
(C) Fleet Auxiliary Force		
Henry J Kaiser, TAO 187	16	$ 39 M
Cimarron (Jumbo), AO 177	5	$ 10 M
Supply, AOE 6	4	$ 23 M

* Number of ships in class presently active or planned.
CG 47, DD 963, and DD 993, share the same hullform

[This Figure shows the potential savings per ship class with a 5% reduction in fuel consumption, with the DDG-51 class potentially saving $283 million.]

Figure 7 - Potential Savings by 5% Reduction in Fuel Consumption[3]

The DDG-51 Arleigh Burke class guided missile destroyer replaced the Kidd class and is the only active class of destroyers in the U.S. Navy. There are 50 Arleigh Burke class destroyers that are currently active, with more being planned and built. The mission of the Arleigh Burke class is to "conduct sustained combat operations at sea, providing primary protection for the Navy's aircraft carriers and battle groups, as well as essential escort to Navy and Marine Corps amphibious forces, auxiliary ships, and independent operations as necessary."[7] The Arleigh Burke class ship is comprised of many systems, including; identification and detection systems, self-defense, control, navigation, communications, engagement and combat, air-conditioning, refrigeration, seawater, drainage, fuel, fire extinguishing, steering, pollution control, as well as outfitting and furnishing.[8] Ultimately the cohort decided to focus efforts on a subset of these systems as a basis for the project.

---

7 Global Security, "*DDG-51 Arleigh Burke-class*," 9 Jan 2008, downloaded 20 July 2010 from http://www.globalsecurity.org/military/systems/ship/ddg-51.htm

8 Sea Forces, *"US Navy Ships / DDG Arleigh Burke - Class, Seaforces.org Naval Information,"* downloaded 20 July 2010 http://www.seaforces.org/usnships/ddg/Arleigh-Burke-class.htm.

Previous energy conservation research efforts have been conducted that were aimed at reducing costs on the Arleigh Burke class. These efforts include such things as hybrid electric drives for the DDG-51 to reduce fuel costs and increase fuel efficiency. [9,10] Other initiatives have examined power distribution upgrades to the DDG-51 class by using one generator at design point rather than two loaded at 50% to gain fuel efficiency. Figure 8 shows several other energy initiatives that are being researched, developed or implemented aboard various hulls, including the DDG-51.[11,12]

---

9 Defense Industry Daily, "*$32.7M to General Atomics for DDG-51 Propulsion System Prototype*," July 2009, downloaded 20 July 2010 from http://www.defenseindustrydaily.com/327M-to-General-Atomics-for-DDG-51-Propulsion-System-Prototype-05598/.

10 Putnam, D., "*Advanced Power Management for In-Service Combatants*," NAVSEA SBIR Office, Washington, DC, November 2009, downloaded 1 September 2010 from http://www.Navysbir.com/n10_1/N101-055.htm.

11 Fikse, T., "*Ship Wide Uninterruptable Power Supply for the DDG-51*," Innovation Inc. et al, downloaded 20 July 2010 from http://www.stephenwmoore.com/SMOORE%20DDG51.pdf, August 2008.

12 McCoy, K., "*Energy Initiatives Roadmap and Implementation*," Naval Energy Forum, 14 October 2009, downloaded on 30 August 2010 from http://www.onr.Navy.mil/naval-energy-forum/~/media/B35D17C4AF47484F8FD14DD442CF2561.ashx.

ENERGY INITIATIVES

Name / Description	Cost Avoidance (CA) ** Pay Back (yrs)		ROI: (10 YR)	INVESTMENT FY09	FY10	FY11	Total *	STATUS
R&D and Fleet Implementation								
Online Gas Turbine Waterwash ~ 800 bbls/ship yr	1	DDG51 & CG47	7:1	$1.0M	$1.4M	$1.4M	$8.2M	Installed on USS PREBLE in Oct 08. MPA onboard advises system is working well.
Advanced Underwater Hull Coating System ~ 5500 bbls/ship yr	< 2	DDG51 & CG47	4:1	$2.5M	$2.0M/$2.1M	$2.9M	$31.6M	Applied to USS PORT ROYAL & USS COLE— evaluation beginning Aug 2009
Stern Flaps (LHD, LSD Ship Classes) ~ 5500 bbls/ship yr ~ 3500 bbls/ship yr	< 1 < 2	LHD LSD	6:1 4:1	$1.3M $1.3M	$0.2M/$0.8M $0.2M/$1.6M	$0.8M $1.6M	$6.5M $12.0M	Install on USS KEARSARGE—evaluation beginning after Nov 09. Installed on USS WHIDBEY ISLAND
Combustion Trim Loop ~ 3060 bbls/ship yr	< 1	LHD & LHA	30:1	$0.6M	$0.7M	$0.3M	$1.7M	Installed on USS PELEIU in Jun/Jul 09 — evaluations beginning in Aug 09
Propeller Coating ~ 1860 bbls/ship yr	< 1	LHA, LHD & LPD4	13:1	$1.0M	$0.4M/$0.5M	$0.6M	$4.2M	Applied to USS GUNSTON HALL — evaluation underway
Directional Stability (L-Ships) *ARRA* ~ 2900 bbls/ship yr	TBD	LSD 41 & LSD 49	4:1	$1.0M	$1.7M	$1.0M	$12.3M	Power & Maneuvering model testing completed 13 July
Solid State Lighting *ARRA* ~ 880 bbls/ship yr]	TBD	LHA 1 & LHD 1	2:1	$0.6M	$0.4M	$1.1M	$7.6M	Contracting actions are underway
Hybrid Electric Drive *ARRA & Adds* ~ 8000 bbls/ship yr	5-10	DDG51 Class Goal is at-sea demo 1 shaft in FY11	TBD	$27.0M	$5.6M	$13.6M	TBD	$13M Contract Award to GA/DRS Team for full scale demonstration
High Energy Efficient HVAC (R-134a) *ARRA* ~ 2400-6400 bbls/ship yr	N/A 8-12	Future Procurements LPD 17-23, DDG-83+	N/A TBD	$2.6M	$0.0M (ARRA will be used in FY10)	$1.9M	TBD	$1.9M Contract Awarded & Staffing Commenced at York Navy Systems on 18 May 09.
High Energy Efficient HVAC (R-236fa) ~ 2400 -3500 bbls/ship yr	8-12	DDG 51-82, CG 60-73 LHD-CL	TBD	$0.0M	$0.0M	$1.0M	TBD	New Project Proposal for PR11.
Fleet Scheduler Planning Tool ~ 2-4% fleetwide	< 1	All Ships	110:1	$0.0M	$0.0M	$2.0M	$5.8M	New Project Proposal for PR11.
Smart Voyage Planning Tool ~ 2-4% fleetwide	TBD	All Ships	22:1	$0.0M	$0.0M	$2.5M	TBD	New Project Proposal for PR11.
Totals (rounded)				**$38.9M**	**$5.6M/$12M**	**$30.7M**		
Operational Programs								
Incentived Energy Conservation (i-ENCON) ~ 2-6% fleetwide	< 1	All	24:1	$1.0M	$1.0M/$4.1M	$4.2M	$61.0M	FY09 3 qtrs exceeds all FY08 (1.043M bbls). On track for record cost avoidance.
Totals (rounded)				**$1.0M**	**$1.0M/$4.1M**	**$4.2M**	**$61.0M**	

ARRA – American Recovery and Reinvestment Act
* Total Cost Investment from Navy Through 2019
** Based on Fully Burdened Cost of $170/bbl

$$s in Blue are potential FY10 marks
$$s in Black are Funded
$$s in Red are Unfunded

[This Figure depicts some of the initiatives being implemented and currently implemented by NAVSEA that were discussed at the Naval Energy Forum in October 2009.]

Figure 8 - NAVSEA Energy Initiatives

Some of the energy conservation efforts discussed at the Naval Energy Forum include energy source and power plant selection, more efficient machinery aboard the ships, more efficient hulls, more efficient combat systems, total ship energy management, and requirements/standards. Figure 8 portrays other energy initiatives that are being developed, researched, or implemented aboard various hulls in the following area: 1) Hull/Hydrodynamics which includes Advanced Underwater Hull Coating System which saves about 5500 barrels per ship per year, 2) Stern Flaps which saves from about 3500 barrels to 5500 barrels per ship per year, and 3) Propeller Coating which saves about 1860 barrels per ship per year.

Other energy initiatives that have significant savings include: the Primary Energy Source (Alternate Fuels), Propulsion/Power Plants, and Ship Machinery. The cohort decided to conduct an analysis of some of these systems to investigate potential savings as well as others.

B. SYSTEMS ENGINEERING APPROACH

Cohort 311-912 elected to apply a tailored version of the Blanchard and Fabrycky analysis process model to conduct the technical approach of this project.[5] This systems engineering approach model was chosen because it focuses on an analysis effort and it maps to the first step of other systems engineering models (i.e., spiral and V-models). The nine steps used in this model correlate better with the expected activities for the Capstone development effort. Applying the approach of this model in the Capstone Project provides the basis for the five following activities:

1. Definition of a solvable subset of the original problem statement.
2. Development of a scoring criterion to analyze and rank solutions.
3. Formulation of alternative solutions.
4. Development of achievable recommendations.
5. Development of a concept of implementation for those recommendations.

Execution of this nine-step process is represented in the process model in Figure 9 below.

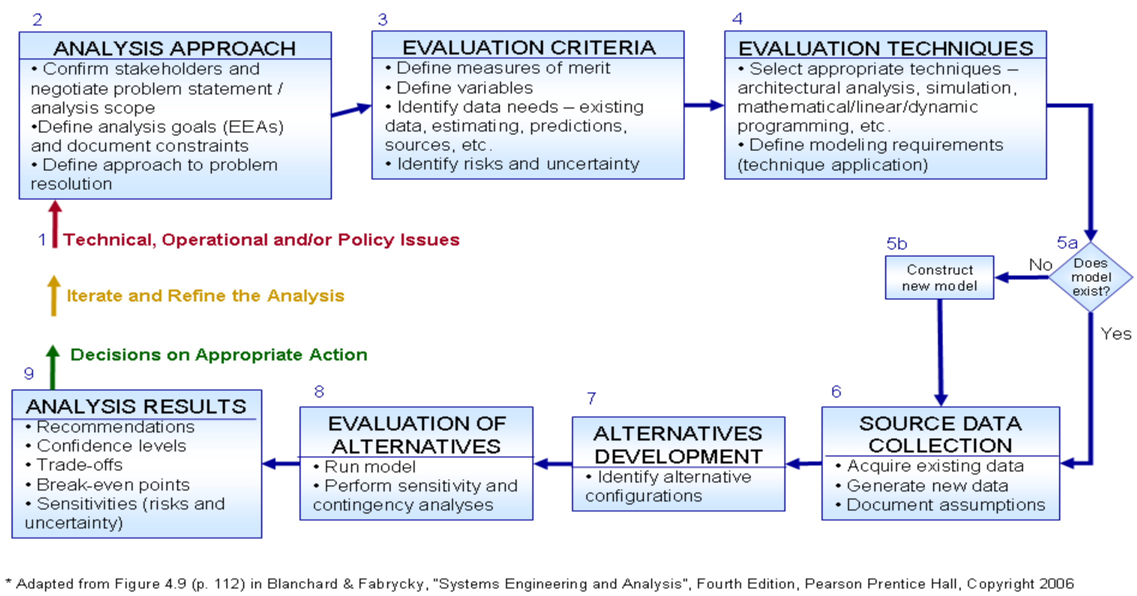


Figure 9 - Process Model Used for Capstone Process Execution

The process model depicted above is iterative by design and was used throughout the entire nine-month Capstone Project with the main objective ultimately to provide alternative solutions to the DoN for possible implementation, supporting their ongoing efforts to ensure efficient, available, secure, and affordable energy. The initial goals and scope of the project, defined in block 2, focused on identifying the measurable elements applied and the analysis method used for the core research of the project (blocks 3-5). The core research concentrated on obtaining data for baselining subsystems for the DDG-51 class ship (block 6), and comparing the available alternatives to this baseline (blocks 7-8). At the end of the research, the analysis provided technology and material solutions and recommendations for implementation. In addition, an HSI component was also included as part of the core research but only qualitative data was obtained. It was not included in the quantitative analysis rankings through these blocks but solely a recommendation based on report findings.

II. ANALYSIS APPROACH

A. STAKEHOLDER NEGOTIATIONS

The identification of stakeholders and stakeholder involvement are critical aspects of the systems engineering process. Stakeholders are especially instrumental during the initial systems engineering phases when requirements and needs are identified, and their involvement throughout the entire execution of a project is also essential. For this project, Stakeholders provided input on the scope of the project, evaluated and ranked the Key Performance Parameters, provided feedback at the in-process reviews, and steered the Capstone team towards applicable research. Also, during the second of three quarters dedicated to this project, a comprehensive questionnaire was developed and sent to various stakeholders to aid in a DDG-51 ship visit at the Naval Facilities Engineering Command (NAVFAC). This questionnaire and the initial survey can be seen in Appendix D of this report.

To ensure the breadth of viewpoints, a list of potential stakeholders representing operators, maintainers, acquisition professionals, resource sponsors, and technology developers was prepared. Consideration was also given to ensuring stakeholders from the energy efficiency community were represented. During the execution of the project, the team determined it also had a stakeholder whose views were not initially represented and a stakeholder for Naval Facilities was added to address shore-side infrastructure. Table 1 represents the results of this effort and the individuals representing their communities.

Stakeholder	**Primary Area of Interest**	**Point of Contacts**
Surface Warfare Development Group (SWDG)	Tactical doctrine and Fleet Operations	David Gilbert, Science Advisor
Surface Type Commander (TYCOM)	Fleet Operations	Did not participate; Replaced by Ships Force of DDG-97

Naval Sea Systems Command (NAVSEA) and its Warfare Centers	Ship certification and sustainment	NAVSEA-05 - Fred Tsao, - Technical Warrant Holder for In-Service Ship Design Manager for DDG NSWC - Richard Griggel
Program Executive Officer for Ships (PEO-SHIPS)	Acquisition manager for ship life-cycle	CDR Todd Hellman
Office of Naval Research	Technology and Sponsor of related study	Unable to participate; (attempted to participate in one IPR) replaced by Chief Technology Officer of NSWC-CD – Scott Littlefield
Chief of Naval Operations (OPNAV)	Resource Sponsor	Did not participate
Navy Task Force Energy	Current and planned Nave Energy initiatives	Thomas Martin, Lead for Surface Ships
Naval Facilities Command	Shore-base infrastructure	CDR Vincent Garcia, XO Naval Base San Diego

[This table describes the key organizations and individuals who were sought for problem scoping and KPP prioritization]

Table 2 - Stakeholder Areas of Interest

The Capstone team did not obtain a stakeholder representing the Office of Chief of Naval Operations. The lack of a resource sponsor was mitigated, but not overcome by reviewing the submittals to the Program Objectives Memorandum (POM) Process by the Navy Energy Task Force.[13]

[13] Martin, T., *"Draft Briefing Materials Task Force Energy POM Submittal FY1,"* Washington, DC, July, 2010, (Unpublished).

Once the list of stakeholder organizations was derived, a survey was generated and distributed to the potential individual stakeholders to gauge who among the entire list would benefit most from the execution of the energy analysis.

In addition to the stakeholders listed in Table 2, subject matter experts (SMEs) were identified and information on their specific area of expertise was sought.

Only a fraction (three out of nine) of the identified SMEs responded to the initial surveys sent out by the team. The input from these experts proved to be vital to the execution of the project. Individual students were assigned to the stakeholders and SMEs to ensure that their views would be reflected in the analysis of the Capstone Project.

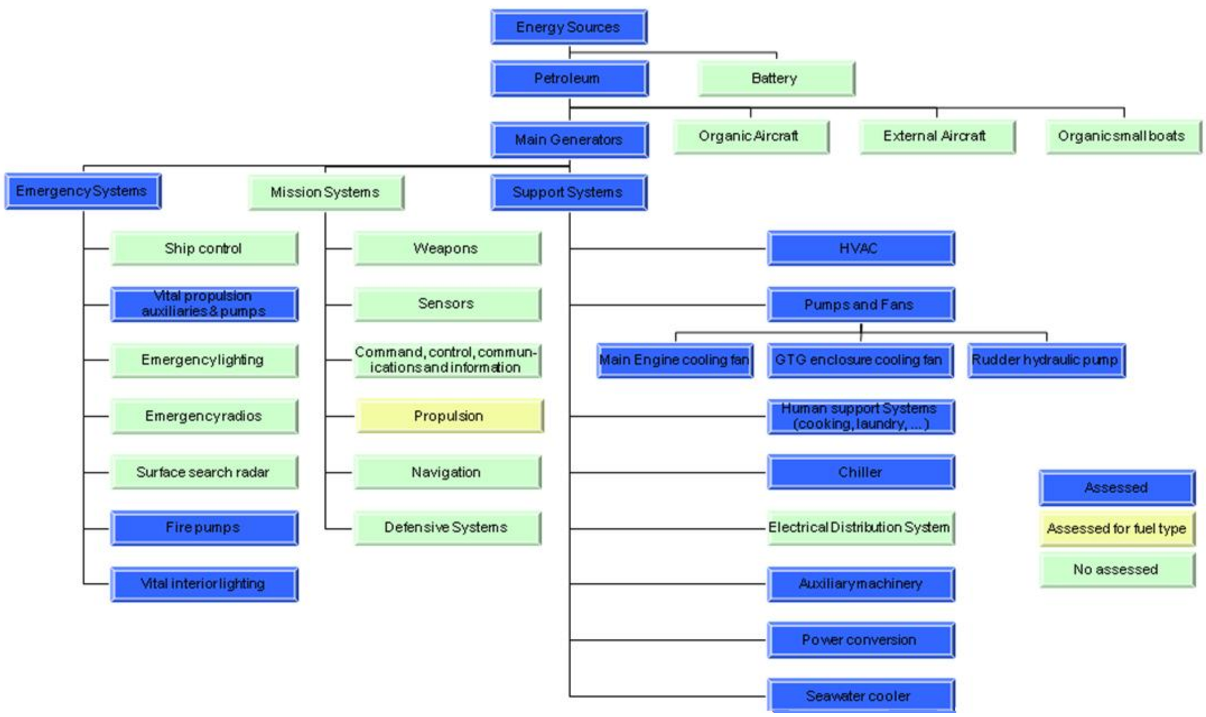
During the nine month Capstone effort, two Internal Program Reviews (IPRs) were held and stakeholders and (SME) were invited to participate in and offer their views, concerns, comments and criticism regarding the progress of the project. This involvement played a critical role in keeping the team's focus on track. Initially the scope of this project was entirely too broad, and it was the direct feedback from the stakeholders that allowed the team to refine the scope to fit more in line with stakeholder interests. The stakeholders did not have a significant interest in energy surety or in energy ecology. Though not very important compared with reliability and availability, energy economy was the most important attribute related to energy for them. The stakeholders and SMEs participation pointed the students towards applicable research.

B. ANALYSIS GOALS AND DOCUMENT CONSTRAINTS

1. Goals

By producing a detailed and well organized systems engineering analysis, the primary goal for this thesis project was to give stakeholders recommendations for energy usage practices that will provide a cost savings, savings that could be substantial over time.

Initially the scope was too much to take on for the nine month timeframe. With guidance from the advisors and stakeholders, the focus of the project was narrowed to several high-energy consuming subsystems. Conversations with stakeholders altered the focus to energy economy, resulting in the systems highlighted in green in Figure 10 below. As part of the data collection performed on a DDG-51 in May of 2010, the systems targeted were primarily HVAC, lighting, cooling elements (such as fans and chillers), auxiliary systems and outfitting and furnishing items (such as laundry and cooking facilities) where Human Systems Integration (HSI) practices could be identified as a means of controlling high energy costs associated with these units. As part of the HSI aspect, crew size could play a significant role but was not included in the analysis. Crew size was left for future research.



[The Figure describes the subset of systems evaluated]

Figure 10 - Systems of Interest

There are several analysis goals addressing the energy conservation problem and more detail is shown in the technical sections that follow later in Section VII of this report. The goals for this team were:

1. Accurately model the DDG-51 energy usage profile for the systems of interest and accurately decompose the usage and load by subsystem.

2. Conduct analyses based on the Key Performance Parameters (KPP) and cost using Quality Function Development (QFD).
3. Identify critical areas of energy inefficiency or easily integrated energy use improvement.
4. Identify commercially available technology solutions to fill energy efficiency gaps.
5. Conduct analyses of the technology and HSI alternatives using evaluation techniques based on systems assessment models presented in the Systems Engineering curriculum.
6. Prioritize and weigh alternatives in the order of implementation based on cost and impact to efficiency.
7. Recommend combinations and/or suites of alternatives based on the findings and resultant savings and impact on energy usage.

In an effort to ensure that we provide useful results and recommendations to the stakeholders, a survey was used to solicit their input on how they prioritized a set of key performance parameters, in terms of highest importance and relevance. The results of this survey are discussed in Section III, Measures of Merit, later in this report.

2. Constraints and Limitations

Constraints on a project like this come in several forms. They may be hard constraints that are externally driven such as laws, regulations, and NPS rules. Some externally driven constraints are soft constraints; for example funding resources, tool usage, and data access. A specific example of a soft constraint was funding for a site visit to a DDG-97 USSHALSEY for data collection. While no upper bound was given on funds availability, the amounts of effort to obtain more funds for data gathering quickly became impossible. The last category of constraints is one that was self-imposed by the Capstone team. The constraints were:

1. The size and duration of the Capstone Project. The project management plan and the system engineering master plan were developed assuming a nine month block of study for the project, with each student working10 hours per week.
2. The number of students and their experience and skill levels. This constraint drove the amount of time that needed to be devoted to arrive at a common language. It also drove which students could be assigned which task without incurring additional project risk.
3. The only networking interface is the Sakai system, which was first used at the start of the Capstone effort. The lack of robustness of this system combined with the Navy Marine Corp Internet restrictions in a Distance Learning environment makes for a fragile backbone on which to hang a project.
4. The analysis tools used for the Capstone completion are limited to those provided by NPS.
5. Availability of stakeholder and SME was viewed as very limited. Data gaps were filled with notional or anecdotal data.
6. The project was unclassified which drove the problem to surface ship hotel services and away from areas such as energy generation on nuclear powered submarines.

Constraints and limitations became risk items that needed to be addressed with specific mitigation plans.

III. EVALUATION CRITERIA

A. MEASURES OF MERIT

Fuel economy, fuel ecology, and fuel surety were determined to be Key Performance Parameters (KPPs) directly from the initial problem statement. Two other KPPs were determined to be the implementation cost and the maintenance time per ship, since the team felt that these cost factors would be important to the acquisition stakeholders. The three remaining KPPs were determined to be changes to availability, reliability, and operational effectiveness of the ship as a weapon system, which were parameters the team believed would be important to operational stakeholders. In the end, the overall key measure of merit for ensuring fuel economy was chosen as "dollars saved per dollars invested," in part driven by the difficulty of directly estimating ecological and surety improvements as well as cost savings directly relating to the fiscally-minded environment that the Navy is current experiencing. Table 3 is an example of a KPP weight distributing scale that was used as a rating scale; in this instance "fuel economy" is shown measured against all other KPPs. This rating scale was sent out to the list of stakeholders who were asked to assign a value representing the importance of the seven KPPs on the right hand side of the table relative to fuel economy, repeated on the left hand side of the table. A value of nine represents the highest possible weight assigned to a KPP, relative to fuel economy, and conversely a value of one is the lowest. Five represents a neutral rating (i.e, same importance as fuel economy).

KPPs											
Fuel Economy ($/mission)	9	8	7	6	5	4	3	2	1	4	Fuel Ecology (mass of pollutants/mission)
Fuel Economy ($/mission)	9	8	7	6	5	4	3	2	1	6	Fuel Surety
Fuel Economy ($/mission)	9	8	7	6	5	4	3	2	1	3	Implementation Cost per Ship ($)
Fuel Economy ($/mission)	9	8	7	6	5	4	3	2	1	3	Maintenance Time (hours)
Fuel Economy ($/mission)	9	8	7	6	5	4	3	2	1	7	Availability (Δ%)
Fuel Economy ($/mission)	9	8	7	6	5	4	3	2	1	7	Reliability (Δ%)
Fuel Economy ($/mission)	9	8	7	6	5	4	3	2	1	9	Effectiveness (Δ%)

Table 3 - KPPs Weight Distributing Scale

Three different stakeholders, representing NSWC, SWDG, and NAVSEA-05, responded to the survey where some difference of opinion emerged, but in general, the responses were fairly consistent as can be seen in Figure 11 below. All three stakeholders rated "Effectiveness" as the parameter that should be weighted the heaviest. "Fuel Ecology" also emerged as the parameter that should be considered the least important which suggests that the SECNAV vision has not yet been fully embraced or incorporated by those who will implement that vision through the acquisition process. Interestingly, results for "Fuel Surety" received very mixed results while two out of three stakeholders agreed on "Implementation Cost," "Training Time," and "Availability".

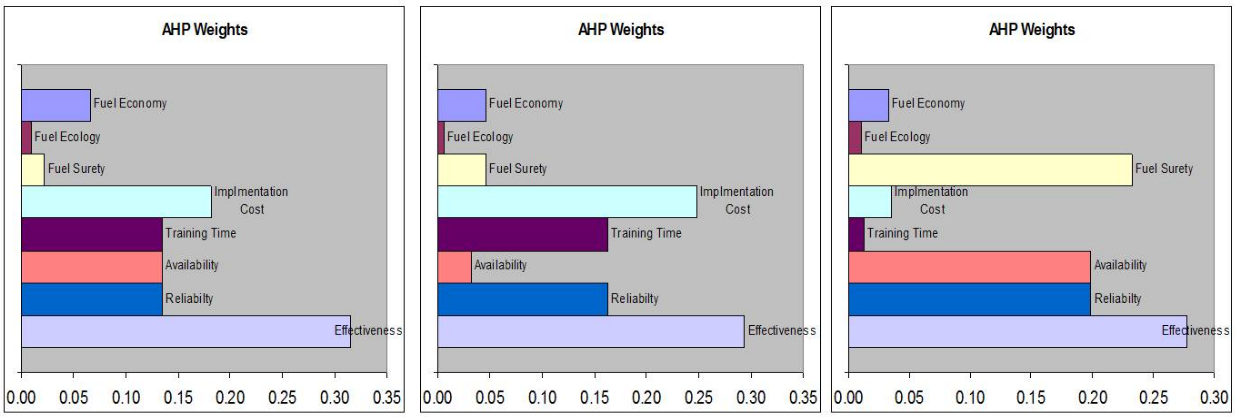


Figure 11 - Stakeholder Rankings

Final results and recommendations at the end of this report will be based on total dollars potentially saved by the Navy if the proposed recommendations are implemented into regular practice.

B. VARIABLES DEFINITION

Key Performance Parameters

The techniques used for comparing the different technological energy economy solutions were quality functional development and overall measure of effectiveness, the variables were comprised of the tentative KPPs that were identified as being applicable to this research effort.

KPPs	*Units*
Fuel Economy	**$/mission**
Fuel Ecology	**mass of pollutants/mission**
Fuel Surety	**days between refueling;** **% likelihood of fuel available**
Implementation Cost per Ship	**$**
Training Time per Sailor	**hr**
Availability	**Δ%**
Reliability	**Δ%**
Effectiveness	**Δ%**

Table 4 - Key Performance Parameters

Single variable KPPs were assessed over predetermined value ranges of interest and compared to the other KPPs which have fixed values that are based on the assessed performance of the technology or procedure. This study focuses on fuel economy and how it changes with respect to different configurations of technology and procedures. The Technology team developed multiple alternative technology configurations (based on stakeholder requirements) for technology and procedures. Those technologies' and procedures' performance data were captured in the KPP units shown above and input into the weighted QFD and Overall Measure of Effectiveness (OMOE) tables for tabulation and comparison. Based on available data and subsystems that were not already being researched by other DoN agencies, the NEST chose a specific set of technologies from the power generation subsystem; more specifically the Heating Ventilation and Air Conditioning (HVAC), Auxiliary Subsystems, and Outfitting and Furnishing (O&F).

Qualitative analysis was conducted based on the Fuel Economy Technology or HSI solutions that were implemented. This analysis focuses on the Fuel Economy solution or variable's impact on the remaining KPPs. For example, if a propulsion plant technology solution was analyzed (varied), implications regarding its Fuel Ecology, Fuel Surety, availability, reliability and overall effectiveness were qualitatively assessed. The primary variable of this study is in the subsystems of the Fuel Economy KPP.

C. DATA NEEDS IDENTIFICATION

Assumptions:

This section describes the derivation of standard energy costs presumed in other calculations unless a different energy cost is explicitly stated. During the site visit to NAVFAC, San Diego, the team was provided a ship study of energy consumed while pier-side onboard the USS HALSEY DDG-97 which also included the class average over 14 ships that NAVFAC collected data for over the period 1 October 2009 to 30 April 2010. Slide 7 of the USS HALSEY Ship Study, indicates that class average daily pier-side electrical cost is $4,891 with an average consumption of 34,454 kWh which results in a pier-side energy rate of approximately $0.14/kWh.[14] This is comparable to the residential rate of $0.13/kWh given by San Diego Gas & Electric for the baseline winter energy charge effective 1 May 2010.[15]

When the ship is generating its own power in the anchor and cruise conditions, the electricity is provided from the Gas Turbine Generators (GTGs). The manufacturer's specified fuel consumption rate is 15,375 BTU/kWh as given in the AG9140 fact sheet.[16] The Bio-energy Feedstock Information Network of the Oak Ridge National Laboratory (ORNL) provides a conversion factor of 130,500 BTU/gal of petro-diesel fuel.[17] The converted fuel consumption rate is approximately 0.11782 gal/kWh. The price of F76 diesel fuel, which is currently used for the gas turbine generators, is given by DESC as $2.81/gal for the price list dated 1 January 2010 which results in a ship-generated energy rate of approximately $0.33/kWh running a single GTG

---

14 Crossan, C., *"USS Halsey DDG-97 Ship Study Presentation,"* NAVFAC, San Diego, CA, 24 May 2010.

15 San Diego Gas & Electric, *"Residential Customer Rate Information, Schedule DR,"* San Diego, CA, 10 May 2010 downloaded 30 August 2010 from http://www.sdge.com/documents/customer/totalrates/5-1-2010/schedule_dr.pdf.

16 Rolls-Royce, *"AG9140 Ship Service Generator,"* London, downloaded 7 June 2010 from http://www.rolls-royce.com/marine/products/diesels_gas_turbines/gas_turbines/ag9140.jsp

17 Oak Ridge National Laboratory, *"Bioenergy Conversion Factors,"* downloaded 7 June 2010 from http://bioenergy.ornl.gov/papers/misc/energy_conv.html

at 2500 kW.[18] However, the typical operational mode is to run two GTGs at 1250 kW which incurs about a 34% penalty in specific fuel consumption as cited in Mahoney, which increases the cost to approximately $0.44/kWh.[19] According to paragraph six on energy considerations in enclosure seven, DoD Instruction 5000.02 states that "The fully burdened cost of delivered energy shall be used in trade-off analyses conducted for all DoD tactical systems with end items that create a demand for energy."[20] The spreadsheet for Interdicted Sea Example one provided by the Defense Acquisition University estimates that for a commodity spot price of $2.81/gal, the resultant Fully Burdened Cost of Fuel (FBCF) is $13.02/gal which adjusts the ship-generated energy rate to approximately $2.06/kWh, or almost 15 times as expensive as energy from the grid pier-side.[21]

It is assumed that the ship-generated rate of $2.06/kWh is constant even for a reduced load on the GTGs in order to simplify the calculations for computing net savings. It is known that the cost is not constant and that the marginal fully burdened cost of electricity for two GTGs will increase as the load is decreased which is shown in Figure 12 below. If the load were reduced by 140 kWh, comparable to the best recommendations identified in Section IX, then the rate load would shift from about 2500 kW to about 2360 kW and the marginal cost would shift from $2.06/kWh to $2.10/kWh. As noted, the net savings identified in Section VIII and IX do not account for this marginal cost increase and therefore the net savings values may be overstated by about 2%. The team did not consider this magnitude of potential error high enough to include in the calculations, but that assumption merits mention here.

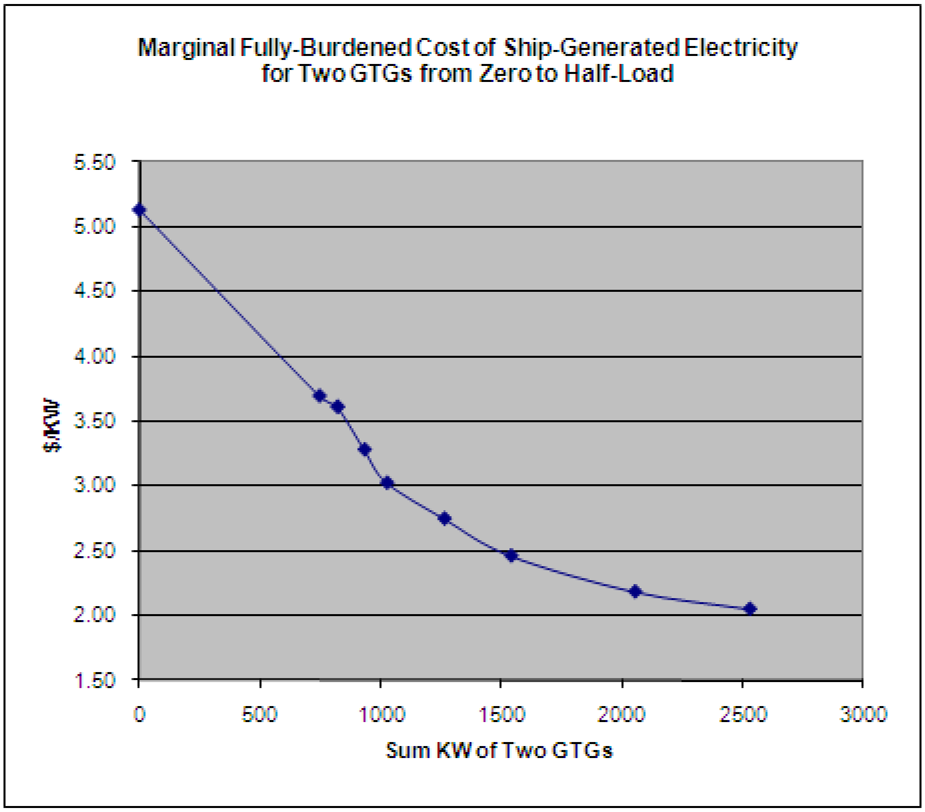
---

[18] Defense Energy Support Center, *"DESC Standard Price List,"* downloaded 7 June 2010 from https://www.desc.dla.mil/DCM/DCMPage.asp?pageid=722

[19] Mahoney, D., Munro, J., Wagner, E., and Lazzari, J. *"Advanced Shipboard Energy Storage System,"* downloaded 7 June 2010fromhttp://www.navalengineers.org/SiteCollectionDocuments/2010%20Proceedings%20Documents/EMTS%202010%20Proceedings/Papers/Thursday/EMTS10_2_14.pdf

[20] Department of Defense, *"Instruction 5000.02 Enclosure 7 Resource Estimation,"* Washington, DC, 8 December 2008, downloaded 7 June 2010 from https://acc.dau.mil/CommunityBrowser.aspx?id=332553

[21] Cotman, R., *"Fully Burdened Cost of Fuel Calculator v7.1,"* downloaded 7 June 2010 from https://acc.dau.mil/CommunityBrowser.aspx?id=318097&lang=en-US



[This Figure shows that the marginal cost per kWh is not constant, but increases as the electrical load decreases.]

Figure 12 - Marginal Cost of Ship-Generated Power

An assumed percentage of time spent pier-side versus at-anchor or at-sea is based on discussions with an SME during the data collection site visit.[22] The assumed values are 67% and 33% respectively resulting in a weighted average energy cost of 0.67 x $0.14/kWh combined with 0.33 x $2.06/kWh for a result of $0.77/kWh. It is noted that a key Figure in Mahoney, “Advanced Shipboard Energy Storage System,” has a labeling error for the specific fuel consumption at 1250 kW (the label is transposed to read 0.76 lb/ship-hr but the data indicates the value is 0.67) which resulted in a 52% penalty, vice the correct 34% penalty, relative to the fuel consumption of the Alison K501-34's design point of 2500 kW (0.50 lb/shp-hr).[19] The error was not detected until near the final submission of this report and is still reflected in Section VII with an average weighted energy cost of $0.86/kWh vice the corrected value of $0.77/kWh. Section VII still reflects the error since the difference in energy cost is an insensitive parameter, as

[22] Williamson, R., private conversation at NAVFAC, San Diego, CA, 24 May 2010.

detailed in Section VIII, and there was insufficient time to correct Section VII without extending the project deadline. The corrected cost factor is accounted for in the common analysis results of Section VIII and the recommendations and conclusions of Section IX.

The labor cost for maintenance personnel has been assumed at $28.00/hour based on the pay for an enlisted petty officer at rate 3 of $1,923/month as cited on the Navy website and assuming 2,080 hours/year and a 2.5 scale factor to account for direct labor rates (employee benefits, facility and management overhead, etc.).[23]

D. RISKS AND UNCERTAINTY IDENTIFICATION

Approach:

Both technical and programmatic risks were monitored throughout the nine month Capstone effort for the analysis of energy security of the DDG-51 class of U.S. Naval Ships. Management of the associated risks was facilitated with a risk management plan (RMP) in direct accordance with the Risk Management Guide for DoD Acquisition, Sixth Edition.[24] All risk related efforts were conducted with this RMP as a guide.

The technical risk was divided into three phases:

Phase 1 risk was related to the implementation of areas explored that included baseline components. User feedback was used in an effort to determine and assess the scoring and ranking of the component risks. The assessment was conducted after prescreening in terms of electrical load levels (kilowatts).

Phase 2 used a list of viable technology solutions in the pre-selected areas to determine the implementation risk, based on both technology readiness levels (TRL) and manufacturing readiness levels (MRL), or other design-related characteristics.

---

[23] United States Navy, *"Navy and Enlisted Pay,"* downloaded on 5 August 2010 from http://www.Navy.com/Navy/joining/benefits/pay.html.

[24] Department of Defense, "*Risk Management Guide for DoD Acquisition*," Washington, DC, August 2006, downloaded on 30 August 2010 from http://www.acq.osd.mil/se/docs/2006-RM-Guide-4Aug06-final-version.pdf.

Phase 3 looked at the results of the first two phases to determine the risk exposure for the top alternatives based on cost (primarily lifecycle) and performance (KPPs or OMOE).

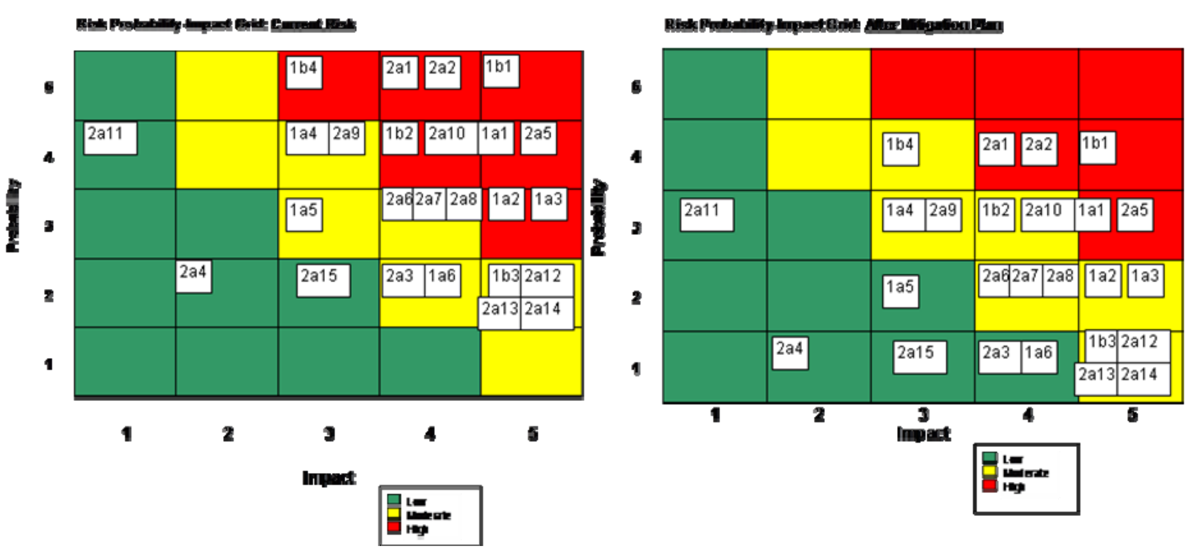
All risks were captured using a risk register from which a 5x5 matrix was populated to capture all risks from three main categories: programmatic, schedule, and performance. Figure 13 shows the current risks associated with the project and the development of alternatives and a comparison of those risks after mitigation plan.

Risk Identification Number	**Risk**
1a1	Student drop out
1a2	Failure to perform given tasks
1a3	poor performance
1a4	limited knowledge of IPT members on scope
1a5	mismatched skills to appropriate areas
1a6	Slow response to incorporating changes
1a7	Wrong Technique Selected (Schedule Line Item 44)
1a8	Variables undefined and unaccounted for (Schedule Line Item 45)
1a9	Data needs misidentified (schedule line item 46)
1a10	Misidentified Risks and Uncertainities (Schedule line Item 47)
1a11	Undefined Modeling Requirements (schedule line item 48)
1a12	New data unavailable (schedule line item 51)
1b1	Unable to collect data needed
1b2	Poor quality ASEO process IRT weights, parameters
1b3	Unable to complete all phases of project timely
1b4	Risk reserved not built into each task
2a1	Unable to obtain appropriate stakeholder feedback to support project
2a2	Unable to obtain appropriate stakeholder feedback to support project

2a3	Unable to obtain appropriate stakeholder feedback to support project
2a4	Change in stakeholder feedback as project progresses
2a5	Develop correct evaluation criteria and techniques
2a6	Obtaining data needed
2a7	Improper AoA results
2a8	Improper AoA results
2a9	Dissatisfaction with AoA results
2a10	Poor execution of the ASEO process
2a11	Final Report is not useful to stakeholders
2a12	Inadequate production of final report
2a13	Inadequate production of final report
2a14	Inadequate production of final report
2a15	Poor model development

[Risk Identification Numbers are denoted by alpha-numeric prefixes. Prefix 1a refers to programmatic resource risk. Prefix 1b refers to programmatic schedule risk. Prefix 2a refers to technical risk.]

Table 5 - Defines the Risk Identification Numbers



[This Figure compares risks probability to impact before and after mitigation.]

Figure 13 - Risk Probability Impact Matrix

Risk Identification Number	Risk
1a1	Student drop out
1a2	Failure to perform given tasks
1a3	poor performance
1a4	limited knowledge of IPT members on scope
1a5	mismatched skills to appropriate areas
1a6	Slow response to incorporating changes
1a7	Wrong Technique Selected (Schedule Line Item 44)
1a8	Variables undefined and unaccounted for (Schedule Line Item 45)
1a9	Data needs misidentified (schedule line item 46)
1a10	Misidentified Risks and Uncertainities (Schedule line Item 47)
1a11	Undefined Modeling Requirements (schedule line item 48)
1a12	New data unavailable (schedule line item 51)
1b1	Unable to collect data needed
1b2	Poor quality ASEO process IRT weights, parameters
1b3	Unable to complete all phases of project timely
1b4	Risk reserved not built into each task
2a1	Unable to obtain appropriate stakeholder feedback to support project
2a2	Unable to obtain appropriate stakeholder feedback to support project
2a3	Unable to obtain appropriate stakeholder feedback to support project
2a4	Change in stakeholder feedback as project progresses
2a5	Develop correct evaluation criteria and techniques
2a6	Obtaining data needed
2a7	Improper AoA results
2a8	Improper AoA results

2a9	Dissatisfaction with AoA results
2a10	Poor execution of the ASEO process
2a11	Final Report is not useful to stakeholders
2a12	Inadequate production of final report
2a13	Inadequate production of final report
2a14	Inadequate production of final report
2a15	Poor model development

[Risk Identification Numbers are denoted by alpha-numeric prefixes. Prefix 1a refers to programmatic resource risk. Prefix 1b refers to programmatic schedule risk. Prefix 2a refers to technical risk.]

Table 5 - Programmatic Risk Identification

Risks are identified by Risk Identification Numbers. Technical risks begin with a number 2 designator while programmatic risks begin with a number 1 designator. Notation (a) refers to resource risks and (b) refers to schedule risks. On the left of Figure 13, the risk as it is currently and on the right we see how the risk has changed post mitigation. Some examples of programmatic risk were limited time to gain knowledge on Capstone related topics or incorrectly identifying SMEs or stakeholders. Examples of technical risk were broad scope, which required time to de-scope, or slow response/lack of a response from key SMEs or stakeholders. Once the risks were identified, a mitigation plan was created for each risk in conjunction with a trigger action. Additionally, the mitigation plan allowed the risk levels to be reduced. The plan was to continually reassess risks and look for opportunities where these high level risks could be reduced to either medium or low thus making risk assessment an iterative process that proved very beneficial in terms of keeping the project risk to a minimum.

The Capstone team developed a methodology to monitor technical and programmatic risk as shown in Figure 14. What we see here is an example of the steps taken to assess a risk factor. In this particular case the steps required for risk mitigation run from the initial analysis approach through the end analysis.

Step	Description of Mitigation Step	Dates of Mitigation		Rating at End	
		Start	End	P	I
1	Analysis Approach			2	2
2	Evaluation Criteria			3	3
3	Evaluation Techniques			3	4
4	Source Data Collection			2	2
5	Analysis of Alternatives Development			3	3
6	Evaluation of Alternatives			3	4
7	Analysis Results			4	4

Date Closed: ____________

Close-out Rationale:

[This Figure is an example of the steps taken to mitigate the risk encountered during the execution of the Capstone project.]

Figure 14 - Example of Steps Taken for Risk Mitigation

IV. EVALUATION TECHNIQUES

A. TECHNIQUES SELECTION

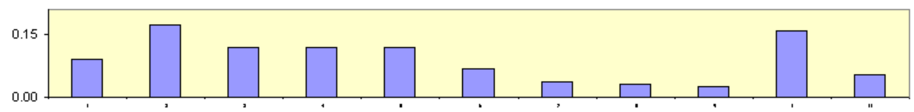
The task description comes from block 4 of Figure 9, which is in turn adapted from the generic systems analysis process shown in Figure 4.9 of Blanchard & Fabrycky Systems Engineering Analysis, 4ed.[5] There is no amplifying language in the text body that refers to this Figure, so the bullets in block 4 are restated here:

- Select appropriate techniques--simulation, mathematical/linear/dynamic programming, queuing, accounting, networking, etc.
- Define modeling requirements (technique application)

The cohort applied the evaluation techniques learned and applied during SE3303 Systems Analysis, under Professor Brigitte Kwinn. Those techniques included a ranking of stakeholder priorities among top-level key performance parameters (KPPs) using the analytical hierarchy process (AHP - pair-wise quick comparison) as previously shown in Figure 11. The AHP ranking then was fed into a two-tier weighted house of quality/Quality Functional Deployment (QFD) table that pits the stakeholder customer requirements against the design requirements or constraints as shown in Table 6 and Table 7. Each subsystem under consideration was quantified in an evaluation matrix with resultant normalized scores as shown in Table 8 below. This data was then placed into an (OMOE) table for comparison and analysis of different alternatives using the weightings of stakeholder rankings flowed down through the QFD to each subsystem. Additionally, the net savings in years 1, 5, and 10 were calculated and plotted against the investment cost in year 1 to reveal a Pareto boundary of optimal solutions.

Customer Requirement (Whats)	Weight	Crew Size	Propulsion	SONAR Range	RADAR Range	ESM Range	HVAC	Aux Sys	Outfitting & Furnishing	Electrical Plant	Armaments	Damage Control	
Fuel Economy	0.0427		9				3	3	1	1			
Fuel Ecology	0.0083	3	3				3	3	1	1			
Fuel Surety	0.1002		9				1	1	1				
Implementation Cost	0.1320	9	3				1	1	3	3			
Maintenance Time	0.0658	9		3	3	3	3	3	3	1	3	3	
Availability	0.1240		3	1	1	1	1	1	1	1	3		
Reliability	0.1782	1	3	3	3	3	3	3	1	1	9	3	
Effectiveness	0.3489	3	9	9	9	9	3				9	3	
Check Sum	1.0000												
Goal Value													
Threshold Value													
Weighted Performance		3.0	5.8	4.0	4.0	4.0	2.3	1.2	1.0	0.8	5.3	1.8	33.3
Percent Performance		0.0911	0.1730	0.1202	0.1202	0.1202	0.0688	0.0373	0.0315	0.0245	0.1598	0.0535	1.0000

Design Characteristics (Hows)

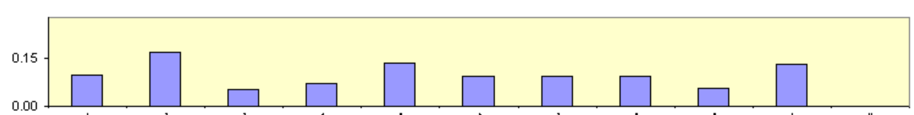


[This table shows the mapping of the average weighting of the customer requirements from the three stakeholders to the weighted performance for design characteristics.]

Table 6 - Quality Function Deployment #1

Design Characteristics (Whats)	Weight	Pre-Heater	AC Chill-Water Pump	Hot Water Heater	Fuel Xfer Heater	Fire Pumps	Ovens	Dryers	Dishwater Heaters	Lighting Fixtures	Fuel Type		
Crew Size	0.0911		3	3		3	9	9	9	3			
Propulsion	0.1730	3			3						9		
SONAR Range	0.1202		3										
RADAR Range	0.1202		3										
ESM Range	0.1202		3										
HVAC	0.0688	9	9										
Aux Sys	0.0373			9	9	9							
Outfitting & Furnishing	0.0315						9	9	9				
Lighting	0.0245									9			
Armaments	0.1598					3							
Damage Control	0.0535					9				3			
Check Sum	1.0000												
Goal Value													
Threshold Value													
Weighted Performance		1.1	2.0	0.6	0.9	1.6	1.1	1.1	1.1	0.7	1.6	0.0	11.7
Percent Performance		0.0975	0.1692	0.0522	0.0733	0.1346	0.0946	0.0946	0.0946	0.0561	0.1334	0.0000	1.0000

Design Forms (Hows)



[This table shows the mapping of the design characteristics to the design forms which represent the eight subsystems, along with fuel type, studied in detail in this report.]

Table 7 - Quality Function Deployment #2

Attribute Table	Baseline	Alternative A	Alternative B	Alternative C
Pre-Heater	Tubular	Chromolax		
AC Chill-Water Pump	Baseline	Variable Freq Drive		
Hot Water Heater	Baseline	Hubbell HWH Only 1000 G; 250kW	Hubbell HWH (XXX G) + Hubbell Tankless Hybrid Combination	X Hubbell Tankless
Fuel Xfer Heater	Baseline	Enhanced BL	Direct Injection	
Fire Pumps	Baseline	Vertical Inline		
Ovens	Baseline	HSI	HE Model	
Dryers	Baseline Electric	A	B	
Dishwater Heaters	Tankless	Hybrid	Solar	
Lighting Fixtures	Incandescent	HSI+Fluorescent	Motion-Activated LED	
Fuel Type	Baseline	Corn Diesel	HE Sugar Diesel	
Attribute Scoring	**Baseline**	**Alternative A**	**Alternative B**	**Alternative C**
Pre-Heater	1.00	0.80		
AC Chill-Water Pump	1.00	1.00		
Hot Water Heater	0.80	0.78	0.45	0.49
Fuel Xfer Heater	1.00			
Fire Pumps	0.75	0.75		
Ovens	0.27	0.49	0.40	0.62
Dryers				
Dishwater Heaters				
Lighting Fixtures				
Fuel Type				

[This table is an example showing the alternatives for each subsystem in the upper half and normalized overall measures of effectiveness in the lower half. The actual table with final results appears in Section VIII of this report.]

Table 8 - Attribute Scoring for Alternatives

B. COST MODELING

The team originally considered that where direct cost data could not be obtained through research and vendors or suppliers that they would use the COSYSMO cost modeling tool in an effort to estimate some or all portions of the life-cycle cost for replacement of baseline subsystems. However, the cost modeling is captured more simply in an Excel spreadsheet and has linear relationships documented for specific subsystem analyses in Section VIII below.[25]

[25] Cohort 311-912, "311-912.xls," Monterey, CA, 2010, downloaded from http://diana.nps.edu/~dholwell/energy/311-0912.xls

V. SOURCE DATA COLLECTION

A. EXISTING DATA

Approach:

To determine relevant existing data, the team elected to explore electrical loads generated by the DDG-51 gas turbine generator (GTG) set. The set consists of two GTGs, (one forward, one aft) operating in parallel and a third GTG operating in stand-by mode in the event of primary GTG overloading. The DDG-51 electrical load analysis details the loading requirement for all systems requiring power on the ship and is organized via a ship work breakdown structure (SWBS). The ship electrical load analysis details operating loads under typical operating conditions.[26] Working with Northrop Grumman Ship Building (NGSB) SMEs on electrical load analysis, initial existing data consisted of collecting the estimated summary data for each of the nine SWBS categories. Table 9 summarizes the ship's electrical loading per SWBS categories for the shore, anchor and cruise operating during winter and summer environmental conditions.[27] Battle operating condition was omitted from this summary and is out of scope for this study. SMEs advised the use of the maximum loading data as opposed to loading after shed condition, as the after shed phenomena functions as a contingency in the event of electrical overloading of the generators.

[26] Naval Sea System Command, *MIL-STD-2189, "Design Methods for Naval Shipboard Systems,"* Section 310-1, Electric System Load and Power Analysis for Surface Ships, Washington, DC, September 2000.

[27] Naval Sea System Command, "*DDG 51 Class Electric Load Analysis,"* NAVSEA Drawing Number 300-7028163, Washington DC, January 2009.

		SUMMARY MAX CONNECTED LOADS									
				WINTER					SUMMER		
SWBS No.	LOAD CATEGORY	CONN LOAD		SHORE Kw	ANCHOR Kw	CRUISE Kw	BATTLE Kw		SHORE Kw	ANCHOR Kw	CRUISE Kw
200	PROPULSION PLANT	2080		280	320	490			280	320	530
300	ELECTRIC PLANT	830		135	230	210			140	220	210
314	POWER CONVERSION EQPT	730		105	120	300			105	120	300
400	COMMAND & SURVEILLANCE	1990		390	450	1310			345	400	1265
500	AUXILARY SYSTEM	2510		565	600	960			530	560	815
514	HVAC SYSTEM	3175		1780	1510	1630			710	840	960
580	MECHANICAL HANDLING SYS	250		3	25	24			3	20	20
600	OUTFITTING & FURNISHING	750		210	260	250			210	220	220
700	ARMAMENT GENERAL	390		120	120	140			15	15	30
	TOTAL	12705		3588	3635	5314			2338	2715	4350

[This Figure shows the total electrical loading required by the GTGs per specified load category or SWBS as it pertains to the ship operating conditions during a 24 hour day. The focus for this study is on the winter shore and cruise conditions with total design operating loads of 3588kW and 5314 kW, respectively. Items in red were out of scope.]

Table 9 - DDG-51 Electrical Load Analyses (Estimate)

The left portion of Table 9 details the SWBS category and the corresponding full load input kilowatts or rated kilowatt input of connected equipment (Connection Load) associated with the SWBS category. Data contained within the winter maximum connected loads specifies the demand load for a10 degree Fahrenheit day and utilizes an operating loading factor (LF) assigned to each individual item of equipment for shore, anchor, cruise and battle operating conditions. The LF is described as a percentage of time in which the equipment is in operation in a 24 hour period. The LF is multiplied by the connected load to obtain the electrical load of the equipment for each operating condition. Similarly, for a summer environmental condition, connected loading is computed in the same manner for a 90 degree Fahrenheit day. NAVSEA Drawing Number 300-7028163 and MIL-STD-2189 define applicable operating conditions as follows:[28]

- Shore – "A condition where the ship receives all electric power for a shore facility or tender. Ship electric power plants and propulsion plants are shut down."
- Cruise – "A condition where the ship cruises at design cruising speed and is underway alert. Ordinary ship functions are performed and two propulsion gas turbine engines are in operation."

- Anchor – "A condition where the ship supplies all electric power while at anchor. Ship propulsion plant is shutdown and electric power generating plant is supplying all electric power."

Load Analysis data is primarily used to aid electrical and mechanical design engineers in the sizing of the GTGs. The maximum load conditions are larger than typical loading estimates and act as an assurance that the GTGs are adequately designed to meet the worst case operating condition scenarios. The cohort utilized the load analysis data as a basis to identify SWBS categories with predicted large energy consumptions for evaluation and further study. Data captured via the NAVFAC visit served as acquired field data and detailed average daily energy consumption and confirms the design data as an over-estimate. Section V.D provides more information on the results of the NAVFAC visit.

Findings:

The summary data was evaluated to determine the SWBS areas with the greatest potential in energy savings for further analysis. The cohort elected to exclude SWBS series 200 propulsion plant, 400 command and surveillance, and 700 armament general due to the potential of recommendations in those areas affecting mission effectiveness, combat systems, and survivability. Additionally, changes in these areas may not be cost effective due to prohibitive operational test and safety recertification. The team elected to perform a tier 1 down-select using the Pareto Analysis to refine the data scope to concentrate on the winter shore and cruise conditions of SWBS 514 HVAC, SWBS 500 auxiliary system, limited portions of SWBS 600 outfitting and furnishing, and the lighting portion of SWBS 300 electric plant. Load analysis data was updated to detail the systems, subsystems and equipment requiring electrical load for the down-selected SWBSs. The winter operating condition was elected for further evaluation due to its consistently higher loading requirements when compared to the summer condition. Table 10 details a snapshot of the equipment load requirements for the HVAC system. Equipment requiring electrical power is listed individually along with the rated horsepower of the electric motor, if required. The equipment electrical demand value per operating condition is also listed including the equipment rated connect loaded, and operating LF. EA Drawing Number 300-7028163.]

Table 11 and Table 12 entail snapshots of auxiliary and outfitting and furnishing (O&F) subsystem and equipment load requirements respectively. Auxiliary subsystem selection was based on those subsystems that were considered to be the heavy hitters or major consumers of electrical power. The power consuming requirements ranged between 100 kW and 250 kW, depending upon operating condition. The selected subsystems were:

- SWBS 521 Firemain and Flushing Seawater Systems (Sea Water Systems)
- SWBS 531 Desalination Plant
- SWBS 533 Potable Water
- SWBS 541 Ship Fuel and Fuel Compensating System
- SWBS 561 Steering and Diving Control System
- SWBS 593 Environmental Pollution Control Systems

O&F subsystem selection consisted of areas where crew habitability changes were considered to have the most potential for improvements as well as opportunities for technology improvements aimed at energy savings. The elected O&F subsystems were:

- SWBS 643 Enlisted Personnel, Berthing and Messing Spaces (Crew Living Spaces)
- SWBS 644 Sanitary Spaces and Fixtures
- SWBS 651 Commissary Spaces (Food Service Spaces)
- SWBS 652 Medical Spaces
- SWBS 655 Laundry
- SWBS 665 Workshops, Laboratories, Test Areas

The following are subcomponents of SWBS 600:

SWBS 514 - HVAC SYSTEM							
		Conn Load	Shore			Cruise	
			Winter			Winter	
Name of Equipment	**Rated HP**	**kW**	**LF**	**kW**		**LF**	**kW**
AC Chilled Water Pump No 1	60	46.6	0.9	43		0.9	42
AC Chilled Water Pump No 2	60	46.6	0	0		0.9	42
AC Chilled Water Pump No 3	60	46.6	0.9	43		0.9	42
AC Chilled Water Pump No 1A	60	46.6	0	0		0	0
AC Chilled Water Pump No 4	60	46.6	0	0		0	0
AC Compressor No.1 (AMR No. 1)	227	171.2	0.2	35		0.3	52
AC Compressor No.1A (AMR No. 1)	227	171.2	0	0		0.1	18
AC Compressor No.2 (AMR No. 2)	227	171.2	0	0		0.3	52
AC Compressor No.3 (AMR No. 2)	227	171.2	0.2	35		0.3	52
AC Compressor No. 4 (A/C MCHRY & PMP RM)	227	171.2	0	0		0.3	52
CL CIR "W" Fan ES 01-192-1 (Item 1B)	15	12.7	0.3	4		0.3	4
CL CIR "W" Fan ES 01-259-2 (Item 9B)	5	3.3	0.9	3		0.9	3
CL CIR "W" Fan SS 2-204-1 (Item 94)	17.5	14.7	0.3	5		0.3	5
CL CIR "W" Fan SS 3-252-2 (Item 98)	5	3.3	0.9	3		0.9	3
CL CIR W Fan ES 01-256-2	7.5	6.4	0.3	2		0.3	2
CL CIR W Fan SS 2-263-2 - ER2	12.5	10.6	0.3	4		0.3	4

[This table displays an example of the listed equipment contained within the HVAC subsystem and their corresponding manufacturer connected electrical loads, loading factors, electrical loading per operating conditions and rated electrical motor horsepower, if required. A complete listing of all HVAC subsystem is located in NAVSEA Drawing Number 300-7028163.]

Table 10 - HVAC System Electrical Load Requirements

SWBS 500 - AUXILARY SYSTEM							
			Conn Load	Shore Winter		Cruise Winter	
Name of Equipment		Rated HP	kW	LF	kW	LF	kW
SWBS: 512 - Ventilation Systems (HVAC System - Excluding SWBS 514)			1.244		0.95		0.95
SWBS: 516 - Refrigeration Systems (Refrigerating Plants)			44.02		28.2		28.2
SWBS: 521 - Firemain and Flushing Sea water Systems (Sea Water Services)	*Totals>*		736.03		240.62		246.7
FIRE PUMP NO. 1		150	119.3	0.2	23.86	0.2	23.86
FIRE PUMP NO. 5		150	119.3	0.2	23.86	0.2	23.86
FIRE PUMP NO. 6		150	119.3	0.2	23.86	0.2	23.86
FIRE PUMP NO.2		150	119.3	0.2	23.86	0.2	23.86
FIRE PUMP NO.3		150	119.3	0.2	23.86	0.2	23.86
FIRE PUMP NO.4		150	119.3	1	119.3	1	119.3
FIREMAIN DISCHARGE VALVE, V0119			0.4	0.1	0.04	0.4	0.265
FIREMAIN DISCHARGE VALVE, V0153			0.662	0.1	0.66	0.4	0.264
FIREMAIN DISCHARGE VALVE, V0217			0.66	0.1	0.66	0.4	0.16
FIREMAIN DISCHARGE VALVE, V0257			0.4	0.1	0.04	0.4	0.16
FIREMAIN DISCHARGE VALVE, V0282			0.662	0.1	0.066	0.4	0.265
FIREMAIN SYSTEM MO VALVE V0128			0.1	0.1	0.1	0.4	0.04
FIREMAIN SYSTEM MO VALVE V0129			0.1	0.1	0.1	0.4	0.04
FIREMAIN SYSTEM MO VALVE V0130			0.1	0.1	0.1	0.4	0.04

[This table displays an example of the listed equipment contained within the Auxiliary subsystem and their corresponding manufacturer connected electrical loads, loading factors, electrical loading per operating conditions and rated electrical motor horsepower, if required. The Firemain and Flushing Sea water system component is highlighted in yellow to indicate its higher electrical load requirements for comparison to other auxiliary subsystem components such as the refrigeration subsystem. A complete listing of all Auxiliary subsystem equipment is located in NAVSEA Drawing Number 300-7028163.]

Table 11 - Auxiliary System Electrical Load Requirements

SWBS 600 - O&F								
		Conn Load		Shore			Cruise	
				Winter			Winter	
Name of Equipment	Rated HP	kW		LF	kW		LF	kW
SWBS: 644 - Sanitary Spaces & Fixtures (Plumbing Fixtures and Fittings)								
Water Cooler	0.3	0.66		0.4	0.264		0.4	0.264
Water Cooler	0.3	0.66		0.4	0.264		0.4	0.264
Water Cooler	0.3	0.66		0.4	0.264		0.4	0.264
Water Cooler	0.3	0.66		0.4	0.264		0.4	0.264
Water Cooler	0.3	0.66		0.4	0.264		0.4	0.264
Water Cooler	0.3	0.66		0.4	0.264		0.4	0.264
Water Cooler	0.3	0.66		0.4	0.264		0.4	0.264
Totals		4.62			1.848			1.848
SWBS: 651 - Commissary Spaces (Food Service Spaces0								
BALDOR MODEL 500 BENCH GRINDER		0.52		0.1	0.052		0	0
BEVERAGE SERVICE STAND	0.3	0.69		0.3	0.207		0.3	0.207
BEVERAGE SERVICE STAND	0.3	0.69		0.3	0.207		0.3	0.207
BREAD SLICER	0.33	0.59		0.1	0.059		0.1	0.059
COFFEE MAKER		1.8		0.2	0.36		0.2	0.36
COFFEE MAKER		2.4		0.2	0.48		0.4	0.96
COFFEE URN (TWIN 3 GALLON)		8		0.2	1.6		0.4	3.2
COMB CONVECTION OVEN STEAMER		44		0.4	17.6		0.4	17.6
COMB CONVECTION OVEN STEAMER		44		0.3	13.2		0.3	13.2
COMBI-PAN SKITTLE COOKER		14.4		0.3	4.32		0.3	4.32
CONVEYER TOASTER		3.6		0.2	0.72		0.2	0.72
DISHWASHER	0.5	2.34		0	0		0.3	0.702
DISHWASHER		22.5		0.3	6.75		0.3	6.75
DISHWASHER BOOSTER HEATER		15		0	0		0.3	4.5
DISHWASHER BOOSTER HEATER		15		0	0		0.3	4.5
DISHWASHER BOOSTER HEATER (SCULLERY)		27		0.3	8.1		0.3	8.1
DISHWASHER HOT WATER HTR (SCULLERY)		54		0.3	16.2		0.3	16.2

[This table displays an example of the listed equipment contained within the O&F subsystem and their corresponding manufacturer connected electrical loads, loading factors, electrical loading per operating conditions and rated electrical motor horsepower required. A complete listing of all the O&F subsystem are located in NAVSEA Drawing Number 300-7028163.]

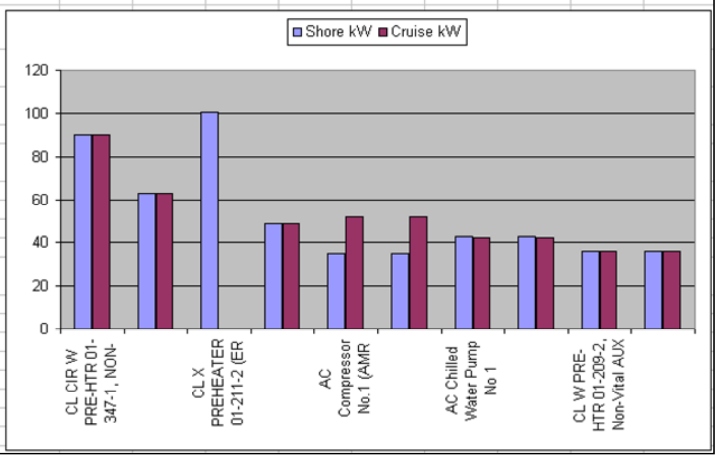
Table 12 - Outfitting and Furnishing (O&F) System Electrical Load Requirements

Final Down-Select:

The existing data evaluation concluded with a second tier selection to condense the number of the subsystems, per the three SWBSs, for further evaluation. The HVAC system consists of 334 equipment items that require electrical power with a loading factor between 0 and 1 during a 24 hour period. Auxiliary systems consist of 6 major electrical power consuming subsystems with varying amounts of equipment per subsystem. Six subsystems of the O& F system were highlighted as area of investigation for this study.

The final selections of subsystems focused on the top 10 consuming equipment items per SWBS category, excluding vital equipment which impacts mission effectiveness and survivability. For the HVAC system the refocusing resulted in Pre-Heaters and AC Chill Water Pumps as items of focus. Figure 15 highlights the results of the HVAC down-select detailing the loading requirements and their weighted average. The total loading based on the weighted average for this subsystem is 447.7 kW. With a $0.14/kW electricity cost for shore power and $ 2.06/kW electricity cost for cruise conditions, the approximate yearly cost to operate the listed equipment in the HVAC subsystem is $3M.

Name of Equipment	0.5 Shore kW	0.5 Cruise kW	WgtAv
CL CIR W PRE-HTR 01-347-1, NON-VTL AUX Z 4 P2	90	90	90
CL CIR W PRE-HTR 01-128-1, NON-VTL AUX Z 2 PNL 3	63	63	63
CL X PREHEATER 01-211-2 (ER NO. 1)	100.6	0	50.3
CL CIR W PRE-HTR 01-339-3, NON-VTL AUX Z 4 P2	49	49	49
AC Compressor No.1 (AMR No. 1)	35	52	43.5
AC Compressor No.3 (AMR No. 2)	35	52	43.5
AC Chilled Water Pump No 1	43	42	42.5
AC Chilled Water Pump No 3	43	42	42.5
CL W PRE-HTR 01-209-2, Non-Vital AUX ZN 2 PNL 3	36.2	36.2	36.2
CL Z PREHEATER 01-339-1, VENT ZN 4	36.2	36.2	36.2

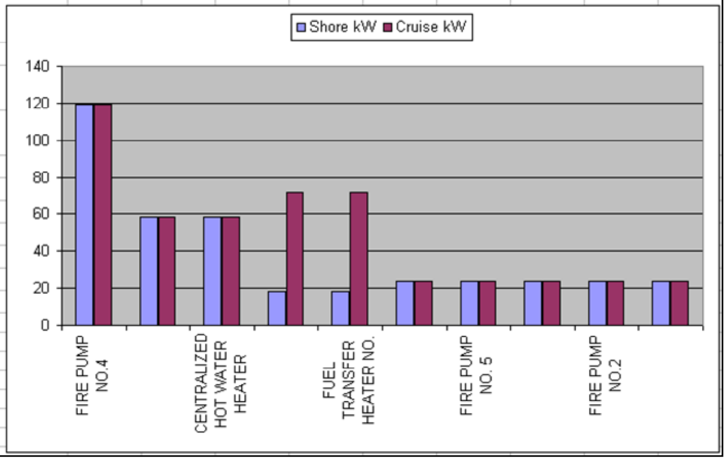


[This Figure displays the top electrical loading equipment in the HVAC subsystem resulting from the down-select process. Although the DDG-51 is pier-side 67% of the time, it was originally assumed to be 50% operating time between shore and cruise conditions from which the weighted average was determined here.]

Figure 15 - HVAC Equipment Tier 2 Down-Select Results

Figure 16 displays the final equipment selection of the Auxiliary System. Hot water heaters, fuel transfer heaters and fire pumps were determined to be items necessitating further evaluation for technology improvements aimed at energy conservation. The design total loading based on the weighted average for this subsystem is 445.6 kW.

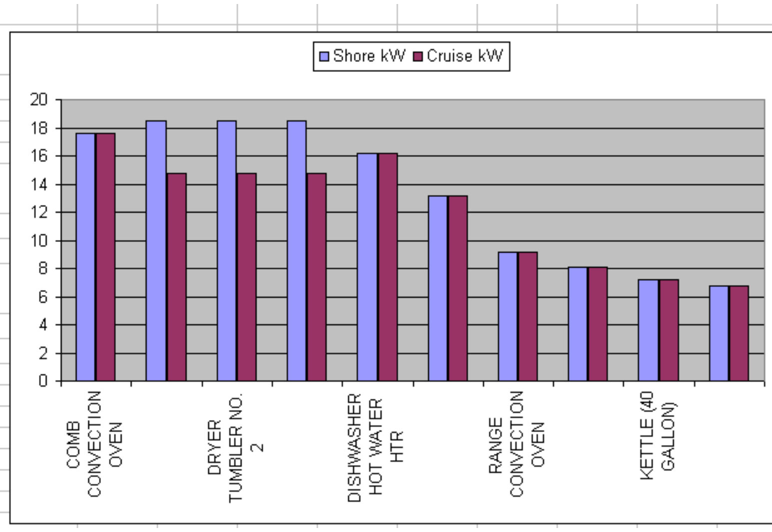
	0.5	0.5	
	Shore	Cruise	
Name of Equipment	kW	kW	WgtAv
FIRE PUMP NO.4	119.3	119.3	119.3
CENTRALIZED HOT WATER HEATER NO. 1A	58.5	58.5	58.5
CENTRALIZED HOT WATER HEATER NO.1B	58.5	58.5	58.5
FUEL TRANSFER HEATER NO. 1	18	72	45
FUEL TRANSFER HEATER NO. 2	18	72	45
FIRE PUMP NO. 1	23.86	23.86	23.86
FIRE PUMP NO. 5	23.86	23.86	23.86
FIRE PUMP NO. 6	23.86	23.86	23.86
FIRE PUMP NO.2	23.86	23.86	23.86
FIRE PUMP NO.3	23.86	23.86	23.86



[This Figure displays the top electrical loading equipment in the auxiliary subsystem resulting from the down-select process. Although the DDG-51 is pier-side 67% of the time, it was originally assumed to be 50% operating time between shore and cruise conditions from which the weighted average was determined here.]

Figure 16 - Auxiliary System Equipment Tier 2 Down-Select Results

	0.5	0.5	
	Shore	Cruise	
Name of Equipment	kW	kW	WgtAv
COMB CONVECTION OVEN STEAMER	17.6	17.6	17.6
DRYER TUMBLER NO. 1	18.5	14.8	16.65
DRYER TUMBLER NO. 2	18.5	14.8	16.65
DRYER TUMBLER NO. 3	18.5	14.8	16.65
DISHWASHER HOT WATER HTR (SCULLERY)	16.2	16.2	16.2
COMB CONVECTION OVEN STEAMER	13.2	13.2	13.2
RANGE CONVECTION OVEN	9.12	9.12	9.12
DISHWASHER BOOSTER HEATER (SCULLERY)	8.1	8.1	8.1
KETTLE (40 GALLON)	7.2	7.2	7.2
DISHWASHER	6.75	6.75	6.75



[This Figure displays the top electrical loading equipment in the O&F subsystem resulting from the down-select process. Although the DDG-51 is pier-side 67% of the time, it was originally assumed to be 50% operating time between shore and cruise conditions from which the weighted average was determined here.]

Figure 17 - Outfitting and Furnishing (O&F) System Equipment Tier 2 Down-Select

As portrayed in Figure 17, the results of the O&F subsystem existing data evaluation include ovens, dryers, dishwasher heaters, and kettles for further analysis. The loading factors for these items range between 0.1 and 0.5 during a 24 hour period. The design total loading based on the weighted average for this subsystem is 128.12 kW.

B. GENERATION OF NEW DATA

Approach:

The task description came from block 6 of the generic systems analysis process shown in Figure 4.9 of Blanchard & Fabrycky Systems Engineering Analysis, 4ed.[5] Just to restate, the bullets in block 6 are:

- Acquire existing data
- Generate new data
- Document assumptions

The cohort used actual existing data provided by design engineers at Northrop Grumman Ship Building as well as from measurements supplied by NAVFAC San Diego in regard to the subsystems of focus that resulted from the Pareto analysis of the Ship Work Breakdown Structure, but for situations where existing data could not be collected, new data was generated by model extrapolation or through use of engineering judgment. In most cases a simple linear model of proportionality is assumed, but specific modeling assumptions are detailed in the individual subsystem analyses in Section VII below.

C. DATA GATHERING METHODOLOGY

The task description came from block 3 of the generic system analysis process shown in Figure 4.9 of Blanchard & Fabrycky Systems Engineering Analysis, 4ed.[5]

The data gathering methodology adopted by the team consisted of using an extensive DDG-51 ship survey questionnaire (Appendix D) to gather additional ship energy related information. Both the template and the questionnaire were utilized during the team's visit at the NAVFAC Facility in San Diego. While the template provided a structured method for the collection of system (KPP), the questionnaire added more specific information in terms of system energy consumption and system performance information of the DDG-51 necessary for the development of system specification baselines and the analysis of alternatives (AoA).

D. ACQUIRED FIELD TEST DATA

Approach:

To acquire actual test or field data, the cohort contacted Naval Facilities (NAVFAC) San Diego to request meetings with Naval Base Energy Infrastructure and to tour a DDG-51 Class Hull to conduct an energy survey to collect data on selective ship technologies, as discussed in Section III-C-2 of this report. This effort was to also validate and update the assumed DDG-51 load analysis to ensure a more accurate analysis of the ship's energy loading profile.[28] Five cohort members, pictured in Figure 18 and Figure 19 below, were approved for a pier-side visit of the DDG-97, USS HALSEY, 24-28 May 2010. Prior to the visit, the team provided the Naval Base staff with a high level summary discussing the main systems of interest to more precisely inform the ship's crew about our Capstone Project data needs. KPPs and additional information to explore possibilities of collecting ecological data was provided as well.

28 Naval Sea System Command, "*MIL-STD-2189, Design Methods for Naval Shipboard Systems, Section 310-1, Electric System Load and Power Analysis for Surface Ships Heaters, Duct Type. Electric, Performance Specification*," Washington, DC, January 1988.

Figure 18 - Five of the Twelve Team Members with Commander Jordy Harrison, USS HALSEY Commanding Officer

Figure 19 - Team Members Onboard DDG-51 Class Ship

The approach to collecting data consisted of conducting interviews with the Commander of the Naval Base and his staff, as well as the Commanding Officer of the USS HALSEY and several of the crew members. The Capstone team recorded data for specific equipment via note taking, photographs and video voice recording by permission of the Naval Base CO and Executive Officer (XO). The team collected data via questionnaires and referenced photos as permitted by the Naval Base CO and XO of equipment as shown throughout the report. The team also acquired data from logs, technical manuals, and sample utility reports supplied by the Shipboard Resource Efficiency Management that show representative data of electricity usage and costs, as shown in Table 13, and the five Figures that follow. These reports are typical for all ported ships that utilize shore power.

The team had hoped to go on an underway tour to actually witness technologies of interest and procedural aspects in operation and to collect real time energy measurements. Unfortunately, arrangements were not made in a timely manner for the ship to conduct an underway exercise at the time of the teams visit. In addition, appropriate energy measuring instrumentation or devices were also not available for taking real time measurements. The best data collected on energy and fuel usage for underway scenario was via an interview with the ship CO and Chief Engineer.

Where data was not available, the team conducted technical discussions with the ship Chief Engineer and designated crew members about areas lacking data to arrive at a set of assumptions for generation of new data. Follow up questions were conducted by means of the telephone and e-mail, and the answers were used to expand and refine the results collected.

Sample Data Collected:

Table 13 below represents what NAVFAC bills the Commander Pacific Fleet for electric and water usage onboard the USS HALSEY. This latest report shows that the USS HALSEY consumed 772,400 kilowatt hours (kWh) of electricity in the billing period 12 May – 8 June 2010 at a cost of $109,563. USS HALSEY was in port in San Diego 21 of 28 days of the billing period. The daily average electricity used was 36,178 kWh. This resulted in a cost of $5,132.00 per day, which equates to roughly $0.14/kWh for pier-side electricity.

Utility	Current Month	Current Monthly Cost ($)	In Port Days	Daily Avg.	Daily Avg. Cost ($)	FY10 In Port Days	FY10 Usage To Date	FY10 Daily Avg. to Date
Electric (kWh)	772,400	109,563	21	36,178	5,132	243	8,652,200	35,541
Class Average				31,831				33,492

[This table represents the USS HALSEY monthly billing report for electricity usage pier-side. It provides a summary of the ship's monthly and daily electricity usage and cost based on a billing cycle of 21 days in port. For the May-June 2010 billing cycle, the USS HALSEY used on average approximately $5,000.00 worth of electricity on a daily basis. This is about $0.14/kWh for pier-side electricity.]

Table 13 - USS HALSEY May-June 2010 Utility Report Summary

Figure 20 below is where data from Table 13 above is captured and expanded to show a more detailed break-out of the monthly and year-to-date usage and cost of electricity from May to June 2010. It is noted that bills can be one to two months delayed and cost does not account for utilities consumed by the ship from other shore facilities.

Total for Facility Number: Ship Number: DDG-97 (HALSEY)   Graph Units | Graph Cost

Fiscal Year	Current Month Usage	Units	Current Month Avg Daily Usage	Year-to-Date Usage	Year-To-Date Avg Daily Usage	Current Month Cost	Year-to-Date Cost
2010	772.4	MWH	N/A	8,652.2	N/A	$109,563	$1,217,911
2009	732.8	MWH	N/A	4,390.3	N/A	$106,474	$625,972

Figure 20 - May-June 2010 Billing Period Electric Usage

Figure 21 below represents the USS HALSEY daily electrical loading from May to June 2010, as consumed from San Diego Naval Station. The flatline starting from 12 May (Wednesday) to some time on 18 May (Tuesday) shows that the ship was not connected to shore power. This is indication that the ship was either underway or on ship's power while pier-side. At the time of shore connection sometime on 18 May, the load increase is typically high as all equipment is running at time of connection. When loads began to decrease, this is indication that equipment is being turned off and the profile becomes pretty constant for the rest of the billing cycle, with the exception of the two upward spikes seen on 27 May and 3 June 2010. These spikes are indications that there was equipment start-up and testing which can account for the maximum demand of 2500 kWh on 3 June 2010. The consistent electric loading is an indication of normal cycling of the ship air compressors and HVAC plants, which are constantly running.

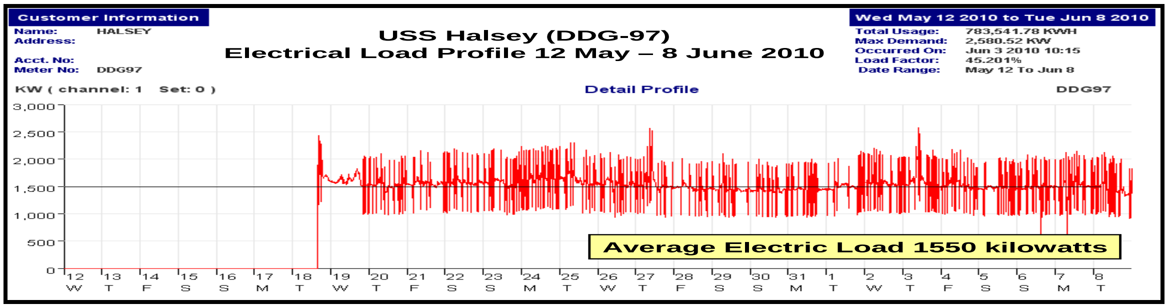
Further discussions with Ships Resource Efficiency Managers, the large drops on about 6 June 2010 again could be due to a loss of pier-side power or the ship shifting to ship's power. The USS HALSEY was scheduled to go underway and prior to doing so, the ship commenced to do what is known as a "fast cruise", which consists of lighting off generators and shifting to ship's power. In the shift from shore power to ship's power, equipment is lit off and the crew simulates training while pier-side, just as though the ship was underway. This exercise is said to conserve fuel while maximizing simulated underway training.

Other factors that could have contributed to the drops are a system ground tripping a circuit breaker on the pier. As a result, one phase of power is inadvertently grounded. The ship loses power on one or more cables. When this happens, a ship sometimes goes onto ship's power to isolate the ground. When the ground is isolated, pier-side power is restored. On occasion, pier-side transformers are grounded. Momentary losses could be a ship breaker that tripped and automatically switched to a secondary power source.

Loading profiles were also noted to be different from month to month because of the sensitivity settings on Remote Transmitter Units (RTUs) at different pier locations (e.g., USS HALSEY moored at pier 10 versus being moored at Pier 3). These are the devices located on each transformer or breaker mount that sends the electrical pulses back to a Supervisory Control and Data Acquisition System (SCADA) that tracks energy usage (see Findings Section for further explanation of system).[29] The USS HALSEY was moored at Pier 3 during the May to June 2010 reporting period and averaged 1550 kW per day. Examples of loading cycles contributing to the average daily electric loading, list not inclusive, are: the use of the scullery and galley during breakfast, lunch, dinner and midnight-rations, the HVAC system, air compressors, refrigeration system, laundry, consistent power draw of certain combat systems subsystems, daily use of central command station systems (computer network), consistent use of lighting throughout the ship. Other factors that also contribute are a consistent power draw of

[29] Crossan, C and Walker, S. *"Naval Facility San Diego Supervisory Control and Data Acquisition System (SCADA),"* Shipboard Resource Efficiency Management, San Diego, CA, 2009.

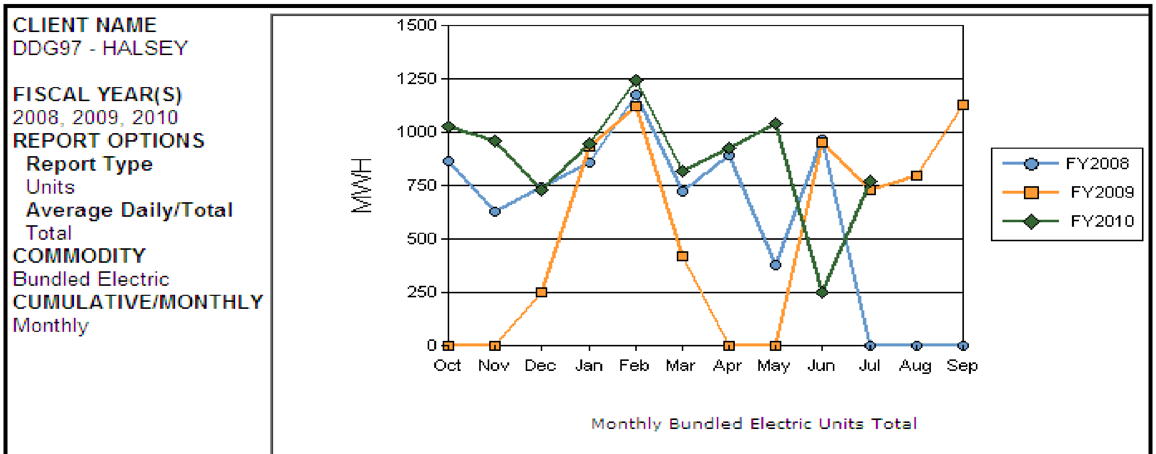
designated pumps, such as fire pumps and lube oil pumps, pre-heaters, such as lube oil, and the reverse osmosis (RO) system used to make the ship clean water supply.



[This Figure represents the USS HALSEY pier-side electrical loading profile for the May-June billing cycle. The profile depicts the rhythm of the ship's energy usage based on a 24 hour cycle. The flat line on the graph represents no connection to the pier. Large spikes may represent equipment light-off or start-up for testing which can account for the max demand of 2500 kWh on 3 June 2010. The consistent electric loading is indication of normal cycling of the ship's air compressors and HVAC plants, which are constantly running. The drops in electrical loading are due to a loss of pier-side power or the ship shifting to ship's power or a system ground tripping off a circuit breaker on the pier, resulting in one phase of power to inadvertently be grounded, causing the ship to lose power on one or more pier connected cables.]

Figure 21 - May-June 2010 Billing Period Electrical Load Profile

Figure 22 below represents the USS HALSEY bundled electric usage for the period spanning FY 2008 to 2010. It also provides further evidence that supports the Naval Base CO statement that ships are in port more often than underway. The Figure shows a three year look at the ship's monthly consumption, which varies as a result of ships being in different states of readiness, which requires more or less equipment to be in operation, or performing planned maintenance during each in-port period. The USS HALSEY underway missions over the course of these periods spanned no more than 7 months, while the rest of the time was spent in port. Seven out of thirty-four months that ship bundled electric is accounted for is an indication that the USS HALSEY is underway roughly 20% of the time. This is a 13% difference in the assumed underway rate of 33%. A 13% difference is a significant finding that can make a major difference in terms of estimated cost savings at sea, as it is cheaper for ships to be pier-side.



FY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2008	867.9	629.9	742.1	857.6	1,174.4	723.2	889.6	379.7	966.3	0.0	0.0	0.0
2009	0.0	0.0	252.7	931.2	1,123.2	416.3	0.0	0.0	953.6	732.8	796.8	1,131.3
2010	1,027.2	957.8	726.4	947.2	1,241.6	816.0	924.8	1,042.5	247.2	772.4		

[This Figure represents the USS HALSEY bundled electricity usage over a 3 year span. It shows the daily average usage of electricity the ship used in each month. Months that show zero indicate that the ship was out to sea. Comparing the fiscal years, FY2010 shows larger energy demands than FY 2008 and 2009, indicating the ship was in port for a longer time period than other representative years. This Figure also provides evidence that ships are underway approximately 20% of the time as opposed to what had been assumed, that is 33%. This is a significant finding that could have a positive impact on the alternative of analysis potential cost savings.]

Figure 22 - Cubic Usage Graph (Monthly Bundled Electric FY 2008-2010)

[This **figure represents a typical rolled up view of in-port ships average daily utilities cost for electricity and water usage by the month and year-to-date. The USS HALSEY is shown to be above the average for energy usage, and is the sixth largest energy consuming ship at NAVFAC San Diego for the May-June billing period. It is also the fifth largest energy consuming ship year to date. The USS JOHN PAUL JONES used the least amount of energy. It is an earlier Flight I Class DDG with a slightly different and smaller configuration and capabilities than the current Flight II Class, such as the USS HALSEY. It averages about 1272 kW a day versus 1389 kW used by the Flight II Class. The smaller configuration and the 8% difference in kW usage partially explain its low energy cost. The USS JOHN PAUL JONES also fully and aggressively implements the Navy energy awareness program into it ship daily operational routine. Compared to the USS HALSEY and the USS GRIDLEY, the USS JOHN PAUL JONES averages a yearly electricity**

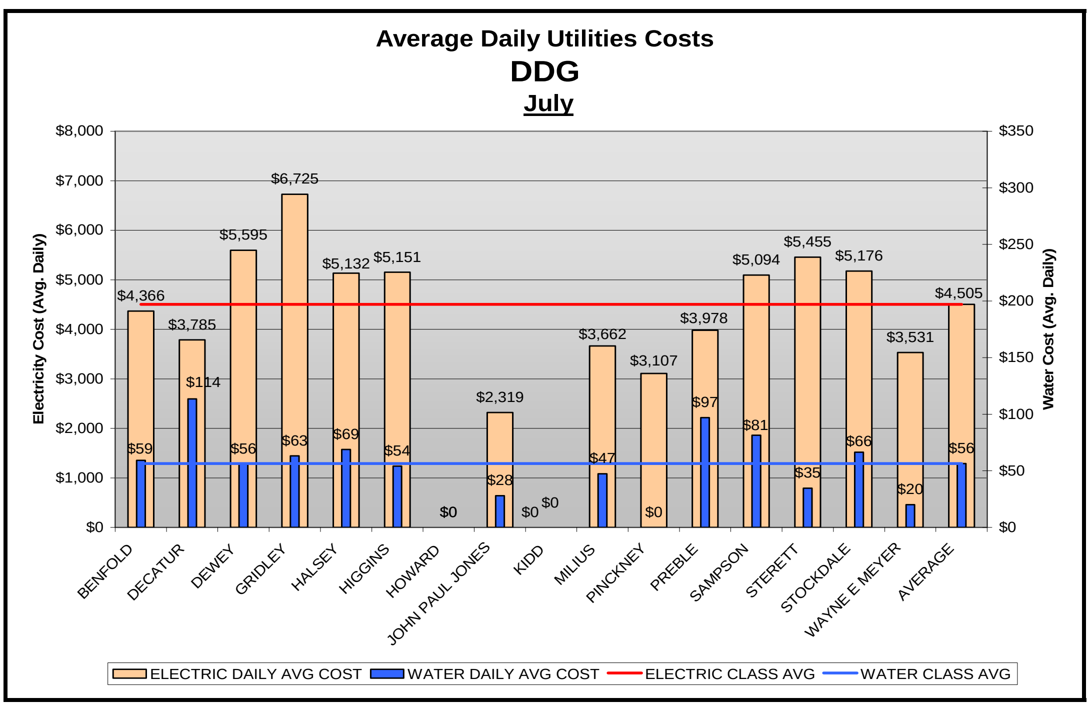
savings of approximately $1M to $1.6M. USS JOHN PAUL JONES makes the case that energy savings are real.]

Figure 23 and Figure 24 below provide a typical rolled up view of in-port ships average daily utilities cost for electricity and water usage by the month and year to date. The USS HALSEY is shown to be above the average for energy usage, and is the sixth largest energy consuming ship at NAVFAC San Diego for the May-June billing period and is the fifth largest energy consuming ship year-to-date.

Some of the ships have been noted to be more energy conscious than others. As an example, the USS JOHN PAUL JONES (DDG-53), as indicated in [This figure **represents a typical rolled up view of in-port ships average daily utilities cost for electricity and water usage by the month and year-to-date. The USS HALSEY is shown to be above the average for energy usage, and is the sixth largest energy consuming ship at NAVFAC San Diego for the May-June billing period. It is also the fifth largest energy consuming ship year to date. The USS JOHN PAUL JONES used the least amount of energy. It is an earlier Flight I Class DDG with a slightly different and smaller configuration and capabilities than the current Flight II Class, such as the USS HALSEY. It averages about 1272 kW a day versus 1389 kW used by the Flight II Class. The smaller configuration and the 8% difference in kW usage partially explain its low energy cost. The USS JOHN PAUL JONES also fully and aggressively implements the Navy energy awareness program into it ship daily operational routine. Compared to the USS HALSEY and the USS GRIDLEY, the USS JOHN PAUL JONES averages a yearly electricity savings of approximately $1M to $1.6M. USS JOHN PAUL JONES makes the case that energy savings are real.]**

Figure 23 used the least amount of electricity compared to all other ships whose daily average utilities costs is recorded. Compared to the USS HALSEY, the USS JOHN PAUL JONES consumed $2,813.00 or roughly 45% less energy. This is approximately $1M in average yearly electricity savings. Compared to the largest energy consuming ship the USS GRIDLEY, the USS JOHN PAUL JONES consumed $4,406.00 or roughly 34% less energy: this is approximately $1.6M in average yearly electricity savings.

The USS JOHN PAUL JONES, as per discussion with ship energy resource managers, fully implements an energy awareness program (ECON), incorporating energy efficiency into the crew daily routine. Their program implements plan of the day (POD) notes to remind the crew to be energy efficient. They also perform an after-hours walk-through to turn off unnecessary and non-vital equipment and lighting. In addition, USS John Paul Jones is an earlier Flight I class DDG. It has been observed by NAVFAC that the Flight I class ships generally use less energy than Flight II class. The Flight I class DDG average approximately 1272 kW and the Flight II class average approximately 1389 kW. This is approximately an 8% difference in the class averages that can be explained by the difference in the Flight configuration and size as Flight I has limited capabilities and is smaller as compared to the later DDGs. Other energy savings are simply attributed to paying serious attention to daily energy conservation efforts and practices and aggressively implementing an energy conservation program. The USS JOHN PAUL JONES makes the case that energy cost savings are real and other ships should take a closer look at its practices and become more committed and consistent with energy conservation efforts.



[This figure represents a typical rolled up view of in-port ships average daily utilities cost for electricity and water usage by the month and year-to-date. The USS HALSEY is shown to be above the average for energy usage, and is the sixth largest energy consuming ship at NAVFAC San Diego for the May-June billing period. It is also the fifth largest energy

consuming ship year to date. The USS JOHN PAUL JONES used the least amount of energy. It is an earlier Flight I Class DDG with a slightly different and smaller configuration and capabilities than the current Flight II Class, such as the USS HALSEY. It averages about 1272 kW a day versus 1389 kW used by the Flight II Class. The smaller configuration and the 8% difference in kW usage partially explain its low energy cost. The USS JOHN PAUL JONES also fully and aggressively implements the Navy energy awareness program into it ship daily operational routine. Compared to the USS HALSEY and the USS GRIDLEY, the USS JOHN PAUL JONES averages a yearly electricity savings of approximately $1M to $1.6M. USS JOHN PAUL JONES makes the case that energy savings are real.]

Figure 23 - Average Daily Utilities Costs – July 2010

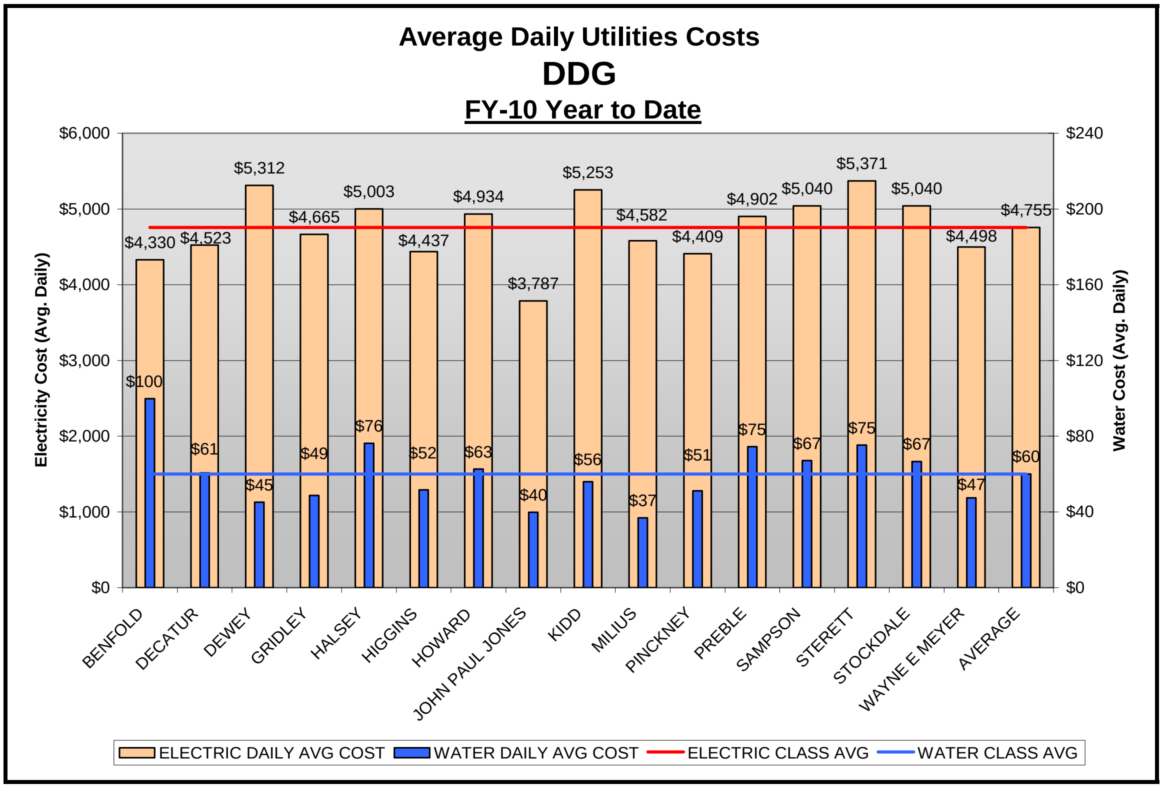


Figure 24 - Average Daily Utilities Cost DDG-51 FY10 Year-to-Date

Findings:

Day One of the team's visit commenced with a briefing and overview of the Capstone Project to the Commanding Officer of the Naval Base, his staff and the Chief Engineer of the USS HALSEY and other supporting Naval base personnel. As per discussion with the Naval

Base CO, the team was surprised to learn of the difference in position of the CO relating to Figure 6 that depicts energy usage of 75% for tactical versus 25% for shore based energy. The CO position was, while he agreed that ships do use a large percentage of electricity and fuel while underway, current mission trends shows majority of ships in port 66% or two thirds of the time, thus there is an increase in shore based electricity usage, thus an increase in cost. The Naval Base CO belief is that the biggest "bang for the buck" would be an ashore based infrastructure study with focus on energy studies of ship systems such as; HVAC, Refrigeration, Lighting and especially Combat Systems as these systems seem to be the biggest power users. Of the systems stated by the CO, special emphasis was put on Combat Systems.

Combat system radars are limited to radiating in port. There is maintenance, testing and training associated with sub-system components which requires large amount of energy usage. One point captured was that some components of the system are never powered down even when not in use for testing or training purposes. Thus, they are suspected to largely contribute to high pier-side energy usage and cost. While the combat systems was not chosen as a focus of the project effort due to reasons that were thought to be classified, the team did learn that there are unclassified areas of the system that could be explored that could potentially produce valuable findings on energy usage and conservation. This is an area that might be productively explored by future researchers.

After the initial meeting with the Naval Base CO and XO, the team was escorted to the USS HALSEY to survey the ship. The team toured the ship each day, mostly capturing data that is primarily qualitative in nature, due to the limited availability of ship's crew, time and limited knowledge about specific or measured energy data for equipment of interest. As a result of the limitations during the visit, energy data for many of the HVAC and Auxiliary subsystems could not be obtained, thus the survey questionnaire in Appendix D, Section B was partially ineffective in capturing key information for the project. As stated earlier, for data that could not be collected from the ship, the team used other means of data estimation such as the baseline load analysis, general ship system specifications, internet sources, and data from similar commercial technologies to arrive at a set of assumptions to support the project analysis of alternatives. See Section VII-C for more detailed information on system descriptions and quantitative data for all subsystems of interest and alternatives.

The paragraphs that follow document the general findings in regard to how the ships are monitored for pier-side energy usage, shipboard fuel usage while underway and general findings of shipboard technology.

General findings: How ships are monitored for pier-side energy usage

While running on shore power, there are essentially 10 receptacles or cables (480 amps each) connected to the NAVFAC SCADA Program, a program that tracks energy usage and provides billing read outs for each ship, per month. SCADA was described as a program that utilize an MV-Web application to provide NMCI browser clients historical electrical load profile information for ships having demand-interval electrical meters and provides near-real-time and historical electrical load profile information for ships that are monitored. SCADA transfers electrical load profile information for ships connected to pier breakers to an Oracle database for the MV-Web application to provide near-real-time graphical display. Ship connection information is natively stored in a Computerized Utility Billing Integration Control (CUBIC). Proxy CUBIC tables associated with ship connections are created in the CUBIC login user of the MV-Web database to assign the monitored usage of a breaker to the appropriate connected ship.[14]

The SCADA program itself does not have the capability to provide a specific breakdown of energy usage per component actively utilized on the ship. However, it was noted that the receptacles or cables connected to the pier-side power breakers do connect back to electrical bus-bars that disseminate energy to various load centers on the ship that distribute power to operating units. A schematic of the connectivity of the bus-bars, load center and components was available at time of visit. However, the schematic was not authorized for distribution.

General Findings: Shipboard fuel usage underway

According to the Commanding Officer of the USS HALSEY, the ship was estimated to use about $5,000.00 a day in energy while pier-side, as duly noted by the energy billing presented earlier in Table 13. While underway, the ship is estimated to carry about 440,000 gallons of fuel onboard. It is estimated to consume about 5.5% to 6% of fuel per day. Assuming an average burn rate of 5.75%, that is approximately $66,593.00 per day at a commodity spot price of $2.63 per/gal, as quoted by the ship CO at the time of the team's visit.

General Findings: Shipboard Technology

Gas Turbine Generators (GTG)

There are three GTGs on-board ship: two primary units and one back-up or stand by unit, all manufactured by Rolls-Royce. All GTGs are rated at 60 Hz, 360 volts, 4800 amps. While pier-side, there are no GTGs operating unless required to "fast cruise" to ensure mission readiness (meaning all systems are functioning) and that temperature requirements are met. A "fast cruise" usually results in a 1-2% fuel burn rate per day, due to exercises requiring full powering of systems, increased speed and requiring two GTGs. As a general consensus, under normal operating or threat conditions, two GTGs are always operational as the following: pumps, engines, AN/SPY-1 radar, sonar, and other essential or critical equipment are all on. This scenario requires about 3000 kW. However, while underway performing basic operations or normal steaming in local waters with very low threat risk, the USS HALSEY platform essentially runs a single GTG in trail shaft mode at a sustained speed of 15 knots for approximately 4-5 hours.

HVAC

The five Freon-based HVAC units onboard ship (units 1, 1A, 2, 3, and 4) are considered to be the biggest energy loading equipment on the ship. All units are used to cool the ship, no matter how many are running, as they all cool the same spaces. The HVAC system requires at least two GTG for initial start up, due to the required initial power draw required for manual start. It was noted that it takes approximately 45 minutes to start up and requires two GTGs. The equipment identified as having its own cooling was the AN/SPY-1 radar. The ventilation system was noted to be a separate system with its own energy loading. However, the loading is not measured. System maintenance, for HVAC, is scheduled every six months as overhaul of the system. Specific requirements for maintenance are enumerated in the ship Maintenance Index Pages for the HVAC System. Of note, Freon in the system is recycled.

Scullery (Dishwasher)

There are three mess halls (crew, wardroom and “goat locker” or Chief’s mess), and each has a dishwasher unit of a different size. Units are operational during breakfast, lunch, dinner and mid-rats. The wash unit temperature was noted to be between 150 -160°F, and the rinse unit temperatures set between 160-180°F. The final rinse unit temperature minimum is 180°F, maximum 190°F. As per ship specification, these temperatures must be maintained for disinfecting, however requirement could be overstated. The Chief Engineer was asked if the ship considered other means to cut energy cost in use of this area, such as using paper plates and plastic ware and maybe having the temperature requirement relaxed on the wash units. The ship does not use paper plates ordinarily, but has used them for special occasions. The reason given for not using the alternative as standard practice was cost. The temperature requirements for the wash units could potentially be lowered and additional energy savings could be realized in this area.

Galley

The galley is a central preparation area, divided into several food stations to optimize the food preparation time. The Wardroom and Chief’s mess were observed to not be attached to the galley, which was noted by the attending Lieutenant and EMI to cause an increase in manning. While underway, the ship can carry 30-40 days of food. Food is replenished every two weeks, or about 16 times on a typical eight month deployment/mission. The ship can go at up to three weeks without replenishment with a crew up to 290 (it was noted that there has been a reduction in crew size). All operating units in the galley were observed to be electrical. Appliances in the space were: electric kettles (three large and one small), two grills, two microwaves, one deep fryer, four chill boxes, one set of stacked steam convection ovens, a freezer, and an ice machine for everyday use.

The ovens take one to two people to operate and are not designed with a broiler. The units are considered to be one of the biggest energy consumers in the space (the other being the ice machine) and are 58-3/4" in height, 37-3/4" in length, and 36" in width. There is a requirement for overhead and floor clearance. However, it was noted that units could increase in size about an additional one inch height. The ovens are original equipment, installed on the ship in 2005. They have a 5-6 year life and at the time of the team visit, the ovens were noted to be due for change out or potential upgrade. Both ovens combined are rated at 450 volts and 25 amps (44kW combined). The ovens were noted to each have a cooking capacity of 4-5 sheet pans each, which equates to approximately 50 portions per oven. Oven prep time was noted to be 15 minutes prior to use and oven maintenance consisted of thermostat calibration, done quarterly or semi-annually. The ovens were cleaned daily, for obvious reasons (sanitation), but also because the units needed to be kept dry.

The freezer and refrigerator boxes were located near, but not adjacent to the galley. The freezers are on 24 hours a day, seven days a week. They are set at a temperature of 0°C and the primary and back-up refrigeration boxes are set at 32° - 41°F. There are two fans per freezer and refrigerator High Voltage (HV) rated at 440 volts, each controlled by four power distribution boxes that also manage the defrost routine and the power draw. As power draw is somewhat dependent on the amount of food stored, the ship can run one or two fans per chill or freeze. There are two power and refrigeration units that are redundant.

The ice machine in the space is a Scotsman and runs continually at 120 volts and 25 amps. It is obviously needed for many galley services, such as chilling foods on the food line that are required to maintain a certain temperature for freshness, as well as for cold beverages. Baking was noted to be done at night when energy usage is presumably low, due to the process taking a longer time than the normal daily cooking process. Energy loadings are typically higher during breakfast, lunch, and dinner, and are typically reduced after dinner until 0500 the next morning.

Laundry

There were two laundry spaces on the ship: one for servicing crew uniforms and linens and another that is self-services used by the crew, per berth, to wash and dry personal garments.

The self-service space is essentially unmanned and contained washer and dryer units that were of residential size, electrically operated and contained the energy star label. The laundry space for washing and drying crew uniforms is a manned space, with 2-3 people authorized to operate equipment and was the space of interest for collecting any available energy data.

The space contains two 60 lb washer extractors and one 20 lb washer extractor. It was noted that washing was done in 20lb increments per machine, with three wash settings – white, blues, and woolen. There are three 50 lb dry weight (75lb wet weight) Cissell Tumble Dryers, each utilizing 15 kW, with 440 volt, 60 Hz, and 3-phase cycle power requirement. Each dryer was noted to not always be utilized at full capacity. Full capacity is defined as 45 lbs wet weight or 20 lbs dry, which equates to one load of washed laundry. Each unit contains two lint traps; a primary trap, cleaned every four hours and a secondary trap, cleaned every eight hours. Lint traps are re-useable, which saves on replacement costs. Drying time per unit is 22 minutes at two temperature settings, 160°F (low) or 180°F (high). Units are usually operated on the high setting.

The laundry operating schedule for pier-side is Monday through Friday between 0830 or 0930, shifts ending around 1500. No washing or drying is done on Saturday or Sunday while pier-side. While underway, the laundry operating schedule is the same as pier-side. There is no washing on Sunday. Saturday is added to the schedule for washing and drying linens only for all berths. The Saturday shift ends around 1800. Each berth is allowed no more than 60 lbs of laundry.

Attention was given to the temperature of the space at the time of the team visit, as it seemed a bit colder than an average 70°F room. The team learned that the space is maintained at 65°F and monitored by central control, even when not in use, and is thermostat controlled within the space and can be set at the sailor discretion. Due to the heat output of the dryers, along with other high heat setting equipment, such as steam presses, there is potential for heat stress if the temperature in the space exceeds 90°F. The space is shut down when temperatures reach or go above 90°F (signs state 100°F) and medical personnel are notified. There are four thermostats in the space to also monitor the space temperature (more personnel safety related versus equipment) and they are checked every four hours.

Three steam presses were noted in the space and have dedicated set dials with lower and upper temperatures of 180°F to 260°F, respectively. The units take 20 minutes to get hot prior to use and can take 2-3 minutes to press a set of coveralls. Periodic maintenance is done on the equipment per maintenance cards on daily, weekly, monthly, semi-annual and annual basis depending on circumstances. There was a computer also noted in the space that sometimes does not get shut-off and there are 2-3 checks a week for space lighting to determine sufficiency and maintenance.

Hot Water Heaters and Fire Pumps

There are two electric hot water heaters, 1A and 1B, rated for 450 gal, 65 kW, 85 amps, and set at a temperature of 130°F. Units are primarily used for hotel services, such as the scullery, galley and laundry. There are two hot water recirculation pumps that were observed to not consume much power. There are six electrically driven fire pumps onboard the ship and each were seen to be of the same horizontal split-case centrifugal type. It was also noted that while in port, one fire pump is on continuously in order to maintain the required pressure at 140 – 170 pounds per square inch (psi) and while at sea, two pumps are constantly running for this purpose. Fire pumps were noted to not have any additional electronics.

Lighting

The shore based infrastructure currently implements the Light Emitting Diode (LED) lighting and sees about a 70% ROI versus an assumed 50%, per the Naval Base CO. Onboard the ship, there are numerous and varied types of lighting such as incandescent, compact fluorescent, halogen, and LED. LED was observed in the freezers, as they are used to alleviate heat in the space to help optimize cooling. LED lighting was not outfitted throughout the entire ship at the time of visit, but is implemented in spaces where heat sources are required to be minimized.

The USS HALSEY is currently doing an assessment to determine if LED lighting will be worth the cost to implement throughout the ship. According to the Ship's CO, if the cost to implement LED is twice as much but the cost of maintenance is about the same as the current lighting; it is likely LED will not be fully adopted. In addition, the ship does not see a huge consumables budget as it is a controlled budget that is approximated to be about $75,000 a quarter used for consumables, such as hazardous materials, light bulbs, rags, paint, and other logistical type items, as directed by the ship CO. This is a factor that plays a big role in the ship's ability to practice and implement "green" initiatives such as purchasing LED to outfit the entire ship.

The ship does participate in the Energy Conservation (ECON) program and in 2009 won the SECNAV top award in the small ship category for being the most fuel efficient Arleigh Burke Class Destroyer in the fleet, saving 33,765 barrels of fuel, resulting in a total incentive award of $120,249.[30] The current energy practice noted for lighting is that the crew provided reminders via email or ship announcement to turn off any lighting not in use.

Ecology

No specific ecology data was available; therefore no CO2 emissions data was obtained. As previously noted, Freon is recycled. Synthetic lube oil for some systems is highly toxic, but no alternative was available. The team observed that the ship does not measure gray or black water discharge; however, black water is not discharged within 3 miles of land.

The team was provided with a great opportunity to tour the DDG-97, USS HALSEY to broaden the team's knowledge and understanding of the ship operational procedures and technological capabilities. The team collected valuable information to help advance the project forward with confidence based on hard data and expert opinion. Information collected included: the amount of time ships are underway versus pier-side, electrical loading profile data, daily and year-to-date electricity cost, information on estimated shipboard fuel usage underway and pier-side, the operational profile of the GTGs and information on other subsystems of interest. The information collected provided significant findings that allowed the team to move forward in formulation of alternative solutions, development of achievable recommendations, and development of a concept of implementation for those recommendations. Sections VI through IX provide further details and discussions of the development and evaluation of alternatives, the analysis results and recommendations and conclusions.

[30] Hein, R., *"Take Action Now to Reduce Fossil Fuel Needs,"* Surface Warfare, Vol. 35 No. 2, pp. 20-21, Spring 2010.

VI. DEVELOPMENT OF ALTERNATIVES

The development of alternatives follows from the existing data collection described in the "Existing Data" section under "Data Needs Identification" in Section III, Evaluation Criteria. As mentioned in the Existing Data section, the SWBS was the primary document used to determine the potential subsystems that the team will investigate for energy and cost savings. Analysis of the existing data led to systems of interest based on high energy consumers as mentioned in Section C, Data Collection, 1 Existing Data, Final Down-Select.

The team elected to concentrate on subsystems and procedures that are not already being addressed by other Naval research efforts, researchable and acquirable in the short duration of this research project, and that have a high potential for insertion or implementation. This would also allow for additional savings versus savings that have resulted from other studies for cost savings. These subsystems were identified prior to a visit to NAVFAC where the team spent one week collecting data and engaging with ship personnel for the current procedures used for the operation of these systems. Eight subsystems, along with fuel type, were chosen and are listed below:

1. Fire Pumps
2. AC Chill-Water Pumps
3. Fuel Transfer Heaters
4. HVAC Pre-heaters
5. Ovens
6. Dryers
7. Hot Water Heaters (Including Dishwater Heaters)
8. Lighting Fixtures
9. Fuel Types

The idea behind the selection of these representative systems is that they can be easily researched to determine the current state-of-the-art system types. Also, they exist not only on a DDG-51 but on many other classes of ships, making them universal, and several viable options or alternatives exist that could be compared for energy usage and energy savings.

In the following section, “Analysis of Alternatives” we take a look at up to three alternatives for each subsystem, perform a Pareto analysis where we give each alternative a weighted score and determine which alternative would provide the best solution for the Navy’s DDG-51 ship class and the Navy’s charter for energy reduction.

VII. EVALUATION OF ALTERNATIVES

A. GENERAL DOCUMENT ASSUMPTIONS

The task of documenting assumptions come from Block 6 of Source Data Collection of the modified generic systems engineering process being implemented for this project. Because some of the necessary data is either unavailable or classified, one of the ways the cohort worked around the gaps in the data was to make certain assumptions.

There are several categories of assumptions that were taken into consideration for the sake of the project. Any data that was not obtained but deemed needed was estimated. The assumption that the estimation is within reason was made, which is classified as an operating assumption in the spreadsheet. There are some preliminary assumptions that were made to move forward.

The methodology for tracking and documenting these assumptions is a simple MS Excel spreadsheet (see Table 14) containing the category of the assumption (e.g., an operating assumption), the applicable process step (e.g., Step 4 – evaluation techniques), a description of the assumption, any comments and a unique identifier for each line item. The assumptions identified in Table 14 are crucial to the project, because they serve part of the general foundation on which the final recommendations are built.

ID	Category	Assumption	Applicable
A0001	Operating Assumption	Electrical loads generated by the DDG 51 gas turbine generator (GTG) set serve as the basis of energy efficiency study.	Step 6 - Source Data Collection
A0002	Preliminary Assumption	Battle operating condition energy efficiency analysis is excluded from this study as to not risk impact to combat systems effectiveness.	Step 6 - Source Data Collection
A0003	Operating Assumption	Maximum connected loading data as opposed to loading after shed condition provide the best potential for analysis. The after shed phenomena functions as a contingency in the event of electrical overloading of the generators.	Step 6 - Source Data Collection
A0004	Preliminary Assumption	Command and Surveillance and Armament General Analysis is excluded from this study due to the potential of recommendations impacting mission effectiveness, combat systems, survivability plus may not be cost effective.	Step 6 - Source Data Collection
A0005	Operating Assumption	Data collected on site visit is applicable to entire DDG 51 class.	Step 6 - Source Data Collection
A0006	Operating Assumption	Site visit will be used to determine gaps in data the team has, which in turn will be used to determine whether or not team needs to generate new data.	Step 6 - Source Data Collection
A0007	Operating Assumption	All assumptions being documented in this spreadsheet will only be applicable to Block 6 - Source Data Collection	Step 6 - Source Data Collection

[This table depicts the general assumptions the cohort made regarding source data collection for the capstone project.]

Table 14 - General Assumptions

The path forward is to collect all of the assumptions made by the team members and internal groups. The assumptions were documented by being given a unique ID, categorized, described, and assigned to an applicable step. Any comments related to that assumption were captured as well. The assumptions were then documented in this final report. A total of seven assumptions relating to Block 6 were documented. For the individual systems, evaluated in subsection C, further assumptions were made for each individual subsystem. An example of an assumption is retrofitting (whether assumed it was not needed or an assumed cost). In some cases, this information was not accessible or would take the scope of this effort beyond the time constraints involved with this Capstone effort.

B. TRADEOFFS

This task description comes from block 8 of the generic system analysis process in Figure 4.9 of Blanchard & Fabrycky Systems Engineering Analysis, 4ed.[5]

Analysis of scenarios and decisions results in identification of risks, non-risks, sensitivity points, and tradeoff points in the systems.

Approach:

Figure 25 shows the notional approach to the tradeoff which was derived from an Architecture Tradeoff Analysis Method. The first block consists of Capstone drivers elicited from project decision makers (stakeholders, maintainers, NAVFAC operators, etc, or our Capstone group). Next, a requirements (quality attributes) utility tree with detailed statements about which quality attribute (or KPP) are the most important for the project to be carried out. These are then refined into scenarios and system decisions are made in support of each of the scenarios considered. The analysis of scenarios and decisions results in identification of risks, sensitivity points, and tradeoff points for the system under consideration. Risks are also considered in terms of how each risk affects a driver. Outputs of the tradeoff process are included in this final report highlighting the major findings of the evaluation.

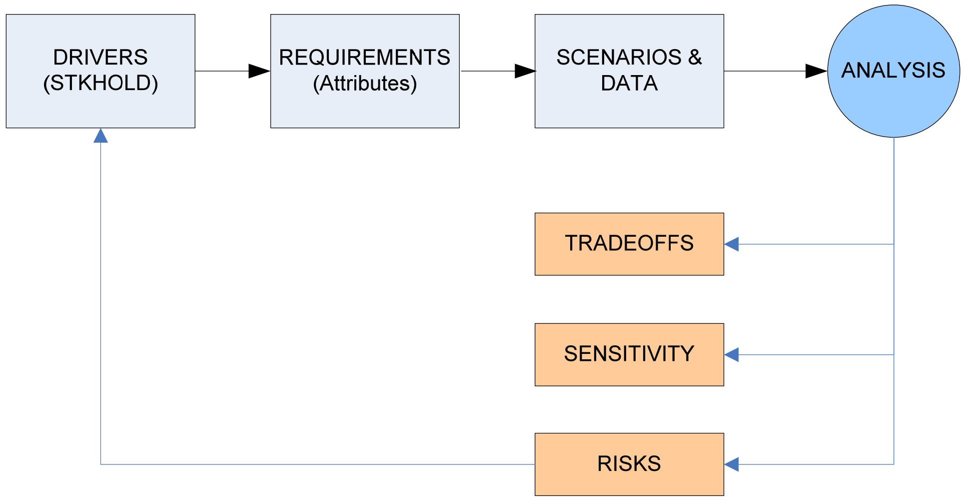


Figure 25 - Process for Tradeoff Studies

C. SYSTEMS EVALUATED

1. Fire Pumps

DDG-51 Fire Pump Background Information:

Fire pumps on the DDG-51 are critical components to put out any fire that may occur anywhere on the ship. In addition to firefighting, the fire pumps are also used for backup cooling and fluid ejecting mechanism while at sea. Since this component is essential in an emergency situation, the reliability must be high and the system must be available at all times and is only permitted to be down for scheduled maintenance. There are a total of six fire pumps onboard the DDG-51 for redundancy and efficiency when the pumps are operated in rotation. It is assumed that the fire pump system is serviced twice a year with 12 – 24 hours of one working person maintenance time for each servicing. According to Rene Lumaban, the HAL MPA on the DDG-51 in San Diego, the current fire pumps in place are the "horizontal split case centrifugal" type of pump.[31] The fire pump manufacturer, Aurora Pentair Water, indicated that this type of pump has a pumping capacity of 250 – 5000 gallon per minute (GPM) and generated pressure ranging from 40 to 490 PSI.[32] Lumaban confirmed through email that the pumps onboard the DDG-51 maintain a flow rate of 1000 GPM and the required pressure between 140 – 170 PSI. It is noted that while in port, fire pump # 4 is on continuously in order to maintain the required pressure at 140 - 170 PSI, and while at sea, two pumps are constantly running for this same purpose. Much energy can be saved on the pumps that need to be operated over a long duration of time.

Problem and Need Statement:

The DoN needs a solution to reduce energy cost of operating the DDG-51. Since fire pump #4 onboard the DDG-51 is constantly running, there is potential to save energy if the pump can be replaced by a more efficient or a less energy intensive pump. Conceptually, the fire

---

[31] Rene Lumaban, private email conversation, 4 August, 2010.
[32] Eric J. Silva, private phone conversation, 30 July, 2010.

pumps are only used in an emergency situation. However, in practice 2 fire pumps out of 6 are operated 24 hours every day of the week to act as backup unit for the cooling system. It is assumed that during a non-emergency period, the pressure in the system must be maintained between 140 – 170 PSI, while the flow rate can be varied. However, in firefighting scenarios, the system must be available to deliver 1000 GPM at 140 – 170 PSI. Significant energy saving can be achieved during the non-emergency period by using a less energy intensive pump.

Fire Pump Alternative Selection Approach and Selection Criteria:

Since the fire pump system is a critical component to guarantee mission survivability for the entire ship, several criteria are considered when looking for alternatives to replace the current configuration. The selection criteria are: flow rate, pressure, and efficiency.

To improve energy efficiency during non-emergency periods, an alternative approach is to add the vertical inline pump along with the set of six pumps. During non-emergency periods, all six split case pumps can be off, while the vertical inline pump will be on to maintain the required pressure. The trade-off is that this pump will have lower flow rate capacity. However, in exchange it is still able to maintain the necessary pressure with less energy consumption. Consultation with a subject matter expert at Aurora Pentair Water, Eric J. Silva, confirms that it is technically possible to use a lower energy intensive pump like the vertical inline pump in conjunction with the six other horizontal split case pumps to maintain the required pressure of 140 - 170 PSI. [32]

At the current configuration on the Navy ship, the split case is pumping 1000 GPM at 155 PSI. According to Aurora Pentair Water, this configuration gives the split case pump 70% efficiency as seen in Figure 27.[33] Maintaining at the equivalent 155 PSI, the inline can pump 300 GPM with 70% efficiency, as seen in Figure 29.[34] This shows that the inline is capable of replacing the split case to maintain the necessary pressure while being equally efficient.

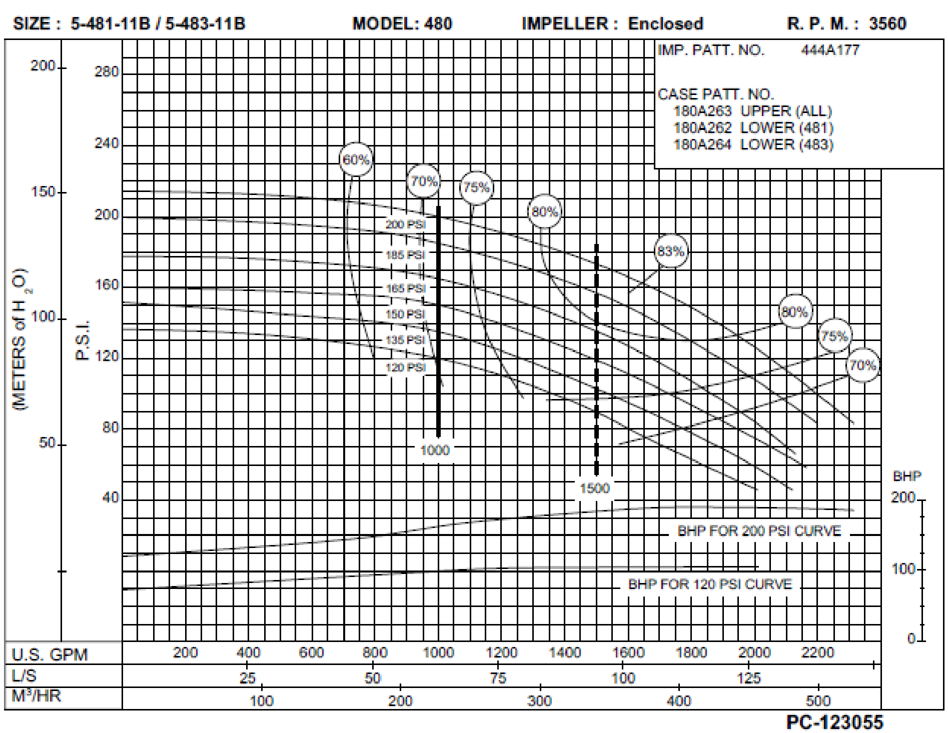
---

33 Aurora,*"Vertical Inline Fire Pump Efficiency Performance,"* downloaded July 14, 2010 from http://www.aurorapump.com/pdf/912/Curve60Hz/1000_5_483_11B_3560.pdf

34 Rishell, J.,*"Split Case Fire Pump Efficiency Performance,"* downloaded July 14, 2010 from http://www.systecoreinc.com/files/Horizontal_Split-Case_Centrifugal_Pumps.pdf

[Taken onboard the DDG-51, while visiting the ship in San Diego]

Figure 26 - Fire Pump on the DDG-51



[This graph indicates that at 165 PSI and 1000 GPM, this pump is 70% efficient.]

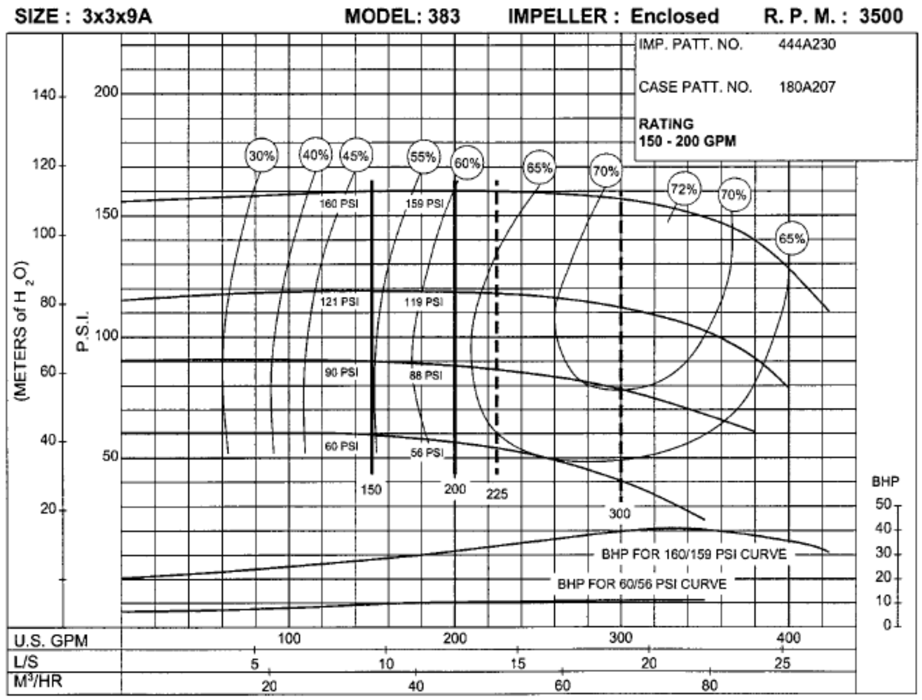
Figure 27 - Efficiency Curve of the Horizontal Split Case

Horizontal Split Case Fire Pump Specifications:

- Flow Rate: 200 – 2000 GPM
- Pressures: 40 – 220 PSI
- Voltage: 440 V
- Ampere: 450 Amps

[The vertical inline pump is smaller and takes up more vertical space and less horizontal space than the current horizontal split case.]

Figure 28 - Vertical Inline Fire Pump Manufactured by Aurora Pentair Water



[The graph indicates that at 160 PSI and 300 GPM this pump is 70% efficient.]

Figure 29 - Efficiency Curves of the Vertical Inline Fire Pump

Vertical Inline Fire Pump Specifications:

- Flow Rate: 56 – 340 GPM
- Pressures: 20 – 160 PSI
- Voltage: 440 V
- Ampere: 302 Amps

Evaluation Matrix	Fire Pump No 4	
Performance Criteria	Baseline	Vertical Inline
Capacity (gal/min)	1000	750
Total Head (psi)	155	155
Reliability	0.995	0.997
Availability	0.995	0.995
Cost Criteria		
Energy Consumption (KW)	198	133
Investment Cost ($)	0	30,000
Operational Savings ($/yr)	0	439,674
Maintenance (h/yr)	24	24
Maint Savings ($/yr)	0	0
Efficiency	0.70	0.70
Savings-1	0	409,674
Savings-5	0	2,168,372
Savings-10	0	4,366,743

[The vertical pump operates at 33% less energy than the baseline unit but 25% of the performance is sacrificed.]

Table 15 - Comparison of Baseline versus Vertical Inline Fire Pumps

Recommendations:

Since the inline pump is as equally efficient as the split case while maintaining the required pressure of 155 PSI, significant savings could be achieved by adding two vertical inline fire pumps to the collection of six fire pumps for a total of eight pumps. The vertical inline should be operated at all times to maintain the required pressure of 140 -170 PSI while the split case will only be turned on during emergency scenarios. According to Mr. Silva, switching on the split case pump in an emergency situation should take around 2-3 seconds with a control box that can be operated from the central control system.[32] (Note: Since this recommendation has not been tested, such a test should be conducted to verify the operating time in an emergency scenario.)

The vertical inline pump is rated for 440 V at 320 Amps, while the horizontal split case operates at 450 Amps. Operating the vertical inline pump will result in a potential savings of $409,674 through the first year and $2.1 million through five years (Table 15 has a completed breakdown of the potential savings).

Due to secondary uses for the fire pump, further consideration is needed to verify whether the inline pump could provide the necessary flow rate for the secondary purpose of backup cooling. Properties such as flow rate and pressure will need to be examined to determine if the inline can provide the necessary PSI and GPM for the backup cooling task.

2. HVAC Pre-heaters

Background:

The DDG-51 HVAC pre-heaters were determined to be one of the highest energy and electric power consuming subsystems of the HVAC systems. When the HVAC system was analyzed, results identified six HVAC pre-heaters that require capacities of 36.2, 53.8, 69.2, 100 and 100.6 kilowatts (kW) of power to perform normal operations. According to the load analysis, these heaters are in operation 90% to 100% of time in a 24 hour period during winter cruise and shore operating conditions. These pre-heaters support overall heating and ventilation of the ship by receiving air flow from the weather through ductwork, preheating it to between 42 and 50 degrees Fahrenheit before traveling to applicable compartments.[35,36]

Alternative Selection Criteria and Approach:

Pre-heaters aboard the DDG-51 ship class are qualified to MIL-H-222594, the electrical duct type heaters standard. MIL-H-22594 specifies various physical and functional characteristics for heaters upon Navy ships. Among the defined characteristics are: duct sizes, wattages, air flow velocities, heating element and power supply. In the absence of DDG-97 baseline data from the NAVFAC visit, it is assumed that the DDG-51 class pre-heater is a similar type military specification (mil-spec) heater as those used on the large-deck-amphibious-assault-ships. Northrop Grumman Shipbuilding functions as the follow yard shipbuilder on the DDG-51 class and is the sole contractor of the LHA 6 Class large deck amphibious assault ship. Bath Iron Works serves as the lead-yard for the DDG-51 class.

Table 16 details the military specified parameters and baseline design for each of the five different types of pre-heaters derived from the DDG-51 load analysis pre-heater kW and vendor furnished information of the LHA 6 procurement.

35 Naval Sea System Command, "*MIL-H-22594B, Heaters, Duct Type. Electric, Performance Specification,*" Washington, DC, December 2004.

36 Chromolax, "*Mil-Spec Duct Heaters,*" downloaded on 30 August 2010 from http://www.chromalox.com/resource-center/product-data-sheets.aspx.

Preheater Characteristics (MIL-H-22594)	Baseline				
	Size = 29EH	Size = 32EH	Size = 33EH	Size = 35EH	Size = 37EH
Medium to be heated	air	air	air	air	air
Heater perfomance/ Heat output	High Heat	High Heat	High Heat	High Heat	Medium Heat
Flow rate (CFM)	**2945**	**4370**	**5625**	**8130**	**9145**
Inlet Temperature(deg F). Load Analysis assumes 10 degree day for winter operation condition	10	10	10	10	10
Outlet Temperature (deg F) DB	42 - 50	42 - 50	42 - 50	42 - 50	42 - 50
Duct Size (width(in) x height (in))	12-1/4 x 30	18-1/4 x 30	16-1/4 x 42	24-1/4 x 42	36-1/4 x 42
Wattage required (kW)	**36.2**	**53.8**	**69.2**	**100**	**100.6**
Supply Voltage available	440V, 3-phase, 60-hz	440V, 3-phase, 60-hz	440V, 3-phase, 60-hz	440V, 3-phase, 60-hz	440V, 3-phase, 60-hz
Operating life (hrs)	126,000	126,000	126,000	126,000	126,000
Maintainance (replacement parts) (hrs)	21,000	21,000	21,000	21,000	21,000
Heating element	Fins	Fins	Fins	Fins	Fins
Weight (lbs) *	63	79	104	113	142
Quantity on Ship	2	1	1	1	1
Hours of operation/day - shore	24	22	22	22	24
Hours of operation/day - Cruise	24	22	22	22	0
Energy Consumption (kWh) per day -shore	**868.8**	**1183.6**	**1522.4**	**2200**	**2414.4**
Energy Consumption (kWh) per day -cruise	868.8	1183.6	1522.4	2200	N/A
Shore/Cruise Weighted Avg Cost of Electricity ($0.77/kW),	244176	362892	466768	674520	678567
Total Cost ($) of Electricity per Year (All Pre-Heaters Total)	**2426923**				

[This table displays the baseline characteristics of the HVAC Pre-heaters assumed from LHA6 comparisons between kW required and the requirements of Mil-H-22594. Hours operation data was obtained from the DDG-51 Electrical Load Analysis and cost was determined via findings from the electricity usage data obtained from NAVFAC]

Table 16 - DDG-51 Baseline Finned Tubular Pre-heater Parameters

The analysis of alternatives criteria and the overall approach began with research in the field of different duct-type heating elements. Among the available heating element technologies are: 1) standard tubular, 2) open coiled, and 3) the finned tubular designs. The heating element currently on the ship as well as defined in the mil-spec, is the finned tubular technology. Comparisons between available performance parameters within individual heating element types versus baseline requirements were analyzed for pre-heater performance and potential energy savings.

Another approach to pursue energy savings in pre-heater electrical loading would be to explore the feasibility of using smaller mil-spec qualified kW heaters for functionality as a means to decrease energy consumption and utility cost onboard ship. The pre-heaters in this study, excluding the 100.6 kW, are all the high heat output type duct heaters. The available types in accordance with the mil-spec are low heat output, medium heat output and high heat output. All heating output outlet temperatures are the same, with the difference in heating resulting from the variances in air flow rate. This approach explores engineering design changes and the success of it is contingent upon verification of the following assumptions:

- Baseline heaters are oversized for high heat output in accordance with HVAC calculations.
- Medium heat output type heaters are sufficient for non-vital specified pre-heaters.
- Performance impact is minimal due to a 10% decrease in baseline air flow rate.

Selection criteria for alternative selection was consolidated an evaluation matrix that centers on the following parameters**:**

Pre-heater Performance Criteria:

- Flow Rate (CFM)
- Outlet Temp (0F)
- Total Weight (lb)
- Reliability
- Availability

Pre-heater Cost Criteria:

- Energy Consumption (kW)
- Investment Cost ($)
- Operational Savings ($yr)
- Maintenance (h/yr)
- Maintenance Savings ($/yr)

Results and Recommendations:

The pre-heater heating element analysis centered on the open coil design and the finned tubular. Standard tubular was not considered due to the finned tubular being preferred, via research, as the better technology and better energy saver over the tubular type design.[37]

[37] WATTCO, "*Duct Heaters/Air Heaters,*" downloaded on 30 August 2010 from http://www.wattco.com/pdf/Duct_Heaters.pdf

The power supply seems to be the biggest issue since the ship's supply is 440 volts and all available alternatives provide heaters in voltages lesser or greater, but not equal to 440 volts. Any alternative that requires a power supply other than 440 volts will result in the Navy purchasing a transformer to convert the 440 volts to the applicable power supply. Electrical engineering SMEs have stated that adding a transformer decreases efficiency, negating any potential energy savings that might be gained, plus may not be cost effective depending on the available funding to implement the change. Shipboard transformers adhere to MIL-T-15108 for 60 hertz applications and must be arranged in three-phase transformer banks that are composed of three single-phase transformers in accordance with ship specification section 314. Inclusion of transformers may also introduce space and weight issues that conflict with approved tolerances, since they are typically located close to the units or panels which they serve ,and can weigh anywhere from 30 pounds to 950 pounds, occupying volumes of 525 cubic inches to 17,200 cubic inches per transformer, depending upon the specified wattage and current.[38,39]

Additionally, the open coil design does not meet other performance characteristics of the standard such as flow rate and duct size.[40] Unqualified finned tubular duct heaters followed a similar trend as the open coiled in not meeting the specified mil-spec parameters: such as power supply, duct size, and air flow rate. Table 17 summarizes the analysis results for heating element technology.

38 Naval Sea System Command, "*MILT-15108C, Transformers, Power, Single-Phase, 60-Hertz, Naval Shipboard Military Specification,"* Washington, DC, August 1955.

39 Naval Sea System Command**,** "*General Specifications for Ships of the United States Navy Section 314 Electric Power Supply Conversion Equipment (Surface Ships),"* NAVSEA S9-AAO-AA-SPN-010/GEN-SPEC, Washington, DC, 1986.

40 INDEECO, "*Choosing Open Coil or Finned Tubular Design,"* http://indeeco.thomasnet.com/item/electric-duct-heaters/standard-duct-heaters-open-coil/pn-4961?

	Alternative 2	Alternative 3
	INDEECO	WATTCO
Preheater Characteristics		
Mil-H-22594 Qualified (Y/N)	No	No
Weight (lbs)	Unknown	70, 95, 105, 150
Flow rate (CFM)	2847, 4170 (minimums)	2050, 3000 , 4000 , 6000
Duct Size (width(in) x height (in))	14x30, 20x30, (largest duct height is 30")	Width requirement met. No Match for Height requirement
Wattage required (kW)	77,123,	40, 60, 80, 120
Supply Voltage available	400V, 3-phase, 415V 3-phase	600 V, 3-phase
Heating element	**Open Coiled**	**Finned Tubular**

[This table displays the distinct characteristics of the alternative heating element technologies. These technologies are not mil-spec qualified. Most notable is the supply voltage is not compatible with the ships required voltage of 440 V.]

Table 17 - Heating Element Technology Analysis

With regard to the heating element technology, maintaining the baseline model of the finned tubular design is the preferred option, as the open coiled and unqualified finned tubular alternatives are not feasible for shipboard design. Additionally, they do not provide any additional energy savings.

The results of smaller kW pre-heater analysis yield some interesting findings. Table 18 highlights some preliminary energy consumption savings calculations, if feasible, to replace the high-heat type heaters with medium-heat type heaters. Pre-heater power (kW) is a function of the difference between inlet and outlet temperatures and air flow rate. When keeping the delta temperature constant and decreasing the air flow rate by 10 percent, energy consumption decreases on average about 33 percent as seen in Table 18.

	Alternative 1a Chromolax	Alternative 1b Chromolax	Alternative 1c Chromolax	Alternative 1d Chromolax	Alternative 1e Chromolax
Preheater Characteristics					
Mil-H-22594 Qualified (Y/N)	Yes	Yes	Yes	Yes	Yes
Heater perfomance/ Heat output	Medium Heat	Medium Heat	Medium Heat	Medium Heat	Medium Heat
Size	29EH	32EH	33EH	35EH	37EH
Weight (lbs)					
Flow rate (CFM)	**2650 (10% decrease from baseline)**	**3933 (10% decrease from baseline)**	**5063 (10% decrease from baseline)**	**7317 (10% decrease from baseline)**	**8330 (10% decrease from baseline)**
Outlet Temperature (deg F)	42 - 50	42 - 50	42 - 50	42 - 50	42 - 50
Duct Size (width(in) x height (in))	12-1/4 x 30	18-1/4 x 30	16-1/4 x 42	24-1/4 x 42	36-1/4 x 42
Wattage required (kW)	24.3	36	46.4	67.1	100.6
Supply Voltage available	440V, 3-phase, 60-hz	440V, 3-phase, 60-hz	440V, 3-phase, 60-hz	440V, 3-phase, 60-hz	440V, 3-phase, 60-hz
Operating life (hrs)	126,000	126,000	126,000	126,000	126,000
Maintainance (replacement parts) (hrs)	21,000	21,000	21,000	21,000	21,000
Heating element	Finned Tubular	Finned Tubular	Finned Tubular	Finned Tubular	Finned Tubular
Hours of operation/day - shore	24	22	22	22	24
Hours of operation/day - Cruise	24	22	22	22	0
Energy Consumption (kWh) per day -shore	**583**	**792**	**1020.8**	**1476.2**	2414.4
Energy Consumption (kWh) per day -cruise	583	792	1020.8	1476.2	N/A
Shore/Cruise Weighted Avg Cost of Electricity ($0.77/kW),	163908	242827	312977	452603	678567
Total Cost ($) of Electricity per Year (All Pre-Heaters Total)	**1850883**				

[This table details the characteristics of the mil-spec qualified pre-heaters. As opposed to baseline model, these heaters distribute medium heat performance, resulting in a lower kW requirement and airflow rates at the inlet and outlet temperature and ducting dimensions. Lower energy consumption results in lower operational cost of electricity for the powering of the pre-heaters.]

Table 18 - Preliminary Energy Consumption Evaluation using smaller Mil-H-222594 kW Pre-heaters

Evaluation Matrix	Pre-Heaters			
Performance Criteria	Baseline	Chromolax		
Flow Rate (CFM)	6043	5459		
Outlet Temp (ºF)	50	50		
Total Weight (lb)	501	501		
Relaibility	0.90	0.90		
Availability	0.90	0.90		
Cost Criteria				
Energy Consumption (KW)	72.0	54.9		
Investment Cost ($)	0	120,000		
Operational Savings ($/yr)	0	577,275		
Maintenance (h/yr)	24	24		
Maint Savings ($/yr)	0	0		
Normalized Score				
Flow Rate (CFM)	1.000	0.000		
Outlet Temp (ºF)	1.000	1.000		
Total Weight (lb)	1.000	1.000		
Relaibility	1.000	1.000		
Availability	1.000	1.000		
Performance	1.00	0.80		
Savings-1	0	457,275		
Savings-5	0	2,766,375		
Savings-10	0	5,652,751		

Table 19 - Pre-heater Evaluation Matrix

In the overall evaluation matrix, the five pre-heaters flow rates and energy consumption were averaged and the performance criteria normalized to present a clear picture of the analysis results. Weighted average electricity cost is derived from the assumption of shore power electricity cost of $0.14 per kWh and a cruise operation electricity cost of $2.06 per kWh. NAVFAC has stated that ships are at port 67% of the year with the remaining time spent in cruise or anchor operations. Assuming equal physical weights for both baseline and Chromolax pre-heaters and 90% reliability and availability, the normalized performance score translates to a 20% lesser performance in the alternative than the baseline because the Chromolax pre-heaters' air flow rate is 10 percent lower than the baseline model. Assuming a total investment cost of $120,000 for the five alternative Chromolax pre-heaters and a maintenance requirement of one day per year for both baseline and alternative, operational savings on a $0.77/kW weighted average cost of electricity for shore and cruise conditions approximate around $580,000.

Operational savings yield an overall cost savings of approximately half a million dollars in the first year, and over a ten-year period the savings observed are a little over $6M.

In conclusion, the cost savings estimated here suggest that a validation of the feasibility of using smaller kW heaters is warranted for follow up energy studies. An engineering design analysis of HVAC pre-heating loading calculations is required to substantiate our claims about the lower performance of the smaller kW pre-heaters. If design change is validated by subsequent testing, it is recommended to replace the high heat output heaters with the medium heat output heaters for non-vital pre-heaters.

3. Fuel Transfer Heaters

Background:

According to the Ship Specification issued by the Naval Sea System Command, there are two fuel transfer heaters for the DDG-51; one for each engine room.[41] The two heaters are provided for redundancy as each heater is capable of handling all of the fuel heating requirements. Therefore, only one operates at any given time. The fuel heating requirements or the temperature of the fuel that leaves the heater is based on the viscosity required at the inlet to the gas turbine.

The results of the Auxiliary Systems cited the fuel transfer heater No.1 and 2 as equipment that qualified for further investigation for technology improvements for the purpose of energy conservation. The source data collection task revealed that both heaters have a 10% load factor in the winter shore scenario and a 40% load factor in the cruise scenario. The required capacity for performance under normal operations is between 18 and 72kW.

According to Ship Spec 541 for DDG-52, the fuel transfer heaters shall be required to operate per defined operational and functional characteristics. Table 20 is a listing of the fuel transfer heater's characteristics.[41]

Baseline	
Fuel Transfer Heater Characteristics	
Medium to be Heated	Fuel
Flow Rate (gal/min)	110
Inlet Temperature (deg F)	30
Outlet Temperature (deg F)	70
Energy Consumption (kW)	45
Watt Density (Watts/square inch)	20
Supply Voltage	480V, 3-Phase
Weight (lbs)	957

[This table lists the fuel transfer heater characteristics. The results were derived from the vendor's information on circulation heaters, the Auxiliary System down-select results on the DDG-51 electrical load analysis, and Ship Specification 541, for DDG-52 and follow, Ship Fuel and Compensating System.]

[41] Naval Sea System Command, *"DDG-52 and Follow-on Ship Subsystem Specification,"* Section 541, Specification Fuel Systems, Washington, DC, Revised 30 Nov 2000.

Table 20 - Fuel Transfer Heaters Baseline Characteristics – DDG-51

The fuel transfer heater characteristics were derived from the vendor's information on circulation heaters. Due to legal considerations, the vendor was not allowed to disclose any details of the exact model used for the fuel transfer heaters on the DDG-51 ships other than that they were circulation heaters.

Results and Recommendations:

As previously noted, due to the fact that vendors did not disclose details of their systems, it was assumed that fuel transfer heater systems exist that would match the baseline in the five following criteria: flow rate, inlet temperature, outlet temperature, reliability, and availability. It is also assumed that a 5%, 10%, and 20% efficiency improvement is attainable as indicated from both research and limited discussions with vendors, and the pursuit of exploring technology advances to attain these efficiency enhancements is worthwhile.

As far as costs are concerned, it is assumed the current fuel transfer heater system cost is comparable to a similar system in this study, the pre-heater that contained similar components, including a heating element. It is also assumed that a 5%, 10%, and 20% efficiency improvement in the fuel transfer heater system would require an investment of $37,500, $39,000, and $41,000, per unit, respectively.

The delta costs for the baseline are zero since there is no investment cost or any operational savings. For a system with a 5% efficiency improvement, a return on investment (ROI) over a ten year period would be about $302,000. Similarly, a system with a 10% efficiency improvement, a return on investment over a ten year period would be about $601,000; for a 20% efficiency improvement, the ROI is about $1.3 million over ten years. Based on the significant savings that could be realized over time and the relatively short break-even point, it is recommended that further investigation be pursued in identifying technology to attain the 20% efficiency improvement.

Evaluation Matrix	Fuel Transfer Heater			
Performance Criteria	Baseline	5% efficiency improvement	10% efficiency improvement	20% efficiency improvement
Flow Rate (gal/min)	110	110	110	110
Inlet Temp (F)	30	30	30	30
Outlet Temp (F)	70	70	70	70
Reiliability	0.995	0.995	0.995	0.995
Availability	0.995	0.995	0.995	0.995
Cost Criteria				
Energy Consumption (KW)	45	42.5	40.5	36
Investment Cost ($)	0	75,000	78,000	82,000
Operational Savings ($/yr)	0	37,750	67,950	135,899
Maintenance (h/yr)	24	24	24	24
Maint Savings ($/yr)	0	0	0	0
Normalized Score				
Flow Rate (gal/min)	1.000	1.000	1.000	1.000
Inlet Temp (F)	1.000	1.000	1.000	1.000
Outlet Temp (F)	1.000	1.000	1.000	1.000
Reiliability	1.000	1.000	1.000	1.000
Availability	1.000	1.000	1.000	1.000
Performance	1.00	1.00	1.00	1.00
Savings-1	0	-37,250	-10,050	53,899
Savings-5	0	113,749	261,748	597,495
Savings-10	0	302,497	601,495	1,276,990

Min	Max	Best Score Type
110	110	High
30	30	High
70	70	High
0.995	0.995	High
0.995	0.995	High

[The fuel transfer heater system cost was derived from a similar system, the pre-heater. The 5%, 10%, and 20% efficiency improvement in the fuel transfer heater system have an estimated investment of $37,500, $39,000, and $41,000, per unit, respectively. The operational savings per year per unit for the 5%, 10%, and 20% efficiency improvement are $37,750, $67,950, and $135,899. This resulted in a return on investment over a ten year period of $302,000 for a 5% efficiency improvement, $601,000 for a 10% efficiency improvement, and $1.3 million for a 20% efficiency improvement.]

Figure 30 - Evaluation for Fuel Transfer Heater

4. Chill-Water Pumps

DDG-51 Chilled Water Pump Background Information:

According to the DDG-52 Ship Subsystem Specification, Section 503, there are four centrifugal chilled water pumps (CWP) under the HVAC system.[42] Pumps 1 and 3 are the 7th and 8th largest consumers of electricity within the top-ten Pareto analysis of the HVAC system which is why they are considered further for energy savings in this section. The specification class is MIL-P-17639, with a rated capacity of 900 gallons per minute and a total head of 70 pounds per square-inch. During the source data collection task, it was discovered that these pumps are 60 horsepower and that pumps 1 and 3 have a 90% load factor in the winter shore scenario, while pumps 1, 2, and 3 have that factor in the cruise scenario as shown in Table 10. Pump 4 always had a zero load factor in all of the scenarios considered, so it may be a battle scenario reserve or a hot stand-by to improve reliability. Recommendations offered by the Rocky Mountain Institute (RMI) in the Energy Efficiency Survey for CG-59[4] are likely to apply to the DDG-51 class as well. Those recommendations were to: "Add a variable frequency drive to the CWP, trim the impeller, and increase motor efficiency to match and serve the load more efficiently." Although those recommendations were for the CWP aboard the Ticonderoga class of cruisers, the same type of CWP subsystem exists aboard the Arleigh-Burke class destroyers, thus the suggestion that RMI's recommendations for the CG-47 class would likely be applicable to the DDG-51 class.

CWP Approach and Selection Criteria for Alternatives

The approach to developing more energy efficient alternatives than the baseline CWP is based on a literature search focused on finding pumping systems that meet the existing specifications, which form the selection criteria. Energy consumption, translated as the major

[42] Naval Sea System Command, *"DDG-52 and Follow-on Ship Subsystem Specification,"* Section 503, Specification Fuel Systems, Washington, DC, January, 1999.

component of cost, then forms the independent variable allowing a trade-off of cost versus performance to be assessed.

In the literature search, Variable Frequency Drive (VFD) pumping systems were consistently recommended by manufacturers (Rockwell Automation, Siemens Industry, and Plant Services) as a means to reduce excessive energy draw for both start-up and stopping transients as well as for pumps that have a variable load during operation.[43,44,45] The aforementioned references cited reduced power consumption of anywhere from 30% to 50% over a fixed pumping system, depending on parameters specific to a given application. The RMI study recommended a retrofit of existing CWPs for the CG-59 to VFD pumping systems as well. Offik identifies that for an application where the pump operates at the full flow rate with a duty factor near 100%, the VFD pumping systems may actually cost more due to inherent losses (harmonic current injection) on the order of 3% relative to a fixed frequency design.[45] Since the CWP has a variable load while in operation, VFD is a viable alternative.

Francis Martino recommended that in applications with a fixed load after start-up, that a Solid-State Reduced Voltage Starter (SRVS) is more appropriate than a VFD as it reduces the excessive power draw during the start-up transient like a VFD but does not introduce harmonic motor currents and therefore avoids the losses inherent in VFD designs.[46] Given that the CWP has a variable rather than fixed operational loading, this alternative is not considered further, but it may be suitable for other pumping systems that have a loading factor at or near 100%, like Fire Pump Number 4.

As mentioned earlier, the performance selection criteria came from "DDG-52 and Follow-On, Ship Subsystem Specification, Section 503." Availability and reliability were initially considered as performance criteria, but upon further consideration, it was determined that the existing performance would define a pass or fail constraint during the acquisition process if these recommendations are pursued for implementation. Given that data for specific commercial-off-the-shelf solutions could not be obtained within the time-frame of the current

---

43 Rockwell Automation, *"Energy savings with variable frequency drives,"* downloaded 20 July 2010 from http://literature.rockwellautomation.com/idc/groups/literature/documents/ar/7000-ar002_-en-p.pdf

44 Prachyl, S., *"Variable frequency drives and energy savings,"* downloaded 20 July 2010 from http://www.sea.siemens.com/us/internet-dms/dt/DrivesComm/Drives/Docs/VariableFrequencyDrives_WhitePaper.pdf

45 Offik, M., Stauble, F., Turley, R., *"Pump energy savings with VFDs,"* downloaded 20 July 2010 from http://www.plantservices.com/articles/2005/491.html

46 Martino, F., *"Energy savings: solid-state reduced voltage starters vs. VFDs,"* downloaded 20 July 2010 from http://www.powerqualityanddrives.com/energy_savings_starters_vfds

research effort, the performance of the alternative VFD pumping system is presumed to be on par with the baseline system with cost being the only differentiator among alternatives, both in terms of investment for acquisition and then savings in reduced energy usage and maintenance cycles.

CWP Performance Criteria

Capacity: 900 gal/min
Total Head: 70 psi
Reliability: 0.995 (assumed)
Availability: 0.997 (assumed)

CWP Cost Criteria

Energy Consumption
Investment Cost
Operational Savings/year
Maintenance Savings/year

Results and Recommendations:

As noted above, it is assumed that a specific VFD pumping system exists that can at least match the baseline in terms of the four performance criteria, for example the Baldor VS1PF.[47] In terms of cost criteria the power consumption savings is identified in the literature as 30% to 50% as given by Rockewell, Siemens, and Plant Services. For this study, the low end of that range is assumed, resulting in a consumption rate of 29.8 kW versus the baseline 42.5 kW. The baseline power consumption rate accounts for loading factors is an average of the pier-side and cruise conditions. The investment cost is based off a scaling to a 60 HP pump from installation estimates of VFD pumping systems given on the California Energy Commission website ($3K for a 5 HP pump and $45K for a 300 HP pump) and then multiplied by four to adjust for the

[47] Baldor - Dodge/Reliance, *"VS1PF AC Drive Data Sheet,"* Greenville, SC, 2007 downloaded 2 September 2010 from http://www.baldor.com/pdf/literature/FL763.pdf.

number of pumps on a single ship.[48] The operational savings is the delta in energy consumption, converted from kWh using the blended pier-side and ship-generated energy rate of $0.77/kWh, and then converted from hours to years to get operational savings in units of dollars per year. The maintenance savings is based off an assumed reduction of five maintenance hours per year for each pump, due to a soft-start that avoids water-hammering and thus reduces wear and tear and extends the time between required maintenance, which is combined with the assumed maintenance labor rate, adjusted for four pumps.

The resultant normalized performance scores are both 1.0, as the performance parameters are assumed to be identical for both the baseline and VFD alternative. The delta costs for the baseline are zero since there is no investment cost or savings in operations and sustainment. However, implementation of VFD on pumps one and three at a cost of about $22K would provide a return on investment within the first year of operation with a net savings of about $160K. Over a ten year period, the accumulated savings, offset by the initial investment cost, would be about $1.8M. The inputs and results discussed above are shown in tabular form in Table 21 below. Based on the very short period for breaking even on investment costs and the significant savings that could be realized over time, it is recommended that VFD pumping systems be implemented as replacements for the baseline CWP.

---

[48] California Energy Commission, *"Variable-frequency drive,"* downloaded 20 July 2010 from http://www.energy.ca.gov/process/pubs/vfds.pdf

Evaluation Matrix	AC Chill-Water Pump 1 & 3					Min	Max	Best Score Type
Performance Criteria	Baseline	VFD						
Capacity (gal/min)	900	900				900	900	High
Total Head (psi)	70	70				70	70	High
Reliability	0.995	0.995				0.995	0.995	High
Availability	0.994	0.994				0.994	0.994	High
Cost Criteria								
Energy Consumption (KW)	42.5	29.75						
Investment Cost ($)	0	21,800					$K	HP
Operational Savings ($/yr)	0	172,170					3	5
Maintenance (h/yr)	288	278					45	300
Maint Savings ($/yr)	0	560					10.83	60
Normalized Score								
Capacity (gal/min)	1.000	1.000						
Total Head (psi)	1.000	1.000						
Reliability	1.000	1.000						
Availability	1.000	1.000						
Performance	1.00	1.00						
Savings-1	0	150,930						
Savings-5	0	841,849						
Savings-10	0	1,705,498						

Table 21 - Evaluation for Chilled Water Pump

5. Ovens

Background Information:

The DDG-51 has two stacked Blodgett Combination Steam/Convection Ovens, pictured in Figure 31, that are used generally four times per day to support each watch for periods up to two hours. The ovens have very basic controls and are not a significant safety risk. Figure 32 is a photograph of the safety precautions and operating instructions. Given that both operating instructions and safety precautions fit a small plate, the human interface with the oven is considered very simple and unlikely to be an area where improved procedures could save energy. Based on the site survey of the DDG-97 and the oven specification, the attributes of the ovens are: [49]

- The physical size is 58 ¾ inches X 37 ¾ inches X 36 inches
- They require clearance above for the fan (6 inches) and below (8 inches) and around the sides (4 inches) for a space requirement of 72" X 45 ¾" X 44"
- There is no broiler
- The ovens have a 5-6 year life
- There is a preheat specification is to heat to 350°F, within 20 minutes starting at 75° F with doors fully closed. The ship observed this to occur in 15 minutes.
- The power source for both ovens combined is 450 volts, 25 amps, 44 kW the ovens are used on multiple classes of Naval platforms
- The ovens are easy to use with minimal safety risks

[49] U.S. Army Natick Soldier RD&E Center, *"Blodgett Double Stack Combi-Oven,"* downloaded on 1 July 2010 from http://nsrdec.natick.army.mil/media/fact/.

[The Figure pictures the ovens onboard DDG-97; not all food racks are installed]

Figure 31 - DDG-57 Ovens

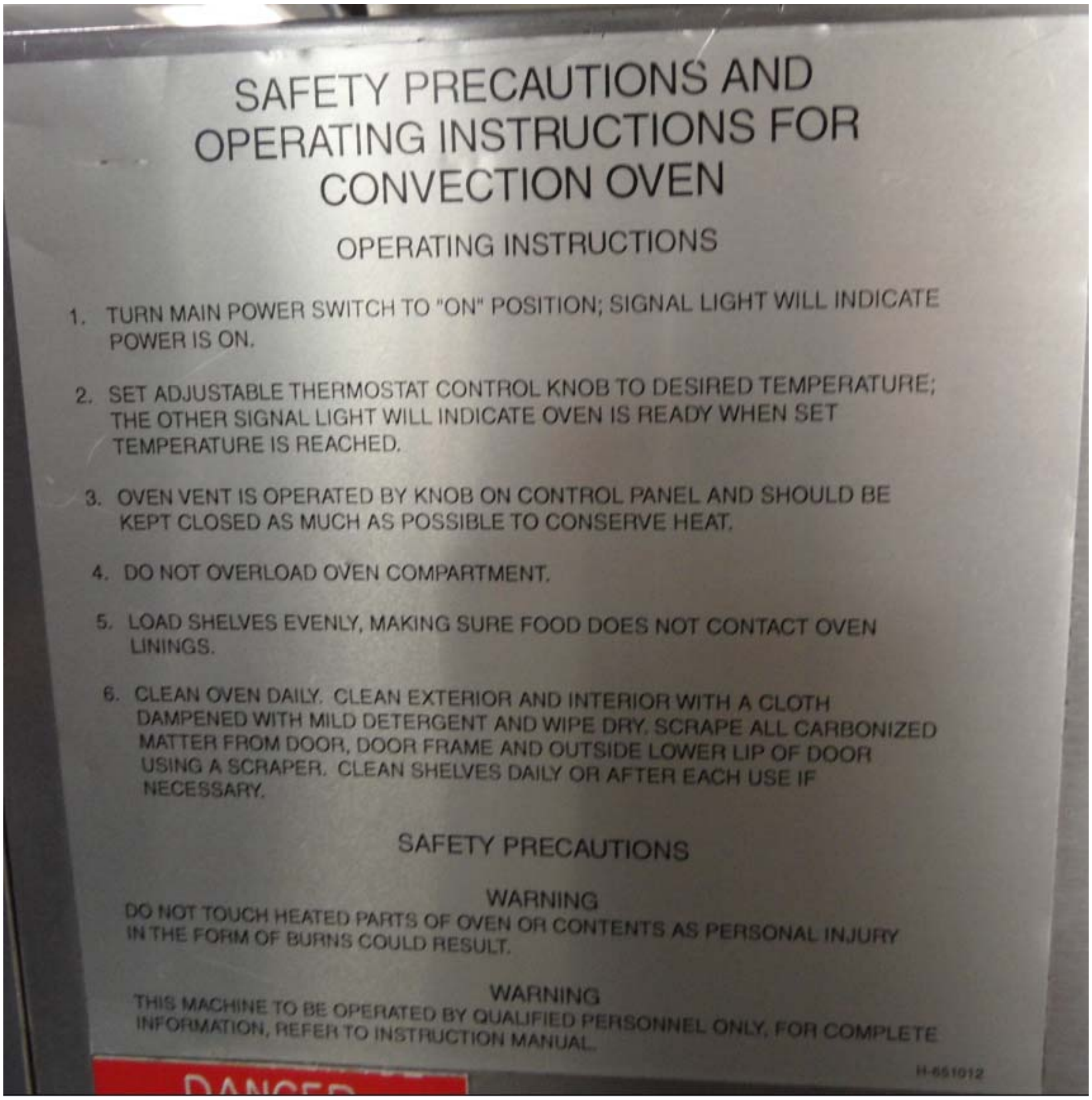


Figure 32 - Safety Precautions for the Operation of DDG-97's Ovens

The maintenance requirements for the ship's ovens are covered in SYSCOM Maintenance Index Page: 6544/001-98 and are described in the table below.[50] There are also some inspections that are routine and are expected to take less than 6 minutes. The crew of the DDG-97 did not indicate they conducted formal inspections.

50 Naval Sea System Command, Maintenance Index Page: 6544/001-98, Washington, DC, June 2007.

MRC NO.	MAINTENANCE REQUIREMENT DESCRIPTION	PERIO-DICITY CODE	RATES	MAN HRS	RELATED MAINT
98 E1ED N	1. Decalcify Steam/Convection Boilers.	M-1	EMFN	1.0	None
C9 Z99Y N	1. Clean Convection Oven Blower Wheel.	A-1	EMFN	0.2	None
B6 C4PQ N	1. Test and Adjust Thermostat Temperature Control.	A-2	EM2 EMFN	1.0 1.0	None
48 C5EM N	1. Test and Adjust Thermostat Temperature Control.	A-3	EM2 EMFN	1.0 1.0	None
B6 E4TY N	1. Clean and Inspect Control Panel. 2. Inspect Insulation and Measure Insulation Resistance.	A-4	EM3	0.8	None

[The table lists the maintenance requirement cards, the type of sailor required to execute them, the periodicity and the length of time to execute them]

Table 22 - Maintenance Requirement Description[50]

This same oven is used on Virginia Class Submarines and non-Naval platforms. The ovens are purchased from the original manufacturer via the Naval Shipyards, not through the Navy stock system. The commercial version of the oven sells for approximately $16,500. The American Testing and Material – Standard Test Methods Society largely determines oven performance for combination ovens. The standard describes the following attributes:

- The energy input rate test and thermostat calibration are used to confirm that the combination oven is operating properly prior to further testing and to ensure that all test results are determined at the same temperature.
- Preheat energy and time to know how quickly the combination oven can be ready for operation.
- Idle energy rate and pilot energy rate can be used to estimate energy consumption during non-cooking periods.
- Cooking-energy efficiency is a precise indicator of combination oven energy performance under various loading conditions.
- Production capacity is a measure of food output requirements.

- Water consumption characterization is useful for estimating water and sewage costs associated with combination oven operation.
- Condensate temperature measurement is useful to verify that the condensate temperature does not violate applicable building codes.

Oven Technology Alternative Selection Approach and Selection Criteria:

The ovens are used across platforms and services and must meet all of the platform requirements or have a new logistics paradigm developed. Technologies that were reliant on natural gas or propane were not included in the alternatives since they would present safety issues on submarines the ovens would need to be installed. The Food Service Technology Center publication 5011.02.26 describes the operations and technologies behind ovens.[51] Their categorization was chosen for the basic alternatives to be considered for electric ovens.

A brief description of the baseline technology and the remainder of existing technologies follows:

Infrared ovens work by focusing the heat source onto a ceramic tile that has thousands of microscopic holes in it. This converts the heat source into infrared energy source. This heat is much higher and more persistent than a standard grill can produce.[52]

Air Impingement technology uses a ported manifold to direct jets of air onto the food's surface. Given that the Navy's ovens cook primarily on stacked trays, this technology was not further evaluated.

Halogen Lamp ovens use infrared and visible light to cook food. Because the lamps perform the heating, no preheating is required. For the same reason, they consume no power while in idle mode. This method does not use ceramic tiles to increase radiated heat.

---

[51] Food Service Technology Center, *"Appliance Technology Assessment Chapter 7 of Publication 5011.02.26 Ovens,"* downloaded on 1 July 2010 from http://www.fishnick.com/equipment/techassessment/7_ovens.pdf

[52] Riches, D., *"About.com Guide,"* downloaded on 1 July 2010 from http://bbq.about.com/cs/infraredgrills/a/aa033101a.htm

Conduction ovens transfer heat to foods via direct contact. The most popular type of ovens using this technology is pizza ovens. Given the diversity of items being cooked, this oven is not suitable for Navy uses.

Combination Convection Microwave ovens combine a fan that forces the hot air to circulate around the food. At the same time, it has a microwave component.

Combination Halogen Microwave ovens combine these two technologies.

The performance measures are described below:

- Energy input rate is the rate is the maximum rate the appliance draws energy
- Preheat time is the time required to raise the oven temperature to 375 degrees F
- Energy consumption is a function of the thermostat set point and an oven's resistance to heat loss Kw/hour
- Production capacity is the amount of food that can be prepared in a given amount of time

Table 23 summarizes the baseline attributes and those of the alternatives chosen. The baseline data for came from the site visit and Blodett Model BCP-102 Programmable Combi Oven. The data in Table 23 comes from extrapolating the results of a few tests of commercial ovens. An ASTM test of a Quadlux Flashbask Model B12 Lightwave oven, was used as the baseline for halogen microwave combination ovens.[53] The data was doubled to represent what could be achieved using the same volume as the baseline oven. An FTSC and Underwriters Laboratories Inc. test of a TurboChef Model C3 oven with a stack kit serves as the primary source of the convection microwave combination oven.[54] The Turbo Chef Oven is not as large as a baseline oven, so two units were assumed FoodService Equipment Reports November 2007 and June 2009 issues, published by Gill Ashton Publishing provided background information on many of alternatives. Of particular value was their review of rapid cooking technology. The green highlighted boxes represent the best alternative for that attribute.

[53] Fisher, D., *"Flashbask Model HFB12 Lightwave oven Product Evaluation,"* downloaded on 1 July 2010 from http://www.fishnick.com/publications/appliancereports/ovens/Hobart_Flashbake_Oven.pdf, May 1999.

[54] TurboChef Global Operations, *"C3 Ventless Submittal Information,"* downloaded on 1 July 2010 from http://www.turbochef.com/filemanager/9/C3_Ventless_Submittal_Package.pdf, Dec 2008.

		Heating Technologies			
		DDG Baseline Convection/Steam	Halogen	Combo Conv./microwave	Halogen Microwave
Performance Attributes at Full Load	Cooking Efficiency	0.7	0.7	0.72	0.7
	Energy Input Rate (kW/hr)	44	24	8	15
	Preheat time (min)	15	1	15	1
	Cook Time (min)	7	4.5	2.5	1.5
	Production Capacity (Full Size Sheets)	10	2	4	3
	Lifespan (years)	5.5	10	3	3
	Maintenance Time (hr/yr)	6	5	6	10
	Remarks	Supports Multiple Platforms	Maintenance Time was Assumed to be 5 min/yr	Model was 2/3 Size of Baseline Used in Subways	No Model Exactly Matched the Baseline Specifications

Table 23 - Performance Attributes for Various Heating Technologies

In order to evaluate the alternatives, the amount of cooked food is an essential input. Table 24 was used for this analysis. The particular values in the table are based on crew size and gross estimates of food consumption. The estimates were chosen as if all meals were chicken breasts, as that was the basic food unit in the performance tables.

		DDG Baseline Convection / Steam	Halogen	Combination Convection Microwave	Halogen Microwave
Cooking evolutions per meal	Breakfast	1	6	3	4
	Lunch	2	8	4	6
	Dinner	2	14	7	10
	Midrats	1	2	1	2
	Sum	6	30	15	22

[This table represents the assumption made on the amount of food to be cooked. It is used to determine operating costs.]

Table 24 - Assumed Cooking Evolutions per Meal

Oven operation time and Energy Usage

	DDG Baseline Convection / Steam	Halogen	Combination Convection Microwave	Halogen Microwave
Preheat time (min)	60	2	60	2
Cook time (min)	42	135	38	33
Total cook time total per day (hr)	2	2	2	1
Cook time total per year (hr)	621	833	593	213
Energy usage total per year (kW)	27302	19835	4448	3194

[This table represents how much energy is consumed and is used to generate operating costs.]

Table 25 - Oven Operation Time and Energy Usage

Table 25 above was developed from the data in Table 23 and Table 24. It describes the amount of time the ovens were needed to be powered on and how much energy they consumed.

Results and Recommendations:

Table 26 summarizes the cost attributes for each of the alternatives. The baseline oven was not the most energy efficient for the assumed amount of food cooked. This also held true if either 20% more or 20% less food was cooked. The microwave combinations ovens were certainly more efficient for energy use. However due to their small size, the number of times trays had to be put in and taken out was greater requiring more manpower to manage the cooking process. The baseline oven was the least manpower intensive. This is illustrated by Table 27.

		Heating Technologies			
		DDG Baseline Convection/Steam	Halogen	Combo Conv./microwave	Halogen Microwave
Annual Costs	Purchase Cost	$16,500	$500	$15,000	$1,100
	Annualized Material Cost	$3,000	$50	$5,000	$367
	Annualized Maintenance Cost	$180	$150	$180	$300
	Annualized 100% In-Port Energy Cost	$3,822	$2,777	$623	$447
	Annualized at-sea (100%) Energy Cost	$63,614	$46,216	$10,365	$7,441
	Annualized energy cost at given in-port/at-sea ratio	$23,480	$17,058	$3,863	$2,747
	Annualized energy cost at given in-port/at-sea ratio (20% increase in food consumed)	$26,702	$21,541	$4,316	$3,217
	Annualized energy cost at given in-port/at-sea ratio (20% decrease in food consumed)	$23,480	$19,051	$2,060	$2,472

[This table summarizes the cost given the operating time. It also describes the results if plus or minus 20% of the assumed food consumption rate.]

Table 26 - Annual Costs for Various Heating Technologies

However, it was the least manpower intensive. This is illustrated by Table 27. The microwave combination ovens were generally smaller requiring more manpower to put trays in and out.

Cooking Evolutions per day

DG Baseline Convection / Steam	Halogen	Combination Convection Microwave	Halogen Microwave
6	30	15	22

Table 27 - Number of Cooking Evolutions Required per Day

When calculating the costs for planning and installing a new design oven, the engineering design work and installation costs may outweigh the cost of the item being installed. Because the oven is used on multiple platforms and welding is required in an enclosed space to install the oven, the estimated costs for these items is high and has an enormous effect on the total cost savings over the lifecycle. The cost data for the engineering change proposal for these calculations was assumed to be $30,000. The installation costs were assumed to be $6,000.

Ovens Heating Technologies Delta from baseline

Cost Criteria	DDG Baseline Convection / Steam	Halogen	Combination Convection Microwave	Halogen Microwave
Purchase Cost new oven	$0	500	15,000	1,100
Annualized material cost	$0	-2,950	2,000	-2,633
Annualized Maintenance Cost	$0	-30	0	120
Annualized energy cost at given in-port/at-sea ratio	$0	-6,421	-13,233	-1,079
NRE (ECP + installation)	$0	36,000	36,000	36,000

Table 28 - Cost Deltas for alternatives (Numbers in Red are Savings)

Cost Change from Baseline at 1, 5, and 10 years

	DDG Baseline Convection / Steam	Halogen	Combination Convection Microwave	Halogen Microwave
1st year cost	\$0	\$30,049	\$37,767	\$36,141
5 year costs	\$0	\$4,743	-\$164	\$32,305
10 year costs	\$0	-\$27,013	-\$66,327	\$27,510

Table 29 - Cost Over Time in Constant Dollars (Numbers in Red are Savings)

Based on this analysis it is recommended that Halogen microwave be considered, but since there are at least some manpower increases. The savings may be offset by the added labor cost which was not quantified in this study.

6. Dryers

Background:

The DDG-51 Class of Ships Manned Laundry Room is used for washing, drying and pressing crew uniforms and linens. The ship also has a self service laundry that is used by ship's crew for washing and drying personal garments. Ships are outfitted with either steam-heated, 50 or 100 pound dry weight tumblers, or electrically heated 50 pound dry weight tumblers, as per (Commercial Item Description (CID) A-A-593643).[55] The ship is also outfitted with a self service laundry facility. The self service laundry is outfitted with residential size dryers that are electrically heated and are the latest Energy Star tm efficiency models. The ships manned laundry is outfitted with three 50 pound capacity electrically heated tumble dryers, manufactured by Cissell.

In researching tumble dryer alternatives, we found that the technologies fall within one of the following categories; vented types (also called traditional) or ventless types. Both vented and ventless types operate using an electrically driven drum and remove warm moist air from the drum to dry clothing. Both use heating elements that can be powered by electricity or gas. Vented types require a ventilation system to exhaust air out into the atmosphere, which can contribute to the carbon footprint. Vented types are typically cheaper to buy, more reliable, and cheaper to run than ventless types.

Ventless dryers do not require any venting or exhaust pipes, which makes them attractive for ease of placement when space is an issue and they contribute less to the carbon footprint. Ventless types drying process involves drawing in air only once and uses that same air repeatedly. When the air becomes full of moisture, it is then dried out again using an evaporator. The excess water is channeled down a drain or recycled, and the air is filled with water again, repeating the process.[56] Ventless types can be more expensive to buy and also provide automated features similar to vented dryers.

---

[55] General Service Administration, *"Commercial Item Description MIL-A-A59364, Tumble Dryer, Laundry, Steam and Electric (Naval Shipboard),"* Washington, DC, 21 January 1999.

[56] Lacoma, T., "*Condenser Dryers versus Vented Dryers,"* downloaded on 1 July 2010 from http://www.ehow.co.uk/about_6497835_condenser-dryers-vs_-vented-dryers.html.

There are several types of tumble dryers. Vented traditional types include: electric, gas and steam options that are readily available for shipboard use. Electric and steam types are already in use on Navy Ships, however discussion with Mr. Chuck Rozanski, DDG-1000 Principal for Safety at the Naval Surface Warfare Dahlgren Division (NSWDD), "use of gas dryers has just never been a preference by the Navy in the past due to typical safety reasons, such as a hit or impact in combat or a potential hazardous gas leak." However, there are no prohibitive requirements against the use of gas onboard ships; therefore ships can carry bottled gas, with special provisions for storage and gas monitoring. Ships currently store bottled acetylene, which is along the same lines as bottled gas, but acetylene tanks are stored in plain lockers under special control and hazardous gas monitoring provisions. Use of gas dryers that utilize bottled gas as the heating source is stated to be a matter of preference by the program manager. Based on this, alternative gas dryer technologies will not be ruled out.

Ventless dryer types include, but are not limited to the following types of dryers: spin dryers, condenser dryers, heat pump dryers, and mechanical steam compression dryers. None of the ventless types researched were designed to military standards, thus are not suitable for shipboard use at this time. Therefore, the vented traditional dryer type is the continued focus of this analysis.

Although we did not analyze the ventless type of dryers in the present work, the Naval Supply Systems Command (NAVSUP) Small Business Innovation Research has put out a request that research be done into the field of ventless dryers.[57] The objective of the project is to develop a 50-pound (dry weight) capacity, electrically-heated tumble-dryer, compatible for operations within a U.S. Navy shipboard laundering environment, which does not require external exhausting and venting of air, has less system-wide energy usage, and can have potential energy savings as a result of the HVAC system not having to heat or cool additional air to replace that exhausted by a traditional dryer. This is a three phase initiative to design, develop, and commercialize a ventless type dryer for shipboard use by 2013.

In comparing electric, gas, and steam commercial dryer types, research showed gas types have a greater initial cost as compared to electrical dryer types. They are approximately $500.00 more than dryers that run on electricity. However, in most areas, gas will cost less to run over their lifetime, by approximately 33-50% cheaper, simply due to low cost of gas. Emissions for

[57] Gallagher, J., "*Clothes Dryer Green Technology Research*," Navy SBIR 2010.2 – Topic# N102.162, Washington, DC, 8 June 2010, downloaded 1 July 2010 from http://www.dodsbir.net/sitis/archives_display_topic.asp?Bookmark=38760.

gas types are also almost half that of electrical types, 0.193 kg/kWh versus 0.432 kg/kWh, respectively.[58,59] Gas types also require installation by a CORGI registered gas fitter, which adds to their cost, and generally speaking the cost of electricity needed to dry a typical load of laundry costs two to three times as much as a load dried with gas. Dryers that utilize steam were found to be more expensive to operate, approximately 4 times more than conventional electric types, and costs approximately $500.00 to $1000.00 more to purchase. Steam dryers also require additional piping installation, which also add to their costs.

Alternative Selection Approach and Selection Criteria:

The approach to researching and selecting potential alternative options for the baseline followed a methodology of first determining relevant performance characteristics (see Table 30) that relate back to the project KPPs. The approach involved researching different types of commercial grade tumble dryers with similar or better performance characteristics and features as the baseline. Each dryer type and its associated parameters, hard and assumed data, is put into an evaluation matrix to arrive at results that would show a potentially better, or "just as good as" alternative than the installed baseline dryers. Data that could not be obtained from the ship's crew was augmented by a local Laundromat business. According to W. Smith, the owner and operator of a local Laundromat, her machines have the following characteristics: a slightly larger rated capacity gas tumble dryer and retrofitting from a local plumbing business with gas piping installation experience.[60,61] Data other than cost that could not be obtained from aforementioned sources for some alternative types, was approximated and assumed as the baseline; using parameters of another similar comparative alternative type whose data was available (e.g., noise/sound levels of Alternative A assumed as baseline for Alternative B).

---

58 REUK.co.uk, "*Gas Tumble Dryers,*" Carmarthenshire, UK, 31 January, 2009, downloaded on 1 July 2010 from http://www.reuk.co.uk/print.php?article=Gas-Tumble-Dryers.htm

59 Leverette, M., "*Natural Gas vs. Electric Clothes Dryers*," downloaded on 1 July 2010 from http://laundry.about.com/od/laundryappliances/a/gasclothesdryer.htm.

60 Smith, W., private conversation at Smitty's Laundromat – Gas Dryers, 1014 3rd Street, Ferriday, LA, 15 July 2010.

61 Johnson, J., private conversation at Jerry's Plumbing Service, Pascagoula, MS, 5 August 2010.

Size (HxWxD) (mm)	Unit Weight (lbs)	Rated Capacity Loading (lbs, kg)
Energy Consumption (kWh)	Heat Emission (% installed power)	Power Supply Voltage (V)
Noise/Sound Level (dB)	Operating Feature (% Usability)	Cost (independent variable) ($) • Per unit • Operation per year • Maintenance per year • Disposal
Reliability (%)	Usability (%)	

Table 30 - Tumble Dryers Performance Characteristics

Results and Recommendations:

The three 50lb baseline dryers installed on the USS HALSEY, as shown in Figure 33 below, are manufactured by Cissell (now Alliance Laundry Systems) and are electrically operated.[62] The tumblers are in operation 5 days a week while pier-side (no laundry done on Saturdays or Sundays) or 6 days a week while underway (laundry done on Saturdays for linens only, no laundry done on Sundays). Figure 34 shows the laundry schedule for the ship. The maximum loading capacity per dryer, as per the dryer specification is 75 lbs wet weight. During the ship visit, the dryers were observed to not be used at full capacity. Maximum loading during operation is approximately 20 lbs dry weight, which equates to a 45 lb (wet weight) load of washed laundry per dryer (20 lbs of laundry from one 60 lb washer extractor (2 observed in the space) or 20 lbs of laundry from the one 20 lb washer extractor as noted in the space). According to data collected from the ship's crew, each berthing is allowed no more than 60 lbs of dry weight laundry. [This **table shows the estimated weekly and yearly cost of operating the three baseline electrically heated 50lb Tumble Dryers pier-side and underway. The cost is based on the number of loads of laundry (24 pier-side and 36 underway) times the**

---

[62] Cissell, *"50 lb. Sectionalized Shipboard Laundry Dryer Models L36TD30ME, L36TD30MS (NSN: 3H 3510-01-340-9419), (NSN: 3H 3510-01-312-4422), 440V. A.C, 60 cycles, 3 phases*," Technical Manual #S6162-BS-MMC-010/12489, Alliance Laundry Systems LLC, Rippon, WI, 1 September 1990.

nominal and fully burdened cost per kWh, and the amount of time required to dry a load of laundry, in addition to the required energy consumption.]

Table 31 below shows the estimates of what it cost the ship weekly and yearly to dry approximately 24 loads of laundry while pier-side (assuming all Sailor's utilize shipboard laundry) and 36 loads of laundry while underway using the baseline electrically operated dryers, assuming a high operating temperature setting of 180°F, a pier-side cost of $0.14/kWh and an underway FBCF of $2.06/kWh, as given in the assumptions of Section III.C. The average yearly cost is about $13,689.04.

Figure 33 - DDG-97 USS HALSEY Cissell 50lb Capacity Tumble Dryer

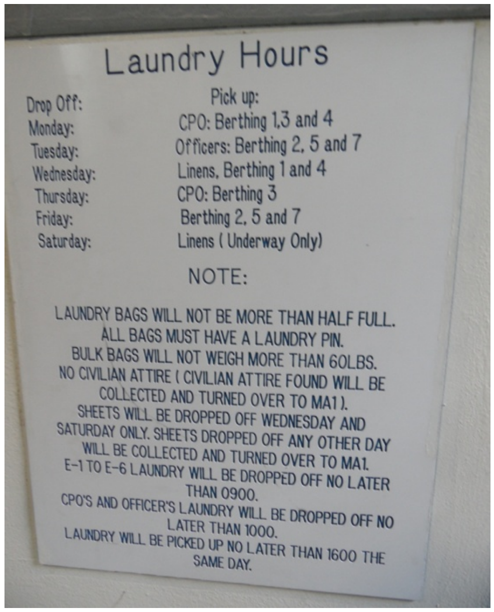


Figure 34 - DDG-97, USS HALSEY Laundry Schedule

Baseline (50lb Cissell Tumble Dryer – Electrically Heated)						
	kWh consumption	Dry Time (min/hrs)	$/kWh	$/load	$/week (24 loads)	$/year
Pier-side	15	22/0.366	0.14	0.77	18.44	885.43
	kWh consumption	Dry Time (hours)	$/kWh	$/load	$/week (36 loads)	$/year
Underway	15	22/0.336	2.06	11.31	407.14	19,542.64
Average Weekly and Yearly Cost					$212.79	$13,689.04

[This table shows the estimated weekly and yearly cost of operating the three baseline electrically heated 50lb Tumble Dryers pier-side and underway. The cost is based on the number of loads of laundry (24 pier-side and 36 underway) times the nominal and fully burdened cost per kWh, and the amount of time required to dry a load of laundry, in addition to the required energy consumption.]

Table 31 - Cost of Operating the 50lb Baseline Tumbler Dryer

There were several manufacturers of 50 lb commercial grade tumble dryers. Among vendors and models found were: Electrolux T3530, EDRO Dyna DD50 (currently manufacturers M-Series tumble dryers for shipboard use), Huebsch HT050, Cissell CHD-50, Speed Queen STO50, and Girbau (UK) GU050. [63,64,65,66,67,68] All alternatives were related in size comparison, but many did not offer the required heating voltage in either the electric, gas or steam type to be compatible with ships electrical services. Electrolux offered dryers in all three dryer types, and also offered the required heating voltage. It also provided a better overall specification, thus reducing the need to make data assumptions. The Electrolux brand was selected for further evaluation against the baseline.

Performance data collected on the electric baseline dryers and the gas and steam alternatives was populated into a scoring evaluation matrix according to Table 32 to determine whether the baseline unit or one of the alternatives is the more feasible solution. In comparing the baseline and the alternative types, observations of the data are noted in the paragraphs that follow.

The baseline and the alternatives did not have a major difference in size, thus it is assumed the laundry space would accommodate either of the alternative dryers, should one of them turn out to be the more feasible solution. The typical drying time for a gas dryer was observed to be the same as the baseline electric dryer and approximately 6 minutes less than a steam dryer. Heat emission data could only be obtained from the Electrolux specification (15%), thus we assumed 15% as the baseline for all dryers. All options met the heating voltage requirement of 440 volts, 60Hz, and 3 phase cycle power requirement for electrical shipboard connection. The gas and steam alternatives were all less in unit weight than the baseline by 8lbs to 59 lbs, with the electric and steam types weighing more than the alternative gas type. Noise

---

[63] Electrolux, "*T3530 Tumble Dryer, 50 lb Capacity Product Specification,*" Electrolux Professional North America, Charlotte, NC, downloaded on 1 July 2010 from http://www.laundrysystems.electrolux.com/Files/Pdf_files2/Ljungby/Brochures/Tumble_Dryers_GB.pdf.

[64] EDRO Dyna Corporation, "*EDRO DynaDryer, M50 Product Specification*," downloaded on 1 July 2010 from http://www.edrodynawash.com/PDF_Literature_Files/AHM50PDF.pdf.

[65] Huebsch, "*50 lb On Premise Tumble Dryer Product Specification*," downloaded on 1 July 2010 from http://www.huebsch.com/adv_pdf/ah09-223.pdf. AH09-223, 2009.

[66] Cissell, "*The CHD 50 lb On Premise Laundry Dryer Product Specification*," downloaded on 1 July 2010 from http://www.luenhingco.com/Cataloge/chd50.pdf.

[67] Speed Queen, "*On Premise Single Pocket 50 lb Drying Tumbler Specification*," downloaded on 1 July 2010 from http://www.speedqueen.com/vend_adv_pdf/ao09-203.pdf, AO09-203, 2009.

[68] Girbau, "*Pro-series II Tumble Dryers for On-premise Laundries – GU050 Specification*," downloaded on 1 July 2010 from http://www.girbau.co.uk/shopimages/products/extras/Pro_Series_II.pdf, 2009.

level data could only be obtained from the Electrolux specification (70 dB), thus we assumed 70 dB as the baseline for all dryers.

The alternatives researched provide automated usability features for ease of use. These are some of the features of the dryers that make them user-friendly: a micro-processor, frequency controlled motors, self-cleaning lint screens, humidity sensors that automatically shut the dryer off when the clothes are dry, and their large ability to dry two full loads per hour due to their large capacity. Automation among the alternatives is assumed to be within the ball park of 95%, with 5% approximated to account for some level of required manual operation. The baseline dryers however, were not equipped with the latest digital or touch screen control panel. It required manual setting of drying time (dial feature) and push-button start, thus 90% automation is assumed. In addition, we assumed 99% reliability for all the alternative dryer types, while the baseline is assumed to be 90% based on discussion with the ship's crew.

Cost data for the baseline or alternatives could not be obtained from specification sheets or vendors. As stated earlier, data was assumed based on information obtained from a locally operating laundromat and plumbing businesses. The dollar values obtained on cost per unit and maintenance was adjusted to reflect an assumed 33% to 50% (gas versus electric) difference in cost. Gas dryers were found to be more expensive to purchase than the electric. The steam types were estimated to be much more expensive to purchase than both the electric and gas types. However, the maintenance cost for electric and steam dryers was approximated to be $50.00 less a year than gas dryers due to additional special gas and pipeline checks of the gas and the requirement of a certified CORGI, which adds to their cost. Although electricity is still used to rotate the drum of a gas and steam dryer, this amount to less than 10% of the total electricity required, therefore the electricity cost is assumed to be negligible. An assumed $3000.00 per year was also added to account for onboard daily, monthly, yearly maintenance by the ship crew. This value was based on approximated man-hours obtained from the dryer maintenance cards and an assumed $28.00 labor rate.[69] Disposal cost was estimated to be a minimum one-time base fee between $0 and $25.00. Disposal and recycling cost can depend on which disposal company is used and where the company is located. There are also organizations that dispose of

[69] OPNAV, *"Maintenance Requirement Cards for Tumble Dryers (6555/005-A8): B9 A2LR N, B7 C2SW N, A8 G2G8 U, A8 G2G7 U, A8 F6XZ N, A8 F6XY N, A8 F6XX N, A8 F6XW N, A5 S87C N, 84 C6US N, 11 C7NJ U, 11 C2WA U, 10 C5NF N,"* Washington, DC, January 1985.

equipment or appliances free of charge, which could make disposal cost negligible. It is also assumed that the installer of the new dryers can also disassemble, remove, and dispose of the older dryers from the ship. Based on this assumption, the disposal cost of the old dryers could potentially be more expensive depending if the cost is determined by the number of man-hours it takes to disassemble and remove the old dryers from the ship versus a base fee. For the purpose of this analysis it is assumed that there is likely to be some minimum disposal cost incurred by the Navy. Therefore, a minimum one time base fee of $25.00 is assumed for disposal cost and is included in the cost analysis that follows.

Evaluation Matrix	Dryers 1, 2, & 3				Min	Max	Best Score Type
Performance Criteria	Baseline Electric	Gas	Steam				
Unit Weight (lb)	790	731	782		731	790	Low
Height (mm)	1,981	1,995	1,995		1981	1995	Low
Width (mm)	990	960	960		960	990	Low
Depth (mm)	1,157	1,180	1,180		1157	1180	Low
Capacity (lb)	50	51	51		50	51	High
Heat Output (%)	15	15	15		15	15	High
Voltage (V)	440	440	440		440	440	=
Noise (dB)	70	70	70		70	70	Low
Usability (%)	90	95	95		90	95	High
Reliability	0.9	0.999	0.999		0.9	0.999	High
Availability	0.9	0.995	0.995		0.9	0.995	High
Cost Criteria							
Energy Consumption (KW)	15	15	23				
Investment Cost ($)	0	13,500	13,800				
Operational Savings ($/yr)	0	201,178	-162,042				
Maintenance (h/yr)	115	113.33	115				
Maint Savings ($/yr)	0	47	0				
Normalized Score							
Unit Weight (lb)	0.000	1.000	0.136				
Height (mm)	1.000	0.000	0.000				
Width (mm)	0.000	1.000	1.000				
Depth (mm)	1.000	0.000	0.000				
Capacity (lb)	0.000	1.000	1.000				
Heat Output (%)	1.000	1.000	1.000				
Voltage (V)	1.000	1.000	1.000				
Noise (dB)	1.000	1.000	1.000				
Usability (%)	0.000	1.000	1.000				
Reliability	0.000	1.000	1.000				
Availability	0.000	1.000	1.000				
Performance	0.45	0.82	0.74				
Savings-1	0	187,724	-175,842				
Savings-5	0	992,621	-824,011				
Savings-10	0	1,998,743	-1,634,221				

[Values highlighted in red are assumed parameters due to non availability of data.]

Table 32 - Tumble Dryer Scoring Evaluation Matrix

To estimate the cost of operating gas, and steam alternative dryers, the same cost approach used for the baseline was used. However, for an underway deployment gas replenishment will be required. As a result, the cost of gas to be delivered to the ship would be fully burdened. The calculation of the fully burden cost of gas delivered to the ship was computed in the same way as the fully burden cost of fuel, using the fully burden cost calculator version 7.1. The commodity spot price for natural gas is estimated to be $1.51/gal, as given by the DESC price sheet dated 1 January 2010.[18] There are 3,143 BTU/kW according to ORNL there are 91,700 BTU/gal as cited by Fairbanks Natural Gas, LLC.[17,70] The resultant pier-side cost is $1.51/gal divided by 91,700 BTU/gal multiplied by 3,143 BTU/kW, which equates to $0.06/kWh. The fully burdened cost of gas is scaled from $0.06/kWh to $0.26/ kWh using the ratio of $13.02/gal over $2.81/gal given in the assumptions of Section III.C of this report. Assuming the same operating temperature of 180°F (high setting), a pier-side nominal cost of $0.06/kWh and a fully burden cost of $0.26/kWh for the gas dryer alternative, Table 33 present estimates of what it would cost the ship to dry approximately 24 loads of laundry while pier-side, and 36 loads of laundry while underway. The average yearly cost is about $1,423.

For the steam alternative, since steam will not be delivered to the ship, the ship would have to make its own. The pier-side and underway cost to operate the steam dryer is assumed to be the same as the baseline, $0.14/kWh and $2.06/kWh, respectively. Table 34 present estimates of what it would cost the ship to dry approximately 24 loads of laundry while pier-side, and 36 loads of laundry while underway. The average yearly cost is about $19,941.

70 Fairbanks Natural Gas, "What is a BTU?," downloaded 3 August 2010 from http://www.fngas.com/calculate.html.

50lb Tumble Dryer – Bottled Natural Gas Alternative						
	kWh consumption	Dry Time (min/hrs)	$/kWh	$/load	$/week (24 loads)	$/year
Pier-side	15	22/0.366	0.06	0.32	7.91	379.47
	kWh consumption	Dry Time (hours)	$/kWh	$/load	$/week (36 loads)	$/year
Underway	15	22/0.336	0.26	1.42	51.39	2,466.55
Average Weekly and Yearly Cost					$29.65	$1,423.01

[This table shows the estimated weekly and yearly cost of operating three 50lb Gas Tumble Dryer Alternatives pier-side and underway. The cost is based on the number of loads of laundry (24 pier-side and 36 underway) times the cost of bottled gas per kWh, and the amount of time required to dry a load of laundry, in addition to the required energy consumption.]

Table 33 - Cost of Operating a 50lb Gas Tumble Dryer

50lb Tumble Dryer – Steam Alternative						
	kWh consumption	Dry Time (min/hrs)	$/kWh	$/load	$/week (24 loads)	$/year
Pier-side	23	28/0.466	0.14	1.50	36.01	1,728.60
	kWh consumption	Dry Time (hours)	$/kWh	$/load	$/week (36 loads)	$/year
Underway	23	28/0.466	2.06	22.08	794.84	38,152.65
Average Weekly and Yearly Cost					$415.43	$19,940.62

[This table shows the estimated weekly and yearly cost of operating three 50 lb Steam Tumble Dryer Alternatives pier-side and underway. The cost is based on the number of loads of laundry (24 pier-side and 36 underway) times the cost of bottled gas per kWh, and the amount of time required to dry a load of laundry, in addition to the required energy consumption.]

Table 34 - Cost of Operating a 50lb Steam Tumble Dryer

Based on the overall scoring matrix and cost analysis, the gas tumble dryer is the more feasible alternative. It can potentially provide an approximated average yearly cost savings of $188K in the first year, $993K over five years and $2M in savings over 10 years by replacing 3 units as opposed to the steam evaluated option which would have higher investment and operation costs. The baseline electric dryer costs less to purchase than the gas or the steam options, as shown in the combined detailed cost comparison in [This table provides a comparison of electric, gas, and steam options for dryers, including the unit cost, the operational cost, the maintenance cost, and the disposal cost. The average operational cost is based on 67% pier-side time and 33% underway time.]

Table 35. The electric option average approximated cost pier-side and underway combined is also 3 times more than the gas alternative. This includes maintenance and the assumed disposal cost. The steam alternative costs more to purchase than the electric and gas

options and are more expensive to operate than the gas dryers, as well. The steam alternative would have additional installation costs, as well. Their average cost to operate is approximately $500.00 more than the electric type, and is also 4 times greater than gas. Clearly there would be no cost savings with implementing a steam dryer.

50 lb Tumble Dryers			Cost ($) Approximations							
			Electricity Rate($): Shore-Based (67%)	Electricity Rate ($): Underway (33%)	Natural Gas Rate ($): Shore-Based (67%)	Natural Gas Rate ($): Underway (33%)	Steam Rate ($): Shore Based (67%)	Steam Rate ($): Underway (33%)		
			0.14	2.06	0.06	0.26	0.14	2.06		
Category	Alternatives	$ Per Unit	Operation $ /Year	Operation $ /Year	Operation $ /Year	Operation $ /Year	Operation $ /Year	Operation $ /Year	Maintenance $ /Year	Disposal $
Vented	Electric	4,000.00	885.43	19,542.64					3,450.00	25.00
	Gas	4,500.00			379.47	2,466.55			3,500.00	25.00
	Steam	4,600.00					1,728.60	38,152.65	3,450.00	25.00
		Average Yearly Cost:	**$13,689.04**		**$4,948.01**		**$23,415.62**			
		Includes estimated maintenance cost and disposal cost ($25.00)								

[This table provides a comparison of electric, gas, and steam options for dryers, including the unit cost, the operational cost, the maintenance cost, and the disposal cost. The average operational cost is based on 67% pier-side time and 33% underway time.]

Table 35 - Combined Detailed Cost Comparison of Electric, Gas and Steam Dryers

The long term recommendation is for the Navy to continue to consider and further pursue research, development and usage of condenser dryers. Such technology can provide the flexibility of unit placement and less footprint within the laundry space, as it offers less exhaust piping, duct work and vent piping, which is what the Navy desires. These dryers may prove to be a little bit more expensive to purchase than both the electric and gas dryers and may require more kWh to operate and a longer drying time. However, the energy savings that result from the HVAC system not having to work so hard to heat or cool additional air to replace exhausted air is sufficient to offset the increase in power draw, longer drying times, and ambient cooling requirements.

For shipboard consideration, the condenser dryer may not require external exhausting or venting of air, but there is likely to be additional cost associated with installation of condensate piping to an existing drain to eliminate the maintenance required to maintain a typical condensate reservoir, which reduces operational cost. Over the long run of operation, the condenser dryers may help the Navy contribute less to the carbon footprint, and the potential costs savings will be well worth it as it provides longevity for the environment and life within it.

Assuming that there is existing and adequate space on the ship to store bottled gas, there is proper ventilation, a gas line hook-up to support the bottled gas to dryer connection, and also assuming the ship center of gravity would not be affected, a short term recommendation the Navy may consider is installation of gas tumble dryer replacement for existing shipboard use. However, the above are very strong assumptions that would need to be validated. Bottled gas is essentially safe to use if the proper handling, storing, monitoring and training measures are in place and correctly followed. There are safety risks and concerns surrounding the use of bottled gas, such as a potential hazardous gas leak, but a mitigation to address such safety risk is to outfit the storage space with a hazardous gas monitoring unit as is done for other systems on the ship that pose potential gas leaks such as: refrigeration leaks, hydrogen sulfide, carbon monoxide and hydrogen gas leaks.

The gas dryer technology is a feasible alternative and can offer real substantial savings in its first year of operation, specifically in the second month of operation. In addition, gas dryers is readily available for installation, the technology is more efficient, offer usability features that allow ease of human integration, reduces greenhouse gas effects and can save on energy usage. Gas dryers are also three to four times cheaper to operate than the electric and steam dryer types, due to the low cost of natural gas required to operate them.

The initial investment cost of purchasing three gas dryers is approximately $14K. However, there may be some additional non-reoccurring infrastructure cost associated with retrofitting existing ships that were not taken into account in earlier research. The initial baseline assumption is that infrastructure and maintenance cost to provide gas on the ship is negligible. Table 36 below provides an excursion analysis of additional assumed costs to retrofit existing ships with gas dryers. Retrofitting existing ships is assumed to be based on worst case laundry operation, which is underway. The underway operation requires laundry to be washed and dried on Saturday's, as opposed to the pier-side operation. This requires more cubic feet of natural gas for operation, thus more bottled gas to be stored on the ship. Assuming a 21 day operational cycle, to operate three gas dryers would require approximately 1970ft^3 of natural gas. This equates to nine, 220 ft^3, 2000 psi gas cylinders. Three additional cylinders are added as reserves, which drives the total cylinder count required onboard ship to twelve.

To properly install gas dryers on the ship requires installation of the gas cylinders, which can be purchased for a one-time fee of $330.00 per cylinder, a cylinder mounting kit that can be purchased and installed at an approximated cost of $5000.00, additional ½" piping for dryer to gas hook-up, vent piping, and a gas cylinder replenishment line that can be purchased for approximately $1900.00.[71] A hazardous gas monitoring unit will also be required and cost an estimated $1000.00.[72] This configuration will require an additional 3'(L) x 2.25'(W) x 4.25'(H) of space and adds an additional 1896 lbs to the ship's weight, which is assumed to be negligible and have minimum impact on the ship's center of gravity. An engineering change notice (ECN) is likely required for the design change, thus an estimated $4000.00 is assumed for the change notice for unit implementation. Based on the overall excursion analysis, to install gas dryers on existing ships will require an estimated non-recurring infrastructure investment cost of about $16K. This increases the total investment cost to implement gas dryer technology onboard the ship to about $30K. This cost can be recouped in the first year ROI, specifically in the second month of operation.

71 J&R Welding Supply Company. Private telephone conversation with Mr. Andrew Booker, Retired 1st Class, ET1, DDG-41, 3 September 2010.

72 DOD Technology, Inc, "PS-7 fixed, XPS-7 portable and PGD-120 portable Universal Gas Detection Systems", 11 October 2001, downloaded on 3 September 2010 from http://www.dodtec.com/sitebuildercontent/sitebuilderfiles/ps7brochurepricing1011.pdf

Assumed Non-recurring Infrastructure Cost for Installation of three Gas Dryers (Supply based on 21 Day operation)		
Assumptions	**Pier-Side- 24 loads**	**Underway – 36 loads**
Amount of Gas Required to operate 3 dryer units	1313.62 ft^3	1970.43 ft^3
Approximate # of Gas Cylinders (220 ft^3/113lbs/2000psi each) (3 reserved as back-up)	9	12
Cylinder Mounting Kit cost & weight (cost includes installation)	$5000.00/200lbs	$5000.00/200lbs
½" Pipe Installation Requirement & weight (25ft of pipe @ $10.00/ft) (Labor – 30 hour installation job @ $55.00/hr) (Cost includes piping from cylinders to dryer units, vent piping and gas replenishment line)	$1900.00/100lbs	$1900.00/100lbs
Gas cylinder one time purchase cost ($330/cylinder)	$2979.00	$3960.00
Hazardous Gas Monitoring Unit	$1000.00	$1000.00
Assumed Engineering Change Proposal Cost	$4000.00	$4000.00
Additional ship weight (cylinders, mounting bracket kit & piping)	1317lbs	1896lbs
Additional space requirement	3'x2.25'x4.25' (LxWxH) (ft)	3'x2.25'x4.25' (LxWxH) (ft)

[This table represents the excursion analysis for additional non-recurring infrastructure cost for implementation of gas dryer's onboard the ship. To properly install gas dryers on the ship requires installation of the gas cylinders, a cylinder mounting, additional ½" piping for dryer to gas hook-up, vent piping, and a gas cylinder replenishment, and a hazardous gas monitoring unit. This configuration will require an additional 3'(L)x2.25'(W)x4.25'(H) of space and adds an additional 1896lbs to the ship's weight, which is assumed to be negligible and have minimum impact on the ship's center of gravity. An engineering change notice (ECN) is likely required and is estimated to cost about $4000.00. The additional infrastructure investment cost is approximately $16K. This increases the total investment cost to implement gas dryer technology onboard the ship to $30K.]

Table 36 - Excursion Analysis of Additional Infrastructure and Operational Cost for Gas Dryers

If retrofitting existing ships with gas dryers is not feasible, the alternative may be considered for future ships if the gas dryer option and sufficient capacity in considered in the initial ship design. If the gas dryer option is simply not a preference of the Navy, consideration can be given to replacing the baseline electric dryers with newer, more energy efficient 50 lb electric dryers. The Navy may also consider replacing the existing dryers with larger capacity size electric dryers such as 75-110 lb tumble dryers, as this can potentially allow the dryer footprint in the laundry space to be reduced from three to two dryers. This is assuming the current footprint for the dryers can accommodate the weight, height, width and depth of 75-110 lb dryers. The larger capacity dryers may use a little bit more kW to operate, however they can dry double the loads of laundry as compared to the baseline dryers. If replacing the current technology is not preferred at all, it is recommended that the current baseline electrically operated dryers be utilized at full capacity, on the highest heat setting and be maintained regularly to be more energy efficient.

7. Hot Water Heaters (Including Dishwater Heaters)

Background:

Hot Water Heaters (HWH) on the DDG-51 are primarily utilized for hotel use. This includes galley sanitation, scullery sinks and dishwashers, berthing sinks and showers, laundry and general cleaning and sanitation throughout the ship. Hot water usage load data was requested numerous times but was not provided in spite of the multiple requests made. Additionally, numerous personnel were contacted at NSWCCD Philadelphia to get higher fidelity baseline ship data concerning hot water usage and HWH system specifications. An assumption had to be made that the maximum hot water requirement over a 1-hour period is 1000 gallons. This assumption was based on the current DDG-51 hot water heater storage capacity. The baseline ship is currently outfitted with two 430 gallon hot water heater tanks and a 140 gallon booster for the galley grease interceptor hoods.[4]

The majority of the HWH load is located within SWBS 500, Auxiliary Systems. The DDG-51 Ship Specification Section 651 Food Service Spaces, 651b Equipment and Installation, indicates an additional heater to be utilized in the scullery to provide the dishwasher final rinse temperature to be 180 degrees minimum. There are two dishwasher heaters within the scullery, a HATCO Model C-27 (27kW/480Vac) and a HATCO Model C-57 (57kW/480Vac). The dishwasher heaters are located within SWBS 600 (Outfitting and Furnishing), specifically 651 (Food Service Spaces).

Data for the baseline dishwasher heaters was gathered from pictures taken during the site visit, combined with the Load Analysis and Ship Specifications. Further information on those models was gathered via spec sheets for the items and interaction with the design engineers from HATCO. Due to the very small size and energy usage of these units, it was decided to include them in the rollup for all hot water heaters versus analyzing them as separate equipment, regardless of the different SWBS numbers.

HWH Alternative Selection Approach and Selection Criteria:

Numerous HWH systems exist in the market today. Most are developed for residential home use. There are three primary methods used to heat water for industrial and residential use. Those methods are solar vacuum-tube, tankless HWH systems and lastly, tank and heater element systems. Solar systems are the cleanest, most efficient systems available. The great benefit of this type of system is the fact that the energy it uses to heat the water with is collected from solar radiation. However these systems require large amounts of surface area to acquire the required amount of solar flux to operate. This coupled with the fact that they are fragile devices, does not make them suitable for maritime or Naval application.

Another HWH alternative technology this study examined was flanged immersion heaters. This piece of equipment is not so much an innovative technology, but more of a method of upgrading the existing HWH tanks. The intention was to replace the existing tank's heating element with modern immersion heating elements in order to reduce implementation and operating cost. This alternative was not selected because the heating elements in existing HWH tanks all operate with high efficiency, and the energy loss comes primarily from the amount of insulation on the tank. Seeing this early, cohort researchers decided this was not a worthwhile option as larger gains in efficiency would ultimately come from replacing the HWH tank. Some areas of the world utilize geothermal heating for hot water, however, this is completely infeasible for use aboard any ship, and thus was not investigated at all.

The remaining alternatives with the most feasibility and effectiveness were the newer HWH tank systems and tankless HWH systems. In order to broaden the scope and get an optimal HWH solution Pareto curve, cohort researchers decided to analyze these two technologies individually as well as from a blended hybrid combination of the two. The following options were analyzed and compared: a dual 500 gallon, 125kW(ea) traditional maritime HWH (baseline); a single 1000 gallon, 250 kW traditional maritime HWH; a hybrid combination of a single 500 gallon 125kW traditional maritime HWH with three 54kW tankless HWH; and six 54kW tankless HWHs. For the dishwasher booster heaters, the baseline 27kW and 54kW heaters were compared to alternative, the tank-style heaters and 27kW/54kW tankless heaters. A hybrid setup comprised of a tank and tankless heater was impractical due to the limited size of the booster heaters.

Selection Criteria:

1000 Gallon Capacity

40-140 deg F heat time for 1000 gallons

Total Watts under 150kW

Performance Attributes	DDG 51 Baseline	Hubbell Tankless 54 kW	Hubbell MSH and MH USCG Compliant	Hubbell MSH and MH USCG Compliant	Warren Electric Flanged Immersion Heater	Niagara Industries Tankless SCR 4	Sunmaxx 30U SolarVacuum Tube HW Heater
Recovery Time: GpH 100F	534	220 gph Real Time	1.94hrs	1.87hrs	~1 Hour	120 gph Real Time	Real Time
Tank Capacity (g):	430	~3.68 gpm @ 100 deg +	1000	500	Needs Tank Constructed	2.0 gpm @ 100 deg +	3-4gpm
Heat Loss:	.62W/hr	0	.62W/hr	.62W/hr	Tank Dependent	0	.7 W /m^2
Efficiency Rating:	99%	99%	99%	99%	No Rating	99.50%	94% (No energy Draw)
Temperature Range:	100-240F	32-194 F	100-240F	100-240F	60-250F	105-120F	
Voltage Range:	110-600V (Any)	208-600V	110-600V (Any)	110-600V (Any)	120-600V	240V	
Power (kW):	15-1600 kw, 65kW(x2)	54	15-1600 kw, 125kW	15-1600 kw, 65kW(x2)	252	18-21 kw	.8/m^2
Operational Environment:	Interior Marine Specific	Interior	Interior Marine Specific	Interior Marine Specific	Needs Tank	Interior	Exterior
Dimensions:	48"Dia x 72"L	16" x 25" x 5"	48"Dia x 138"L	48"Dia x 72"L	Tank Dependent	1.5" x 10.5" x 3	5.5'x7.6'
Purchase Cost ($):	$280,000	$10,550 ea	$215,000	$110,000	$9,389	$459	$1239/panel
Lining:	Cement / Phenolic / Non-Ferrous Metallic	NA	Cement / Phenolic / Non-Ferrous Metallic	Cement / Phenolic / Non-Ferrous Metallic		NA	

[This table depicts the hot water performance and cost selection criteria that were used to assess the different alternatives.]

Table 37 - Hot Water Heater Performance and Cost Selection Criteria[73],[74]

The Hubbell Water Heaters Incorporated specification sheet provided USCG compliant marine/industrial grade hot-water solutions. Hubbell was the most responsive and knowledgeable company that was solicited for HWH data and provided ship specific data for

73 Hubbel, "*Hubbell Shipboard (MSH) Hot Water Heater System Specification Sheet*," downloaded on 1 July 2010 from http://www.Hubbellheaters.com/html/selection%20guide.html.

74 Hubbel, "*Hubbell Tankless (TX) Hot Water Heater System Specification Sheet*," downloaded on 1 July 2010 from http://www.hubbellheaters.com/html/selection%20guide.html.

their systems that are currently integrated on ships. Their respective systems were modeled as the alternative solutions for this effort.

Results and Recommendations:

The analysis performed on the cost and performance aspects of the different setups of traditional tank heaters and hybrid heaters is depicted in Table 38 and Table 39.

Evaluation Matrix	Hot Water Heaters						
Criteria	BASELINE: Hubbell; 2x 430 G @65kW ea.	Hubbell HWH Only 1000 G; 125kW	Hubbell HWH(1x 430 G) + 6x Hubbell 24kW Tankless Hybrid Combination	12x Hubbell Tankless 24kW	Min	Max	Best Score Type
(100degF): GpH	534	513	857.4	1180.8	513	1180.8	High
Time to Heat 1000 Gallons (hrs)	1.87	1.94	1.16	0.84	0.84	1.94	Low
Tank Capacity (G):	860	1000	430	0	0	1000	Low
Heat Loss * Gallon: (W*G)/hr	533.2	620	310	0	0	620	Low
Efficiency Rating:	0.99	0.99	0.99	0.99	0.99	0.99	High
Temperature Range (deg F):	208	208	185	162	162	208	High
Voltage:	392	392	392	392	392	392	High
Max Power (kW):	130	125	209	288	125	288	Low
Operating Power	117.2	112	202.6	259.2	112	259.2	Low
Current (Amps):	?	?	?	?	0	0	Low
Operational Environment:	Internal	Internal	Internal	Internal	0	0	Low
Dimensions Volume (in^3):	260568.576	249711.552	135909.288	12000	12000	260568.6	Low
Purchase Cost ($):	$280,000.00	$215,000.00	$203,300.00	$126,600.00	126600	280000	Low
Operational Cost Cruising ($):	$74.52	$73.88	$79.91	$74.03	73.8752	79.90544	Low
Operational Cost Hotel ($):	$30.68	$30.42	$32.90	$30.48	30.4192	32.90224	Low
Maintenance Cost $/yr ($):	$985.20	$492.60	$2,443.80	$3,902.40	492.6	3902.4	Low
Lining:	1**	1**	0	0	0	0	Low
Reliability	0.95	0.95	0.9	0.85	0.85	0.95	High

[This table represents the raw scores for the evaluation criteria for the selections of alternatives.]

Table 38 - Water Heater Raw Scores

Table 38 shows the raw values for each option. Table 39 contains the weighted values for each of the options, and a final score.

Normalized Score	BASELINE: Hubbell G; 2x 430 G @65kW ea.	Hubbell HWH Only 1000 G; 125kW	Hubbell HWH(1x 430 G) + 6x Hubbell 24kW Tankless Hybrid Combination	12x Hubbell Tankless 24kW	
Recovery Capacity to heat (100degF): GpH	0.031	0.000	0.516	1.000	High
Time to Heat 1000 Gallons (hrs)	0.064	0.000	0.709	1.000	Low
Tank Capacity (G):	0.140	0.000	0.570	1.000	Low
Heat Loss * Gallon:	0.140	0.000	0.500	1.000	Low
Temperature Range (deg F):	1.000	1.000	0.500	0.000	High
Max Power (kW):	0.969	1.000	0.485	0.000	Low
Operating Power	0.965	1.000	0.385	0.000	Low
Dimensions Volume (in^3):	0.000	0.044	0.502	1.000	Low
Reliability	1.000	1.000	0.500	0.000	High
Carry-Through Score	0.479	0.449	0.518	0.556	
Purchase Cost ($):	0.000	0.424	0.500	1.000	Low
Operational Cost Cruising ($):	0.894	1.000	0.000	0.975	Low
Operational Cost Hotel ($):	0.894	1.000	0.000	0.975	Low
Maintenance Cost ($):	0.856	1.000	0.428	0.000	Low
Carry-Through Score	0.661	0.856	0.232	0.737	

[This table depicts the weighted scores for the selection criteria grouped into cost and performance.]

Table 39 - Water-Heater Weighted Scores and Carry-Through Scores

Savings per year	BASELINE: Hubbell; 2x 430 G @65kW ea.	Hubbell 1000 G; 125kW	Hubbell(1x 430 G) + 6x Hubbell 24kW	12x Hubbell Tankless 24kW
Savings-1	$0	-$416,294	-$516,546	-$249,339
Savings-5	$0	-$361,472	-$549,831	-$233,894
Savings-10	$0	-$292,945	-$1,506,060	-$214,589

[This table depicts the total savings gained by switching to the alternative solutions.]

Table 40 - Total Savings Gained Through Alternatives

Based on the performance characteristics, the 12x Hubbell tankless setup was the highest performing option, followed by the hybrid setup, then the baseline, and finally by Hubbell 1000g tank setup. These criteria included recovery capacity to heat water, time to heat water, the tank capacity (tankless being zero), heat loss, the temperature range, maximum power, operating power, dimensions (size), reliability, efficiency rating and voltage. The tankless setup seems to be at a distinct advantage with performance characteristics due to its small footprint, minimal heat loss, fast recovery time and heating time. Based on the cost criteria only, the Hubbell 1000g tank only option was the best, followed by the 12x tankless option, then the baseline and finally the Hybrid setup. The single unit 1000g tank only had a cost advantage because it scored very well on operating and maintenance cost. The tankless setup also scored very high on operational cost, was the cheapest setup to purchase. However, maintenance costs were higher due to the fact that the procedures needed to be repeated many times for the multiple unit setup. Based on cost alone, the single 1000g tank setup and 12x tankless setup are both very slightly cheaper than the baseline. However, once maintenance costs are factored in, the tankless alternative becomes more expensive. Table 40 shows the total savings of the alternatives compared to the baseline for one year, five years, and ten years. While further exploration into some cost factors, such as engineering change notices, must be conducted to fully determine the costs associated with switching technologies for water heating, findings from this study are that none of the alternatives suggested show any savings.

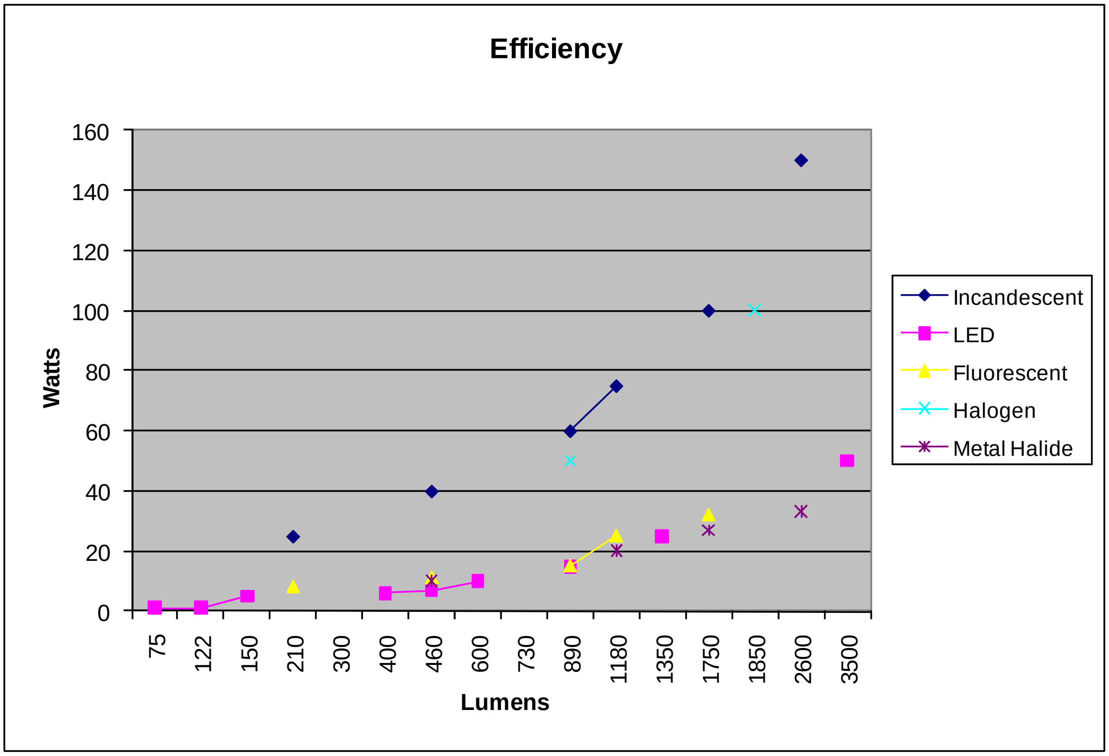
8. Lighting Fixtures

Background Information:

Lighting needs are numerous and varied. Some of the needs are low heat lights inside of the chill boxes, personal lights in sailor's rack spaces, variable intensity lighting for alleyways and compartment spaces, emergency lights and spotlights. The lights vary in the intensity required, the amount of time they are typically on and their accessibility for maintenance and repair. For these reasons, no single lighting technology can meet all of the requirements.

Lighting costs can be reduced by purchasing longer life bulbs, reducing the manpower to change them, using more energy efficient bulbs, ensuring that light is focused on the areas that need it so it is not lost in nooks and crannies, supplying just enough light for the task, or using the bulbs less often. Research and interviews can obtain information to assess long-life bulbs, manpower to change a bulb, energy efficient bulbs, but not the other methods to reduce energy costs. They require engineering studies. To determine if the source of the light exposes the correct area requires special equipment such as photo detectors. Human factor studies would be required to determine the minimum levels of light to safely operate without sacrificing performance. Engineering studies and human factor studies would be required to determine if partial light solutions for work areas is viable. The Capstone Project focused on areas that can be addressed via research and interviews.

DDG-97 did not use motion detectors or have any signs near lights reminding personnel to shut the lights off if not in use. The Commanding Officer (CO) of the DDG-97 did issue general guidance to save electricity. Each of the DDG-51 class has a fixed budget for maintenance and may choose what type of lighting to purchase. The CO at the time of the visit had not considered options that would include changing fixtures. Based on the site survey with DDG-97, the lighting technology in use included incandescent, compact fluorescence, light emitting diodes (LEDs), and halogen. Halogen lights were only used for spotlights. The number of each type of light was not available. This paper uses the assumption that there are a total of 3000 lights. This number was estimated considering the number of personnel racks, the number of compartments, and the alleys. Figure 35 below describes the general trends for how much power is required to produce light for different types of bulbs. The source data for this graph came from examining the selection of bulbs from a Home Depot and a Lowes Department Store in Dartmouth, MA in July 2010.

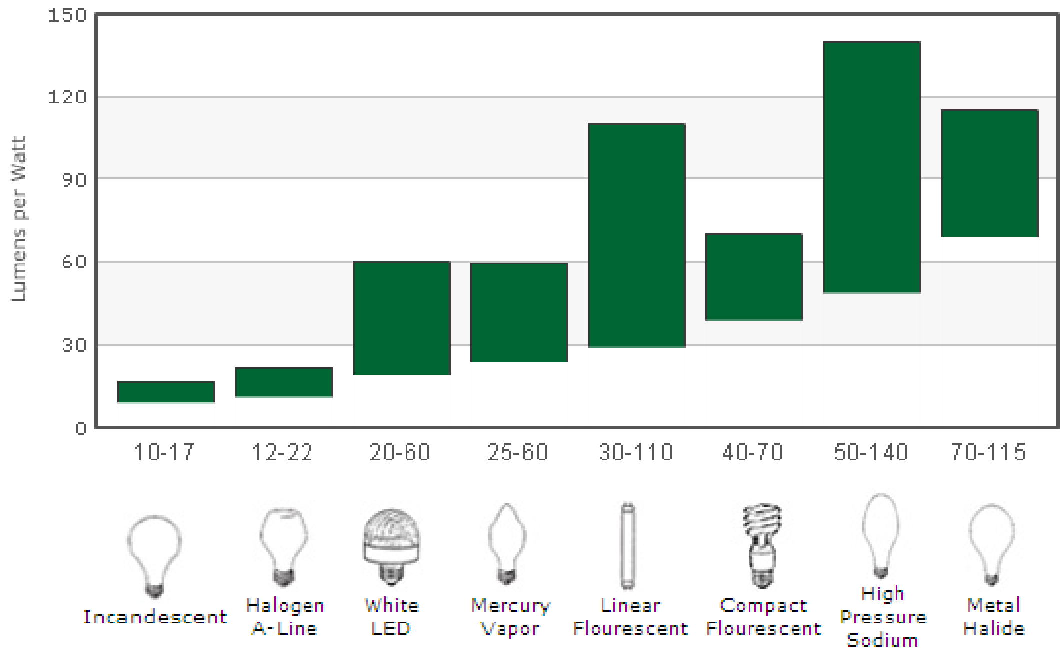


[This Figure illustrates the efficiency of lighting technologies across the intensity spectrum.]

Figure 35 - Ratio of Energy Required to Produce Light

The graph below in Figure 36 normalizes the above data and provides a range for both watts and lumens.[75]

[75] Madison Gas and Electric, *"Lighting Efficiency Comparison,"* Madison, WI, 2010 downloaded on 1 July 2010 from http://www.mge.com/home/appliances/lighting/comparison.htm.



[This Figure illustrates the efficiency ranges for numerous lighting technologies, not all of which were evaluated.]

Figure 36 - Lumens per Watt for Various Lighting

The color of light produced by the each of the light sources is different but not included as part this analysis. All were deemed acceptable for general-purpose lighting. Temperature also affects the efficiency of the lighting sources, but was not included since there is little variation inboard on shipboard systems.

Energy Federation Incorporated provided information on the lifespan of the lighting technologies.[76] Given the number of bulbs and the varying intensity, Table 41 was used for the analysis. It assumes that three different wattage levels are used onboard. They are the equivalent of incandescent 40W, 75W and 100W bulbs.

[76] Energy Federation Incorporated, *"Fluorescent Lighting » Standard Base,"* downloaded 7 August 2010 from http://www.energyfederation.org/consumer/default.php/cPath/25_44_784

Lighting Technology		Wattage	
Incandescent	40	75	100
LED	7	20	28
Fluorescent	11	25	32
Metal Halide	9	20	27

[The table details the amount of energy required to produce the same intensity of light as three common incandescent light bulbs and as derived from Figure 35.]

Table 41 - Equivalent Lighting Comparisons

Lighting Technology Alternative Selection Approach and Selection Criteria:

DDGs use many of the available lighting technologies. Halogen bulbs were not considered for general-purpose use due to their cost and high operating temperature (480 degrees F).[77] The alternative evaluation construct is based on changing the distribution of the lighting technologies and on implementing technologies to improve the efficiency of lighting that is selected. The distributions (in percent) selected are described in the four Tables that follow. None of the distributions move to solely one type of light since there are advantages of the various types of light for light directionality, color, heat output and accessibility. However, the Navy has been discussing in several forums the desire to remove incandescent light bulbs entirely from the fleet.

[77] Klipstein, D., *"The Great Internet Light Bulb Book, Part I,"* downloaded 7 August 2010 from http://members.misty.com/don/bulb1.html#hb, Copyright (C) 1996, 2000, 2005, 2006.

Lighting Technology		Wattage		
		40	75	100
	Incandescent	10%	12%	12%
	LED	3%	2%	1%
	Fluorescent	2%	10%	48%
	Metal Halide	0%	0%	0%

[This is the assumed distribution of lighting technology and lighting intensity that is compared with for each alternative.]

Table 42 - Baseline Distribution

Lighting Technology		Wattage		
		40	75	100
	Incandescent	2%	8%	6%
	LED	3%	2%	1%
	Fluorescent	10%	14%	54%
	Metal Halide	0%	0%	0%

[Increases the percentage of CFBs while decreasing the percentage of incandescent in comparison with the baseline distribution.]

Table 43 - Distribution with Increase in CFB

Lighting Technology		Wattage		
		40	75	100
	Incandescent	2%	8%	6%
	LED	10%	14%	44%
	Fluorescent	3%	2%	11%
	Metal Halide	0%	0%	0%

[Increases the percentage of LEDs while decreasing the percentage of incandescent in comparison with the baseline distribution.]

Table 44 - Distribution with Increase in LED

Lighting Technology		Wattage		
		40	75	100
	Incandescent	8%	6%	6%
	LED	2%	4%	10%
	Fluorescent	3%	2%	11%
	Metal Halide	2%	12%	34%

[Increases the percentage of CFBs while decreasing the percentage of incandescent and CFBs in comparison with the baseline distribution.]

Table 45 - Distribution with Increase in Metal Halide

Table 46 below summarizes the performance attributes for the lighting. The notes refer to the predominating light source when describing the values of the performance attributes. The majority of the information in it was compiled from Klipstein and Goldwasse's work.[78] According to the Naval Ship Systems Engineering Station Letter, serial number 9342/032 dated 3 May 2004, the use of qualified LED Battle Lanterns for shipboard emergency and damage control fighting applications is authorized.

Performance Attributes	**DDG-51 Baseline**	**Baseline with motion detector**	**Distribution with increase in CFB**	**Distribution with increase in LED**	**Distribution with increase in Halide**
Efficiency Lumens/watt	32.29	32.29	39.91	43.06	42.32
Heat Output degree F	150	150	Ambient	150	500*
Safety	Negligible	Negligible	Contains Mercury	Negligible	Bulb can explode
Maintenance time to replace bulbs in hours	94	94	61	43	67
Remarks:		It takes longer to get hours of on time since the sensor shuts off the light. The sensor will require repair adding to the maintenance load	Short power up time; Cannot be dimmed	Naval Ship Systems Engineering Station ltr Ser 9342/032 of 3 May 2004: "NAVSEA Philadelphia Code 934 (Electric Power Life Cycle Manager) authorizes the use of qualified LED Battle Lanterns for shipboard	Slightly larger than other bulbs for the same - flood light shape; takes longer to turn on; requires off period prior to repower on

Table 46 - Lighting Performance Attributes[79]

[78] Goldwasse, S. M., *"Sam's F-Lamp FAQ >>Fluorescent Lamps, Ballasts, and Fixtures, Principles of Operation, Circuits, Troubleshooting, Repair >>Version 1.90,"* downloaded 7 August 2010 from http://members.misty.com/don/f-lamp.html.

[79] NSWC, *"NAVSEA Philadelphia Code 934 (Electric Power Life Cycle Manager),"* Naval Ship Systems Engineering Station Letter Serial Number 9342/032 of 3 May 2004, Philadelphia, PA, 2010.

Lighting Technology		Material cost in dollars to purchase one bulb		
	Incandescent Wattage equivalent	**40**	**75**	**100**
	Incandescent	**$0.65**	**$0.95**	**$1.49**
	LED	**$37.50**	**$49.99**	**$99.00**
	Fluorescent	**$9.05**	**$9.05**	**$10.60**
	Metal Halide	**$16.99**	**$39.05**	**$50.63**

Table 47 - Cost Data for Various Lighting Technologies

Results and Recommendations:

Given the assumptions of 3000 bulbs, the distributions described above and the material cost data from the Table 47 above and Table 48 below determines the material cost per hour of operation, and the operating cost per hour of operations using $0.14/kWh for in-port and 2.33/kWh or at-sea with a merged profile of $0.86/kWh. After these tables were prepared, it was determined that the correct merged profile cost should have been $0.77/kWh as mentioned in section II.C, Evaluation Criteria. Figure 46 describes the cost savings over different time periods.

Motions sensors cost about $12 per sensor without installation cost. This paper assumes two hours to install and design and assumes drawing changes of $300 per installation. This results in a total of $512 per installation. A usage study would have to be done to determine what compartments could generate cost savings if a motion sensor is installed. This might results in few stations since many parts of the ship are manned 24 hours per day, have a roving watch, or have few lighting requirements generating no return on investment.

Lighting Technologies Delta from baseline

Cost Criteria	DDG-51 Baseline	Distribution with increase in CFB	Distribution with increase in LED	Distribution with increase in metal Halide
Purchase Cost light bulbs	$0	$5,166	$153,853	$96,721
Labor Cost per year to replace bulbs	$0	-$17	-$26	-$14
Annualized material cost to replace bulbs	$0	$1,382	-$1,661	$61,357
Annualized energy cost at given in-port/at-sea ratio	$0	-$142,385	-$186,457	-$176,625
NRE (ECP + installation)	$0	$12,000	$12,000	$12,000

Table 48 - Delta Cost from Baseline

	DDG-51 Baseline	Distribution with increase in CFB	Distribution with increase in LED	Distribution with increase in metal Halide
1st year cost	$0	-$125,236	-$20,630	-$67,918
5 year costs	$0	-$689,677	-$612,707	-$677,753
10 year costs	$0	-$1,396,520	-$1,391,266	-$1,464,226

Table 49 - Savings Trends

The recommendation from this analysis of alternatives is to validate the assumptions. If they are confirmed, our recommendation would be to replace all incandescent bulbs with LED bulbs. When the compact fluorescent bulbs burn out, they should be replaced with LED bulb. This should be followed by an analysis of replacing the fixtures associated with some of the fluorescent bulbs to fixtures that support LED bulbs.

9. Fuel Types

Background:

This section details an investigation into alternative fuel types as an option for powering gas turbine generators aboard the DDG-51 Class Ship. This destroyer class currently uses three Allison 2500 kW Gas Turbine Generators to power all electrical equipment onboard.[16] The Gas turbine generators use diesel fuel (F76) at a current commodity cost of $2.81 per gallon equivalent to $2.01 per 100,000 BTU.

The Navy Ship Propulsion Technologies study titled "Options for Reducing Oil Use" discusses a strategy for using alternative hydrocarbon fuels in all Navy and Marine non-tactical vehicles. Hydrocarbon fuels were officially mandated by the Secretary of Defense as an alternative for diesel fuel in 2005.[80] Other ongoing Navy efforts include the initiative "i-ENCON," in which ships are provided monetary awards for their successful efforts leading to energy reduction programs and strategies.[81] This section discusses the types of bio-fuels such as corn ethanol, cellulosic ethanol, ethanol produced from waste, bio diesels, and biomass using coal. Identification of potential options for improving the current state is made with attention to fuel reduction and green house gas reduction. Options that accomplish this should not be at the expense of performance.

Bio-Fuels:

Corn Ethanol

This renewable fuel resource is derived from corn and contains a formulation of ethyl alcohol; this type of fuel is utilized in the transportation industry as motor fuel and for flexible

80 O'Rourke, R., "*Navy Ship Propulsion Technologies: Options for Reducing Oil Use,*" downloaded 5 July 2010 from http://www.swonet.Navy.mil/docs/SWMagazine/2010/SW_1sthalf_spring10.pdf. December 11, 2006.

81 Naval Sea System Command, *"Shipboard Energy Conservation Guide,"* SL101-AA-GYD-010, Washington, DC, 1 April 2009, Downloaded 5 July 2010 from http://i-encon.com/ENCON%20Guide%202010.pdf.

fuel vehicles (FFV's) as well as in small craft aviation as an e-diesel replacing leaded fuel. The corn ethanol fuel is produced via fragmentation and mixed with gasoline in concentrations of 5%. In the case of E85, the concentration ratio is (85% ethanol, 15% gasoline).[82]

With regard to performance, corn ethanol contains cold weather engine starting properties and due to its high octane rating, can increase engine efficiency and performance. Corn ethanol can also enhance flame luminosity in the case of fire. On the down side, corn ethanol contains lower energy than gasoline, requiring 33% more corn ethanol fuel to travel the same distance as regular gasoline.

As far as environmental impacts, corn ethanol reduces green house gas emissions when used as motor fuel. Additionally, in California, the use of corn ethanol is considered a pollution risk reduction to the water supply sources.

Infrastructure is in place to accommodate the supply and transportation of E85 (an alcohol fuel with 85% denatured fuel ethanol). It can be stored in the same facilities as non ethanol gas. However, dispensers need to be upgraded with materials compatible with ethanol chemical properties. The economic climate for use of E85 is favorable. There are current federal tax incentives to promote competition, although there is a need for advanced production technology to bring costs in line with petroleum.

Cellulosic Ethanol

Ethanol in this case comes from a variety of fuel sources, such as feedstock from agricultural plant waste or industrially made plant waste or switch grass. It can also be produced from two distinctive processes, acid hydrolysis and enzymatic hydrolysis, and in both instances the last step creates the microbial fermentation of sugars which yield the ethanol and carbon dioxide.[83]

---

[82] US Department of Energy. "*E85 emissions*," 8 September 2009, downloaded 5 July 2010 from http://www.afdc.energy.gov/afdc/vehicles/emissions_e85.html. September 8, 2009.

[83] Feldman S., "*Biofuels Industry Blames Washington for Holding Back Cellulosic Ethanol,*" 19 July 2010 downloaded on 5 August 2010 from http://solveclimate.com/blog/20100719/biofuels-industry-blames-washington-holding-back-cellulosic-ethanol.

Bio-Diesels

Biodiesel is produced from domestic, renewable resources that contain fat or oil such as soybean oil, through a refinery process called transesterification. Although it contains no petroleum, it can be blended at any level with petroleum diesel to create a biodiesel blend as in the case of B20. B20 is composed of a blend of 20% biodiesel and 80% petroleum diesel fuel. Applications include compression-ignition (diesel) engines with minor, if any, modifications. The biggest advantage of this bio-diesel fuel lies in the fact that it is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics.[84]

The infrastructure needed for implementing the use of B20 is almost the same as current diesel fuel, minor retrofit to seals and hoses may be required. B20 is dispensed in exactly the same manner as petroleum diesel fuel, and diesel powered vehicle require no modification to switch to B20.

Environmental aspects of B20 currently comply with ASTM International's Standard D6751 and B20 is legally registered with the Environmental Protection Agency as a legal motor fuel for sale and distribution. This type of biodiesel has passed health effects testing requirements against the 1990 Clean Air Act Amendments. B20 has demonstrated significant environmental benefits with a minimum increase in cost for fleet operations or changes in infrastructure.

Coal with Biomass

Another alternative for diesel fuel replacement is the used of synthetic fuels such as biomass to liquids (BTL), and other variations from BTL as in the production of Fischer-Tropsch liquids (FTL). The greatest advantage lies in the production of FTL without a significant impact to transportation fuel infrastructure and the various biomass feedstock from which it can be produced. However, a change in the economic climate has led interest into the production of synthetic fuels from coal such as coal to liquid (CTL) fuel. Especially for CTL, there is abundant availability of coal throughout the world at a very low price relative to oil, but an even

[84] National Biodiesel Board, "*Biodiesel,*" 23 July 2009, downloaded on 5 August 2010 from http://ww.biodiesel.org/resources/faqs/.

better alternative is the use of coal with biomass to produce FTL. The added advantages are energy security and providing a synthetic fuel that is cleaner than current oil byproducts such as zero sulfur, as well as extremely low air pollutant emissions. The disadvantage, however, is the need to capture and store CO_2 (CCS) which can be cumbersome and costly. Emitting the CO2 byproducts back into the atmosphere produces a significant impact into green house gases. One way to address this challenge would be if both products are produced in the same facility (co-firing) thus reducing the risk and cost associated with this alternative. Despite ongoing research to improve the production of co-firing biomass in coal power stations, there has not been significant improvement in fuel efficiency, operation or lifespan.[85]

Alternative Selection Criteria and Approach:

To facilitate the down-selection process for the different fuel types under consideration, a Pugh matrix was utilized to capture both the alternatives for fuel type and the engineering metrics that best describe all fuel type alternatives. The selection of the metric parameters was based on information obtained from web-based research for both industry and government efforts for the area of interest. As seen in Table 50, the criteria for down-selection included: Environmental (greenhouse gas emissions), Performance (heat of combustion) and Cost (dollars per 100 kBTU). Consideration was also given to infrastructure, economics and availability, although these criteria were not the included as part of the Pugh Matrix due to a lack of available data.

85 Kreutz, T., Larson, E., Liu, G., Williams. R., *"Fishcher-Tropsch Fuels from Coal and Biomass,"* Princeton Environmental Institute, Princeton, NJ, 2 October 2008, downloaded 5 July 2010 from http://web.mit.edu/mitei/docs/reports/kreutz-fischer-tropsch.pdf.

		BASELINE	ALTERNATIVES				
METRICS		f76 Fuel	Biofuel Corn ethanol, E85	Biofuel cellulosic ethanol	Biofuel from waste	Biodiesel, B20	CTL coal with biomass
Environmental:	ghg reduction	0%	23%	85%	18%	18%	12%
Performance:	*heat of combustion (Btu/gal)*	140,000	77,000	77,000	77,000	138,000	85,000
Cost:	per energy unit (100,000BTUs)	$ 2.01	$ 2.88	$ 2.92	$ 2.88	$ 1.91	$ 2.59

Table 50 - Pugh Matrix for Fuel Type Alternatives Down-Selection

The three metrics described above were populated with quantitative data and the top performers highlighted. The metrics were equally weighed and individual data points were compared to indicate the highest performers and create a comparison to the baseline (in this case, F76 diesel fuel). The results from the Pugh Matrix were plotted separately for each metric using a Pareto chart, to enabling better visualization of performance characteristics, as seen in Figure 37, Figure 38, and Figure 39 below.

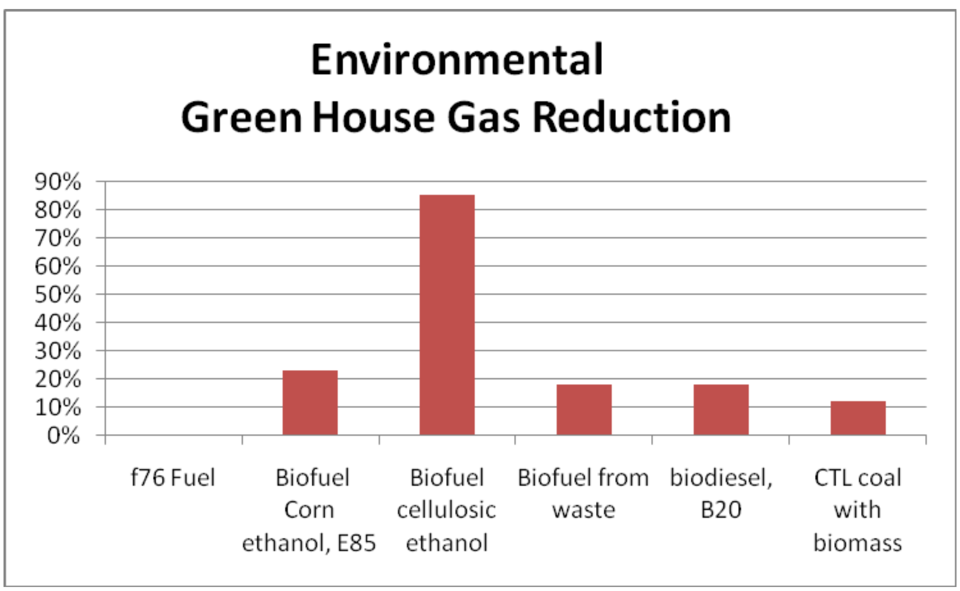


Figure 37 - Histogram on Top Environmental Performers from Fuel Type Alternatives

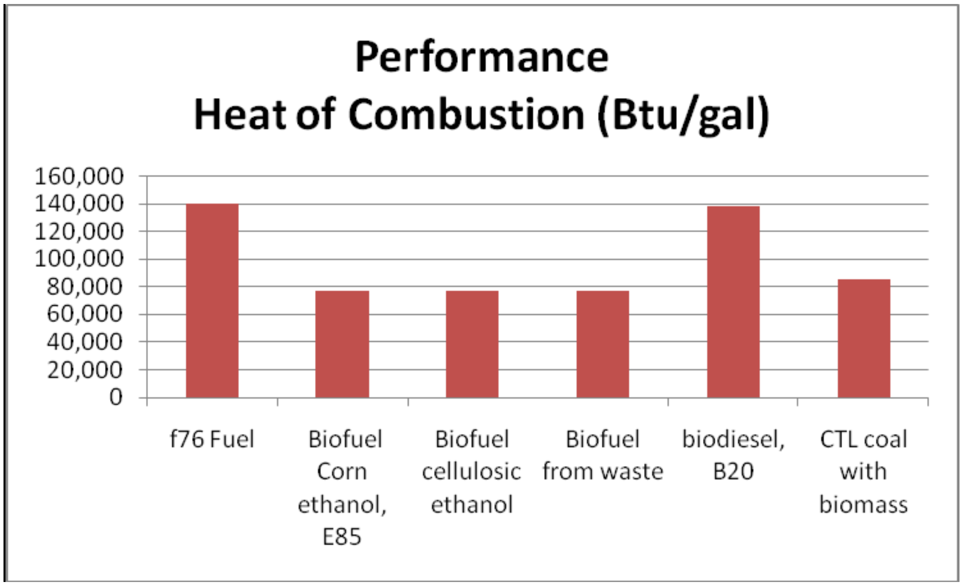
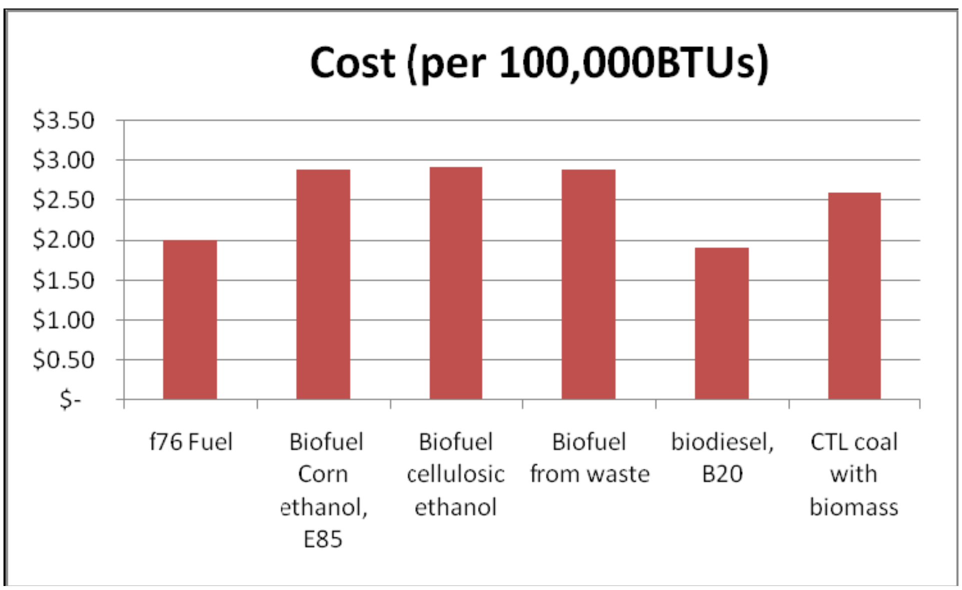


Figure 38 - Histogram on Top Performance Performers from Fuel Type Alternatives



[Figures 43 through 45 are Histograms of highest performers for each one of the metrics. Starting with Environmental Performance in respect to green house gas reduction, biofuel produced from cellulosic ethanol provides the highest reduction on GHG (85%) followed by biofuel from corn ethanol E85. Next chart shows the Performance comparison of alternatives as it refers to heat of combustion of each alternative, the closest match to the baseline is provided by biodiesel B20, followed by CTL coal with biomass. Last is the Cost comparison per 100,000BTUs, biodiesel B20 is the least expensive of all the alternatives a lower cost than baseline fuel F76.]

Figure 39 - Histogram on Top Performance Performers from Fuel Type Alternatives

Results and Recommendations:

As described in the previous section, the Pugh Matrix was utilized to allow for down-selection of the metrics for the various fuel types selected. The criteria that needed to be met were that the alternative fuels would reduce cost, enable the reduction of green house gas emissions, and would be able to maintain the performance (energy combustion content) needed to power the turbo generator engines in use aboard DDG-51 class ships. Based on the criteria stipulated in this study, Biodiesel B20 provides the lowest cost per energy unit at $1.91 per 100 kBTU, lower than the current cost of diesel F76 and lower than the other alternatives included in this research. B20 can provide a reduction in green house gas emissions by 18%. Bio-fuel Cellulosic Ethanol is predicted to provide 85% reduction on green house gases, but the cost per energy unit of $2.91 per 100 kBTU is higher than the current cost of Biodiesel B20. This does not meet satisfy the criteria set forth in this study. The research results indicate that the Department of the Navy should look into expanding the use of B20 fuel to the DDG-51 class of ships.

Towards the end of this research, the Capstone team was provided unpublished information from subject matter experts at DESC which suggested several concerns with use of B20 on surface ships. There may be stability concerns with storing B20 longer than 3 months. Tanks used for storing B20 may need to be cleaned before converting to B20 which would result in an additional unknown investment cost. The use of B20 may have cold-flow issues and thus may not be suitable for use everywhere. Finally, it may require more frequent fuel filter changes due to solvent properties associated with biodiesel. This incurs an added maintenance cost that is also unknown. If these issues prove to be valid concerns for the DDG-51 class, then the consideration of B20 as an immediate replacement for F76 may have a non-zero investment cost.

VIII. ANALYSIS RESULTS

A. ANALYSIS OVERVIEW

This section describes the results of block 9 of the systems analysis process that was utilized for the Capstone project. The task description comes from block 9 of the generic systems analysis process shown in Figure 4.9 of Blanchard & Fabrycky Systems Engineering Analysis, 4ed.[5] There is no amplifying language in the text body that refers to this Figure, so the bullets in block 9 are restated here:

- Recommendations
- Confidence levels
- Trade-offs
- Break-even points
- Sensitivities

Recommendations are given in Section IX of this report. No experimentation was conducted for this research study and so there is no analysis of variance to compute confidence intervals, however, the reader should take note of the sensitivity analysis to gain some qualitative feel for confidence in the results. Trade-offs were considered as a function of investment cost versus predicted net savings over five years and are presented both in tabular and graphical forms in Section IX.B below. Prior to making trade-offs, the individual research results of Section VII of this report were transcribed to a common analysis framework. The cohort has defined that break-even points are defined as the length of time for a specific alternative to reach a zero net savings (i.e, when dollars saved equals dollars invested). The analysis of break-even points is given in Section IX.C below. Sensitivity analysis was conducted on a small number of parameters that were judged to have a potentially significant effect on the resultant calculations and are presented in Section IX.D below.

B. TRADE-OFFS

The process of establishing the resultant trade-off of investment cost versus predicted savings over five years required transcribing the individual analysis results given in Section VII into a common frame of reference. The specific transcriptions are shown in Figure 40 and all Figures up to Figure 48 below. Parameter inputs which could not be determined through research have been estimated through use of comparable inputs for another known subsystem or by engineering judgment. Such assumed inputs have been highlighted in light red in the Figures throughout the set of transcribed analyses for each subsystem. The performance criteria are normalized by the range of minimum and maximum values and a simple average is then calculated for the normalized performance score. This is an input to the Overall Measure of Effectiveness (OMOE) in subsequent calculations.

The investment cost is defined as the unit acquisition and installation cost multiplied by the number of units to be upgraded, along with any non-recurring cost such as processing of Engineering Change Proposals (ECPs) to update drawings. Net savings by year is based on the operational and maintenance savings (or cost, if negative) multiplied by the number of years less the investment cost in year one and any replacement due to end-of-life in out-years. For example, the halogen ovens need to be upgraded in year one to replace the baseline ovens, but then need to be replaced again in years five and ten since they only have a five-year life-span. In that alternative, the unit and installation cost is incurred three times over a ten-year assessment period, while the ECP cost is only incurred once.

For the AC pre-heaters, the individual analysis is given in Section VIII.C.3. The flow-rate and the power consumption are specified in Table 16 for each of the five individual pre-heaters. For the common analysis shown in Figure 40, the average of the five pre-heaters resulting in flow-rates is 6043 and 5459 cubic feet per minute for the baseline and Chromolax respectively. The average power consumption is 72.0 and 54.9 kWh for the baseline and the Chromolax respectively.

Evaluation Matrix	Pre-Heaters					Min	Max	Best Score Type
Performance Criteria	Baseline	Chromolax						
Flow Rate (CFM)	6043	5459				5459	6043	High
Outlet Temp (ºF)	50	50				50	50	Low
Total Weight (lb)	501	501				501	501	Low
Relaibility	0.90	0.90				0.9	0.9	High
Availability	0.90	0.90				0.9	0.9	High
Cost Criteria								
Energy Consumption (KW)	72.0	54.9						
Investment Cost ($)	0	120,000					= Assumed Inputs	
Operational Savings ($/yr)	0	577,275						
Maintenance (h/yr)	24	24						
Maint Savings ($/yr)	0	0						
Normalized Score								
Flow Rate (CFM)	1.000	0.000						
Outlet Temp (ºF)	1.000	1.000						
Total Weight (lb)	1.000	1.000						
Relaibility	1.000	1.000						
Availability	1.000	1.000						
Performance	1.00	0.80						
Savings-1	0	457,275						
Savings-5	0	2,766,375						
Savings-10	0	5,652,751						

[This Figure shows that the Chromolax alternative has a reduced flow rate of about 10% which translates to a normalized average performance score of 0.8 relative to the baseline performance of 1.0. However, the Chromolax reduces power consumption by about 24% which is enough to provide a net significant savings within the first year of operation.]

Figure 40 - Common Analysis for Pre-heaters

For the AC chill-water pump (CWP), units one and three are considered for replacement due to their high loading relative to the other CWPs. The individual analysis is given in Section VIII.C.5. The performance criteria are specified in Table 21 for baseline and alternative variable frequency drive (VFD). The investment cost for a single pump was $10,090 based on linear interpolation of the acquisition and installation price of a 5 HP pump at $3K and a 300 HP pump at $45K. The total investment cost of $21,800 shown in Figure 41 reflects the investment cost for two pumps, numbers one and three.

Evaluation Matrix	AC Chill-Water Pump 1 & 3					Min	Max	Best Score Type
Performance Criteria	Baseline	VFD						
Capacity (gal/min)	900	900				900	900	High
Total Head (psi)	70	70				70	70	High
Reliability	0.995	0.995				0.995	0.995	High
Availability	0.994	0.994				0.994	0.994	High
Cost Criteria								
Energy Consumption (KW)	42.5	29.75						
Investment Cost ($)	0	21,800					$K	HP
Operational Savings ($/yr)	0	172,170					3	5
Maintenance (h/yr)	288	278					45	300
Maint Savings ($/yr)	0	560					10.83	60
Normalized Score								
Capacity (gal/min)	1.000	1.000						
Total Head (psi)	1.000	1.000						
Reliability	1.000	1.000						
Availability	1.000	1.000						
Performance	1.00	1.00						
Savings-1	0	150,930						
Savings-5	0	841,849						
Savings-10	0	1,705,498						

[This Figure shows that a variable frequency drive pump will provide comparable performance to the baseline, but at a 30% reduced power load with a net savings realized after the first year of operation.]

Figure 41 - Common Analysis for AC Chill-Water Pumps 1 & 3

For the hot water heaters, units one and two are considered for replacement due to their high loading relative to the other water heaters. For the common analysis, the dishwater heater is assumed to be unchanged. The individual analysis is given in Section VIII.C.8. The performance criteria are specified in Table 37 for the baseline and the three alternatives: 1000 gallon tank; hybrid tank and tankless; and the tankless only option. The full operating power from that table is transcribed to an hourly power draw by applying the 0.5 loading factor to match the 58.5 kW given for the baseline in Figure 42 below for these two heaters. Additionally, availability has been assumed to be comparable for the tankless hybrid (6 additional units) and tankless (12 units) which is reflected in higher total labor but about the same maintenance down time. The resultant common analysis is shown in Figure 42.

Evaluation Matrix	Hot Water Heaters 1 & 2 + Dishwater Heaters				Min	Max	Best Score Type
Performance Criteria	Baseline	Hubbell HWH Only 1000 G; 250kW	Hubbell HWH(XXX G) + Hubbell 6 Tankless Hybrid Combination	12 Hubbell Tankless			
Recovery Time (gph 100F)	534	513	857.4	1180.8	513	1180.8	High
Tank Capacity (g)	860	1000	430	0	0	1000	High
Heat Loss (W-G/hr)	533.2	620	310	0	0	620	High
Efficiency Rating	0.99	0.99	0.99	0.99	0.99	0.99	High
Temp Range (°F)	208	208	185	162	162	208	High
Reliability	0.95	0.95	0.9	0.85	0.85	0.95	High
Availability	0.9	0.95	0.96	0.96	0.9	0.96	High
Cost Criteria							
Time to Heat 1000g (h)	1.87	1.94	1.16	0.84			
Energy Consumption (KW)	58.6	56.0	101.3	129.6	<-- 0.5 LF to match Pareto		
Investment Cost ($)	0	215,000	203,300	253,200			
Operational Savings ($/yr)	0	6,360	-53,514	4,848			
Maintenance (h/yr)	35	18	87	139			
Maint Savings ($/yr)	0	493	-1,459	-2,917			
Normalized Score							
Recovery Time (gph 100F)	0.031	0.000	0.516	1.000			
Tank Capacity (g)	0.860	1.000	0.430	0.000			
Heat Loss (W-G/hr)	0.860	1.000	0.500	0.000			
Efficiency Rating	1.000	1.000	1.000	1.000			
Temp Range (°F)	1.000	1.000	0.500	0.000			
Reliability	1.000	1.000	0.500	0.000			
Availability	0.000	0.833	1.000	1.000			
Performance	0.94	1.00	0.59	0.20			
Savings-1	0	-208,147	-258,273	-251,269			
Savings-5	0	-180,736	-478,165	-243,547			
Savings-10	0	-146,472	-753,030	-233,894			

[This Figure shows that all the alternatives evaluated for hot water and dish water heaters never had a positive net savings, even when projected out to ten years of operation.]

Figure 42 - Common Analysis for Hot Water Heaters 1 & 2 and Dishwater Heaters

For the fuel transfer heaters, the individual analysis is given in Section VIII.C.4. The performance criteria are specified in Figure 30 for baseline and the three hypothetical alternatives offering 5%, 10%, and 20% efficiency improvements respectively. No modifications were required to transcribe the source Figure to the common reference framework shown in Figure 43.

Evaluation Matrix	Fuel Transfer Heater				Min	Max	Best Score Type
Performance Criteria	Baseline	5% efficiency improvement	10% efficiency improvement	20% efficiency improvement			
Flow Rate (gal/min)	110	110	110	110	110	110	High
Inlet Temp (F)	30	30	30	30	30	30	High
Outlet Temp (F)	70	70	70	70	70	70	High
Reiliability	0.995	0.995	0.995	0.995	0.995	0.995	High
Availability	0.995	0.995	0.995	0.995	0.995	0.995	High
Cost Criteria							
Energy Consumption (KW)	45	42.5	40.5	36			
Investment Cost ($)	0	75,000	78,000	82,000			
Operational Savings ($/yr)	0	33,759	60,766	121,532			
Maintenance (h/yr)	24	24	24	24			
Maint Savings ($/yr)	0						
Normalized Score							
Flow Rate (gal/min)	1.000	1.000	1.000	1.000			
Inlet Temp (F)	1.000	1.000	1.000	1.000			
Outlet Temp (F)	1.000	1.000	1.000	1.000			
Reiliability	1.000	1.000	1.000	1.000			
Availability	1.000	1.000	1.000	1.000			
Performance	1.00	1.00	1.00	1.00			
Savings-1	0	-41,241	-17,234	39,532			
Savings-5	0	93,794	225,829	525,658			
Savings-10	0	262,588	529,658	1,133,316			

[This Figure shows nominal Figures for a hypothetical function item replacement that can provide the stated reduction in power consumption of 5%, 10%, and 20% respectively for the assumed investment costs. Only the 20% improved efficiency device provides a net savings in the first year of operation.]

Figure 43 - Common Analysis for Fuel Transfer Heater

For the fire pumps, only unit number four is considered for replacement due to its high loading relative to the other fire pumps. The individual analysis is given in Section VIII.C.1. The performance criteria are specified in Table 15 for baseline and the vertical inline. No modifications were made in transcribing that information to the common reference framework as shown in Figure 44.

Evaluation Matrix	Fire Pump No 4			
Performance Criteria	Baseline	Vertical Inline		
Capacity (gal/min)	1000	750		
Total Head (psi)	155	155		
Reiliability	0.995	0.997		
Availability	0.995	0.995		
Cost Criteria				
Energy Consumption (KW)	198	133		
Investment Cost ($)	0	30,000		
Operational Savings ($/yr)	0	439,674		
Maintenance (h/yr)	24	24		
Maint Savings ($/yr)	0	0		
Normalized Score				
Capacity (gal/min)	1.000	0.000		
Total Head (psi)	1.000	1.000		
Reiliability	0.000	1.000		
Availability	1.000	1.000		
Performance	0.75	0.75		
Savings-1	0	409,674		
Savings-5	0	2,168,372		
Savings-10	0	4,366,743		

Min	Max	Best Score Type
750	1000	High
155	155	High
0.995	0.997	High
0.995	0.995	High

* Doesn't match Pareto baseline load of 119 KW, 198 KW is based on NAVFAC measured data

Note: kW's baseline component is calculated under the assumption that the Voltage is 200V at 150 Amps. Baseline is 3-phase synchronous motor with 50 HP

[This Figure shows that the vertical inline alternative pump has a 25% degradation in flow capacity relative to the baseline, but has about a 33% reduction in power usage. A net savings after investment costs is realized in the first year of operation. The vertical inline fire pump is one of the top three single-option alternatives for five-year ROI.]

Figure 44 - Common Analysis for Fire Pump 4

For the two ovens and range, the cost and savings associated with the ovens in the common reference framework is assumed to be comparable to the range, so the oven costs are multiplied by three. The individual analysis is given in Section VIII.C.6. The performance criteria are specified in Table 23 for the baseline and the three alternatives: halogen; combination convection/microwave; and halogen microwave. In transcribing cost criteria, the oven on-time was transcribed directly from cook-time per year given in Table 25. The full operating power for each oven is scaled by the oven on-time to derive the energy consumption show in Figure 45. As noted in the introduction of this section, the halogen ovens have a unit acquisition and installation cost in year one for the initial replacement and again in years five and ten due to the short life-cycle of this alternative. The combination convection/microwave ovens incur a unit acquisition and installation cost in year one for the initial replacement and again in year five. The halogen microwave only incurs a replacement cost in the first year.

Evaluation Matrix	Ovens (2) + Range				Min	Max	Best Score Type	Note
Performance Criteria	Baseline	Halogen	Combination Convection Microwave	Halogen Microwave				
Cooking efficiency	0.7	0.7	0.72	0.7	0.7	0.72	High	
Preheat time (min)	15	0.5	15	0.5	0.5	15	Low	
Cook time (min)	7	4.5	2.5	1.5	1.5	7	Low	
Production capacity (full size sheet pans)	14	2	4	3	2	14	High	
Lifespan (years)	5.5	10	3	3	3	10	High	
Reliability	0.995	0.995	1.000	1.000	0.995	1	High	
Availability	0.995	0.995	1.000	1.000	0.995	1	High	
Cost Criteria								
Oven On-Time	620.0	833.4	593.1	212.9				
Full Power (KW)	44.0	23.8	7.5	15.0				
Energy Consumption (KW)	3.1	2.3	0.5	0.4				<-- Use the Oven On Time to scale from full power
Unit Cost + Install	0	500	15,000	1,100				
NRE (ECP)	0	5,900	5,900	5,900				
Investment Cost ($)	0	7,400	50,900	9,200				
Operational Savings ($/yr)	0	17,215	52,793	55,694				
Maintenance (h/yr)	6	5	6	10				
Maint Savings ($/yr)	0	84	0	-336				
Normalized Score								
Cooking efficiency	0.000	0.000	1.000	0.000				
Preheat time (min)	0.000	1.000	0.000	1.000				
Cook time (min)	0.000	0.455	0.818	1.000				
Production capacity (full size sheet pans)	1.000	0.000	0.167	0.083				
Lifespan (years)	0.357	1.000	0.000	0.000				
Reliability	0.000	0.000	1.000	1.000				
Availability	0.000	0.000	1.000	1.000				
Performance	0.27	0.49	0.40	0.62				
Savings-1	0	9,899	1,893	46,158				
Savings-5	0	77,594	168,063	267,589				
Savings-10	0	162,588	432,026	544,379				

[This Figure shows that all of the oven alternatives have significant production capacity degradation relative to the baseline (70-85%) which is offset somewhat by reduced cooking time (35-80%), but all would yield a net savings within the first year of operation due to significant reduction in power (45-80%). Note that halogen ovens need to be replaced every five years while the combination convection oven is replaced in years one and five, but not year ten. The halogen microwave is only replaced in the initial upgrade over the ten year assessment period.]

Figure 45 - Common Analysis for Ovens

For the dryers, all three units are considered for replacement due to their equally high loading. The individual analysis is given in Section VIII.C.7. The performance criteria are specified in Table 32 for baseline and the two alternatives, gas and steam. The information given in that table was transcribed to the common reference framework without modification as shown in Figure 46.

Evaluation Matrix	Dryers 1, 2, & 3					Min	Max	Best Score Type
Performance Criteria	Baseline Electric	Gas	Steam					
Unit Weight (lb)	790	731	782			731	790	Low
Height (mm)	1,981	1,995	1,995			1981	1995	Low
Width (mm)	990	960	960			960	990	Low
Depth (mm)	1,157	1,180	1,180			1157	1180	Low
Capacity (lb)	50	51	51			50	51	High
Heat Output (%)	15	15	15			15	15	High
Voltage (V)	440	440	440			440	440	=
Noise (dB)	70	70	70			70	70	Low
Usability (%)	90	95	95			90	95	High
Reliability	0.9	0.999	0.999			0.9	0.999	High
Availability	0.9	0.995	0.995			0.9	0.995	High
Cost Criteria								
Energy Consumption (KW)	15	15	23					
Investment Cost ($)	0	13,500	13,800					
Operational Savings ($/yr)	0	201,178	-162,042					
Maintenance (h/yr)	115	113.33	115					
Maint Savings ($/yr)	0	47	0					
Normalized Score								
Unit Weight (lb)	0.000	1.000	0.136					
Height (mm)	1.000	0.000	0.000					
Width (mm)	0.000	1.000	1.000					
Depth (mm)	1.000	0.000	0.000					
Capacity (lb)	0.000	1.000	1.000					
Heat Output (%)	1.000	1.000	1.000					
Voltage (V)	1.000	1.000	1.000					
Noise (dB)	1.000	1.000	1.000					
Usability (%)	0.000	1.000	1.000					
Reliability	0.000	1.000	1.000					
Availability	0.000	1.000	1.000					
Performance	0.45	0.82	0.74					
Savings-1	0	187,724	-175,842					
Savings-5	0	992,621	-824,011					
Savings-10	0	1,998,743	-1,634,221					

[This Figure shows that the gas alternative would have a net savings after investment in the first year of operation while the steam alternative never achieves a positive net savings in when projected out to ten years of operation. Note that gas and steam have been converted to an equivalent kW usage as noted in Section VIII. The gas dryer is one of the top three single-option alternatives for five-year ROI.]

Figure 46 - Common Analysis for Dryers

For the lighting fixtures, the individual analysis is given in Section VIII.C.9. The performance criteria are specified in Table 47 for baseline and the three alternatives: more compact fluorescent bulbs; more light emitting diodes; and more metal halide. The total wattage for the baseline and three alternatives is given in Table 43 through Table 46 and is scaled for the total number of bulbs on the ship as shown in Figure 47. The energy consumption in the common reference framework assumes a bulb on-time of 6570 hours per year.

Evaluation Matrix	Lighting Fixtures				Min	Max	Best Score Type
Performance Criteria	DDG 51 Baseline	Distribution with increase in CFB	Distribution withincrease in LED	Distribution with increase in metal Halide			
Efficiency Lumens/watt	32.3	39.9	43.1	42.3	32.3	43.1	High
Heat Output degree F	150	72	150	500	72	500	Low
Safety	Negligible	Contains Mercury	Negligible	Bulb can Explode	0	0	Qualitative
Reliability	0.995	0.995	1.000	1.000	0.995	1	High
Availability	0.995	0.995	1.000	1.000	0.995	1	High
Cost Criteria							
Total Wattage (W)	131,910	106,710	98,910	100,650			
Energy Consumption (KW)	99	80	74	75	6,570	on-time (h/yr)	
Cost of Bulbs ($)	0	5,166	153,853	96,271			
Investment Cost ($)	0	17,166	165,853	108,271	Add NRE of $12k for ECP + Install		
Operational Savings ($/yr)	0	127,608	167,106	158,295			
Maint Materials ($/yr)	32,854	32,617	25,450	89,243			
Maintenance (h/yr)	160	80	40	80			
Maint Savings ($/yr)	0	2,477	10,764	-54,149			
Normalized Score							
Efficiency Lumens/watt	0.000	0.708	1.000	0.931			
Heat Output degree F	0.818	1.000	0.818	0.000			
Safety	1.000	0.500	1.000	0.000			
Reliability	0.000	0.000	1.000	1.000			
Availability	0.000	0.000	1.000	1.000			
Performance	0.36	0.44	0.96	0.59			
Savings-1	0	112,919	12,017	-4,125			
Savings-5	0	633,257	723,499	412,458			
Savings-10	0	1,283,681	1,612,850	933,186			

[This Figure shows that the Compact Fluorescent Bulbs (CFBs) and Light Emitting Diodes (LEDs) provide a net savings within the first year of operation, but that LEDs provide greater savings over CFBs as the assessment period is extended. Also note that CFBs contain mercury while metal halide has a significant increase in heat output, neither of which is desirable.]

Figure 47 - Common Analysis for Lighting Fixtures

For the fuel type, the individual analysis is given in Section VIII.C.10. The performance criteria are specified in Table 50. The ship consumption in gallons per year is based on the assumption that ship burn about 31,000 gallons per day when not pier-side, and that is 33% of the time or about 121 days, which results in a baseline consumption of a little over 3.7 million gallons per year as shown in Figure 48. The alternatives have this annual consumption rate adjusted by their associated heat of combustion (fuels with a lower rating of BTU per gallon are assumed to burn more total fuel to achieve the same performance).

Evaluation Matrix	Fuel Type				Min	Max	Best Score Type	
Performance Criteria	F76 Baseline	Corn Ethanol E85	Cellulosic Ethanol	Biodiesel B20				
Greenhouse Gas Reduction (%)	0	23	85	18	0.0	85.0	High	
Heat of Combustion (BTU/gal)	140,000	77,000	77,000	138,000	77000	140000	High	
Infrastructure	3	3	1	3	1	3	High	
Access	3	3	1	2	1	3	High	
Independence from Petroleum	1	3	3	2	1	3	High	
Cost Criteria								
Ship Consumption (gal/yr)	3,733,950	6,789,000	6,789,000	3,788,065				Infrustructure, Access, and Independence
Fuel Cost ($/gal)	2.81	2.75	4.08	2.71				are assessed as High (3), Med (2), and Low (1)
Investment Cost ($)	0	0	5,000,000	0				All fuels are available on DESC price list except Cellulosic
Operational Savings ($/yr)	0	-8,177,351	-17,221,582	226,743				
Maintenance (h/yr)	0	0	0	0	3,733,950			<- 33% at-sea/anchor w/31,000 gal/day
Maint Savings ($/yr)	0	0	0	0				burned per site-visit data (fo+usage.xls)
Normalized Score								
Greenhouse Gas Reduction (%)	0.000	0.271	1.000	0.212				
Heat of Combustion (BTU/gal)	1.000	0.000	0.000	0.968				
Infrastructure	1.000	1.000	0.000	1.000				
Access	1.000	1.000	0.000	0.500				
Independence from Petroleum	0.000	1.000	1.000	0.500				
Performance	0.60	0.65	0.40	0.64				
Savings-1	0	-8,177,351	-22,221,582	226,743				
Savings-5	0	-40,886,753	-91,107,910	1,133,714				
Savings-10	0	-81,773,505	-177,215,820	2,267,428				

[This Figure shows that the heat of combustion for corn and cellulosic ethanol is significantly lower than diesel F76, while biodiesel B20 is comparable. Due to the lower energy density, the two ethanol options never achieve a positive savings even when projected out to ten years. However, even with the marginally lower energy density for B20, it provides a significant net savings even in the first year of usage. Biodiesel B20 is one of the top three single-option alternatives for five-year ROI.]

Figure 48 - Common Analysis for Fuel Type

The summary of results from the common analysis of the eight subsystems, along with fuel type, that were analyzed is given in Figure 49 and Figure 50 below. The upper half of Figure 49 lists the eight subsystems along with fuel type in the first column, and then the corresponding baseline and alternative technologies for that attribute across the row. The lower half of Figure 49 repeats the list of subsystems with fuel type, but average normalized performance for the baseline and alternatives appears across the row. For example, the dryers performance is 0.45 for the baseline, 0.82 for alternative A (gas), and 0.74 for alternative B (steam). These average normalized performance numbers come directly from the common analysis for Dryers 1, 2, and 3 shown in Figure 46. Note that while normalized individual performance criteria always have a best and worst score at 1.0 and 0.0 respectively, that the simple average performance may not cover the entire normalized range, as is the case for the AC compressor. Dollar figures in red parentheses represent a negative savings. The dishwater heaters, part of the outfitting and furnishing ship work breakdown structure, were originally intended to be assessed separately, but in fact were assessed together with hot-water heaters. The column for it remains as a placeholder in the analysis tables, since the stakeholder rankings were carried through to a weighting for this parameter, but is not populated with any inputs or results. In Figure 50, the first four columns of numbers show the five-year net savings while the second four columns of numbers show the fixed investment cost incurred in year one. The significant cost incurred for fuel type options A (corn ethanol E85) and B (cellulosic ethanol) is adverse enough that those two options were dropped from the trade-off analysis.

Attribute Table	Baseline	Alternative A	Alternative B	Alternative C
Pre-Heater	Tubular	Chromolax		
AC Chill-Water Pump	Baseline	Variable Freq Drive		
Hot Water Heater	Baseline	Hubbell HWH Only 1000 G; 250kW	Hubbell HWH (XXX G) + Hubbell Tankless Hybrid Combination	X Hubbell Tankless
Fuel Xfer Heater	Baseline	Enhanced BL	Direct Injection	
Fire Pumps	Baseline	Vertical Inline		
Ovens	Baseline	Halogen	Combination Convection Microwave	Halogen Microwave
Dryers	Baseline Electric	Gas	Steam	
Dishwater Heaters	<See Entry for Hot Water Heater Above>			
Lighting Fixtures	DDG 51 Baseline	Distribution with increase in CFB	Distribution with increase in LED	Distribution with increase in metal Halide
Fuel Type	Baseline	Corn Ethanol E85	Cellulosic Ethanol	Biodiesel B20

Attribute Scoring	Baseline	Alternative A	Alternative B	Alternative C
Pre-Heater	1.00	0.80		
AC Chill-Water Pump	1.00	1.00		
Hot Water Heater	0.94	1.00	0.59	0.20
Fuel Xfer Heater	1.00	1.00	1.00	1.00
Fire Pumps	0.75	0.75		
Ovens	0.27	0.49	0.40	0.62
Dryers	0.45	0.82	0.74	
Dishwater Heaters	<See Entry for Hot Water Heater Above>			
Lighting Fixtures	0.36	0.44	0.96	0.59
Fuel Type	0.60	0.65	0.40	0.64

[This Figure shows a qualitative description of the alternatives along with their simple average normalized performance scores drawn from Figure 40 through Figure 48.]

Figure 49 - Common Analysis Summary Results Performance

Attribute Table	Baseline	Alternative A	Alternative B	Alternative C		Baseline	Alternative A	Alternative B	Alternative C
	Savings -	5				Investment Cost (1st yr)			
	Min	($824,011)				Min	$0		
	Max	$2,766,375				Max	$5,000,000		
Attribute Scoring									
Pre-Heater	$0	$2,766,375				$0	$120,000		
AC Chill-Water Pump	$0	$841,849				$0	$21,800		
Hot Water Heater	$0	($180,736)	($478,165)	($243,547)		$0	$215,000	$203,300	$253,200
Fuel Xfer Heater	$0	$93,794	$225,829	$525,658		$0	$75,000	$78,000	$82,000
Fire Pumps	$0	$2,168,372				$0	$30,000		
Ovens	$0	$77,594	$168,063	$267,589		$0	$7,400	$50,900	$9,200
Dryers	$0	$992,621	($824,011)			$0	$13,500	$13,800	
Dishwater Heaters									
Lighting Fixtures	$0	$633,257	$723,499	$412,458		$0	$17,166	$165,853	$108,271
Fuel Type	$0	($40,886,753)	($91,107,910)	$1,133,714		$0	$0	$5,000,000	$0

[This Figure shows the savings over five years after the investment cost incurred in the first year for each of the alternatives. The two alternatives colored orange have a significant cost over time, rather than savings, and were discounted from further consideration.]

Figure 50 - Common Analysis Summary Results Five-Year Savings and First-Year Cost

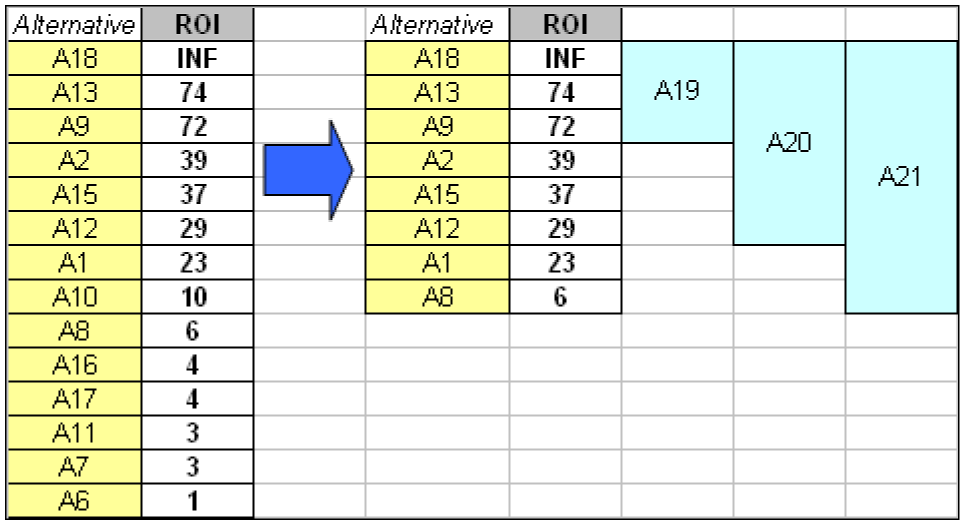
For the trade-off analysis of investment cost versus cumulative net savings over five years, combinations of the basic alternative for each subsystem were synthesized including the baseline system (A0), single-option upgrades (A1 through A18), the top-three by five-year return on investment (ROI) all combined (A19), the top-six net by five-year ROI all combined (A20), and then finally the combined best positive five-year ROI for each of the eight subsystems plus fuel-type (A21). The individual performance scores sourced from Figure 49 above contribute to a sum-product against the stakeholder weights that defines the OMOE. The net savings and investment costs are sourced from Figure 50 above. The stakeholder weights are in the row 3 of Figure 51, all highlighted in yellow. The baseline (A0), highlighted in light red, is shown in row 4 with no net savings and no investment cost as it is the reference datum. Rows 5 through 22 of Figure 51 show the single-option upgrades, highlighted in yellow, where the column labeled "nSav" is the normalized five year net-savings relative to the baseline and "ROI" is the five-year return on investment for the given investment cost in the first year. Rows 23 through 25 of Figure 51 show the combination upgrade alternatives, highlighted in cyan.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10					
2		Pre-Heater	AC Chill-Water Pump	Hot Water Heater	Fuel Xfer Heater	Fire Pumps	Ovens	Dryers	Dishwater Heaters	Lighting Fixtures	Fuel Type					
3	*Alternative*	0.098	0.169	0.052	0.073	0.135	0.095	0.095	0.095	0.056	0.133	OMOE	Savings-5	nSav	Investment Cost (1st yr)	ROI
4	A0	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.36	0.60	0.66	$0	0.08	$0	N/A
5	A1	0.80	1.00	0.94	1.00	0.75	0.27	0.45		0.36	0.60	0.64	$2,766,375	0.35	$120,000	23
6	A2	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.36	0.60	0.66	$841,849	0.16	$21,800	39
7	A3	1.00	1.00	1.00	1.00	0.75	0.27	0.45		0.36	0.60	0.66	($180,736)	0.06	$215,000	(1)
8	A4	1.00	1.00	0.59	1.00	0.75	0.27	0.45		0.36	0.60	0.64	($478,165)	0.03	$203,300	(2)
9	A5	1.00	1.00	0.20	1.00	0.75	0.27	0.45		0.36	0.60	0.62	($243,547)	0.06	$253,200	(1)
10	A6	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.36	0.60	0.66	$93,794	0.09	$75,000	1
11	A7	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.36	0.60	0.66	$225,829	0.10	$78,000	3
12	A8	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.36	0.60	0.66	$525,658	0.13	$82,000	6
13	A9	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.36	0.60	0.66	$2,168,372	0.29	$30,000	72
14	A10	1.00	1.00	0.94	1.00	0.75	0.49	0.45		0.36	0.60	0.68	$77,594	0.09	$7,400	10
15	A11	1.00	1.00	0.94	1.00	0.75	0.40	0.45		0.36	0.60	0.67	$168,063	0.10	$50,900	3
16	A12	1.00	1.00	0.94	1.00	0.75	0.62	0.45		0.36	0.60	0.69	$267,589	0.11	$9,200	29
17	A13	1.00	1.00	0.94	1.00	0.75	0.27	0.82		0.36	0.60	0.69	$992,621	0.18	$13,500	74
18	A14	1.00	1.00	0.94	1.00	0.75	0.27	0.74		0.36	0.60	0.69	($824,011)	0.00	$13,800	(60)
19	A15	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.44	0.60	0.66	$633,257	0.14	$17,166	37
20	A16	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.96	0.60	0.69	$723,499	0.15	$165,853	4
21	A17	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.59	0.60	0.67	$412,458	0.12	$108,271	4
22	A18	1.00	1.00	0.94	1.00	0.75	0.27	0.45		0.36	0.64	0.66	$1,133,714	0.19	$0	INF
23	A19	1.00	1.00	0.94	1.00	0.75	0.27	0.82		0.36	0.64	0.70	$4,294,707	0.50	$43,500	99
24	A20	1.00	1.00	0.94	1.00	0.75	0.62	0.82		0.44	0.64	0.74	$6,037,403	0.68	$91,666	66
25	A21	0.80	1.00	0.94	1.00	0.75	0.62	0.82		0.44	0.64	0.72	$9,329,436	1.00	$293,666	32

[This Figure shows the baseline (A0 in pink), each alternative as a stand-alone upgrade (A1 through A18 in yellow), and then combinations of the best savings alternatives (A19 through A21 in cyan). Cells in columns B through K, indexed by rows 5 through 22, are highlighted in yellow to show the average normalized performance of the underlying technology options while column L shows the stakeholder weighted OMOE. Columns M ($) and N (normalized) show five-year net savings, column O ($) shows 1st-year investment cost, while column P shows the ratio of savings to cost as return on investment (ROI).]

Figure 51 - Tabular Trade-Off Analysis

The combination of single-option alternatives to form numbered alternatives A19 through A21 merits further discussion. The single-option alternatives, A1 through A18, were sorted by ROI in descending order and only positive values were retained as shown in left side of Figure 52. Starting at the top of this list and working down to eliminate inferior options: A15 (lighting, CFB) eliminates A16 (lighting, LED) and A17 (lighting, metal halide); A12 (ovens, halogen microwave) eliminates A10 (ovens halogen) and A11 (ovens, combination convection microwave); and finally A8 (fuel transfer heater with 20% improved efficiency) eliminates A7 (fuel transfer heater with +10% efficiency) and A6 (fuel transfer heater with +5% efficiency). Combination alternative A19 consists of the top three remaining single-option alternatives, A18 (fuel type, biodiesel B20), A13 (dryers, gas), and A9 (fire pump number four, vertical inline). Combination alternative A20 adds A2 (chill water pump, variable frequency drive), A15 (lighting with more CFB), and A12 (ovens, halogen microwave). Combination A21 adds the remaining two on the list which includes A1 (AC pre-heaters, Chromolax) and A8 (fuel transfer heater with +20% efficiency).



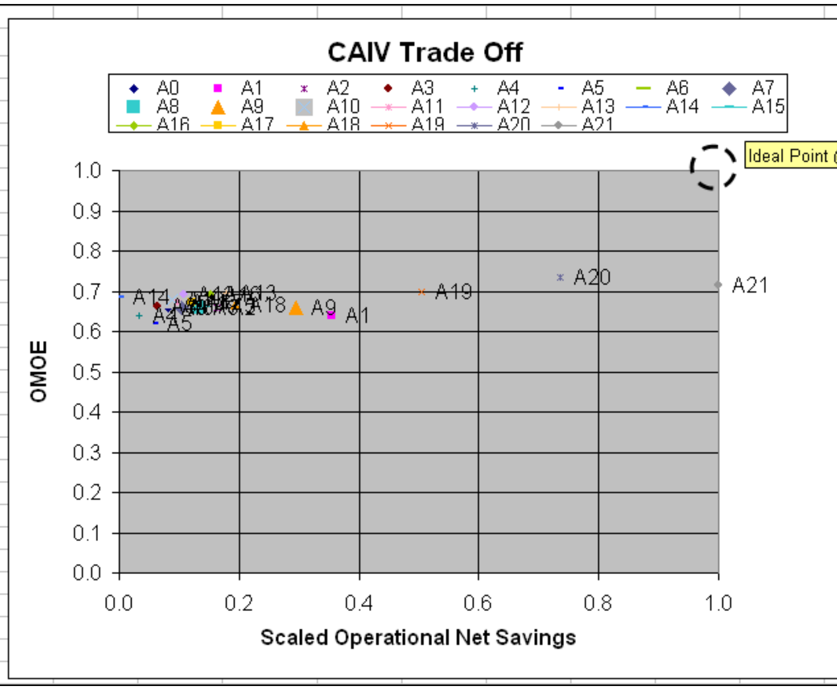
[This Figure shows how the combination alternatives, A19 through A21, were selected based on return on investment of single option alternatives and elimination of inferior options for the same subsystem.]

Figure 52 - Process for Selection of Single-Option Alternatives to Combine

The information from Figure 51 is presented graphically in Figure 53 as normalized net savings over five years versus OMOE. The information is presented again in Figure 54 as normalized investment cost versus normalized net savings over five years. Each of the two Figures also includes an L_1 Norm calculation of the $\Delta x + \Delta y$ distance to the ideal point which is a suitable norm-space for results involving dollars (nominal or normalized). This is a modification to the systems engineering plan as defined in Appendix C, Section 2 of this report where an L_2 Norm was originally identified to distinguish among alternatives. Given that the cost versus performance in Figure 53 does not clearly reveal a Pareto boundary and that investment cost versus savings, where both axes are in dollars, the decision was made to utilize an L_1 Norm.

It is observed in Figure 53 that the scaled cost savings shows a spread over the entire range from zero to one, while the OMOE values for all the alternatives tend to be clustered around 0.58 to 0.62. As noted in Section III.C of this report, ship work-breakdown components that were assessed as potentially having an adverse impact on the effectiveness of the ship as a weapon system were pruned from consideration in the analysis. This was due to the consistently high stakeholder ranking assigned to overall system effectiveness along with the cohort's desire to develop recommendations that would be aligned with stakeholder priorities and minimize significant test and evaluation costs. Subsequently the systems which were considered further have moderate to little impact on OMOE, explaining the clustering of values observed.

Alternative	nSav	OMOE	L_1 Norm
A0	0.08	0.66	1.26
A1	0.35	0.64	1.01
A2	0.16	0.66	1.18
A3	0.06	0.66	1.27
A4	0.03	0.64	1.33
A5	0.06	0.62	1.32
A6	0.09	0.66	1.25
A7	0.10	0.66	1.24
A8	0.13	0.66	1.21
A9	0.29	0.66	1.05
A10	0.09	0.68	1.23
A11	0.10	0.67	1.23
A12	0.11	0.69	1.20
A13	0.18	0.69	1.13
A14	0.00	0.69	1.31
A15	0.14	0.66	1.19
A16	0.15	0.69	1.15
A17	0.12	0.67	1.21
A18	0.19	0.66	1.14
A19	0.50	0.70	0.80
A20	0.68	0.74	0.59
A21	1.00	0.72	0.28



[This Figure shows that the OMOE is about the same for all the numbered alternatives, indicating that net savings are a better metric than OMOE for identifying recommended solutions.]

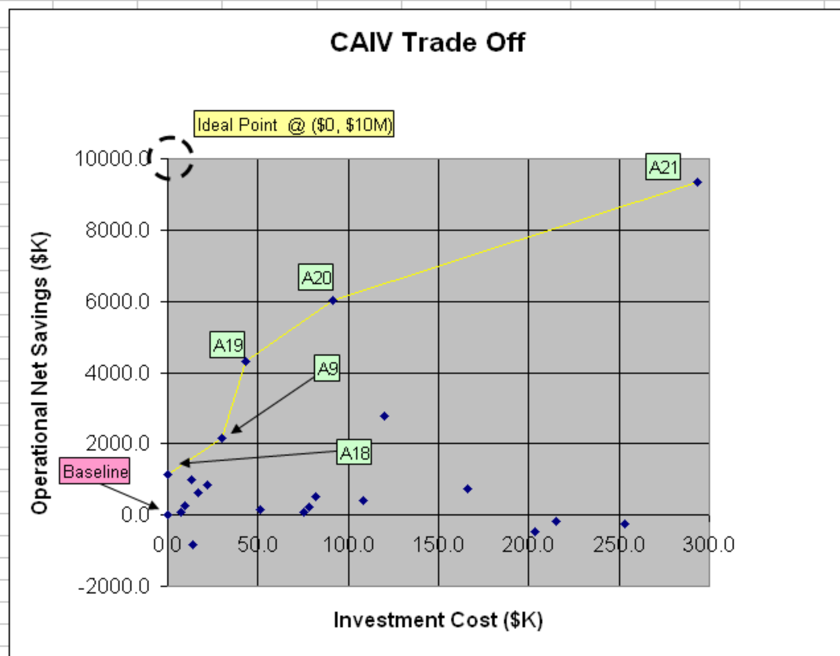
Figure 53 - Five-Year Net Savings versus OMOE

Figure 54 provides a more useful data view for making a decision as a Pareto boundary of optimal solutions is clearly apparent among the alternatives A11 with A20 through A23, labeled in green in the graph. The Pareto boundary is marked with a yellow line in the Figure. All other alternatives are dominated and can be removed from further consideration, subject to sensitivity analysis that might affect which alternatives lie on the Pareto boundary. The L_1 Norm calculation for alternative A23 is highlighted in light green in the tabular portion of the Figure on the left, but there is no compelling basis for selecting among any of the alternatives that lie on the Pareto boundary. The preference of the stakeholders or some budgetary constraint on initial investment cost is recommended to determine a specific combination of single-option alternatives to pursue.

Savings-5

Alternative	Cost	Sav-5	L_1 Norm
A0	0	0	12,600
A1	120	2766	9,714
A2	22	842	11,736
A3	215	-181	12,566
A4	203	-478	12,875
A5	253	-244	12,590
A6	75	94	12,431
A7	78	226	12,296
A8	82	526	11,992
A9	30	2168	10,402
A10	7	78	12,515
A11	51	168	12,381
A12	9	268	12,323
A13	14	993	11,594
A14	14	-824	13,410
A15	17	633	11,950
A16	166	723	11,711
A17	108	412	12,079
A18	0	1134	11,466
A19	44	4295	8,262
A20	92	6037	6,471
A21	294	9329	2,977

	Pareto Points	
A20	0	1134
A11	30	2168
A21	44	4295
A22	92	6037
A23	294	9329



[This Figure shows that numbered alternatives A9 and A18 through A21 lie on the Pareto boundary of efficient solutions. Note that the scale of the vertical axis (savings) is ten times the scale of the horizontal axis (cost).]

Figure 54 - Investment Cost versus Five-Year Net Savings

C. BREAK-EVEN POINTS

As stated in the analysis overview of Section VIII, the break-even point is the length of time for a specific alternative to reach a zero net savings given the initial investment cost. Figure 55 shows a tabular summary of the calculated net savings for each alternative in years 1, 5, and 10. This data is used to forecast the time in months to where the net savings are zero. All of the optimal solutions identified on the Pareto boundary of Figure 54 (e.g., A9 and A18 through A21) have a break-even time that is less than 6 months, suggesting a near-immediate return on investment. Of the remaining dominated alternatives, A13 (dryers gas), A2 (AC chill-water pump, variable frequency drive), A15 (lighting, more compact fluorescent bulbs), A12 (ovens, halogen microwave), A1 (pre-heaters, Chromolax), and A10 (ovens, halogen) also have a break-even time that is less than 6 months. Dominated alternatives A8 (fuel transfer heater, 20% savings device), A16 (lighting, more light-emitting diodes), A17 (lighting, more metal halide bulbs), and have a break-even time that is less than 12 months. Dominated alternatives A11 (ovens, combination convection-microwave), A7 (fuel transfer heater, 10% savings device), and A6 (fuel transfer heater, 5% savings device) have a break-even time that is approximately less than 24 months. A5 and A7 (hot water heaters, Hubbell and Tankless) have a calculated break-even point in excess of 60 months. Note that alternatives A4 (hot water, Hubbell-Tankless Hybrid) and A14 (dryers, steam) never reach a break-even point.

Alternative	*Alternative Name*	1	5	10	**Break-Even (months)**
A18	Fuel type Biodiesel B20	$226,743	$1,133,714	$2,267,428	**0**
A19	A9+A13+A18	$824,141	$4,294,707	$8,632,914	**1**
A13	Dryers Gas	$187,724	$992,621	$1,998,743	**1**
A9	Fire Pump Vertical Inline	$409,674	$2,168,372	$4,366,743	**1**
A20	A19+A2+A12+A15	$1,134,148	$6,037,403	$12,166,471	**1**
A2	AC Chill Water Pump	$150,930	$841,849	$1,705,498	**2**
A15	Lighting CFB	$112,919	$633,257	$1,283,681	**2**
A12	Ovens Halogen Microwave	$46,158	$267,589	$544,379	**2**
A1	Preheater	$457,275	$2,766,375	$5,652,751	**2**
A21	A20+A1+A8	$1,630,954	$9,329,436	$18,952,538	**2**
A10	Ovens Halogen	$9,899	$77,594	$162,588	**5**
A8	Fuel Xfer Heater 20%	$39,532	$525,658	$1,133,316	**8**
A16	Lighting LED	$12,017	$723,499	$1,612,850	**11**
A17	Lighting Metal Halide	($4,125)	$412,458	$933,186	**12**
A11	Ovens Combo Convection/Microwave	$1,893	$168,063	$432,026	**14**
A7	Fuel Xfer Heater 10%	($17,234)	$225,829	$529,658	**15**
A6	Fuel Xfer Heater 5%	($41,241)	$93,794	$262,588	**27**
A3	HWH HWH Only	($208,147)	($180,736)	($146,472)	**376**
A5	HWH Tankless	($251,269)	($243,547)	($233,894)	**1574**
A0	Baseline	$0	$0	$0	**N/A**
A4	HWH Tankless Hybrid	($258,273)	($478,165)	($753,030)	**Never**
A14	Dryers Steam	($175,842)	($824,011)	($1,634,221)	**Never**

[This Figure shows the numbered alternatives ranked by their break-even period in months. Note that the baseline (A0) is included for context, but is not applicable in the break-even analysis.]

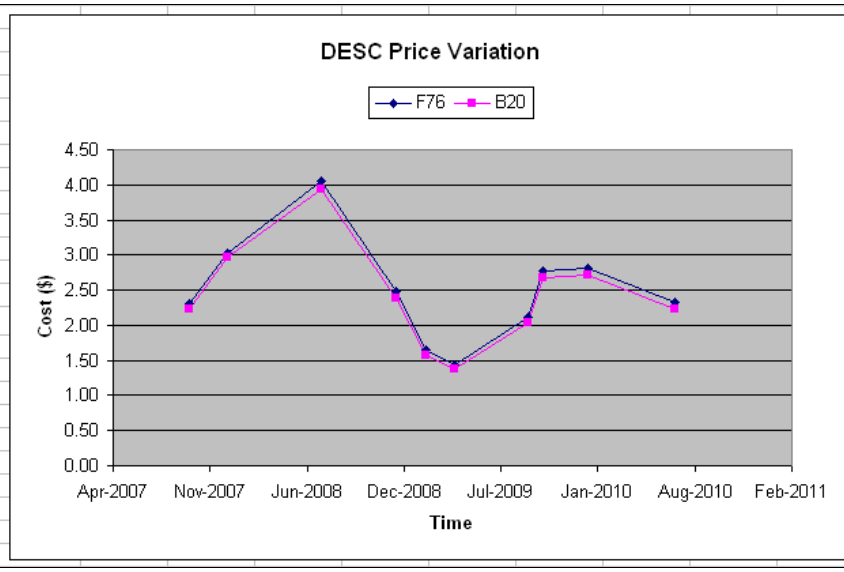
Figure 55 - Break-Even Tabulation of Alternatives

D. SENSITIVITIES

The assessment of sensitivity of the resultant solution rankings for changes in input parameters is limited to variations on the global inputs of the spot price of diesel F76 and biodiesel B20, as well as the operational tempo for pier-side versus anchor/cruise. The reason for assessing B20 is due to the fact that the top-ranked (by return on investment) single-option alternative A18 (fuel type) has a significant influence on the ranking of all the combination options that also lie on the Pareto boundary and which include A18 (i.e., A19 through A21). The other two single-option alternatives that rise to the top-three in the ROI rankings, A13 (dryers, gas) and A9 (fire pump number 4, vertical inline), are considered as well for sensitivity as these single-options appear in the combined options that fall on the Pareto boundary.

The 95% confidence upper and lower limits, based on historical price data from DESC, were calculated for both F76 and B20 as shown in Figure 56 below. What becomes apparent from the graph is that it is not realistic to vary the price of F76 and leave the price of B20 fixed, since price movements are highly correlated. Additionally, it is worth noting that for all ten price sheets that were examined, B20 is always lower in price than F76 which suggests that the savings estimated for alternative A18 has higher confidence than if the pricing had shown cross-over points among F76 and B20.

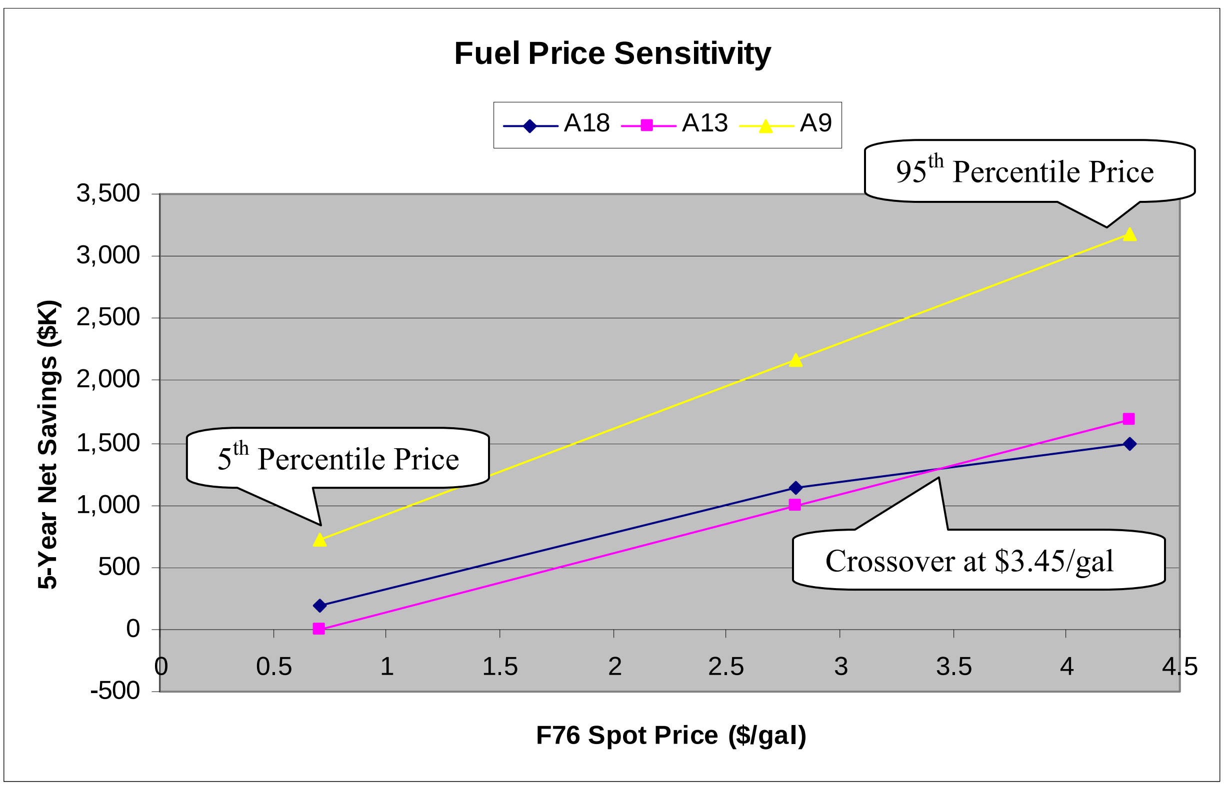
Date	F76	B20	n
1-Jul-10	2.33	2.24	1
1-Jan-10	2.81	2.71	2
1-Oct-09	2.77	2.67	3
1-Sep-09	2.12	2.04	4
1-Apr-09	1.43	1.37	5
1-Feb-09	1.65	1.58	6
1-Dec-08	2.48	2.39	7
1-Jul-08	4.06	3.94	8
19-Dec-07	3.03	2.97	9
1-Oct-07	2.30	2.23	10
	2.50	2.41	Average (S)
	1.79	1.73	$t_{\alpha/2,n-1}$ x S / sqrt(n)
	4.28	4.14	95% UCL
	0.71	0.69	95% LCL



[This Figure shows that the price movement of F76 and B20 is highly correlated and that these two parameters should be varied together in the analysis.]

Figure 56 - Price Variation for Diesel F76 and Biodiesel B20

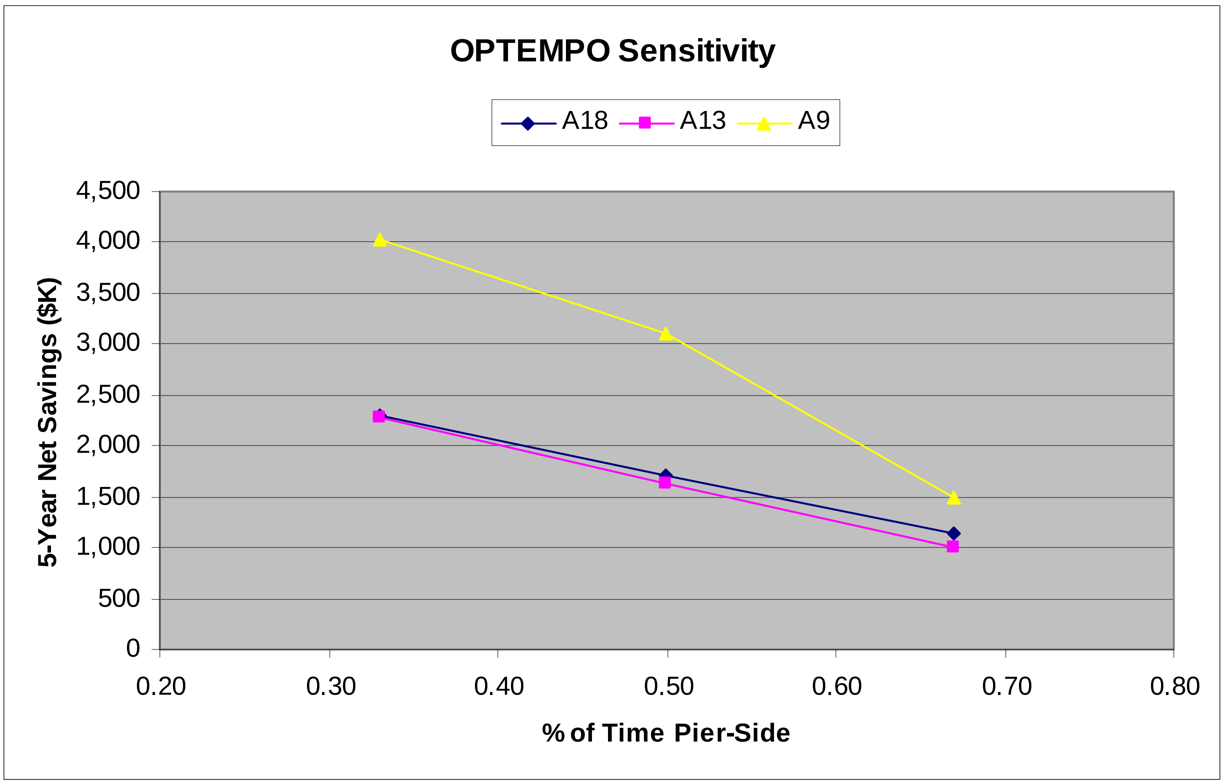
When the input spot price of F76 and B20 are both raised to $4.28/gal and $4.14/gal respectively, the ranking of top three ROI single-option solutions (A18 fuel type biodiesel B20, A13 dryers gas, and A9 fire pump number four vertical inline) is flipped among A18 and A13. Net savings over five years is magnified for all three single-options, but there is a diminishing return for A18 which falls below A13 on a five-year net savings at a spot price of $3.45/gal for F76. When the spot price of F76 and B20 are both lowered to $0.71/gal and $0.69/gal respectively, the rankings are unchanged relative to the baseline spot price of $2.81/gal, but as expected the savings over five years are reduced. This is illustrated in Figure 57 which shows there is some sensitivity for the ranking of biodiesel B20 among other single-option alternatives to the fluctuations in the price of fuel.



[This Figure shows that there is a cross-over among the top three single-option alternatives when varying prices to the 5th percentile and 95hth percentile values for the 10 data price points examined. The resultant ranking of solutions favors gas dryers (A13) over biodiesel B20 (A18) when the spot price of F76 exceeds $3.45/gal.]

Figure 57 - Fuel Price Sensitivity

For the operational tempo (OPTEMPO) that drives the 67% pier-side and 33% at-sea/anchor weightings, the sensitivity variation is simply to swap these two numbers which may be representative of a significantly increased OPTEMPO during a prolonged conflict requiring DDG-51 class ships to be engaged throughout. When the pier-side time percentage is changed to 33% and 50%, the end results are consistent with the original input assumptions as none of the solution rankings are affected. As expected with ships spending more time at-anchor/at-sea, the five-year net savings is increased. The cost lines in Figure 58 do not show any cross-over among the top three ROI alternatives A18, A13, and A9 which indicates that the rankings are insensitive to variations in OPTEMPO.



[This Figure shows that the top three single-option alternatives have no cross-over points when pier-side time is lowered from the baseline assumption of 67% down to 33%. The resultant ranking of solutions is insensitive to OPTEMPO although the magnitude of savings will increase with OPTEMPO.]

Figure 58 - OPTEMPO Sensitivity

THIS PAGE INTENTIONALLY LEFT BLANK

IX. FINAL RECOMMENDATIONS AND CONCLUSIONS

For the given set of inputs for this analysis, the resultant recommendation clearly flows from Figure 54 of Section VIII. Alternatives A18, A9, A19, A20, and A21 all lie on the Pareto boundary and represent a set of non-dominated solutions. Any particular solution from this set can be selected by stakeholder preference or by budgetary constraints. To reiterate, alternative 20 is the combination of the top-six ranked single-combination alternatives by return on investment for fuel type (biodiesel B20), dryers (gas), fire pump number four (vertical inline), AC chill water pump (variable frequency drive), lighting fixtures (more compact fluorescent bulbs), and ovens (halogen microwave). The first-year investment cost for A20 is about \$92K with a net savings through year one of \$1.1M, through year five of \$6.1M, and through year ten of \$12M, where these savings all utilize the fully burdened cost of fuel. Other solutions on the Pareto boundary include A21 which offers the highest net savings through year ten of \$19M for a higher investment cost of \$294K, as well as A18 which offers both the lowest net savings by year ten of \$2.3M for the lowest investment cost of \$0. Although rankings are based on return on investment, different ranking criteria based on total net savings could be considered, as shown in Table 1, if investment cost is less important than total savings.

The ranking of solutions is largely insensitive to changes in the spot price of fuel, assuming that F76 and B20 continue to move in lock-step, as well as to changes in the operational tempo driving the percentage of time ships spend pier-side versus at-anchor/at-sea. There is a point of diminishing returns for B20 as the spot price of fuel moves past about \$3.50/gal. The single-option alternatives that combine to form A19 through A21 all reduce the power consumed on the ship with the exception of fuel type. In descending order of return on investment in year five, those component alternatives that provide a reduction in power consumed are: A13 (dryers, gas), A9 (fire pump number 4, vertical inline), A2 (AC chill-water pumps, variable frequency drive), A15 (lighting fixtures, increase in distribution of Compact Fluorescent Bulbs), A12 (ovens, halogen microwave), A1 (pre-heaters, Chromolax), and A8 (fuel transfer heater, 20% savings device). Reducing power consumption for all of these subsystems contributes significantly to meeting the SECNAV's energy vision. Reduced power consumption results in improved fuel economy and indirectly adds to improved fuel surety as the need for petroleum fuel is reduced, and improved fuel ecology as less fuel is burned producing fewer pollutants. Considering the non-subsystem alternative for fuel type, switching from the current F76 petroleum distillate to biodiesel B20 partially addresses the SECNAV's energy vision as follows: economically, B20 is consistently lower in cost than F76; from a surety perspective, reliance on petroleum would be reduced by 20% for this ship class; and from an ecological perspective, B20 emits fewer pollutants than F76 per gallon burned. Further studying the feasibility of switching ships over to this existing alternative fuel is recommended.

Procedural recommendations that coincide with the specific systems that the cohort analyzed were mentioned within those system write-ups. Some other recommendations that were not quantified within by this Capstone Project warrant further investigation for feasibility as energy saving options for the DDG 51 class ship. Amongst these are general procedural recommendations, which include having an optimized control set-point for the HVAC system. That is, having a procedure for a set temperature point when spaces are occupied and not occupied. For the Outfitting and Furnishing system, a procedural HSI consideration is to utilize duty-cycle scheduling. This is time that is scheduled when a system, equipment, or component is operational. Examples are ovens, dishwasher heaters, and laundry dryers where the operational duty cycle is set to operate 3 days a week or at several times during the day in order to maximize energy savings. The Electrical Plant may employ motion-activated lighting control and also have areas where retrofit/replacement opportunities may exist for more efficient lighting.

Other procedural HSI recommendations include turning off unnecessary equipment. This may be as simple as requiring lights to be turned off when leaving a room or, as stated previously, having motion sensors for lights in infrequently occupied spaces. Other occurrences are when backup equipment is operated at the same time for redundancy even when the requirement for survivability is not necessary. Requiring auto-start systems on backup devices might allow the primary source to maintain a higher utilization factor while satisfying the same operational requirements. This occurs with the added benefit of saving energy and at the same time reduces unnecessary wear and tear on the unit. Along the same line, another procedural change is to minimize parasitic loads which are created when unnecessary work is required due to the system's design. Implementing proper procedures will help to ensure a system is designed or operated properly to meet required loads and not be oversized or inefficient.

Recommendations for Future Work:

It is the team's conclusion that the Navy should prioritize efforts to refine the analysis of the recommended solutions above by funding a feasibility study sponsored by OPNAV to pursue an acquisition strategy to implement some or all of the recommendations. In particular, the issues surrounding adoption of biodiesel B20 for use with the LM2500 propulsion engines and the Alison K-501 gas turbine generators should be further explored, as well as the full costs for supporting use of gas for dryers onboard the DDG-51 ship class. Research on fuel transfer heater alternatives was particularly limited in the team’s findings, so this is another area of focus for future studies. OPNAV should also consider reapplication of this approach to other ship classes.

In addition, procedural changes recommended above should be investigated more thoroughly given the wide variance in power consumed while pier-side. As an example, in Figure 24 it shows that USS JOHN PAUL JONES consumed an average of about $4K/day while USS STERETT consumed about $5K/day. It is known that the USS JOHN PAUL JONES fully embraces the ECON program, which is largely about procedural savings, and that the magnitude of savings across the 50 ships in the class could be on the order of $12M per year for a nominal price of pier-side electricity of $0.14/kWh.

It is also noted that, given the consistently low stakeholder rankings for fuel economy, surety (with the exception of one stakeholder), and ecology, that the Office of the SECNAV needs to develop a strategy that includes measurable, objective metrics for adoption that will ensure that the energy vision is taken on with full force by those who execute the acquisition of petroleum-consuming Navy systems.

Final Thoughts:

The results indicate that considering the fully burdened cost of fuel, an appreciable net savings on the order of $1.9M per ship can be achieved within a year for an investment cost of less than $300K, and that over a ten-year period the net savings can be on the order of $19M. If this savings per ship is realized over the 50 ships in the class, the total savings over ten years could reach $950M. Savings of that magnitude are equivalent to a significant portion of the acquisition of another ship to add to the fleet's arsenal.

APPENDIX A. PROJECT MANAGEMENT PLAN

NAVAL
POSTGRADUATE
SCHOOL

MONTEREY, CALIFORNIA

A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships
(Project Management Plan)

by

Systems Engineering Analysis Cohort 311-912

January 2010

Approved for public release; distribution is unlimited.
Prepared for: Naval Postgraduate School

Signature Page

Submitted by:

____

Joseph Cannon
NPS MSSE Cohort 311-912 Program Lead
SI 0810 Capstone Project

____

William Jones
NPS MSSE Cohort 311-912 Technical Lead
SI 0810 Capstone Project

Reviewed by:

OLWELL.DAVID.
HANLEY.JR.1160447288

Digitally signed by OLWELL.DAVID.HANLEY.
JR.1160447288
DN: c=US, o=U.S. Government, ou=DoD,
ou=PKI, ou=USN, cn=OLWELL.DAVID.HANLEY.
JR.1160447288
Date: 2010.02.11 12:48:01 -08'00'

____

Dr. David Olwell
MSSE Project Advisor

/s/
____

Kristin Giammarco
MSSE Project Advisor

____

Dr. Eugene Paulo
MSSE Academic Associate

Approved by:

____

Dr. Clifford Whitcomb
Chair: Dept. of Systems Engineering

Table of Figures

PROJECT MANAGEMENT PLAN

A. ADMINISTRATIVE

1. Students

The following students will be involved in the capstone project effort for the Naval Postgraduate School's (NPS) distance learning cohort 311-912: Joseph Cannon, Vesmiene Ceasor, Fernando Escobar, Gloria Huapaya, William Jones, Deepak Kumar, Eric Lavetti, Stephen Lucero, Anthony Nguyen, Vincent Picicci, Shirlean Todd, and David Toth. In order to keep advisors apprised of the relative effort of individuals, each team member shall keep a log to include date, hours spent, and a one or two sentence task description. Each team member shall submit their effort log to the advisors quarterly.

2. Advisors

The following faculty members are advising the students in this effort: Dr. David Olwell and Prof. Kristin Giammarco.

B. PROJECT IDENTIFICATION

1. Title

The title that the students have tentatively selected for this effort is "A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships," which reflects the intent to apply the systems engineering principles we have learned in the past eight quarters of our curriculum and identifies the scope we have bounded for the effort.

2. Topic

The original problem statement provided to the students is as follows: "Develop a technically feasible, cost effective approach to address and balance the Department of the Navy (DoN) energy surety, economy, and ecology goals."

3. Objectives

The team's objectives are to apply a sound systems engineering process to define a solvable subset of the original problem statement, formulate alternative solutions, develop a scoring criteria, analyze and rank these solutions, and develop achievable recommendations. This includes developing a concept of operations for those recommendations that can be implemented to help the DoN achieve its energy goals for 2020.

4. Abstract

NPS distance learning cohort 311-912 has been assigned a capstone topic to address DoN energy surety, economy, and ecology goals. The team has organized itself into technical and programmatic divisions that are cross-matrixed to ensure that each participant is involved in both technical and programmatic efforts. The team is being advised by two NPS faculty members. Dr. Olwell is a recent chair of the Systems Engineering Department and Prof. Giammarco is a PhD. candidate that previously instructed several of the cohort members for SE4003 Systems Software Engineering. Although potential stakeholders have been identified, no formal stakeholders have been confirmed at the time of this writing. The team has scoped the problem to focus on the economy aspect of the DoN's energy goal, and has further limited the scope of the problem to the DDG-51 class of surface combatants which appears to be an area with potentially high return on investment based on a review of background information provided by the advisors and initial research conducted by the team. The team will apply a tailored version of the Army Systems Engineering Office (ASEO) analysis process model to define the problem, establish evaluation criteria and techniques, collect data for alternative solutions, analyze and rank those solutions, and develop conclusions and recommendations. Expected deliverables include a formal systems engineering report of the process and results and a briefing presentation of the report. The team also has an objective to provide recommended modifications to the existing DDG-51 capability development document suitable for future use by an acquisition sponsor. The effort and culminating products will be developed over a three-quarter schedule spanning January to September 2010. No additional resources beyond the personnel of the team and access to NPS facilities (e.g., Sakai repository, Knox Library, virtual private network servers for ExtendSIM access, etc.) have been identified at the time of this writing.

C. ACTIVITIES

1. Problem Definition

As noted in section B.2 above, the original problem statement given to the team by the advisors was to "Develop a technically feasible, cost effective approach to address and balance the DoN energy surety, economy, and ecology goals." A problem of such broad scope is intractable given the team-size and hard schedule constraint for completion within nine months.

One of the first activities the team engaged in was to review the background information provided by the advisors and down-scope the problem to a subset that has an achievable solution within the schedule constraint. Two briefings in particular were prevalent in the discussion process of selecting a reduced scope. The briefing on Navy energy initiatives by CAPT Mitchell of reference [1] indicates that efforts to reduce DoN energy consumption at shore based facilities has been underway since 2006 and that current results actually surpass the reduction goal as noted on slide 6 of the brief. Slide 23 of the backup in that same brief shows that overall energy consumption has 75% attributed to tactical, while only 25% is attributed to shore-based usage as show in Figure 1. Additionally it shows that 57% of DoN's energy consumption is petroleum, while only 26% is electricity, natural gas, and other sources, besides nuclear and renewable, as shown in Figure 2. Also, evidence was provided indicating that energy consumption of ships is a significant proportion of the total DoN energy consumption and that within ships, surface combatants represent a majority of the usage as show in Figure 3.

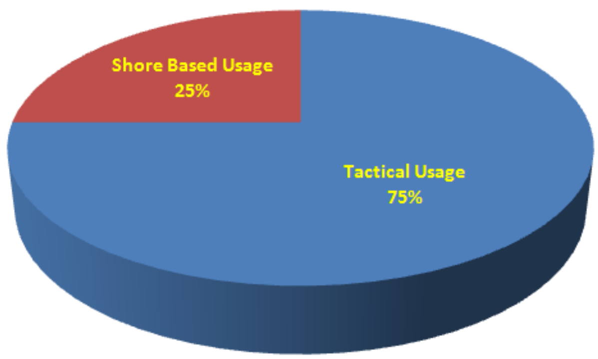


Figure 1. DoN Energy Consumption Overview

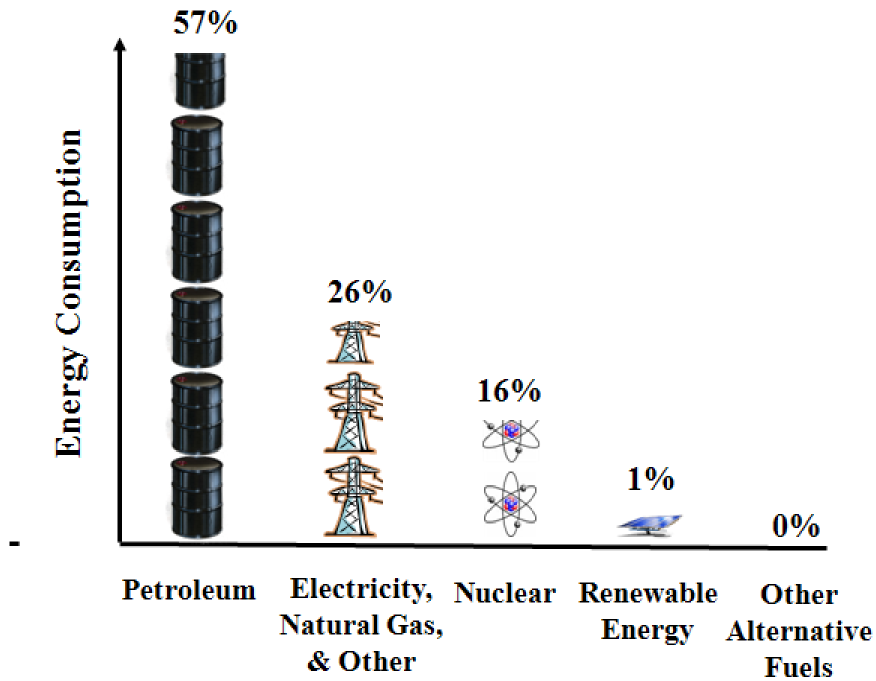


Figure 2. DoN Energy Consumption by Fuel Type

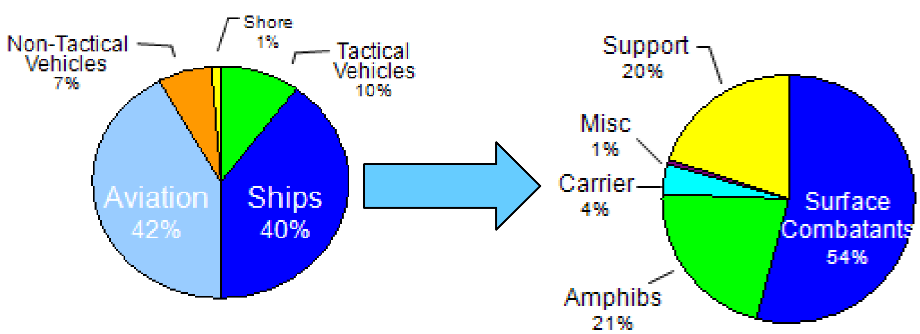


Figure 3. DoN Energy Consumption Breakdown

In the energy strategy pamphlet by SECNAV of reference [2], a vision for improved energy security is stated as deploying a "green" fleet, reducing reliance on fossil fuels, and to secure a sufficient, reliable, and sustainable energy supply. It goes on to say:

> The Department of Navy's current energy demand creates multiple vulnerabilities for tactical platforms. Ships, aircraft, and ground vehicles must frequently receive new supplies of fuel. At sea, ships are most vulnerable alongside an oiler during underway replenishment. In the air, refueling costs are increased by an expensive

> logistics tail. On the ground, convoys of tanker trucks are magnets for insurgent attacks, putting lives at risk and drawing forces away from the fight. To mitigate these risks, the maritime, aviation, and expeditionary communities are developing policies and technologies that will lead to greater combat capability, less dependence on petroleum, and a reduced carbon footprint.

Based on the 75% consumption attributed to tactical systems, some evidence that shore-base installations already have a successful program in place for reducing energy consumption, and personal interests among various team members to consider the security aspects of the SECNAV strategy, the team has focused the scope of the problem on the economy aspects for tactical systems, which is how surety will be achieved per the SECNAV strategy. Initial research conducted by the team revealed an existing report cited in reference [3] which provides evidence of the return on investment for a 5% reduction in fuel usage over the remaining life cycle of eleven surface combatant ship classes. The DDG-51 (Arleigh-Burke) class was projected to have a $283M fuel savings and the CG 47 (Ticonderoga) class was projected to have a $129M fuel savings. None of the other classes examined had triple-digit projected savings. Another significant study, cited as reference [4], that drove the scope was an "unclassified survey of energy efficiency potential aboard USS PRINCETON CG-59. Energy efficiency seeks to deliver the same service with less fuel and uncompromised or improved war-fighting capability via improved technologies or operational practices". Based on these additional findings, augmenting what the advisors have provided as background, the team has further narrowed the scope of this effort to the DDG-51 class of surface combatants.

It is recognized that there is interdependence among surety, economy, and ecology for any given domain solution, but rankings will be weighted to assign higher importance to economy than the other two factors. At the time of this writing, tentative external stakeholders have been identified but not confirmed, however the team plans to develop a standardized questionnaire, to be vetted through NPS internal review board, and try to gain a consensus on stakeholder views to further refine the problem to be solved, identify sources of data to be collected, weights and criteria of key parameters, and identify potential solutions for consideration.

2. Solution Strategy

Figure 2.5 of reference [5] discusses several systems engineering process models including: the waterfall, spiral, and "Vee". Additionally, Section III.C of reference [6] presents the ASEO system engineering analysis process which is an adaptation of the analysis process in Figure 4.9 of reference [5].

The first three models mentioned represent the systems engineering process throughout the entire life-cycle from requirements analysis, through specification, design, implementation, test, usage, and disposal while the last model focuses on an analysis process. The waterfall conveys a process that has a single-pass through its steps, although it does account for evaluation and feedback to previous process blocks. The spiral model is more iterative in nature and is intended to allow for a risk-driven program that may be subject to changing objectives over time. The "Vee" model is very similar to the waterfall in that it presents a "single-pass" feel through a number of developmental process steps, but it also conveys an emphasis on verification of products delivered at each process step (the right side verification of the "Vee" that horizontally links back to the left side development activity). The ASEO analysis process model, shown in Figure 4 below, provides more of a focus on analysis that would map to the first step of other models (i.e., requirements analysis). The steps of this model, analysis approach, evaluation criteria, evaluation techniques, source data collection, evaluation of alternatives, and analysis results, correlate better with the expected activities cited in reference [7] which is intended to guide the capstone development effort. Although feedback loops are not graphically depicted in Figure 4, stakeholder involvement is intended at each process output.

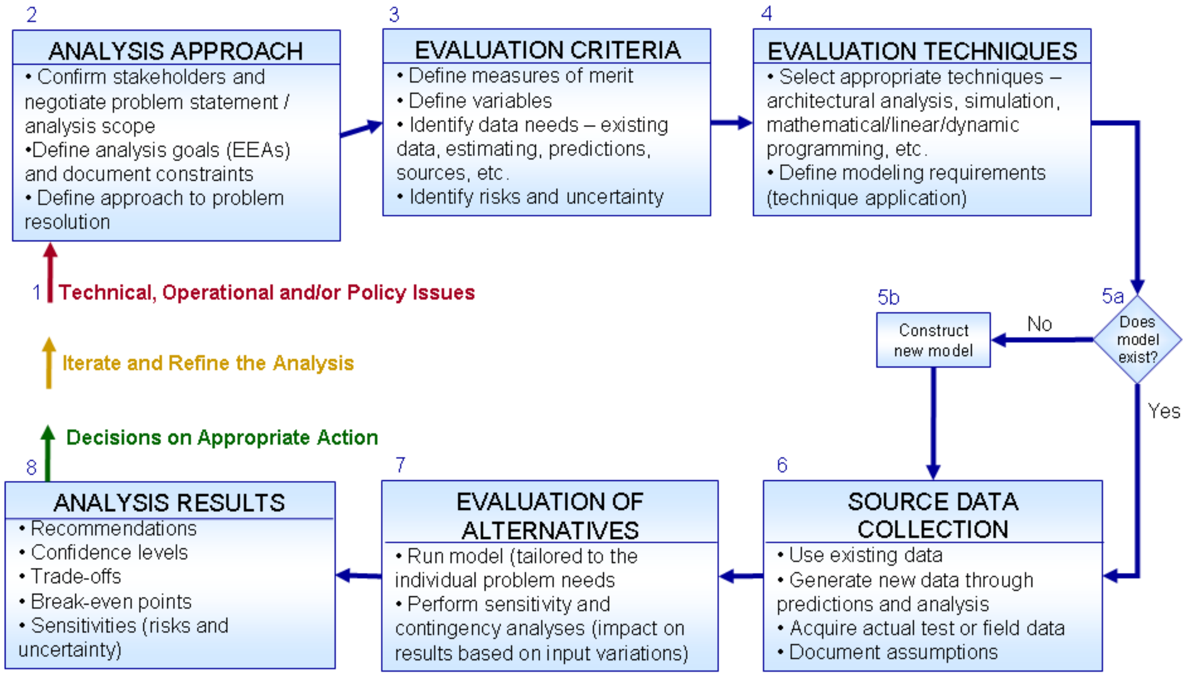


Figure 4. ASEO Systems Engineering Analysis Process

For the 311-912 Cohort, the project effort ends in a formal report documenting the analysis of alternatives with recommendations and a goal to deliver recommended changes to the existing DDG-51 capability development document, which is a top-level requirements document. System specification, detailed sub-system and component specification, design, implementation, test, usage, and disposal will not be executed under this capstone, although costs for varying alternatives throughout these life-cycle phases will be considered in the analysis effort. Given the focus on requirements analysis, it is most appropriate to adopt the ASEO system engineering analysis process as the systems engineering process for the limited scope of the project.

3. Formulation of Alternatives

The team will define measures of merit to be vetted with stakeholders (step 2 of the process, task ID 34 of the schedule in Figure 8); conduct research on existing technology and procedures (step 3 of the process, task ID 35 of the schedule); develop alternatives that are implementable (e.g., Technology Readiness Level 5 or higher; step 4 of the process, task ID 37 of the schedule); gather supporting data on cost, schedule, performance, and risk associated with these alternatives; and supplement data with modeling results as required per the evaluation criteria (step 6 of the process, task ID 36 of the schedule). The team expects to draw heavily on the prior work of reference [4] with respect to this portion of the project effort.

4. Analysis of Alternatives

The team will translate the evaluation criteria (including existing key performance parameters and new criteria related to energy surety, economy, and ecology) to an overall measure of effectiveness (OMOE) for each alternative solution using stakeholder weightings (step 3 of the process, task ID 35 of the schedule); normalize the OMOE and cost to evaluate performance with cost as an independent variable; identify the Pareto boundary of optimal solutions; and perform a sensitivity analysis of the evaluation criteria (step 7 of the process, task ID 38 of the schedule). The team expects to apply the principles learned in SE3303 System Assessment with respect to this portion of the project effort.

5. Develop Conclusions and Recommendations

The team will provide a summary of the findings from the analysis of alternatives as well as ranked recommendations to be considered by the research, acquisition, and operational departments of the Navy for further development and/or implementation (step 8 of the process, task ID 39 of the schedule). Caveats based on assumptions or risk uncertainties will be identified as well.

D. EXPECTED ACCOMPLISHMENTS

There are two expected products from this effort: 1) a formal engineering report documenting our process and results; and 2) a presentation summarizing the report to be out-briefed to the faculty and stakeholders at the conclusion of the effort. The team also has an objective to produce a third product in the form of a proposed set of modifications to the existing DDG-51 capability development document that can be refined by a potential sponsor and used in the acquisition process to implement the recommendations from this effort.

E. ORGANIZATION AND ROLES

1. Organization

The team will be organized into two main divisions that are cross-matrixed; a technical division and a programmatic division as shown in Figure 5 below. In the cross-matrixed approach, each team member has a primary role that they are responsible for but also has a secondary technical role. The primary role could be either PM or Technical but their secondary role would have to be technical to ensure each member is taking part in the research and that we are fulfilling the expectation of a full 9 credits of effort for the quarter. The Chief Systems Engineer would be responsible for all activities related to research and analysis of technical and procedural solutions. The Chief Program Executive would be responsible for all programmatic activities (e.g., meetings, schedules, budget, administration, overall risk, etc.). Neither Chief would have authority outside their primary responsibility, but must concur with one another for a decision to take effect. Conflict Resolution between the two structures (if necessary) would be left to be voted by the collective team. This keeps a good balance of power and emphasis between the two aspects. In addition, the group is small enough where a simple majority vote can quickly solve the problem and avoid issues of single authority roles in peer groups.

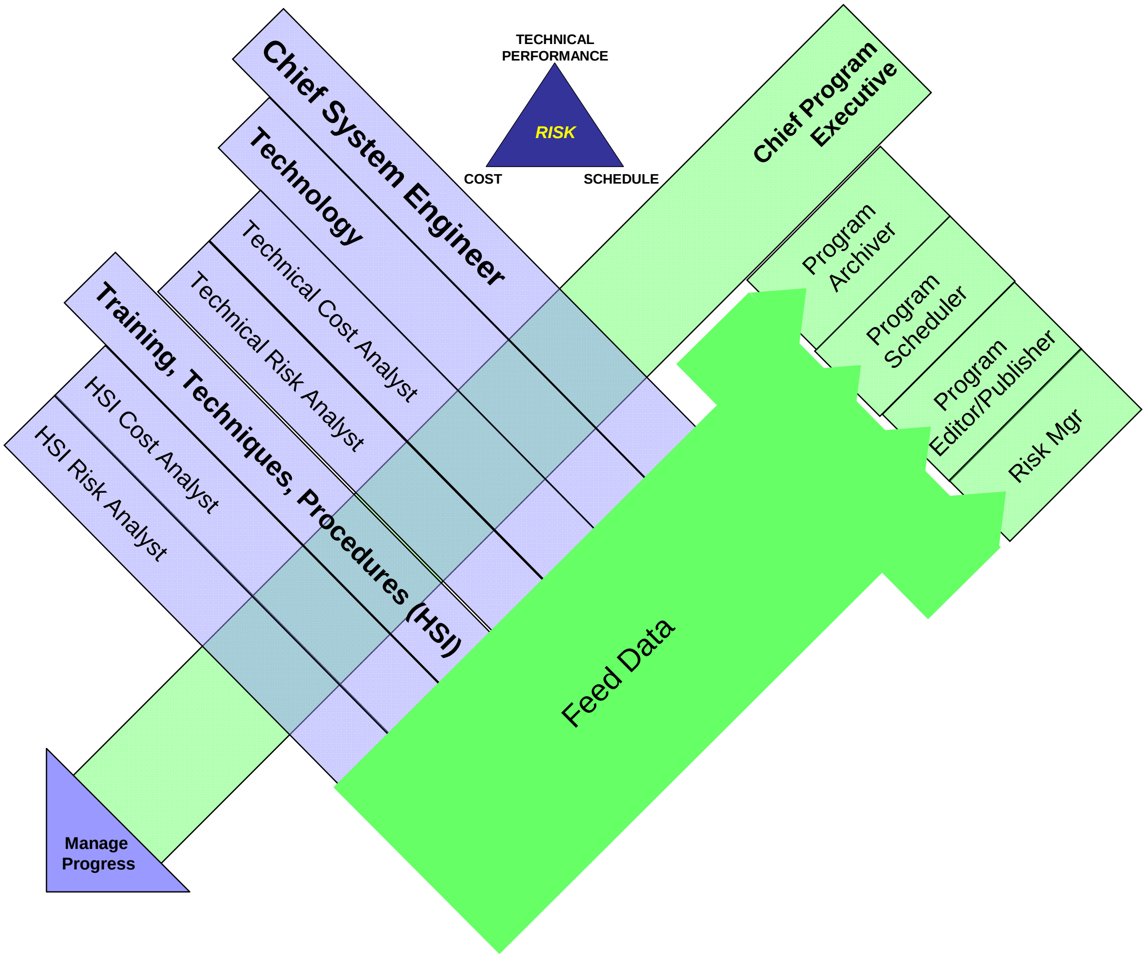


Figure 5. Organizational Cross-Reference

	Chief Program Executive	Program Archiver	Program Scheduler	Program Editor/Publisher	Risk Manager	Chief Systems Engineer	Technology SE	Tech Cost Analyst	Tech Risk Analyst	Training, Tactics, Procedures SE	HSI Cost Analyst	HSI Risk Analyst
Project Management Plan	X				X							
Problem Definition	X				X	X	X			X		
Solution Strategy	X		X		X	X	X	X	X	X	X	X
Data Collection		X						X	X		X	X
Data Compilation/Management		X		X								
Develop Alternatives					X	X	X	X	X	X	X	X
Analaysis of Alternatives					X	X	X	X	X	X	X	X
Conclusions & Recommendations					X	X	X	X	X	X	X	X
Report	X		X	X		X	X			X		
Presentation	X		X	X		X	X			X		
CDD						X	X			X		
Risk Management	X		X		X							
Status Reports	X	X	X	X								
Technical Reviews	X	X		X		X	X			X		
Schedule Review	X		X			X						

Figure 6. Organizational Map of Roles to Tasks

2. Roles

Programmatic Roles:

Chief Program Executive: Responsible for schedule, budget, risk management, procedural and administrative activities for the Project. Works closely with the Chief System Engineer to ensure technical research activities are executed in symphony with the project plan.

Program Archiver: Responsible for the collection, compilation and organization of all data, products, and sources.

Program Scheduler: Responsible for the updating and tracking of activities. Chairs schedule reviews and informs Chief Program Executive of schedule status.

Program Editor/Publisher: Responsible for the production and publication of all written documentation, reports and minutes. Takes notes during meetings and reviews. Works closely with technical roles to input information into final report/CDD.

Risk Manager: Responsible for managing over all project risk; to include capstone "programmatic effort" risk (schedule, performance) as well as technical research risk (technology and HSI implementation with respect to cost, schedule and performance). Conducts risk analysis and risk mitigation in these area. Advises Chief Program Executive and Chief System Engineer of programmatic and technical risk. The team's risk management plan is provided in appendix A.

Technical Roles:

Chief System Engineer: Responsible for technical execution of the project. Oversees and directs research and analysis efforts. Works closely with the Chief Program Executive to ensure technical research activities are executed in symphony with the project plan. Primary POC for the Project effort. The two key personnel supporting the Chief System Engineer are the Technology System Engineer (material solutions) and the HSI engineer (non-material solutions)

Technology System Engineer: Responsible for the execution of technological research. Orchestrates and directs research efforts with respect to technological solutions to the problem. Reports to the Chief System Engineer.

Technology Cost Analyst: Responsible for technological cost analysis. Reports to the Technology System Engineer.

Technology Risk Analyst: Responsible for technological risk analysis. Reports to the Technology System Engineer. Interfaces with the Program Risk Manager.

Human System Integration (HSI) Engineer: Responsible for the execution of HSI research. Orchestrates and directs research efforts with respect to technological solutions to the problem. Reports to the Chief System Engineer.

Human System Integration Cost Analyst: Responsible for HSI cost analysis. Reports to the HSI Engineer.

Human System Integration Risk Analyst: Responsible for HSI risk analysis. Reports to the HSI Engineer. Interfaces with the Program Risk Manager.

3. Stakeholders

A list of potential stakeholders and the team's best estimate of their primary concern with regards to this project is given in Figure 7 below.

Stakeholder	**Primary Concern**
Surface Warfare Development Group (SWDG)	Tactical doctrine
Surface Type Commander (TYCOM)	Fleet Operations
Commander, Naval Sea Systems Command (NAVSEA)	Oversight of ship development and sustainment
Program Executive Officer for Ships (PEO-SHIPS)	Acquisition manager for ship life-cycle
Office of Naval Research	Sponsored study of reference [4]

Figure 7. Potential List of Stakeholders

F. OTHER

1. Schedule

The preliminary schedule is derived from hard milestones that have been provided by the advisors and is illustrated in Figure 8 below. Although the granularity of the schedule presented in this document does not show it, stakeholder involvement is intended to be associated with task ID 34 (Analysis Approach) through task ID 39 (Analysis Results). The process steps of Figure 4 are mapped to aforementioned task IDs of Figure 8 in sections C.3 through C.5 above.

ID	Task Name	% Work Complete	Duration	Start	Finish
1	**Capstone 311-0912**	**0%**	**174 days**	**Wed 1/13/10**	**Fri 9/10/10**
2	**Program Milestones and Reviews**	**0%**	**160 days**	**Mon 2/1/10**	**Fri 9/10/10**
3	**Project Management Plan**	**0%**	**10 days**	**Mon 2/1/10**	**Fri 2/12/10**
4	Draft PMP Team Review	100%	2 days	Mon 2/1/10	Tue 2/2/10
5	Draft PMP Due	100%	0 days	Wed 2/3/10	Wed 2/3/10
6	Final PMP Team Review	0%	3 days	Mon 2/8/10	Wed 2/10/10
7	Final PMP Due	0%	0 days	Fri 2/12/10	Fri 2/12/10
8	**System Engineering Management Plan**	**0%**	**9 days**	**Mon 2/15/10**	**Fri 2/26/10**
9	Draft SEMP Development	0%	4 days	Mon 2/15/10	Thu 2/18/10
10	Draft SEMP Team Review	0%	2 days	Fri 2/19/10	Mon 2/22/10
11	Final SEMP Team Review	0%	1 day	Tue 2/23/10	Tue 2/23/10
12	Final SEMP Due	0%	0 days	Fri 2/26/10	Fri 2/26/10
13	**In Process Reviews**	**0%**	**65 days**	**Mon 3/8/10**	**Fri 6/4/10**
14	**IPR 1**	**0%**	**10 days**	**Mon 3/8/10**	**Fri 3/19/10**
15	IPR1 Presentation Development	0%	4 days	Mon 3/8/10	Thu 3/11/10
16	IPR1 Team Review, Refinements, Dry Run	0%	3 days	Fri 3/12/10	Tue 3/16/10
17	IPR1	0%	1 day	Fri 3/19/10	Fri 3/19/10
18	**IPR 2**	**0%**	**19 days**	**Tue 5/11/10**	**Fri 6/4/10**
19	IPR2 Presentation Development	0%	3 days	Tue 5/11/10	Thu 5/13/10
20	IPR2 Team Review, Refinements, Dry Run	0%	3 days	Fri 5/14/10	Tue 5/18/10
21	IPR2	0%	1 day	Fri 6/4/10	Fri 6/4/10
22	**CDD, Final Report & Presentation**	**0%**	**61 days**	**Fri 6/18/10**	**Fri 9/10/10**
23	CDD Development	0%	15 days	Fri 6/18/10	Thu 7/8/10
24	CDD Team Initial Review	0%	3 days	Fri 7/9/10	Tue 7/13/10
25	CDD Final Team Review	0%	1 day	Fri 7/16/10	Fri 7/16/10
26	Final Report Development	0%	15 days	Mon 7/19/10	Fri 8/6/10
27	Final Report Team Initial Review	0%	3 days	Mon 8/9/10	Wed 8/11/10
28	Final Report Final Team Review	0%	1 day	Tue 8/17/10	Tue 8/17/10
29	Final Report & CDD Due	0%	0 days	Fri 8/20/10	Fri 8/20/10
30	Final Presentation Development	0%	5 days	Mon 8/23/10	Fri 8/27/10
31	Final Presentation Team Review, Refinements, Dry Ru	0%	6 days	Mon 8/30/10	Mon 9/6/10
32	Final Presentation Due	0%	1 day	Fri 9/10/10	Fri 9/10/10
33	**Technical**	**0%**	**105 days**	**Mon 1/25/10**	**Thu 6/17/10**
34	Analysis Approach	0%	25 days	Mon 1/25/10	Thu 2/25/10
35	Evaluation Criteria & Techniques	0%	15 days	Fri 2/26/10	Thu 3/18/10
36	Source Data Collection	0%	20 days	Fri 2/26/10	Thu 3/25/10
37	Alternative Development	0%	20 days	Fri 3/26/10	Thu 4/22/10
38	Evaluation of Alternatives	0%	20 days	Fri 4/23/10	Thu 5/20/10
39	Analysis Results	0%	15 days	Fri 5/21/10	Thu 6/10/10
40	Risk Reserve	0%	5 days	Fri 6/11/10	Thu 6/17/10
41	**Programmatic**	**0%**	**161 days**	**Wed 1/13/10**	**Tue 8/24/10**
42	Organizational Structure	0%	3 days	Wed 1/13/10	Fri 1/15/10
43	Roles & Responsibilities	0%	5 days	Mon 1/18/10	Fri 1/22/10
44	Initial Schedule	0%	5 days	Mon 1/18/10	Fri 1/22/10
45	Risk Management	0%	153 days	Mon 1/25/10	Tue 8/24/10
46	Resource Management	0%	153 days	Mon 1/25/10	Tue 8/24/10

Figure 8. Preliminary Schedule

2. Resources

The initial list of resources expected to be utilized during the project effort are currently available to the team and are enumerated below:

a) Sakai Internet Repository and Workspace

b) Dudley Knox Library

c) NPS Virtual Private Network for access to ExtendSIM

d) Microsoft Office Suite (Word, Excel, Powerpoint, Access, Project)

3. Literature References

[1] Mitchell, "Navy Energy Initiatives," MORS Energy Meeting, December 2009

[2] Mabus, "Naval Energy, A Strategic Approach," SECNAV, October 2009

[3] Cusanelli & Karafiath, "U.S. Navy Surface Ship Fleet: Propulsion Energy Evaluation, and Identification of Cost Effective Energy Enhancements Devices," NSWC, Division Carderock, December 2006

[4] Lovins, "Energy Efficiency Survey Aboard USS PRINCETON CG-59," Rocky Mountain Institute, © June 2001

[5] Blanchard & Fabrycky, <u>Systems Engineering and Analysis</u>, 4ed, Pearson, ©2006

[6] Giammarco, "Data Centric Integration and Analysis of Information Technology Architectures," Master's Thesis, Naval Postgraduate School, September 2007

[7] "Capstone Project Guide for DL Programs," Department of Systems Engineering, Naval Postgraduate School, March 2006

APPENDIX B. RISK MANAGEMENT PLAN

Change Record		
Revision	Revision Date	Revision or Change Description
1.00	29 January, 2010	Baseline Plan developed

LIN	Plan Element	Description
1.0	**General**	
1.1	Purpose	Captured all Risks Related to Project
1.3	Roles and Responsibilities	a. The Risk Manager is responsible for oversight of the project risk management function. b. Technical Risk Lead: Accountable for risk management in the technical area. c. IPT Members: Serve as Risk Owners as designated by the PM or Risk Manager. The Risk Owner is responsible for performing duties. d. Facilitator: Risk Manager, for the Risk Identification and Risk Assessment processes. e. Recorder: Risk Manager or IPT Lead
1.4	Tools and Techniques	A Risk Register will be developed and maintained as designated by the Risk Manager.
2.0	**Risk Identification**	
2.1	Process	Risk Owners will be defined as part of the Risk Identification process and annotated in the Risk Register.
2.2	Tools	Per paragraph 1.4 and use FMEA as directed.
2.3	Risk Categories	Programmatic and Technical
2.4	Risk Statement	The impact or effect of the risk on the project will be annotated in the Risk Register in a separate column as a C for Cost, S for Schedule or P for Performance for the primary driver of the risk. A combination of these will be annotated for risks with two primary and equal project impacts or effects.
3.0	**Risk Assessment**	
3.2	Risk Probability-Impact Matrix (RiskPIM)	Use the standard: 5x5 matrix. A summary Risk will be developed for each sub-category level
3.2.1	Risk Probability of Occurrence (P)	The Probability of Occurrence scale for the Risk PIM will be defined as: 1 – Very Low ($P \leq 14\%$) 2 – Low ($15\% \leq P \leq 39\%$) 3 – Likely ($40\% \leq P \leq 60\%$) 4 – High ($61\% \leq P \leq 75\%$) 5 – Very High ($76\% \leq P \leq 85\%$)

3.2.2	Risk Impact (I)	The Impact scale for the RiskPIM will be defined as: a. COST (C): 1 – Minimal or No Impact (I<5% budget) 2 – Marginal (5%≤I<10% budget) 3 – Moderate (10%≤I<15% budget) 4 – Major (15%≤I<20% budget) 5 – Unacceptable (I>20% budget) b. SCHEDULE (S): 1 – Minimal or No Impact (Able to meet key milestones with minor schedule slip ≤ 2 weeks.) 2 – Minor (Able to meet key milestones with slip in schedule activities resulting in ≤ 1 month slip.) 3 – Moderate (Slip in milestones or key dates and schedule activities resulting in ≤ 1.5 month slip; can still meet customer delivery requirements with re-planning.) 4 – Major (A significant slip in milestones or key dates, schedule activities and delivery schedule impacting the critical path resulting in ≤ 2.0 month slip; may not be able to meet customer delivery requirements without significant re-planning and resourcing, and requires leadership in and/or customer intervention.) 5 – Unacceptable (Cannot meet milestones or key dates, schedule activities and delivery schedule resulting in a slip > 2.5 months; requires leadership and/or customer intervention) c. PERFORMANCE (P): 1 – Minimal or No Impact (No or minimal consequence to technical performance or meeting technical requirements) 2 – Minor (A tolerable, minor reduction in technical or logistics/sustainment performance or achieving the performance requirements) 3 – Moderate (A moderate reduction in technical performance or logistics/sustainment with limited impact on achieving project objectives and/or requirements) 4 – Major (A significant degradation in technical performance or a major shortfall in logistics/sustainment performance or requirements that may jeopardize project success) 5 – Unacceptable (A severe degradation in technical or logistics/sustainment performance; and/or cannot meet key technical and/or logistics/sustainment performance measures or thresholds that will jeopardize project success)

		d. COMBINATION. If there is more than one assessment driver or impact to the project, the impact assessed will be the greater assessed impact on the project of the two impacts (C/S, C/P, or S/P), or as otherwise decided by the APO and/or the team.
3.2.3	Risk Score	Determined by multiplying P by I. Standard rounding practices will apply. Technique: (a) In an IPT or larger group as designated by the APO, a facilitator will solicit a P and I for each risk from each team member designated to score a risk; (b) all scores will be summed and averaged and rounded (no scores will be eliminated); (c) a sensitivity analysis will be performed on any scores for P and I rated a 1 or 5 with a re-assessment on all scores for a specific risk (sum and average). The recorder will document all voting for each risk; determine the sum of all votes for a risk and average the vote to yield a score for P and I; and determine the risk score. The raw, unrounded score for P or I for each risk will be saved.
3.2.4	Risk Zones	The Risk Zone of the risk will correspond to the Risk Score. Use per the standard RiskPIM: High is 15-25 and is RED; Medium is 5-12 and is YELLOW; and Low is 1-4 and is GREEN.
3.3	Risk Rank	Each risk will be ranked (1 through n) at the project level and at the risk category level, or as designated by the PM. Any risks with equal scores will be ranked by multiplying the raw scores and comparing to determine the higher rated risk.
3.4	Top Risks	For reporting purposes, the top risks will be any risk rated HIGH-RED with a risk score of 15-25, or as defined by the PM. Priority of effort is HIGH risks.
3.5	Watch List	Any risk rated LOW-GREEN with a risk score of 1-4.
4.0	**Risk Response Planning**	
4.1	Process	Refer to Risk Manager
4.2	Risk Mitigation Strategy	A mitigation strategy will be defined for each risk: avoid, transfer, mitigate or accept.
4.3	Contingency Plans and Trigger	The contingency plan and trigger will be developed for each risk by the designated Risk Owner and approved by the PM. These will be recorded within, or attached to, the Risk Register.
4.5	Triggers	As captured in Risk Register
5.0	**Risk Monitoring & Control**	
5.1	Process	Risk Manager

5.2	Meetings and Reviews	During Capstone Meetings and Status Reporting to the Project Management Plan. Risk Register data will be stored in Sakai and a Summary will be included as part of the Project Management Plan.
5.3	Reporting Tools	Risk Register and 5X5 Matrix
5.4	Plan Implementation	The PM reserves the explicit authority to approve implementation of any risk plan. In the event the PM is not available, the Risk Manager is delegated the authority to approve implementation of a risk plan. In all cases the IPT Lead responsible for the risk will provide advice and supervise plan implementation.

APPENDIX C. SYSTEMS ENGINEERING MANAGEMENT PLAN

NAVAL
POSTGRADUATE
SCHOOL

MONTEREY, CALIFORNIA

A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships

(Systems Engineering Management Plan)

by

Systems Engineering Analysis Cohort 311-912

February 2010

1. INTRODUCTION

This document, the Systems Engineering Management Plan (SEMP), serves as the blueprint for the conduct, management and control of the technical aspects of the Naval Postgraduate School's (NPS) Systems Engineering Analysis Cohort 311-912 Capstone Research Project, *A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships*. The SEMP captures technical program planning, implementation and control, the systems engineering process and integration with overall project management to be conducted by the team in fulfillment of the requirements of the NPS Masters of Science in Systems Engineering degree. The capstone project covers the final three quarters of the MSSE program beginning in January 2010 and completing in September 2010.

1.1. Project Description and Applicable Documents

The Department of the Navy (DoN) energy topic capstone project will provide the U.S Navy with a study of improved energy efficient technologies and conservative operational practices targeted for usage on the DDG-51 class surface combatants and a concept of operations (CONOPS) for recommendations that can be implemented in support of the DoN energy surety, economy, and ecology goals for 2020. The project will employ a systems engineering process aimed at an analysis which focuses on the energy economy aspect of the DoN Energy goals, while maintaining the interdependence among surety and ecology for any given domain solution.

In addition to the application of a sound systems engineering process, other objectives for this project include: formulate alternative solutions; develop scoring criteria, analyze and rank elected solutions, and develop achievable recommendations; manage project risks; prepare and maintain a Project Management Plan (PMP) including a schedule of tasks and deliverables; meet scheduled objectives as indicated in the project schedule, as provided Figure 3-1.

This project will consider providing recommended modifications to an existing DDG-51 Operational Requirements Document (ORD).

1.1.1. Applicable Documents

[1] Mitchell, "Navy Energy Initiatives," MORS Energy Meeting, December 2009

[2] Mabus, "Naval Energy, A Strategic Approach," SECNAV, October 2009

[3] Cusanelli & Karafiath, "U.S. Navy Surface Ship Fleet: Propulsion Energy Evaluation, and Identification of Cost Effective Energy Enhancements Devices," NSWC, Division Carderock, December 2006

[4] Lovins, "Energy Efficiency Survey Aboard USS Princeton CG-59," Rocky Mountain Institute, © June 2001

[5] Blanchard & Fabrycky, Systems Engineering and Analysis, 4ed, Pearson, ©2006

[6] Giammarco, "Data Centric Integration and Analysis of Information Technology Architectures," Master's Thesis, Naval Postgraduate School, September 2007

[7] "Capstone Project Guide for DL Programs," Department of Systems Engineering, Naval Postgraduate School, March 2006

[8] Operational Requirements Document, Unclassified, - To Be Determined (TBD)

1.2. Current Project Status

Cohort 311-912 has elected to apply a tailored version of the Army Systems Engineering Office (ASEO) analysis process model to implement the technical approach of the project. The process model technical approach entails analysis approach, evaluation criteria and techniques, source data collection, alternative development, evaluation of alternatives, and the analysis results process steps. The following systems engineering management and project activities associated with the analysis approach task have been completed:

- Official schedule of project tasks and milestones
- Initial submittal and approval of the capstone Project Management Plan (PMP)
- Defined organizational structure
- Preliminary plan for addressing and managing project risks
- Initial stakeholder identification
- Initial stakeholder survey development

At the time of this document submittal, the evaluation criteria and techniques phase and source data collection phase are being executed.

1.3. Approach for SEMP Updates

The SEMP serves as a second tier document to the capstone PMP and will be updated, as required.

2. PROJECT REQUIREMENTS

Capabilities, requirements, and a concept of operations for the DDG-51 already exist as part of the program document suite maintained by PEO-SHIPS. This capstone effort seeks to modify these three aspects of the program to reduce fuel consumption with a minimal impact to existing capabilities. There is a constraint that the project remain at the UNCLASSIFIED level for all intermediate and final products generated.

The tentative Key Performance Parameters (KPPs) are enumerated in Table 2-1 below. They assume a constant volume and weight on any changes to baseline. Note that overall system availability, reliability, and effectiveness are relative delta measurements in order to assess any degradation or improvement to capability as a predicted result of implementing any fuel economy option. These KPPs will be evaluated against cost (fully burdened cost in $/lbm of fuel) as an independent variable.

KPP	**Units**
Fuel Economy	lbm/min
Fuel Ecology	liters of carbon exhaust gas/lbm of fuel consumed
Fuel Surety	days between refueling
Implementation Cost per Ship	$
Training Time per Sailor	hr
Availability	%
Reliability	%
Effectiveness	%

Table 2-1. Tentative Key Performance Parameters

The students of the 311-912 Cohort will be responsible for executing all the process steps in the ASEO which is given in section C of reference [1], but is reprinted for convenience in Figure 2-1 below.

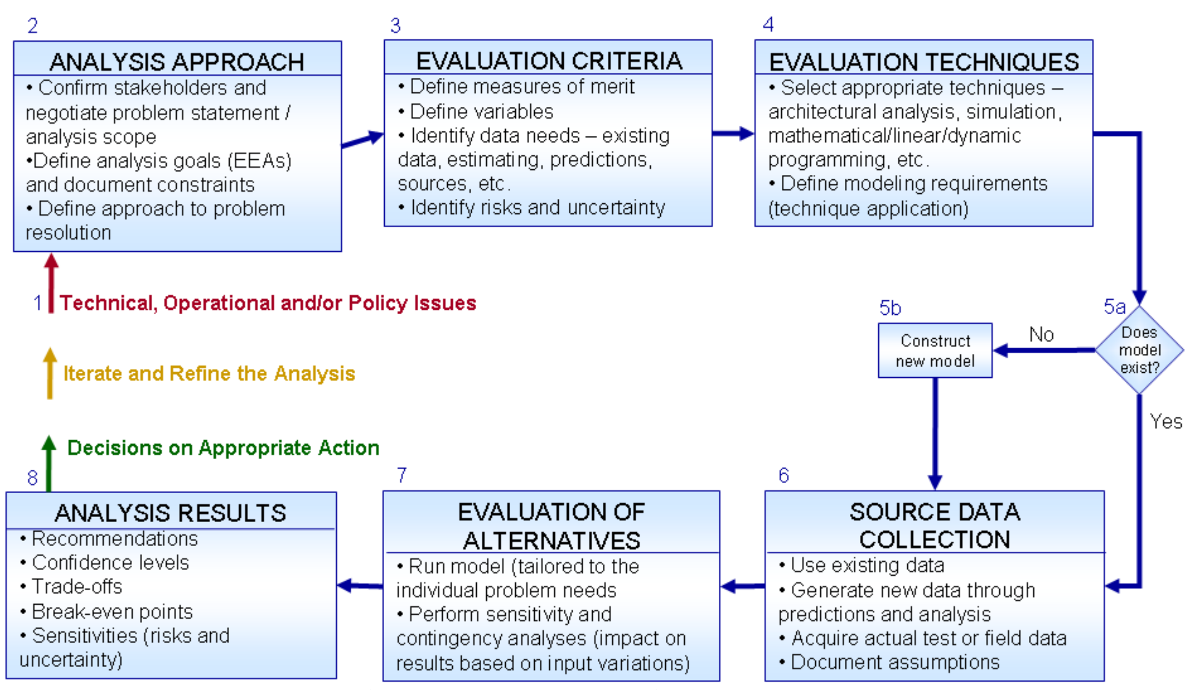


Figure 2-1. ASEO Analysis Process

The tentative KPPs will be refined through stakeholder surveys and interviews during the definition of measures of merit as a sub-task of evaluation criteria. Lower level design parameters that map to the KPPs in a House of Quality (HOQ) Quality Function Deployment (QFD-1) will also be defined at this time (see the example of Figure 2-2).

Customer Requirement (Whats)	Weight	Design Characteristic (Hows): Crew Size	Vehicle Top Speed	SONAR Range	RADAR Range	ESM Range	HVAC	Lighting	Life Cycle Cost (LCC)	Operational Availability (Ao)	Mission Reliability (DRM)
			ounces	km	km	km	BTUs	lumens	$		
Fuel Consumption	0.080	9	9	3	3	3	3	3			3
Fuel Ecology	0.080	3	3								
Fuel Cost	0.160	3	3	3	3	3	3	3	9		
Training Time	0.160									3	3
Availability	0.160			3	3	3				9	
Reliability	0.160			3	3	3	3	3			9
Effectiveness	0.200	3	9	3	9	3				3	3
Check Sum	1.000										
Goal Value											
Threshold Value											
Weighted Performance		2.0	3.2	2.3	3.5	2.3	1.2	1.2	1.4	2.5	2.8
Percent Performance		0.091	0.144	0.102	0.155	0.102	0.053	0.053	0.064	0.112	0.123

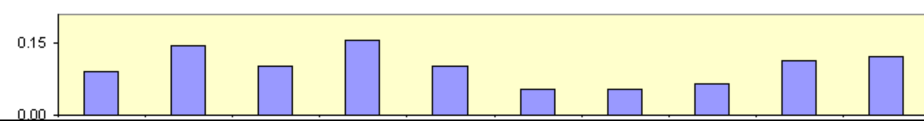


Figure 2-2. Example HOQ QFD-1 Matrix

Existing data will be collected and where required, unavailable data may be estimated through modeling and simulation. Sensitivity analysis will be conducted on the parameters. An Overall Measure of Effectiveness (OMOE) will be calculated for each option and normalized to a range of 0 (threshold) to 1 (goal) within the trade space on each KPP, then plotted against a normalized cost. The Pareto boundary of this analysis will be identified using the L2 Norm method (shortest distance from the goal; see the example of Figure 2-3).

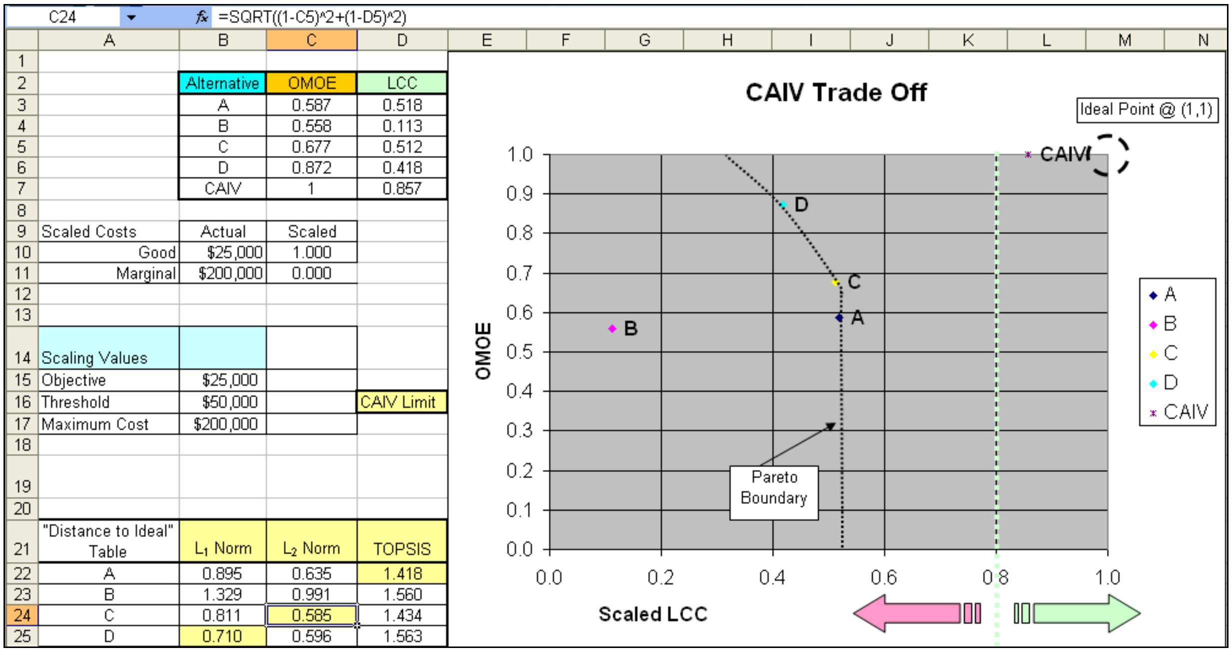


Figure 2-3. Example of Cost as an Independent Variable versus OMOE

Uncertainty and sensitivity analysis will be performed on our analysis of alternatives. The specific method is TBD. It will be used to test the quality of our assumptions and reveal and identify the critical variables for further research. Figure 2-4 is an example of a Tornado Plot though other sensitivity plots may be used.

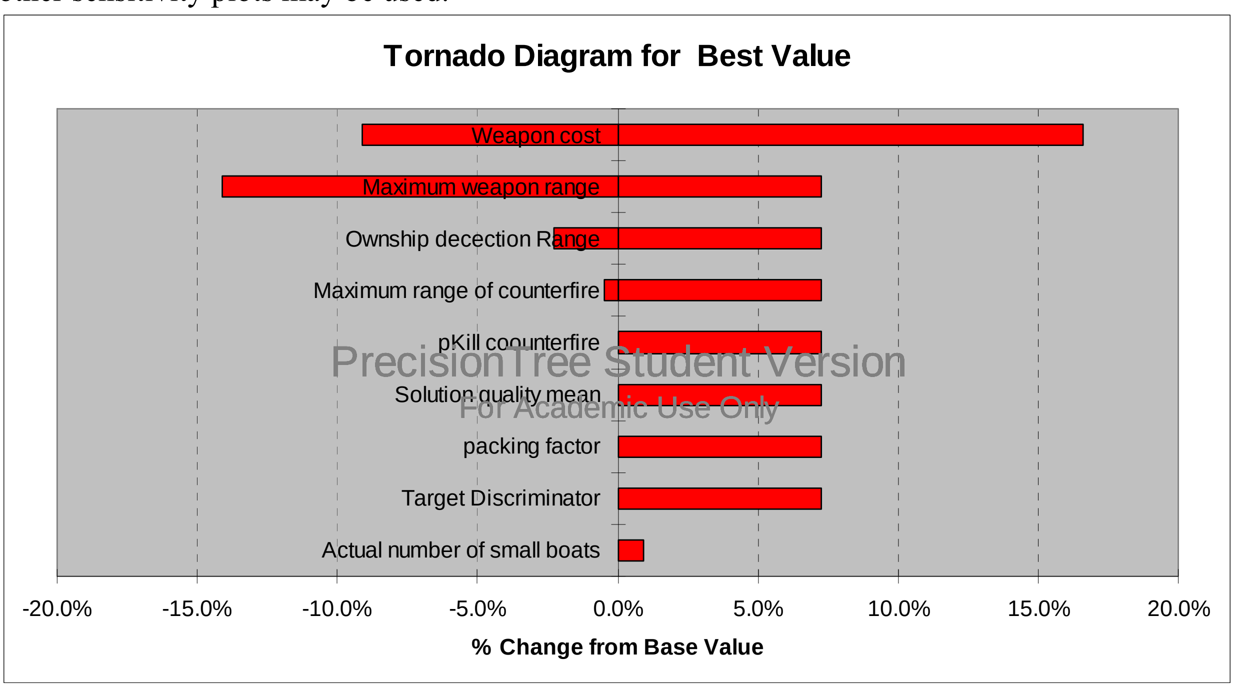


Figure 2-4. Example of Sensitivity Plot

This research will be self-limited and further limited based upon responses from stakeholder and subject matter expert surveys and discussions. The limiting aspects will take the form of hard and soft constraints during the analysis. Some of the specific limitations are: material solution options must have at least achieved Technology Readiness Level 4; solutions will not change the ship's volume; ship's weight will be close to unchanged; total operating costs will be close to or less than our baseline; and tactical capability will be close to unchanged.

3. TECHNICAL STAFFING AND ORGANIZATIONAL PLANNING

This section delineates how the capstone effort will be integrated organizationally to accommodate the assigned technical roles and engineering responsibilities commensurate with the requirements of the project. Primary and secondary responsibilities of team members are given in Table 3-1.

3.1 Team Roles and Responsibilities

Function	Primary Personnel	Secondary Personnel
Chief Program Executive	Joe Cannon	David Toth
Risk Manager	Deepak Kumar	Gloria Huapaya
Chief Systems Engineer	William Jones	Vesmiene Ceasor
Technology Systems Engineer	Fernando Escobar	DavidToth/ Shirlean Todd
HSI Engineer	Eric Lavetti	Deepak Kumar
Technology Cost Analyst	Steven Lucero	William Jones
Technology Risk Analyst	Gloria Huapaya	Joe Cannon
HSI Cost Analyst	Vincent Picicci	Eric Lavetti
HSI Risk Analyst	Anthony Nguyen	Vincent Picicci
Program Editor/Publisher	Steven Lucero	Fernando Escobar
Program Scheduler	Vesmiene Ceasor	
Program Archive	Shirlean Todd	

Table 3-1. Capstone Team Roles & Responsibilities.

The sub-teams under the Technology Systems Engineer are described in sections 3.4 and 3.5. The team roles and functions listed below are defined in the PMP.

3.1.0 Chief Program Executive
3.1.1 Risk Manager
3.1.2 Chief System Engineer
3.1.3 Technology Systems Engineer

3.1.4 HSI Engineer
3.1.5 Technology Cost Analyst
3.1.6 Technology Risk Analyst
3.1.7 HSI Cost Analyst
3.1.8 HSI Risk Analyst
3.1.9 Program Editor/Publisher
3.1.10 Program Scheduler
3.1.11Program Archiver

3.2 Team Coordination

The program will integrate and coordinate systems engineering activities through adherence to the schedule of planned tasking, tracking the project risk of executing the planned tasking, tracking of action items that don't merit a line in the schedule, and soliciting feedback from the advisory oversight panel to address any programmatic or technical concerns. To ensure good communications, the aforementioned activities will be reviewed with all team members at semi-weekly meetings via Elluminate on Tuesdays and Fridays, with meetings of sub-teams as required by the leaders of those sub-teams. The semi-weekly meetings will be co-facilitated by the chief program executive and the chief systems engineer who will respectively cover a standing agenda to include administrative topics (schedule, risk, actions, publisher notes), research topics (accomplishments and near-term objectives for technology and HSI efforts), a confirmation of new actions, and solicitation of closing comments from all participants. The publisher will be responsible for capturing meeting minutes, including the origination of action items, and posting those on the Sakai resource folder for group access. The Sakai resource folder also serves as the "playground" for sharing research and intermediate deliverables as well as the repository for sharing final drafts for external comment and storing final deliverables. In addition to Elluminate, it is expected that the individual team members will communicate as required via Sakai Messages, Sakai Discussion Forum, email, and/or telephone.

External stakeholders will be invited to complete a survey to help guide the project effort, will be asked to participate in technical reviews (see section 5) at various milestones in the schedule, and will be included in the distribution of the final report. Team communications with external stakeholders will be vetted through the advisory panel in advance of such communications.

3.3. Integration with Contractors and External Organizations

There are five primary classes of external organizations: Student's home organizations, NPS capstone advisors, NPS degree administration, subject matter experts and stakeholders. There are no contractors for this project.

External Organizations	Primary Interface	Communication plan

Student's home organizations	Each Student	Their supervisor's desired frequency
NPS capstone advisors	Chief Engineer or Chief Program Executive	Weekly
NPS degree administration	Chief Program Executive	Quarterly
Subject matter experts	Student Lead per SME	As necessary
Stakeholders	One Student per stakeholder	Every six weeks until AoA is completed

Table 3-2. Capstone Team Interfacing with Dignitaries

3.4 Technology Assessments

A team will conduct technology assessments on baseline and new technologies. This includes determining all the parameters required as input to the models. Some of the expected parameters are: Technology Readiness Level, energy consumption over time curves, peak energy consumption, backup requirements, instant on requirements and risk of transition. The data will be incorporated with the data from the HSI and Cost teams to serve as the initial inputs.

3.5 Analysis

A team including the HSI and technology cost analysts will perform the analysis of the model results including the sensitivity and uncertainty analysis. They will make the recommendation to the Chief Engineer on where to improve the research into concepts of operations, tactics, techniques, and procedures and material solutions to improve the quality of the analysis.

3.6 Schedule

The project schedule is provided as Figure 3-1 below. It will be used to identify the critical path for the project and assess progress as the project matures toward completion.

ID	Task Name	% Work Complete	Duration	Start	Finish	Predecessors
1	**Capstone 311-0912**	**8%**	**174 days**	**Wed 1/13/10**	**Fri 9/10/10**	
2	**Program Milestones and Reviews**	**8%**	**160 days**	**Mon 2/1/10**	**Fri 9/10/10**	
3	**Project Management Plan**	**100%**	**10 days**	**Mon 2/1/10**	**Fri 2/12/10**	
4	Draft PMP Team Review	100%	2 days	Mon 2/1/10	Tue 2/2/10	
5	Draft PMP Due	100%	0 days	Wed 2/3/10	Wed 2/3/10	4
6	Final PMP Team Review	100%	3 days	Mon 2/8/10	Wed 2/10/10	
7	Final PMP Due	100%	0 days	Fri 2/12/10	Fri 2/12/10	
8	**System Engineering Management Plan**	**0%**	**9 days**	**Mon 2/15/10**	**Fri 2/26/10**	
9	Draft SEMP Development	0%	4 days	Mon 2/15/10	Thu 2/18/10	7
10	Draft SEMP Team Review	0%	2 days	Fri 2/19/10	Mon 2/22/10	9
11	Final SEMP Team Review	0%	1 day	Tue 2/23/10	Tue 2/23/10	10
12	Final SEMP Due	0%	0 days	Fri 2/26/10	Fri 2/26/10	
13	**In Process Reviews**	**0%**	**65 days**	**Mon 3/8/10**	**Fri 6/4/10**	
14	**IPR 1**	**0%**	**10 days**	**Mon 3/8/10**	**Fri 3/19/10**	
15	IPR1 Presentation Development	0%	4 days	Mon 3/8/10	Thu 3/11/10	
16	IPR1 Team Review, Refinements, Dry Run	0%	3 days	Fri 3/12/10	Tue 3/16/10	15
17	IPR1	0%	1 day	Fri 3/19/10	Fri 3/19/10	16
18	**IPR 2**	**0%**	**19 days**	**Tue 5/11/10**	**Fri 6/4/10**	
19	IPR2 Presentation Development	0%	3 days	Tue 5/11/10	Thu 5/13/10	
20	IPR2 Team Review, Refinements, Dry Run	0%	3 days	Fri 5/14/10	Tue 5/18/10	19
21	IPR2	0%	1 day	Fri 6/4/10	Fri 6/4/10	20
22	**Risk Management Reviews**	**0%**	**111 days**	**Fri 3/12/10**	**Fri 8/13/10**	
23	RMR 1	0%	1 day	Fri 3/12/10	Fri 3/12/10	
24	RMR 2	0%	1 day	Fri 5/28/10	Fri 5/28/10	
25	RMR 3	0%	1 day	Fri 8/13/10	Fri 8/13/10	
26	**CDD, Final Report & Presentation**	**0%**	**61 days**	**Fri 6/18/10**	**Fri 9/10/10**	
27	CDD Development	0%	15 days	Fri 6/18/10	Thu 7/8/10	43
28	CDD Team Initial Review	0%	3 days	Fri 7/9/10	Tue 7/13/10	27
29	CDD Final Team Review	0%	1 day	Fri 7/16/10	Fri 7/16/10	28
30	Final Report Development	0%	15 days	Mon 7/19/10	Fri 8/6/10	29
31	Final Report Team Initial Review	0%	3 days	Mon 8/9/10	Wed 8/11/10	30
32	Final Report Final Team Review	0%	1 day	Tue 8/17/10	Tue 8/17/10	
33	Final Report & CDD Due	0%	0 days	Fri 8/20/10	Fri 8/20/10	
34	Final Presentation Development	0%	5 days	Mon 8/23/10	Fri 8/27/10	33
35	Final Presentation Team Review, Refinements, Dry Ru	0%	6 days	Mon 8/30/10	Mon 9/6/10	34
36	Final Presentation Due	0%	1 day	Fri 9/10/10	Fri 9/10/10	
37	**Technical**	**0%**	**105 days**	**Mon 1/25/10**	**Thu 6/17/10**	
38	Analysis Approach	0%	25 days	Mon 1/25/10	Thu 2/25/10	46,47
39	Evaluation Criteria & Techniques	0%	15 days	Fri 2/26/10	Thu 3/18/10	38
40	Source Data Collection	0%	20 days	Fri 2/26/10	Thu 3/25/10	38
41	Alternative Development	0%	20 days	Fri 3/26/10	Thu 4/22/10	40
42	Evaluation of Alternatives	0%	20 days	Fri 4/23/10	Thu 5/20/10	41
43	Analysis Results	0%	15 days	Fri 5/21/10	Thu 6/10/10	42
44	Risk Reserve	0%	5 days	Fri 6/11/10	Thu 6/17/10	43
45	**Programmatic**	**0%**	**161 days**	**Wed 1/13/10**	**Tue 8/24/10**	
46	Organizational Structure	0%	3 days	Wed 1/13/10	Fri 1/15/10	
47	Roles & Responsibilities	0%	5 days	Mon 1/18/10	Fri 1/22/10	
48	Initial Schedule	0%	5 days	Mon 1/18/10	Fri 1/22/10	
49	Risk Management	0%	153 days	Mon 1/25/10	Tue 8/24/10	
50	Resource Management	0%	153 days	Mon 1/25/10	Tue 8/24/10	

Figure 3-1. Capstone Project Schedule

4. TECHNOLOGY MATURATION AND PLANNING

Given the research nature of this capstone project, there is no planned maturation of materiel technology solutions that may be evaluated as alternatives. However, recommendations for implementing both material and procedural solutions in the way of a concept of operations is an intended outcome of the project effort.

4.1. Technology Maturation Responsibility

The chief systems engineer is responsible for validating the Technology Readiness Level (TRL) assessed by the technology systems engineers for each alternative solution. The TRL will be considered as a major factor in calculating the risk score for each alternative.

The program manager for the acquisition sponsor that chooses to adopt any of the project recommendations is responsible for assigning a developmental lead/chief systems engineer to maturing the technologies and requirements to the point that they will pass the criteria for entry to production (Milestone C) under the milestone decision authority's decision.

4.2. Technology Maturation and Risk

Technologies of lower TRL have schedule, cost, and performance risk greater than technologies with higher TRL. In our research effort, we will need to define what thresholds for TRL would we allow to be considered in going forward with a particular technology (or solution or alternative) given stakeholder inputs, and also given what timelines we anticipate for fielding these capabilities. We will also need a scoring methodology to translate the TRL for a given alternative to an objective risk score so that alternatives may be ranked by this criteria.

In terms of the DDG-51 Energy Efficiency problem, we know that the at-sea environment poses unique challenges to new technologies and new systems. Example questions to aid in defining the TRL thresholds for Energy Efficiencies AoA for the DDG-51 may include:

- Has the affect of ship motion and weather variables been considered?
- Are batteries and power supplies needed by the sensor system compatible with the ship's power grid?
- Does the alternative system or hull itself use new materials?
- Have these materials been evaluated in terms of energy efficiencies?
- How does the weight of a new hull compare with previous designs?
- If the new hull (or other component) system comes from a commercial application, has it been evaluated for military usage? For a subsystem, has it been to sea on a ship previously?
- For new propulsion systems, does the new system provide an improvement in propulsive efficiency?
- Does the propulsion system cavitate during operation, thus reducing efficiency?
- Will the system or subsystem be adversely affected by the motions and accelerations caused by waves?
- Will the system or subsystem increase the ship's drag in any way?
- Will the system or subsystem have an environmentally unacceptable discharge? (The Ecology Piece?)

For those technologies that have no established TRL, the team will estimate the TRL based on the definitions of Table 4-1 below.

TRL	Definition	Description	Supporting Information
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	Component and/or breadboard validation in a laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5	Component and/or breadboard validation in a relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	Results from testing a laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?

Table 4-1. Technology Readiness Level Definitions

TRL	Definition	Description	Supporting Information
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	OT&E reports.

Table 4-1. Technology Readiness Level Definitions (continued)

5. TECHNICAL REVIEW PLANNING

The program's plan is to establish schedule-driven technical reviews over a nine month period. The technical reviews will be in-progress reviews (IPR) and will be held quarterly throughout the Cohort 311-912 Capstone Research Project. The Chief Program Executive and Chief System Engineer will be responsible for the readiness of the technical reviews, the overall management of the reviews, and will have the responsibility for making the decision to authorize the review. The IPRs will be conducted with all cohort members, academic advisors, technical advisors, and stakeholders. The Program Editor/Publisher will be responsible that all applicable technical documentation for the IPRs are available as read-ahead material to the appropriate stakeholders.

Stakeholder participation in the IPRs will be highly encouraged to address any concerns with the schedule, research, project products, and to ensure objectives are being accomplished and the program is on track. If possible, stakeholder participation will be conducted face to face with the cohort and the academic advisors. The academic advisors will resolve any resource constraints to have stakeholders present at the reviews. The reviews can be conducted via Elluminate if preferred meeting option does not materialize.

6. INTEGRATION WITH OVERALL PROGRAM MANAGEMENT

6.1. Critical Paths

Due to the time constraint of the capstone project, the critical path schedule follows a single, logical path with “Start to Start” and “Start to Finish” dependencies between activities. The path represents the planned, prioritized and timed activities required for successful completion of the capstone project within the designated timeframe. It also represents the path in which none of the planned activities, including any associated sub-tasks have slack time. A delay in the critical path is potential delay in the project.

The critical path for this project is defined to be the technical activities as defined by the project system engineering process Figure 2-1 and Figure 6-1. It provides the following benefits,

- A graphical view of the project
- Identify what tasks must be carried out.
- Shows sequencing and priority of relevant activities and time required to complete
- Shows which activities are critical to maintaining the schedule
- Shows where parallel activity can be performed.

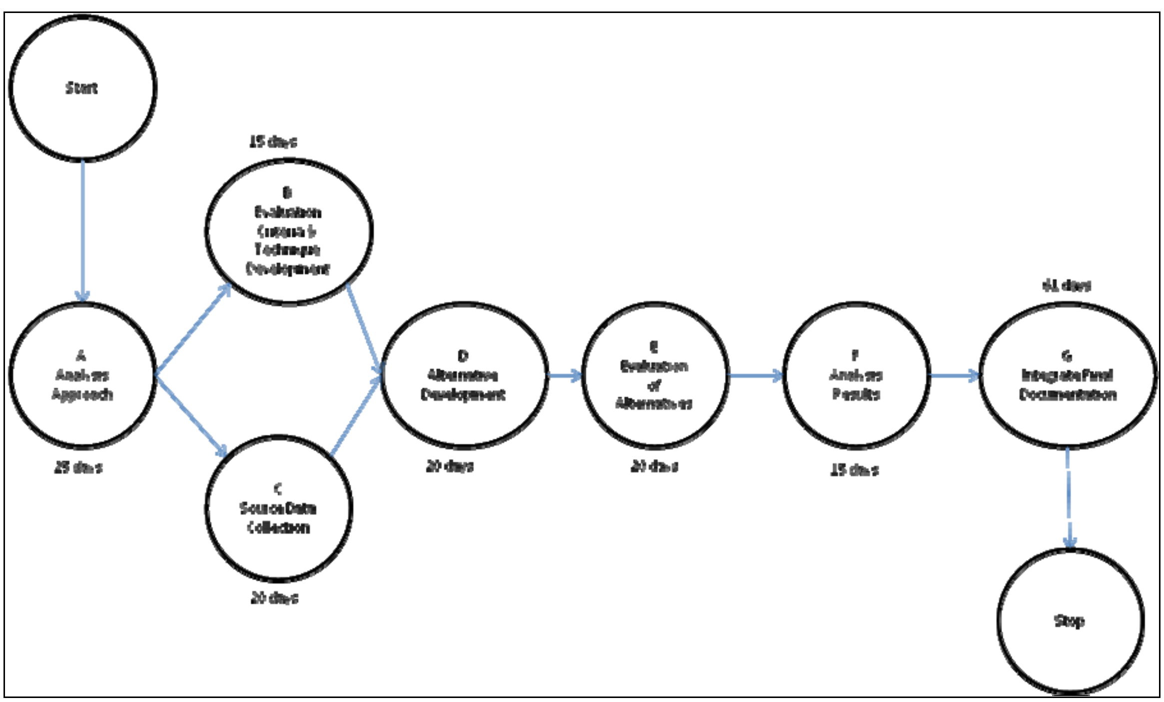


Figure 6-1: Critical Path

The project manager will use the critical path schedule to assess the progress and impacts of activity completions. Based on potential impacts, it will allow the project manager to make decisions about the project, such as conduct more activities in parallel or shorten activity duration time to fast track the project to ensure a successful project completion within the project timeframe.

As shown in the schedule of Figure 3-1, activities B and C represent the only “Start to Start” activities that will be conducted in parallel as there is no dependency between the activities. All other activities are interdependent representing sequential activities that require a prior activity to “Start and Finish” before the next activity is performed. This critical path, as aforementioned contains no slack time and therefore is essential for the project manager to monitor and track closely for effective management of project completion.

The critical path schedule will be continuously monitored and reviewed on a weekly basis to assess any potential impacts in activity development and duration. As the project progresses and should project objectives, goals or requirements change, or a need for project acceleration emerges, impacts will be assessed based on quality and time and the critical path schedule and this plan will be updated accordingly. The critical path schedule risk will be managed per the risk management plan.

6.2 Risk Management Integration

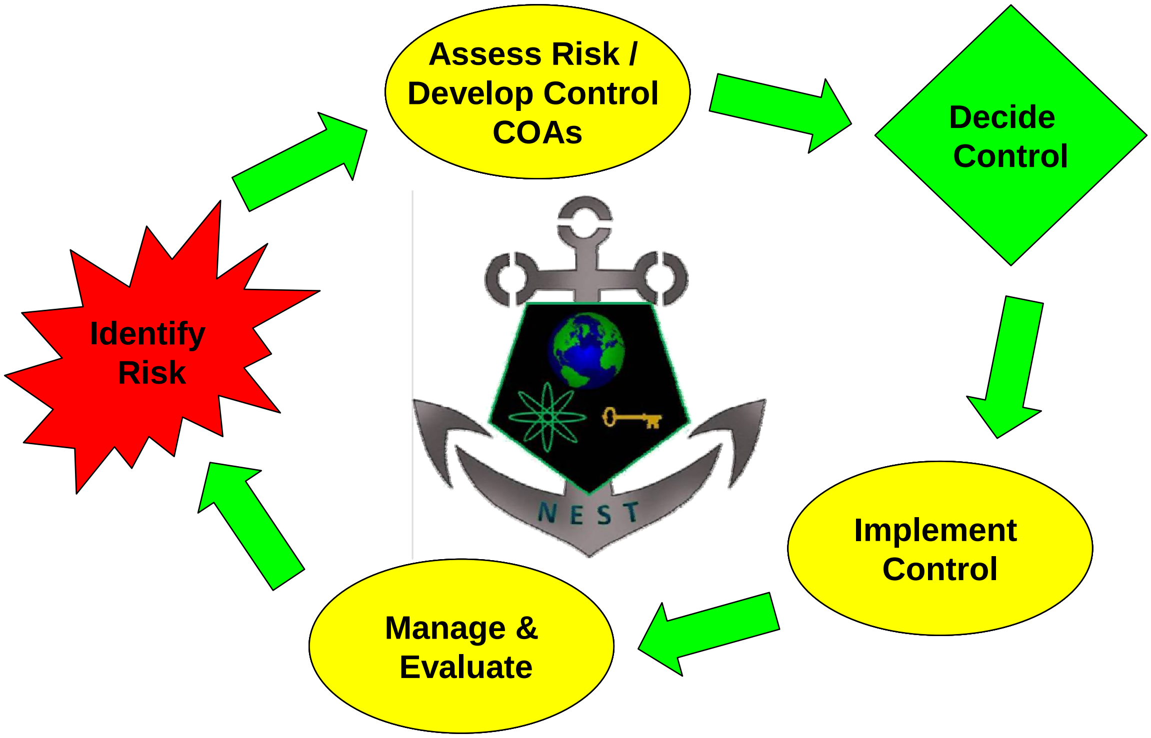


Figure 6-3. Risk Management Cycle

Composite Risk Management (CRM) is the Department of Defense's primary decision making process for identifying hazards and controlling risks across the full spectrum of defense missions, functions, operations, and activities. It is only suitable that this process is used in the decision making and execution of this research effort. CRM will be integrated into this project in two ways; concurrent risk management by the risk management team and risk management reviews prior to each major milestone. The risk management team consists of 4 team members who analyze the programmatic, technical and HSI risks of the effort. The team will initially assess and manage the programmatic and technical risks as they are discovered. This management will occur in parallel to the execution of the research. 5 days prior to every IPR, a Risk Management Review (RMR) will be held. RMR will have a review panel that will be chaired by Program Risk Manager. The Chief System Engineer, the Chief Program Executive and Scheduler will also be members of the review panel. The purpose of the RMR is to validate the risk management efforts of the Risk Management team as well maximize situational awareness of all programmatic, technology and HSI risks prior to the execution of the IPR. This will ensure the most up-to-date risk assessment is available going into the IPR.

6.3 Test and Evaluation

Due to the inability to foresee which technologies and procedures have the most impact, a very generalized approach to testing and evaluation will be described here. With that said, technologies and procedures that show potential for application toward the increase of energy economy of the DDG-51 will be validated through numerical modeling and simulation. If a technology or procedure is numerically shown to have significant impact to the energy economy of the DD51, efforts will be made to empirically validate the impact through test and evaluation.

6.4 Life-Cycle Sustainment Integration

Capitalizing off of the findings during Test and Evaluation, a cradle to grave risk and cost analysis will be conducted to metrically measure the cost and implications of integrating a high payoff technology or procedure for lifecycle integration. Stakeholder input will be critical to this analysis in order to steer the integration research analysis in the correct direction.

7.0 REFERENCES

[1] A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships (Program Management Plan), Naval Postgraduate School, January 2010

APPENDIX D. SURVEYS

A. STAKEHOLDER SURVEY

Subject

Naval Postgraduate School capstone project on Energy Economy for DDG-51 Class Ships

Purpose

There are two purposes for this point paper: Request that a member of your organization act as a stakeholder for this capstone project. Second, that you or your staff completes the enclosed survey to guide the capstone team.

Background

As part of the graduation requirements for a Masters in Systems Engineering from the Naval Postgraduate School, a capstone project is being performed to be completed in September of 2010. This capstone project is titled "A Systems Engineering Analysis of Energy Economy for the DDG-51 Class of U.S. Naval Ships".

The team is being advised by two NPS faculty members: Dr. David Olwell and Prof. Kristin Giammarco from the Systems Engineering Department. The students come from the Naval Warfare Centers, Program Executive Office for Science & Technology (PEO C4I S&T), Air Force Research Laboratory, the US Army at Picatinny Arsenal, US Army Armament Research, Development and Engineering Center, Northrop Grumman Corporation, Defense Manpower Data Center, and active duty US Army.

The purpose of the project is to: Develop a technically feasible, cost effective approach to address and balance the Department of the Navy (DoN) energy surety, economy, and ecology goals focusing on the DDG-51 Class. The capstone team will apply a tailored version of the Army Systems Engineering Office (ASEO) analysis process model to define the problem, establish evaluation criteria and techniques, collect data for alternative solutions, analyze and rank those solutions, and develop conclusions and recommendations. Expected deliverables include formal systems engineering report of the process and results and a briefing presentation of the report.

Discussion

As part of a good system engineering effort, the key organizations that will be impacted for better or worse should be engaged during the solution development. These key organizations are called stakeholders. The capstone project team (or any project team) engages with the stakeholder to better understand the nature of the problem and the expectations in order to adjust and improve the solutions.

Duties of a stakeholder for this capstone project:

1. The stakeholders would be expected to participate in two in-process reviews and one final review. The reviews would be held electronically and would take less than three hours each. Read ahead material would be provided.

2. Complete the survey in enclosure (1)

3. Respond to requests for amplifying information on the survey and during the analysis as it is performed

The invited stakeholders for this project are: Surface Warfare Development Group (SWDG), Surface Type Commander (TYCOM), OPNAV (represented by T&E solutions LLC - David Klinkhamer), Naval Sea Systems Command (NAVSEA), Program Executive Officer for Ships (PEO-SHIPS), Office of Naval Research, and Naval Surface Warfare Center - Carderock .

Request for action

1. Complete the stakeholder survey and return it Mr. David Toth via email at david.toth@Navy.mil or mail to: Naval Undersea Warfare Center, Attn: David Toth, Building 990, Code 01C, Newport RI 02841.

2. Act as or assign a stakeholder to perform the duties described in the discussion section

Point of contacts:

- Dr. David Olwell, dholwell@nps.edu, 831.656.3583
- Prof. Kristin Giammarco, kmgiamma@nps.edu, 831.240.0761
- Mr. David Toth - 401.832.8999, david.toth@Navy.mil

Capstone Stakeholder Survey on Energy Surety

Name:

Organization:

Purpose of Research:		
1	The project description is clear. Comment:	**Please Select from Drop Down**
2	The Capstone's expected would be useful to my organization. Comment:	**Please Select from Drop Down**
33	The project report will be timely for my organization. Comment:	**Please Select from Drop Down**
4	The proposed stakeholder list is complete. Comment: I recommend the following additional Stakeholders:	**Please Select from Drop Down**
Project Relation to My Organization:		
1	The project scope is useful for my organization. Comment:	**Please Select from Drop Down**
2	The project goals are useful for my organization.	**Please Select from Drop Down**

	Comment:	
Information Sought		
1	I can provide "points of contact" for raw data sources. Comment: They are:	**Please select from Drop Down**
2	My organization is interested in specific measures of merit. Comment:	**Please select from Drop Down**
3	I can provide some insight on measures of merit. Comment:	**Please select from Drop Down**
4	I can provide information on energy alternatives explored (accepted). Comment:	**Please select from Drop Down**
5	I can provide information on energy alternatives explored (dismissed). Comment:	**Please select from Drop Down**
6	Non-material data exists that may impact the solution space. Comment:	**Please select from Drop Down**
7	Material data exists that may impact the solution space.	**Please select from Drop Down**

	Comment:	
8	I can provide/recommend data on cost and/or schedule and/or performance and/or risk associated with these alternatives. Comment:	**Please select from Drop Down**
9	I can provide criteria for consideration in evaluating alternatives. Comment:	**Please select from Drop Down**
10	I can provide all useful data as unclassified. Comment:	**Please select from Drop Down**
11	I am aware of related efforts in this energy area. Comment:	**Please select from Drop Down**
12	Barriers exist that preclude me from endorsing this effort/solution. They are:	**Please select from Drop Down**
13	I can recommend other sources (POCs/data). Comment:	**Please select from Drop Down**
14	I am able to make introductions possible to other sources. Comment:	**Please select from Drop Down**
15	I am open to further conversation/meetings as the program progresses. Comment:	**Please select from Drop Down**

16	I am willing to assist in trade-off discussions. Comment:	**Please select from Drop Down**

B. DDG-51 SHIP TOUR DATA COLLECT QUESTIONNAIRE

Naval Post Graduate School
Cohort 311-0912
Capstone Project

"A Systems Engineering Analysis of Energy Economy Options for the DDG-51 Class of U.S. Naval Ships"

DDG-51 Class Ship Survey
NAVFAC San Diego, CA

Purpose

To conduct an unclassified survey of specified shipboard technology within the Heating, Ventilation and Air Conditioning (HVAC) System, Auxiliary Systems, Lighting System and Outfitting and Furnishing, as well as, relating standard operational practices for energy efficiency opportunities in support of the data gathering process step of the capstone project on energy economy options for the DDG-51 Class.

Objective

To collect and assess existing and measured energy consumption data of specified shipboard technology on the DDG-51 Class Ship while in a pier-side loading condition and in cruise condition. The information gathered on the technologies (existing and future) and standard operating practices will be used to develop alternative energy economy options with improved efficiencies and war-fighting capabilities.

Visit Duration

5 days, May 24-28, 2010

Survey Team & Responsibility

1. Ceasor, Vesmiene – Technical (Procedural)
2. Escobar, Fernando – Technical (Technology)
3. Huapaya, Gloria – Risk
4. Lucero, Steve – Human Systems Integration (HSI) & Photography
5. Nguyen, Anthony – Technical (Technology)
6. Toth, David – Technical (Procedural)

Information Gathering Sources

1. Available Information – Logs, manuals
2. Interviews with Key DDG-51 Crew Members & NAVSEA
    a. Ship Chief Engineer
    b. Ship Electrical Plant Manager and/or Energy Officer
    c. Ship Engineers knowledgeable about operating and maintaining equipment
    d. Ship Environmental Engineers
3. Existing Ship Instrumentation
    a. Meters
    b. Gauges
    c. Other
4. Previous Research

Survey Checklists to Complete

1. Energy Survey Checklist – Appendix A
2. HSI Survey – Appendix B
3. Risk Survey – Appendix C

Survey Questions

1. What is the current mission / operational profiles of the ship while at sea in cruise winter condition? Shore winter condition?
    a. What would be considered the biggest energy savings under these conditions?
    b. Geographical operating locations?
    c. Transit Time, speed and distance?
        i. Does the CO have authorization to transit at less than top speed and if so, is that done in practice or typically always run at top speed when in transit?
    d. Cruise condition electric load?
    e. Shore condition electric load?
    f. How do you account for activity aboard ship? (i.e., Duty assignments within 8, 12 or 24 hour shift….etc.)

g. Based on SPAWAR System Center, San Diego DDG-51 manning study, there are 8 ship operational areas; is the current manning profile consistent with that study to date?
    i. If not, what is the current manning profile and how is that number dispersed throughout the ship operational areas?
    ii. What is the component breakdown of each operational area?
    iii. How many personnel are assigned to each component?
    iv. What are their duties/tasks to be performed?
    v. When are they performing their tasks / duties?
    vi. What are the procedural aspects of their duties?
    vii. How long are they performing their tasks/duties?
    viii. What energy sources are necessary / required?
    ix. How much or how long use is required?

h. What is the workload overlap?

2. What is the total fuel usage and cost?
    a. Are fuel consumption curves available?
3. What is the average cost of shipboard delivered fuel?
4. How is fuel usage measured? (methods / instrumentation)
5. Are efficiencies measured, rated or estimated?
6. During what time of the day is energy loading the highest? Why?
7. During what time of the day is energy loading the lowest? Why?
8. What equipment on ship currently draws the largest electrical load?
9. What energy efficiency retrofits has the ship already completed?
    a. Do any include COTS replacements?
    b. Do any include energy star options?
10. What energy efficiency changes/improvements does the ship plan to complete; operational and procedural?
    a. What alternatives are being considered & schedule opportunities?
    b. What are the TRLs for such alternatives?
11. What energy efficiency strategies are currently being practiced aboard ship (ECON, engineering operations sequencing system manual EOSS?
12. Types of questions to ask on the GTGs – typical practices
    a. How many generators are usually running at any given time?
    b. At what capacity are the generators usually running?
    c. At what efficiency are the generators usually running?
    d. Are there safety/survivability issues you're aware of for running fewer generators (but at least one)?
    e. Under what conditions would you consider it safe to run with one generator?
    f. How many hours of maintenance do you spend on a generator besides what is required by the MRCs?

13. For Anchored ships and fuel consumption, what are the minimum loads for stand by only?
14. What is the energy usage while the ship is on shore-based power?
15. What is the granularity of your ability to measure energy usage?
16. How much power is fed to the ship from shore-base generation plants vs. How much power is coming from the ship's own GTGs when in pier-side
    a. Are ship services fully connected to the shore?
    b. What % of power fed to a ship from shore-based plants is petroleum based?
    c. What is the cost of power when connected to shore?
17. How long is a ship typically dock-side vs. at sea? (Scenario)
18. Are there records of emissions measurements?
    a. Types of emissions?
    b. Under what circumstances?
19. What are the "SHED" impacts...or issues...vulnerabilities...costs?
20. When less critical equipment is off what are the estimated savings?
21. From your experience aboard ship, while underway and / or in port what are some energy saving opportunities you think might be beneficial to consider?
22. How do you measure effectiveness?
23. Are there records of the volume or weight of waste generated by the ship and crew?
    a. How do these measurements change over the operating cycle

DDG-51 System Focus

Energy efficiency focus is on the following systems and associated equipment.

SWBS 514 HVAC Systems: SWBS 514

a. Pre-heaters
b. AC Compressor
c. AC Chill Water Pumps

SWBS 500 Auxiliary Systems: Sub-SWBS 521, 533, 541, 593

a. Fireman and Flushing Sea water Systems (Sea Water Services)
    1. Fire Pumps
b. Potable Water
    1. Hot Water Heaters
c. Ship Fuel and Fuel Compensating System
    1. Fuel Transfer Heaters
d. Environmental Pollution Control Systems

SWBS 300 Electric Plant: Sub- SWBS 332

a. Illumination Systems

SWBS 600 Outfitting & Furnishing: Sub-SWBS 651, 655

a. Commissary Spaces (Food Service Spaces)

1. Ovens
2. Dishwasher Heaters

b. Laundry
    1. Dryers

General System Questions

a) What is the purpose of the equipment listed?
b) Which would be considered the biggest energy consumer per existing/measured data?
c) Are there any other areas that are not considered that contribute to a large percentage of energy consumption aboard ship?

System Specific Questions

SWBS 514 HVAC

a) General HVAC system questions
    1. Where is the HVAC plant located on the ship?
    2. What is the HVAC plant configuration?
    3. What codes does HVAC plant follow for plumbing, electric, mechanical, fuel gas– international, Navy?
    4. What are the (fuel) inputs for HVAC plant operations?
    5. What is the plants full capacity Vs actual energy loading?
    6. Does the HVAC system have Variable Volume Variable Temperature Boxes? Are they manual or automatic?
    7. What are the maintenance requirements for the overall plant?
    8. What are the parts inventory requirements for the HVAC plant?
    9. What is the HVAC plant contingency back-up plan in case of battle damage?
    10. What is the stress level of the HVAC operators – are they overworked, underpaid?
    11. How many shutdowns in a year does the HVAC plant go through? When and how long do the shutdowns last?
    12. What type of cooling liquid is used to cool the plant motors?
    13. How much is the vibration and acoustics?
    14. How is the indoor air quality of the current system?
    15. How is the ship compartments insulated? Type of material?
    16. Does the ship apply principles of zoned heating such as thermostats in various compartments; dampers inside the vents?
    17. Does ship have heat pump devices?
    18. Is the ship's exhaust air used to reheat the utility water?

19. Does ships use mix flow impeller fan (25% more efficient) or the traditional centrifugal exhaust fan?
20. How is heat loss prevented?

b) Pre-Heaters

1. What types of pre-heaters are installed aboard ship? Where located?
2. What is the rated efficiency?
3. What is the operating efficiency?
4. What type of energy is used to operate units?
5. What is the measured energy consumption?
6. Are heaters baseline technology or new energy efficiency upgrade?
7. What are the governing standard operating procedures for the equipment?
    a. Are there any deviations from the standards currently being practiced?
    b. What are the manning requirements for standard operation?
    c. Has anyone modified the equipment in any way?
        i. If so, how?
8. How is maintenance addressed?
    a. What energy related resources are required for task performance?
    b. What are the manning requirements for maintenance?
    c. How much energy is consumed?
    d. What additional maintenance is done on equipment besides what is required by MRC's?
    e. What is the reliability and availability of the equipment?
    f. What equipment do you consider redundant?
9. Is accessibility to equipment easy or difficult for repair or replacement?
    a. If so, how often does that equipment need to be accessed for repair or replacement?
10. What units are measurements expressed?

c) AC Compressor

1. What types of compressors are installed aboard ship? Where located?
2. What are the condensing and evaporative temperatures?
3. What type of refrigerant?
4. What is the motor RPM setting? Rated output?
5. Are all settings for the above consistent across the ship or vary?
6. What is the efficiency of the compressors? Partial and Full Load?
7. Can standard set of conditions above be adjusted for optimum efficiency, less use of energy?
8. Are compressors baseline technology or new energy efficiency upgrade?
9. What are the governing standard operating procedures for the equipment?

a. Are there any deviations from the standards currently being practiced?
b. What are the manning requirements for standard operation?
c. Has anyone modified the equipment in any way?
    i. If so, how?

10. How is maintenance addressed?
    a. What energy related resources are required for task performance?
    b. What are the manning requirements for maintenance?
    c. How much energy is consumed?
    d. What additional maintenance is done on equipment besides what is required by MRC's?
    e. What is the reliability and availability of the equipment?
    f. What equipment do you consider redundant?
11. Is accessibility to equipment easy or difficult for repair or replacement?
    a. If so, how often does that equipment need to be accessed for repair or replacement?
12. What units are measurements expressed?

d) AC Chill Water Pumps

1. What types of chill water pumps are installed aboard ship? Where located?
2. What is the rated efficiency?
3. What is the operating efficiency?
4. What type of energy used to operate units?
5. What is the measured energy consumption?
6. Are pumps baseline technology or new energy efficiency upgrade?
7. What are the governing standard operating procedures for the equipment?
    a. Are there any deviations from the standards currently being practiced?
    b. What are the manning requirements for standard operation?
    c. Has anyone modified the equipment in any way?
        i. If so, how?
8. How is maintenance addressed?
    a. What energy related resources are required for task performance?
    b. What are the manning requirements for maintenance?
    c. How much energy is consumed?
    d. What additional maintenance is done on equipment besides what is required by MRC's?
    e. What is the reliability and availability of the equipment?
    f. What equipment do you consider redundant?
9. Is accessibility to equipment easy or difficult for repair or replacement?

a. If so, how often does that equipment need to be accessed for repair or replacement?

10. What units are measurements expressed?

SWBS 500 AUXILIARY

SWBS: 521 - Fireman and Flushing Sea water Systems (Sea Water Services)

a) Fire Pumps

1. What type of fire pumps are installed aboard ship? Where located?
2. How many? Location?
3. How often used?
4. What is the rated efficiency?
5. What is the operating efficiency?
6. What type of energy is used to operate units?
7. What is the measured energy consumption?
8. Are pumps baseline technology or new energy efficiency upgrade?
9. Do you know of any special certifications (e.g., safety?) required for modification or replacement of the fire pumps?
    a. Special training?
10. What are the governing standard operating procedures for the equipment?
    a. Are there any deviations from the standards currently being practiced?
    b. What are the manning requirements for standard operation?
    c. Has anyone modified the equipment in any way?
        i. If so, how?
11. How is maintenance addressed?
    a. What energy related resources are required for task performance?
    b. What are the manning requirements for maintenance?
    c. How much energy is consumed?

d. What additional maintenance is done on equipment besides what is required by MRC's?
e. What is the reliability and availability of the equipment?
f. What equipment do you consider redundant?

12. Is accessibility to equipment easy or difficult for repair or replacement?
    a. If so, how often does that equipment need to be accessed for repair or replacement?
13. What units are measurements expressed?

SWBS: 533 - Potable Water

a) Hot Water Heaters

1. What types of water heaters are install aboard ship? Where located?
2. What is the current operating temperature and is it adjustable?
    a. How is hot water usage by crew governed?
3. Do any conform to the energy star?
4. Are there any retrofit/replacement opportunities underway? If so, what are the alternatives being pursued?
5. What percentage of energy is expected to be reduced by such changes?
6. What percent efficiency is expected to be gained?
7. What type of energy is used to operate units?
8. What is the measured energy consumption?
9. Are heaters baseline technology or new energy efficiency upgrade?
10. What are the governing standard operating procedures for the equipment?
    a. Are there any deviations from the standards currently being practiced?
    b. What are the manning requirements for standard operation?
    c. Has anyone modified the equipment in any way?
        i. If so, how?
11. How is maintenance addressed?
    a. What energy related resources are required for task performance?
    b. What are the manning requirements for maintenance?
    c. How much energy is consumed?
    d. What additional maintenance is done on equipment besides what is required by MRC's?
    e. What is the reliability and availability of the equipment?
    f. What equipment do you consider redundant?
12. Is accessibility to equipment easy or difficult for repair or replacement?
    a. If so, how often does that equipment need to be accessed for repair or replacement?
13. What units are measurements expressed?

SWBS: 541 - Ship Fuel and Fuel Compensating System

a) Fuel Transfer Heaters
    1. What types of heaters are installed aboard ship? Where located?
    2. What is the rated efficiency?
    3. What is the operating efficiency?
    4. What type of energy is used to operate units?
    5. What is the measured energy consumption?
    6. Are heaters baseline technology or new energy efficiency upgrade?
    7. What are the governing standard operating procedures for the equipment?
        a. Are there any deviations from the standards currently being practiced?
        b. What are the manning requirements for standard operation?
        c. Has anyone modified the equipment in any way?
            i. If so, how?
    8. How is maintenance addressed?
        a. What energy related resources are required for task performance?
        b. What are the manning requirements for maintenance?
        c. How much energy is consumed?
        d. What additional maintenance is done on equipment besides what is required by MRC's?
        e. What is the reliability and availability of the equipment?
        f. What equipment do you consider redundant?
    9. Is accessibility to equipment easy or difficult for repair or replacement?
        a. If so, how often does that equipment need to be accessed for repair or replacement?
    10. What units are measurements expressed?

SWBS: 593 - Environmental Pollution Control Systems

1. Is gray water measured? If so, how?
2. Is (weight or volume) of waste material measured? (Paint cans, cardboard, light bulbs, scrap metal...)
3. Under what conditions is material disposed of overboard?
4. Is soot or other pollutants measured? If so, what are they, how measured and under what conditions?
5. Is there a recycling program? What gets recycled? Is there compensation for recycling?
6. Are any of the recycled products used as alternative energy aboard ship? If so, for what applications and under what conditions?
7. For all of the above what are the results?
8. What is the ship hazardous waste process or what are the governing standard operating procedures for the equipment?
    a. Are there any deviations from the standards currently being practiced?

b. What are the manning requirements for standard operation?
c. Has anyone modified the equipment in any way?
    i. If so, how?

9. How is maintenance addressed?
    a. What energy related resources are required for task performance?
    b. What are the manning requirements for maintenance?
    c. How much energy is consumed?
    d. What additional maintenance is done on equipment besides what is required by MRC's?
    e. What is the reliability and availability of the equipment?
    f. What equipment do you consider redundant?
10. Is accessibility to equipment easy or difficult for repair or replacement?
    a. If so, how often does that equipment need to be accessed for repair or replacement?
11. What units are measurements expressed?

SWBS 300 Electric Plant
SWBS 332 – Illumination Systems

1. What type of lighting is currently used aboard ship? Any special types?
2. Which types require frequent maintenance activity? (e.g., frequent failures)
3. Are there any retrofit/replacement opportunities underway for replacing lighting types and/or complete fixtures? If so, what are the alternatives being pursued? (e.g., LED, etc.)
4. What percentage of energy is expected to be reduced by such changes?
5. What percent efficiency is expected to be gained?
6. What are the governing standard operating procedures for the equipment?
    a. Are there any deviations from the standards currently being practiced?
    b. What are the manning requirements for standard operation?
    c. Has anyone modified the equipment in any way?
        i. If so, how?
7. How is maintenance addressed?
    a. What energy related resources are required for task performance?
    b. What are the manning requirements for maintenance?
    c. How much energy is consumed?
    d. What additional maintenance is done on equipment besides what is required by MRC's?
    e. What is the reliability and availability of the equipment?

f. What equipment do you consider redundant?

8. Is accessibility to equipment easy or difficult for repair or replacement?
   a. If so, how often does that equipment need to be accessed for repair or replacement?
9. What units are measurements expressed?

SWBS 600 OUTFITTING & FURNISHING

SWBS: 651 - Commissary Spaces (Food Service Spaces)

a) Ovens
   1. What types of ovens are installed aboard ship?
   2. What are the operational duty cycles? (e.g., 3 days a week or in use several times a day)?
   3. Are there any restrictions on when ovens can be in use or must be secured?
   4. Is there any guidance on minimum temperature set-points?
   5. Are ovens baseline technology or new energy efficiency upgrade?
   6. What are the governing standard operating procedures for the equipment?
      a. Are there any deviations from the standards currently being practiced?
      b. What are the manning requirements for standard operation?
      c. Has anyone modified the equipment in any way?
         i. If so, how?
   7. How is maintenance addressed?
      a. What energy related resources are required for task performance?
      b. What are the manning requirements for maintenance?
      c. How much energy is consumed?
      d. What additional maintenance is done on equipment besides what is required by MRC's?
      e. What is the reliability and availability of the equipment?
      f. What equipment do you consider redundant?
   8. Is accessibility to equipment easy or difficult for repair or replacement?
      a. If so, how often does that equipment need to be accessed for repair or replacement?
   9. What units are measurements expressed?

b) Dishwasher Heaters
    1. What types of heaters are installed?
    2. What are the operational duty cycle (e.g., 3 days a week or in use several times a day)?
    3. Is temperature set-point fixed or controllable by an operator?
    4. Are heaters baseline technology or new energy efficiency upgrade?
    5. What are the governing standard operating procedures for the equipment?
        a. Are there any deviations from the standards currently being practiced?
        b. What are the manning requirements for standard operation?
        c. Has anyone modified the equipment in any way?
            i. If so, how?
    6. How is maintenance addressed?
        a. What energy related resources are required for task performance?
        b. What are the manning requirements for maintenance?
        c. How much energy is consumed?
        d. What additional maintenance is done on equipment besides what is required by MRC's?
        e. What is the reliability and availability of the equipment?
        f. What equipment do you consider redundant?
    7. Is accessibility to equipment easy or difficult for repair or replacement?
        a. If so, how often does that equipment need to be accessed for repair or replacement?
    8. What units are measurements expressed?

SWBS: 655 – Laundry

a) Dryers
    1. What types of dryers are installed aboard ship?
    2. Quantity?
    3. What is the Capacity/Loading?
    4. How often operated? Peak usage?
    5. What are the maintenance schedules for the dryers?
    6. What amount of energy is required for operation?
    7. Are dryer's baseline technology or new energy efficiency upgrade?
    8. What are the governing standard operating procedures for the equipment?
        a. Are there any deviations from the standards currently being practiced?
        b. What are the manning requirements for standard operation?
        c. Has anyone modified the equipment in any way?
            i. If so, how?
    9. How is maintenance addressed?
        a. What energy related resources are required for task performance?

b. What are the manning requirements for maintenance?
c. How much energy is consumed?
d. What additional maintenance is done on equipment besides what is required by MRC's?
e. What is the reliability and availability of the equipment?
f. What equipment do you consider redundant?

10. Is accessibility to equipment easy or difficult for repair or replacement?
    a. If so, how often does that equipment need to be accessed for repair or replacement?
11. What units are measurements expressed?

APPENDIX A
NAVSEA ENCON ENERGY SURVEY CHECKLIST

http://www.navsea.Navy.mil/encon/checklist.htm.

ENERGY SURVEY CHECKLIST FOR IMPROVED FUEL ECONOMY

The purpose of this checklist is to assess whether the ship is following good energy conserving practices.

The energy survey check list below is generally applicable to all types of nonnuclear ships. It can be utilized by ship's command to identify the areas where a ship needs better energy conservation practices which will result in improved fuel economy.

1. Is energy conservation considered?
    a. When planning ship operations?
    b. When reviewing fuel and water consumption?

2. Is an energy efficient plant alignment consciously selected for each day's operations in accordance with the POG?

3. Are fuel consumption and economical speed curves maintained to reflect current performance?

4. Are reasonably current fuel consumption and economical speed curves posted on the bridge, engine room and fire room?

5. Are machinery alignment tables and fuel consumption tables available for development of fuel curve data?

6. Are fuel consumption and economical speed curves used for planning ship's daily operations?

7. Are a minimum number of evaporators operated when water supplies are adequate for mission to meet anticipated periods of peak demand?

8. Is the minimum number of ship service generators operated when the total electrical load is below 90 percent rated capacity of the generators in operation?

9. Is the minimum number of fire pumps used whenever possible? Are MD vice TD fire pumps operated when needed?

10. Is a machinery alignment status board conscientiously maintained?

11. Is permission obtained from EOOW for all equipment status changes?

12. Is EOSS validated, properly maintained, and routinely used?

13. Does ship attempt to operate at or near economical speed as much as possible during independent operations or long transits?

14. Does ship attempt to minimize speed change: whenever possible while maintaining station frequency and magnitude)?

15. Does ship use acceleration/deceleration tables?

16. Are all gauges critical to plant performance properly calibrated?

17. Does ship have personnel trained and certified in gauge calibration?

18. Does ship have an on-condition hull and propeller maintenance program (*e.g.*, when inspection determines need based on significant fouling)?

19. Does engineering department have a valve maintenance program?

20. Is there a program to minimize fresh water usage such as daily announcements for water conservation?

21. Are low flow shower heads installed and in good operating condition?

22. Are faucets in heads spring loaded or metering and in good operating condition?

23. Does ship minimize fresh water leaks throughout ship (e.g., laundry, showers, galley, etc.)?

24. Is there a program to promote electric load reduction?

25. Does ship secure electrical/electronic equipment when not required to meet ship operational requirements?

26. Is minimum number of A/C units operated when conditions permit?

27. Are A/C boundary doors in good condition and identified with posted signs?

28. Are light fixtures clean and well maintained?

29. Are lights turned off in unmanned spaces?

30. Is the insulation of piping in machinery spaces and throughout ship maintained in good condition?

31. Is crew responsive to maintenance requirements and the need to promptly correct deficiencies?

32. Are interdepartmental zone inspections conducted to uncover deficiencies such as leaks, missing insulation, etc., for tagging and corrective action?

33. Does ship adjust liquid load for slight trim by bow prior to getting underway and does engineering department assure maintenance of trim by the bow?

34. Does ship keep speed at a minimum while independent steaming overnight (6 knots or less)?

35. Is fuel and water usage: a. Documented for trend analysis? b. Published in Plan of the Day?

36. Does ship utilize shore services to: a. Minimize in port steaming? b. Minimize use of its distilling plant?

37. Are ship's personnel aware of the importance of energy conservation?

38. Does ship have an Energy Officer recognized as such with his responsibilities designated in writing?

APPENDIX B

HSI SURVEY

1. How often [HVAC] ship crew is trained and where?

2. How many operators required for HVAC operations? Of these how many are standbys?

2. What are the warning systems for oil leak, duct leaks, fire, flooding in main space, unusual vibration and acoustics and loss of chilled water system?

3. Does the crew have signs posted to shut-off lights, heat, A/C for compartments not in use?

4. How many technicians are required to deal with HVAC related emergencies in worst case scenario?

5. Do you cross train the [non-HVAC] crew for HVAC duties?

6. How many [training] drills it require to gain proficiency to meet minimum standards of effectiveness?

7. How close the simulator training is to real environment? Does it provide 3-D graphics, actual noise and vibration encountered in underway operations, series of commands from senior officers for regular operations and emergencies, panic mode scenarios etc?

8. How many yearly injuries or incapacitation occur to HVAC technicians during regular operations? What are their causes?

9. HVAC displays – are they colored touch screen or conventional type?

10. Regular maintenance alerts – automated or chart-paper?

11. Does the chilling plant uses Variable frequency drive (VFD) for chiller or [less reliable] electro-mechanical motor starters?

12. Vibration and acoustics level at HVAC, Chilling plant?

APPENDIX C
RISK SURVEY

The following survey addresses HVAC, Auxiliary, and Lighting Systems, and Outfitting & Furnishing.

1. Which of the below systems presents the most risk to implement new components into in terms of Man Hours needed to replace:

HVAC	Auxiliary	Lighting	Outfitting &Furnishings

Rate the amount of Risk for the selected system above, 5 is for High, 3 is Medium and 1 is Low

5	**3**	**1**

2. Which of the above systems presents the most risk to implement new components into in terms of Design Complexity:

HVAC	Auxiliary	Lighting	Outfitting &Furnishings

Rate the amount of Risk for the selected system above, 5 is for High, 3 is Medium and 1 is Low

5	**3**	**1**

3. Which of the above systems presents the most risk to implement new components into in terms of Availability of Replacements:

HVAC	Auxiliary	Lighting	Outfitting &Furnishings

Rate the amount of Risk for the selected system above, 5 is for High, 3 is Medium and 1 is Low

5	**3**	**1**

4. Which of the above systems presents the most risk to implement new components into in terms of Interoperability with other subsystems/components:

HVAC	Auxiliary	Lighting	Outfitting &Furnishings

Rate the amount of Risk for the selected system above, 5 is for High, 3 is Medium and 1 is Low

5	**3**	**1**

5. Which of the above systems presents the most risk to implement new components into in terms of Enablers:

HVAC	Auxiliary	Lighting	Outfitting &Furnishings

Rate the amount of Risk for the selected system above, 5 is for High, 3 is Medium and 1 is Low

5	**3**	**1**

6. Which of the above systems presents the most risk to implement new components into in terms of down time:

HVAC	Auxiliary	Lighting	Outfitting &Furnishings

Rate the amount of Risk for the selected system above, 5 is for High, 3 is Medium and 1 is Low

5	**3**	**1**

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX E. STUDENT BIOGRAPHIES

JOSEPH PATRICK CANNON

Joseph Patrick Cannon was born and raised in Kalkaska County, Mi. Upon completion of High School Joe Cannon attended Michigan Technological University where he studied Mechanical Engineering and Military Science. Joe Cannon graduated from Michigan Technological University with Cum Laude honors and was commissioned into the U.S. Army Infantry Branch as a Second Lieutenant.

Joseph Cannon attended the Infantry Officers Basic Course and graduated with Commandant Honors. Immediately following the basic course, Joe endured and graduated the U.S. Army Ranger School. Upon completion of Ranger School, Joe Cannon was assigned to the 10MTN Division (LI) where he served 16 months as a light Infantry Platoon Leader and 22 Months as a Weapons Company Executive Officer. Joe Cannon conducted 16 months of combat operations in support of Operation Enduring Freedom VII and VIII, Afghanistan. Upon his return from Afghanistan, Joe served 8 months as the Assistant S3 Operations Officer for 2-87IN 10 MTN (LI). Captain Cannon left Active Duty and accepted a commission in the Michigan Army National Guard. CPT Cannon is currently in command of Alpha Company,1-125 IN, 37th IBCT, MIARNG and is preparing to deploy on his second tour to Operation Enduring Freedom.

In January 2008 Joseph Cannon began working as a federal employee for the U.S. Army Tank Automotive Research Development Engineering Center in Warren, Mi as the Deputy of the MRAP Objective Armor Program. Since then he has worked as a MRAP Expedient Armor Project Engineer and MRAP Expedient Armor Technical Program Manager. Joe is currently leading an armor development effort for extra-large anti-armor threats. Joseph Cannon is the recipient of the George C. Marshall ROTC Leadership Award, Expert Infantry Badge, Combat Infantry Badge and Army Commendation Medal. Joseph Cannon and his team also received the Army's Greatest Invention Award for 2008 for efforts in developing novel armor systems for large threats on the MRAP vehicle. Joseph currently resides in Richmond, Mi where he enjoys hunting, fishing, training and working on his hobby farm.

VESMIENE CEASOR

Vesmiene Ceasor is a native of New Orleans, LA. She earned her high school diploma from Saint Mary's Academy and earned her B.S. in Civil Engineering, with a concentration in Environmental Engineering from Southern University A&M College in Baton Rouge, LA in December 2000. She has received numerous honors, such as awards in academic achievement, graduating in the top 10 of her high school class, receiving the US Army Reserve National Scholar/Athlete Award, making the Dean's list throughout her college career, as well as being recognized as the most outstanding Civil Engineering Student. Other honors include receiving the corporate "Rising Star Award" from Women of Color in Excellence and National Women of Color STEM recognition.

Vesmiene is currently employed with Northrop Grumman Shipbuilding Sector-Gulf Coast (NGSB) in Pascagoula, Mississippi. She is a Systems Engineer IV currently assigned to the DDG-1000 Program Office. Her responsibility includes, but is not limited to performing as NGSB Schedule Integration Lead (SIG) for Government Furnished Equipment (GFE). In this role she is responsible for schedule interdependencies and integration between prime sub-contracting companies and the Navy. She manages NGSB J-16 contract, which is all Government Schedules comprised of Government products and services required to be delivered to NGSB for the successful design and construction of the Zumwalt Class of Ships Superstructure. Vesmiene is also responsible for coordination and facilitation of ship unit readiness reviews (URR) to ensure that all ship composite panels, assembly plans and outfitting material are available before moving forward with construction. She is also responsible for execution and delivery of program Technical Instructions (TI) that are tied to program incentive award fees. Vesmiene's experience also spans to designing and developing auxiliary piping systems for large Deck Amphibious Ships, Environmental, Safety, and Occupational Health (ESOH), design verification and interface management.

Vesmiene resides in Mobile, AL along with her wonderful husband Taurus Ceasor Sr., and her son Taurus Ceasor Jr. She enjoys playing golf, shopping, reading and gathering with friends and family, as well as, spending time alone and attending and participating in church activities.

FERNANDO ESCOBAR

After graduating from college with a BS in Mathematics and an MS in Physics from Utah State University, Mr. Escobar moved to China Lake, CA, where he held a job with the Research Branch at the Naval Air Warfare Center Weapons Division for about 10 years. At China Lake most of his work was in Computational Physics utilizing Supercomputers for electromagnetic energy calculations. Main areas of research included parallelization methods of E&M codes for multiprocessor machines and for massively parallel architectures. He then moved to SPAWAR Systems Center in San Diego and worked mostly developing programs advancing unmanned system technology. In particular, work developed with ONR and DARPA on Intelligent Autonomy, autonomous intelligent networks, and autonomous operations. He now holds a position at the Program Executive Office for Science & Technology (PEO C4I S&T) at SPAWAR Systems Command where he supports the Program Offices in Technology Readiness Assessments (TRA), Rapid Technology Transition (RTT) programs, FNCs and other venues with DARPA & OSD. For his work at the PEO, he was recently the recipient of the Space and Naval Warfare System Center Pacific Award for Exemplary Achievement.

He is an avid reader of political science and philosophy. He's been playing the guitar for about 35 years and is a soccer fanatic. His personal achievements include summiting a couple of 20,000 foot peaks in the Andean Range. He is a family man with 5 children, ranging from 26 to 9 years old. He and his wife love to travel internationally and sample regional wines at every stop.

GLORIA HUAPAYA

Gloria Huapaya was born in Peru, parents and siblings moved to the states back in 1992, like most immigrants looking for a better opportunity than what the old country could provide. She went to High School in Ft Lauderdale Florida and then moved to New Jersey where she met her lovely husband. She decided to pursue Bachelors in Mechanical Engineering from the New Jersey Institute of Technology from which she graduated Magna Cum Laude back in 2003.Her first year after school, she worked as a Tool Die Designer for a small company and then landed a job as a Quality Engineer with the Army Research Development and Engineering Center (ARDEC) in 2004. Her initial years were spent working as the Primer and Small Caliber 5.56mm Lead and then moved on to other calibers within the Ammunition family including 25mm, 30mm and 40mm for both Research Development and Production type Programs.

She was given the opportunity to join the NPS Systems Engineer Master's program brought to her place of work in 2006 with an initial concentration in Reliability.

A new assignment in 2007 allowed her to obtain hands on experience in System Engineering where she worked in matching capability gaps out of theater to ongoing research programs and interacting with the user in identifying and developing requirements to be pursued in the next phase of the acquisition cycle. This assignment gave her a lot of exposure for all types of existing systems and how a systems engineer can be a part of systems acquisition from beginning to end which she found fascinating. She then worked as a Systems Engineer for a program called Ripsaw where she was in charge of finding other feeding opportunities for this system by integrating with other R&D programs where more capability gaps could be met and thus allowing the system to further expand its utility to the Army in terms of Weaponization in theater.

In 2008 she landed her current assignment as the System Engineer Lead for STAR (Scaleable Technologies for Adaptive Response), a highly complex ATO-D program currently at ARDEC in which she has to lead a group of engineers and technical personnel to implement and integrate the latest advances in technology developments for Technology development life cycle phase in areas such as Fuze, Warhead, Power, Propulsion and Energetics; the main objective being to demonstrate a prototype solution TRL-6 that can transition into a Systems Development and Demonstration life cycle DOD phase at the end of the ATO. Demonstrations will be produced for Medium Caliber Ammunition 30mm; Large Artillery 105mm and GMLRS 250mm. This assignment has been the most rewarding career experience she has had thus far.

Gloria is also a mother of 3 children ages 6, 2 and 1, which keep her very occupied during her "free time" and she tries for her family to go and visit as many new places as they possibly can; in addition, she has found out that having a good sense of humor is key to conquer the many challenges that life brings their way.

WILLIAM JONES

Mr. Jones is currently residing in Jamestown, RI. He graduated from high school in Portsmouth, RI in 1981 and completed undergraduate studies in computer science and statistics at the University of Rhode Island (URI) in 1985. His graduation from high school was with national honors and he was admitted to the dean's list of the college of arts and sciences at URI in the first year of study.

He has been employed in various titles at the Naval Undersea Warfare Center, Division Newport since June 1981. Initially he was a part-time summer aid and helped with implementation and verification of a software-driven torpedo trade-off assessment tool for which he earned the first of several Special Achievement Awards. On graduation from URI, Mr. Jones became a full-time computer scientist in the advanced concepts department and later worked on torpedo silencing research vehicles, next generation guidance and propulsion upgrades for the Torpedo Mk 48 Mod 6 (special act award), and the large-diameter advanced test vehicle (letter of appreciation). In 1991 he transferred to the torpedo systems department and became the lead on maintaining the six degree of freedom hydrodynamics trajectory prediction model. In 1997 Mr. Jones served a 6-month rotational assignment as the lead software engineer for the Undersea Weapons Program Office (PMS404) in Washington, DC. Upon returning to Division Newport, he subsequently became the lead developer for the Advanced Capability Post-Launch Trainer development (a computer-based simulation and training tool for Torpedo Mk 48 Mod 6 and Mod 7) and later was assigned as the lead systems engineer for the Torpedo Mk 48 Mod 6 and Mod 7 upgrade efforts (two special act awards). The most three recent awards were all in recognition of exemplary performance during unplanned work efforts (one in 2007 and two in 2008).

Mr. Jones is married with two adult sons living on the west coast. He is interested in computer game design, graphite drawing, and bass guitar. He was also a member of a 4-person rock band called "The Bones" that produced a 9-track CD of original music in 1995.

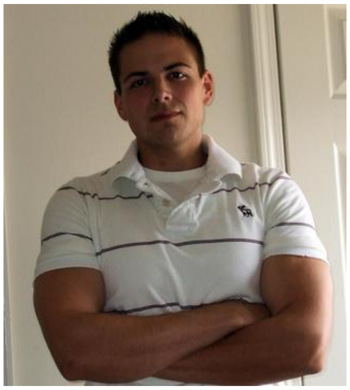
DEEPAK KUMAR

Mr. Deepak Kumar was born and raised in New-Delhi, India. He attended D C Arya Senior Secondary School at Lodhi Colony and completed Diploma in Production Engineering from G B Pant Polytechnic, Okhla, New Delhi in first division with distinction. He migrated to USA in 2002. He attended Farmingdale State University of New York where he obtained BS in Manufacturing Engineering Technology. At farmingdale, he was awarded the outstanding academic excellence award for the highest grade point average. He is pursuing masters degree at NPS California. He has achieved PQM level III and SPRDE Level III certifications for DAU and passed the nationally recognized FE/EIT exam.

Mr. Kumar has worked as machinist and manufacturing engineer in industry. Since June 2006 he is working as Product Quality Manager for Abrams Tanks at Armament Research, Development and Engineering Center at Rock Island, IL. He determines and enforces contract quality clauses, witness and reviews first article tests and the do field inspection of Abrams tanks. He is a member of ABRAMS spare parts configuration control board.

Mr. Kumar is married to his wife Suki and have two sons, Sukhdeep (8) and Jatin (4). He likes to go movies and play with his kids, remodel the house and work with his wife in gardening and planting vegetables.

ERIC LAVETTI



Eric Lavetti was born in Bethesda Maryland in February of 1980. His hometown is Bryantown Maryland, where he spent most of his life. He went to high school in southern Maryland, at The Calverton School, and graduated in 1998. He then attended Shippensburg University of Pennsylvania from 1998 to 2002 receiving a B.S. in criminal justice. He returned from 2004 to 2006 to complete his M.S. in psychology. He currently resides in Ocean Springs Mississippi.

During graduate school, he had a graduate assistantship where he was responsible for managing undergraduate tutors at the campus learning center, as well as assessment of the learning center's programs. After graduation he began working for Northrop Grumman as a human factors engineer, from 2007 until 2008. Eric transferred to systems engineering in 2008 and has been operating as a systems engineer since then. His current tasking mostly revolves around bid and proposal work for the LHA 7. He am also working part time on some ESOH Hazard Action Reports.

Eric's mother and father still reside in Bryantown, and he has one brother, Kurt, who currently lives in Ithica New York. Eric's hobbies include weightlifting, video games, mixed martial arts, movies, and relaxing.

STEPHEN LUCERO

Stephen L. Lucero was born in Albuquerque, New Mexico and has managed to maintain lifelong residence there. He graduated from Albuquerque's Rio Grande High School and attended the University of New Mexico where he obtained a Bachelor of Science Degree in Electrical Engineering.

Mr. Lucero has worked for the Air Force Research Laboratory, Kirtland AFB, NM and its predecessor laboratories for 25 years. Early in his career he studied the effects of High Altitude Nuclear Detonations (HAND) on space-based Assets. In mid-career, Mr. Lucero performed modeling and simulation for satellite nuclear radiation threat assessments. Currently he works on programs in Defensive Counter Space and Space Situational Awareness and has several publications to his credit. In 2007, Steve received the Meritorious Civilian Service Medal for his career contributions to the Air Force. He is a member of the American Institute of Aeronautics and Astronautics (AIAA) as well as the Institute of Electrical and Electronics Engineers (IEEE).

Steve is single but much of his family resides in the greater southwest area of the U.S. In his spare time, Steve enjoys many outdoor activities including cycling, mountain climbing, and landscaping.

ANTHONY NGUYEN

Anthony Nguyen and his family came to the United States as refugees of political discrimination by the Viet Nam communist government. He grows up in Orange County and graduated from Orange High School in 2000. Mr. Nguyen went on to receive his Bachelor of Computer Science from the University of California, Irvine and is currently working at DMDC in Seaside as a software developer. Mr. Nguyen and his team are currently working on the Defense Biometric Identification System (DBIDS). It is a network centric software that integrate many different biometric devices to help enforce physical security for military bases.

Mr. Nguyen likes to play sports and exercise to keep physically and mentally sharp. In his spare time Anthony likes to learn about ways to revert global warming.

VINCENT PICICCI

Vincent (Vinnie) Picicci is originally from Oakdale, New York, a Long Island suburban town about 90 miles from New York City. Vinnie graduated from Connetquot High School. He has a BS in Manufacturing Engineering from Boston University.

Mr. Picicci began his career at Grumman Aircraft Systems Division in Bethpage, New York. As a Manufacturing Engineer he was responsible for estimating engineering change proposals for US Navy contracts concerning manufacturing process and tooling requirements for the E-2C reconnaissance aircraft. From there, Vinnie took a position with the company in Melbourne, Florida, to work on the Joint STARS program as a Process Engineer where he did more producibility work in reviewing aircraft design drawings for manufacturing feasibility and cost effectiveness. Vinnie decided to expand his work experience outside the defense industry and took a job in the Raleigh, North Carolina area, first in the food processing industry, and then in the pharmaceutical industry in Research Triangle Park. There, he worked on more traditional industrial engineering tasks in improving production and packaging line efficiencies by examining such inputs as labor, equipment, line speed, and workflow analysis. After a few years Mr. Picicci decided to take the experience he had acquired in the commercial field and return back to the defense industry, specifically, shipbuilding. Mr. Picicci joined Northrop Grumman Ship Systems in February in 2003 in Pascagoula, Mississippi as an Industrial Engineer. He worked in the Productivity Improvement Department to evaluate, quantify, and develop cost reducing methods and changes pertaining to all aspects of shipyard operations. From there he accepted a promotion to the producibility group as a Production Engineer. His primary task was to evaluate producibility and production concepts in terms of cost and schedule requirements. It was here where Vinnie gained exposure to working with Systems Engineers and developed an appreciation for Systems Engineering and its importance to the acquisition process. These past experiences associated with process development made it a natural transition to pursue Systems Engineering to further his career.

Personally, Vinnie has been happily married for 16 years and has three wonderful children, ages 14, 8, and 7. Most of his personal time involves being a coach in his kids activities in soccer, basketball, and baseball.

SHIRLEAN TODD

Shirlean Todd is a native of Mt. Vernon, Alabama and graduated in the top 10 percent of her Citronelle High School graduating class. While at Citronelle, she was member of the National Honor Society, yearbook staff, JROTC and served as her senior class secretary. Shirlean is a graduate of the University of South Alabama (USA) with Bachelors of Science degrees in Chemistry (1995) and Chemical Engineering (1999). At USA, she became a member of the Delta Sigma Theta Inc. community service sorority and served as the president of the National Society of Black Engineers (NSBE).

Shirlean has been employed with Northrop Grumman Corporation – Shipbuilding Sector since 2000 when the company was Ingalls Shipbuilding. Her initial assignment began in the Marine Technical organization as an Associate Engineer assigned to the Auxiliaries group. Her duties included piping diagram development support for various ship systems; cognizant engineer for nitrogen (LHD & DDG) and freshwater firefighting (DDG) systems and engineering support to the countermeasure wash down nozzle enhancement design special study. A year later, she was promoted to Engineer and transferred to the 2D Detail Design Structures and Corrosion Control group where the next six years of her career was spent performing various corrosion control tasks for LHD, LHAR and DDG ship classes.

In, 2006, Shirlean accepted a position as a Systems Engineer in the Advanced Capabilities Systems Engineering group where she was assigned to the Environmental, Safety and Occupational Health (ESOH) team for the DDG1000 program. Her ESOH responsibilities included leading ESOH activities in design change management and functional system level drawing reviews in addition to supporting other team members in their lead roles. After serving as the ESOH Lead for a period of time, she was assigned to the DDG-1000 program Systems Engineering (SE) Lead role. The DDG-1000 SE Lead task included Systems Engineering Management Tasks at the program level that oversaw Design Verification and Validation and ESOH. In 2009, she was the Systems Engineering Lead assigned to the United States Coast Guard Deepwater National Security Cutter (NSC) program where responsibility entailed the overall development, tracking and completion of a Request for Proposal (RFP) compliance matrix for the NSC 4 proposal effort. Currently, Shirlean is assigned to the LPD Program leading systems engineering tasks in interface verification and quality assurance. In her career at NGC, she received the corporate “Rising Star Award” from Women of Color in Excellence and National Women of Color STEM recognition.

Shirlean is married to her best friend Hal (a recent NPS graduate) and has a beautiful daughter named Halle who is “a Ray of Sunshine”. She is an outgoing, proactive, energetic person that has learned to embrace being challenged. When not working, Shirlean enjoys reading, exercising, attending church and spending time with her family.

DAVID TOTH

A resident of Westport, Ma and a graduate of Virginia Polytechnic Institute with a Bachelor's Degree in Computer Science, Mr. David Toth has over 25 years of experience at the Naval Undersea Warfare Center (NUWC) Division Newport in a variety of systems engineering, research and development, test and evaluation, and management positions.

Mr. Toth is currently the Division Chief Engineer and is responsible for ensuring that Division Newport employs rigorous engineering discipline to create effective Undersea Warfare (USW) products, services, and solutions. The CHENG is the principal advisor for design, development, test and evaluation, and integration activities for USW systems. Previously Mr. Toth has served as the Customer Advocate for Experimentation including Silent Hammer, a sea trial and joint test and evaluation event that demonstrated how a network of forces can conduct a large-scale clandestine operation to fill joint "gaps" in areas including Intelligence, Surveillance, and Reconnaissance, and Time-Sensitive Strike. Mr. Toth also served as Combat Systems Advisor to the Commander, Submarine Force Pacific. During is career, Mr. Toth has earned four Engineering Excellence Awards, one Secretary of the Navy Citation, and numerous Special Act and Superior Performance Awards. He holds a Defense Acquisition Workforce Improvement Act (DAWIA) Level III in Systems Planning, Research, and Development for Systems Engineering.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Ackerman, J., *"What a water cooled HVAC system can do for your building,"* downloaded on 26 July 2010 from http://www.buildings.com/ArticleDetails/tabid/3321/ArticleID/5757/Default.aspx; last updated March 2008.

Aurora,*"Vertical Inline Fire Pump Efficiency Performance,"* downloaded July 14, 2010 from http://www.aurorapump.com/pdf/912/Curve60Hz/1000_5_483_11B_3560.pdf

Beida, G., "*Arleigh Burke Class Destroyer Profile Drawings*," downloaded 22 August 2010 from http://www.usmilitaryart.com/DDG51_07_18349-1200.jpg

Blanchard, B.S., Fabrycky, W.J., "*Systems Engineering and Analysis,"* Prentice Hall, Upper Saddle River, NJ, 2006, 4th Edition.

California Energy Commission, *"Variable-frequency drive"* downloaded 20 July 2010 from http://www.energy.ca.gov/process/pubs/vfds.pdf

Chromolax, "*Mil-Spec Duct Heaters,"* downloaded on 30 August 2010 from http://www.chromalox.com/resource-center/product-data-sheets.aspx.

Cissell, *"50 lb. Sectionalized Shipboard Laundry Dryer Models L36TD30ME, L36TD30MS (NSN: 3H 3510-01-340-9419), (NSN: 3H 3510-01-312-4422), 440V. A.C, 60 cycles, 3 phases,*" Technical Manual #S6162-BS-MMC-010/12489, Alliance Laundry Systems LLC, Rippon, WI, 1 September 1990.

Cissell, "*The CHD 50 lb On Premise Laundry Dryer Product Specification*," downloaded on 1 July 2010 from http://www.luenhingco.com/Cataloge/chd50.pdf.

Cotman, R., "*Fully Burdened Cost of Fuel Calculator v7.1,"* downloaded 7 June 2010 from https://acc.dau.mil/CommunityBrowser.aspx?id=318097&lang=en-US

Crossan, C and Walker, S. *"Naval Facility San Diego Supervisory Control and Data Acquisition System (SCADA),"* Shipboard Resource Efficiency Management, San Diego, CA, 2009.

Crossan, C., *"USS Halsey DDG 97 Ship Study Presentation,"* NAVFAC, San Diego, CA, 24 May 2010.

Cusanelli, D. & Karafiath, G., *"U.S. Navy Surface Ship Fleet: Propulsion Energy Evaluation, and Identification of Cost Effective Energy Enhancements Devices,"* NSWC, Division Carderock, December 2006.

Defense Energy Support Center, *"DESC Standard Price List,"* downloaded 7 June 2010 from https://www.desc.dla.mil/DCM/DCMPage.asp?pageid=722

Defense Industry Daily, "*$32.7M to General Atomics for DDG-51 Propulsion System Prototype*," July 2009, downloaded 20 July 2010 from http://www.defenseindustrydaily.com/327M-to-General-Atomics-for-DDG-51-Propulsion-System-Prototype-05598/.

Department of Defense, "*Instruction 5000.02 Enclosure 7 Resource Estimation,*" Washington, DC, 8 December 2008, downloaded 7 June 2010 from https://acc.dau.mil/CommunityBrowser.aspx?id=332553

Department of Defense, "*Risk Management Guide for DoD Acquisition*," Washington, DC, August 2006, downloaded on 30 August 2010 from http://www.acq.osd.mil/se/docs/2006-RM-Guide-4Aug06-final-version.pdf.

DOD Technology, Inc, "PS-7 fixed, XPS-7 portable and PGD-120 portable Universal Gas Detection Systems", 11 October 2001, downloaded on 3 September 2010 from http://www.dodtec.com/sitebuildercontent/sitebuilderfiles/ps7brochurepricing1011.pdf

EDRO Dyna Corporation, "*EDRO DynaDryer, M50 Product Specification*," downloaded on 1 July 2010 from http://www.edrodynawash.com/PDF_Literature_Files/AHM50PDF.pdf.

Electrolux, "*T3530 Tumble Dryer, 50 lb Capacity Product Specification,*" Electrolux Professional North America, Charlotte, NC, downloaded on 1 July 2010 from http://www.laundrysystems.electrolux.com/Files/Pdf_files2/Ljungby/Brochures/Tumble_Dryers_GB.pdf.

Energy Federation Incorporated, *"Fluorescent Lighting » Standard Base » Spirals: Medium,"* downloaded 7 August 2010 from http://www.energyfederation.org/consumer/default.php/cPath/25_44_784

Fairbanks Natural Gas, "What is a BTU?," downloaded 3 August 2010 from http://www.fngas.com/calculate.html.

Feldman S., "*Biofuels Industry Blames Washington for Holding Back Cellulosic Ethanol,*" 19 July 2010 downloaded on 5 August 2010 from http://solveclimate.com/blog/20100719/biofuels-industry-blames-washington-holding-back-cellulosic-ethanol.

Fikse, T., "*Ship Wide Uninterruptable Power Supply for the DDG-51*," Innovation Inc. et al, downloaded 20 July 2010 from http://www.stephenwmoore.com/SMOORE%20DDG51.pdf, August 2008.

Fisher, D., *"Flashbask Model HFB12 Lightwave oven Product Evaluation,"* downloaded on 1 July 2010 from http://www.fishnick.com/publications/appliancereports/ovens/Hobart_Flashbake_Oven.pdf .

Food Service Technology Center, *"Appliance Technology Assessment Chapter 7 of Publication 5011.02.26 Ovens,"* downloaded on 1 July 2010 from http://www.fishnick.com/equipment/techassessment/7_ovens.pdf.

Gallagher, J., *"Clothes Dryer Green Technology Research*," Navy SBIR 2010.2 – Topic# N102.162, Washington, DC, 8 June 2010, downloaded 1 July 2010 from http://www.dodsbir.net/sitis/archives_display_topic.asp?Bookmark=38760.

General Service Administration, *"Commercial Item Description MIL-A-A59364, Tumble Dryer, Laundry, Steam and Electric (Naval Shipboard),"* Washington, DC, 21 January 1999.

Girbau, "*Pro-series II Tumble Dryers for On-premise Laundries – GU050 Specification*," downloaded on 1 July 2010 from http://www.girbau.co.uk/shopimages/products/extras/Pro_Series_II.pdf.

Global Security, "*DDG 51 Arleigh Burke-class*," 9 Jan 2008, downloaded 20 July 2010 from http://www.globalsecurity.org/military/systems/ship/ddg-51.htm

Goldwasse, S. M., *"Sam's F-Lamp FAQ » Fluorescent Lamps, Ballasts, and Fixtures, Principles of Operation, Circuits, Troubleshooting, Repair » Version 1.90,"* downloaded on 1 July 2010 from http://members.misty.com/don/f-lamp.html.

Hein, R., "Take Action Now to Reduce Fossil Fuel Needs," *Surface Warfare*," Vol. 35 No. 2, 2010, pp. 20-21.

Hubbell, "*Hubbell Shipboard (MSH) Hot Water Heater System Specification Sheet*," downloaded on 1 July 2010 from http://www.Hubbellheaters.com/html/selection%20guide.html.

Hubbell, "*Hubbell Tankless (TX) Hot Water Heater System Specification Sheet*," downloaded on 1 July 2010 from http://www.hubbellheaters.com/html/selection%20guide.html.

Huebsch, "*50 lb On Premise Tumble Dryer Product Specification*," downloaded on 1 July 2010 from http://www.huebsch.com/adv_pdf/ah09-223.pdf. AH09-223.

INDEECO**,** "*Choosing Open Coil or Finned Tubular Design,"* downloaded on 30 August 2010 from http://indeeco.thomasnet.com/item/electric-duct-heaters/standard-duct-heaters-open-coil/pn-4961.

INDEECO**,** "*Electric Heaters for Naval and Marine Applications,"*downloaded on 30 August 2010 from http://indeeco.thomasnet.com/viewitems/vent-duct-heaters/mil-spec-duct-heaters?&pagenum=1&measuresortid=0.

J&R Welding Supply Company. Private telephone conversation with Mr. Andrew Booker, Retired 1st Class, ET1, DDG-41, 3 September 2010.

Johnson, J., private conversation at Jerry's Plumbing Service, Pascagoula, MS, 5 August 2010.

Klipstein, D., *"The Great Internet Light Bulb Book, Part I,"*Upper Darby, PA, 2006, downloaded on 1 July 2010 from http://members.misty.com/don/bulb1.html#hb.

Kreutz, T., Larson, E., Liu, G., Williams. R., *"Fishcher-Tropsch Fuels from Coal and Biomass,"* Princeton Environmental Institute, Princeton, NJ, 2 October 2008, downloaded 5 July 2010 from http://web.mit.edu/mitei/docs/reports/kreutz-fischer-tropsch.pdf.

Lacoma, T., "*Condenser Dryers vs. Vented Dryers,"* downloaded on 1 July 2010 from http://www.ehow.co.uk/about_6497835_condenser-dryers-vs_-vented-dryers.html.

Leverette, M., "*Natural Gas vs. Electric Clothes Dryers*," downloaded on 1 July 2010 from http://laundry.about.com/od/laundryappliances/a/gasclothesdryer.htm.

Lovins, A., *"Energy efficiency survey aboard USS Princeton CG-59,"* Rocky Mountain Institute, Snowmass, CO, June 2001.

Lumaban, R., private email conversation, 4 August, 2010.

Mabus, R., "*Briefing:Naval Energy, A Strategic Approach,"* SECNAV, Washington, DC, October 2009 downloaded on 24 August 2010 from http://www.onr.Navy.mil/Naval-energy-forum/~/media/5EFD428CFEB0412391CC321DCAF67138.ashx

Madison Gas and Electric, *"Lighting Efficiency Comparison,"* Madison, WI, 2010 downloaded on 1 July 2010 from http://www.mge.com/home/appliances/lighting/comparison.htm.

Mahoney, D., Munro, J., Wagner, E., and Lazzari, J. "*Advanced Shipboard Energy Storage System,"* downloaded 7 June 2010 from http://www.Navalengineers.org/SiteCollectionDocuments/2010%20Proceedings%20Documents/EMTS%202010%20Proceedings/Papers/Thursday/EMTS10_2_14.pdf

Martin, T., *"Draft Briefing Materials Task Force Energy POM Submittal FY11,"* Washington, DC, July, 2010 (Unpublished).

Martino, F., *"Energy savings: solid-state reduced voltage starters vs. VFDs,"* downloaded 20 July 2010 from http://www.powerqualityanddrives.com/energy_savings_starters_vfds.

McCoy, K., "*Energy Initiatives Roadmap and Implementation*," Naval Energy Forum, 14 October 2009, downloaded on 30 August 2010 from http://www.onr.Navy.mil/Naval-energy-forum/~/media/B35D17C4AF47484F8FD14DD442CF2561.ashx.

Mitchell, C., *"Navy Energy Initiative,"* MORS Energy Meeting, Reston, VA, December 2009.

National Biodiesel Board, "*Biodiesel,"* 23 July 2009, downloaded on 5 August 2010 from http://ww.biodiesel.org/resources/faqs/.

Naval Sea System Command, *"DDG-52 and Follow-on Ship Subsystem Specification,"* Section 503, Specification 52503 Pumps, Washington, DC, January 1999.

Naval Sea System Command, *"Shipboard Energy Conservation Guide,"* SL101-AA-GYD-010, Washington, DC, 1 April 2009, Downloaded 5 July 2010 from http://i-encon.com/ENCON%20Guide%202010.pdf.

Naval Sea System Command, "*DDG 51 Class Electric Load Analysis,"* NAVSEA Drawing Number 300-7028163, Washington DC, January 2009.

Naval Sea System Command, *"DDG-52 and Follow-on Ship Subsystem Specification,"* Section 541, Specification Fuel Systems, Washington, DC, Revised 30 Nov 2000.

Naval Sea System Command**,** "*General Specifications for Ships of the United States Navy Section 314 Electric Power Supply Conversion Equipment (Surface Ships),"* NAVSEA S9-AAO-AA-SPN-010/GEN-SPEC, Washington, DC, 1986.

Naval Sea System Command, "*MIL-H-22594B, Heaters, Duct Type. Electric, Performance Specification,"* Washington, DC, December 2004.

Naval Sea System Command, "*MIL-STD-2189, Design Methods for Naval Shipboard Systems, Section 310-1, Electric System Load and Power Analysis for Surface Ships Heaters, Duct Type. Electric, Performance Specification*," Washington, DC, January 1988.

Naval Sea System Command, "*MILT-15108C, Transformers, Power, Single-Phase, 60-Hertz, Naval Shipboard Military Specification,"* Washington, DC, August 1955.

Naval Sea System Command, Maintenance Index Page: 6544/001-98, Washington, DC, June 2007.

Naval Sea System Command, *MIL-STD-2189, "Design Methods for Naval Shipboard Systems,"* Section 310-1, Electric System Load and Power Analysis for Surface Ships, Washington, DC, September 2000.

NSWC, *"NAVSEA Philadelphia Code 934 (Electric Power Life Cycle Manager),"* Naval Ship Systems Engineering Station Letter Serial Number 9342/032 of 3 May 2004, Philadelphia, PA, 2010.

O'Rourke, R., "*Navy Ship Propulsion Technologies: Options for Reducing Oil Use,"* downloaded 5 July 2010 from http://www.swonet.Navy.mil/docs/SWMagazine/2010/SW_1sthalf_spring10.pdf. December 11, 2006.

Oak Ridge National Laboratory, *"Bioenergy Conversion Factors,"* downloaded 7 June 2010 from http://bioenergy.ornl.gov/papers/misc/energy_conv.html

Offik, M., Stauble, F., and Turley, R., *"Pump energy savings with VFDs,"* downloaded 20 July 2010 from http://www.plantservices.com/articles/2005/491.html.

OPNAV, *"Maintenance Requirement Cards for Tumble Dryers (6555/005-A8): B9 A2LR N, B7 C2SW N, A8 G2G8 U, A8 G2G7 U, A8 F6XZ N, A8 F6XY N, A8 F6XX N, A8 F6XW N, A5 S87C N, 84 C6US N, 11 C7NJ U, 11 C2WA U, 10 C5NF N,"* Washington, DC, January 1985.

Prachyl, S., *"Variable frequency drives and energy savings,"* downloaded 20 July 2010 from http://www.sea.siemens.com/us/internet-dms/dt/DrivesComm/Drives/Docs/VariableFrequencyDrives_WhitePaper.pdf.

Putnam, D., "*Advanced Power Management for In-Service Combatants*," NAVSEA SBIR Office, Washington, DC, November 2009, downloaded 1 September 2010 from http://www.Navysbir.com/n10_1/N101-055.htm.

REUK.co.uk, "*Gas Tumble Dryers,"* Carmarthenshire, UK, 31 January, 2009, downloaded on 1 July 2010 from http://www.reuk.co.uk/print.php?article=Gas-Tumble-Dryers.htm.

Riches, D., *"About.com Guide,"* downloaded on 1 July 2010 from http://bbq.about.com/cs/infraredgrills/a/aa033101a.htm.

Rishell, J., *"Split Case Fire Pump Efficiency Performance,"* downloaded July 14, 2010 from http://www.systecoreinc.com/files/Horizontal_Split-Case_Centrifugal_Pumps.pdf

Rockwell Automation, *"Energy savings with variable frequency drives,"* downloaded 20 July 2010 from http://literature.rockwellautomation.com/idc/groups/literature/documents/ar/7000-ar002_-en-p.pdf.

Rolls-Royce, *"AG9140 Ship Service Generator,"* downloaded 7 June 2010 from http://www.rolls-royce.com/marine/products/diesels_gas_turbines/gas_turbines/ag9140.jsp.

Royce, R., Allison A., G9140 and AG9140RF. "*Ship Service Generators,*" downloaded 5 July 2010 from http://www.rolls-royce.com/Images/MMS%20FS%2053%2008%201%20Allison%20AG9140%20and%20AG9140RF%20_tcm92-9234.pdf. 2008.

San Diego Gas & Electric, *"Residential Customer Rate Information, Schedule DR,"* San Diego, CA, 10 May 2010 downloaded 30 August 2010 from http://www.sdge.com/documents/customer/totalrates/5-1-2010/schedule_dr.pdf.

Sea Forces, *"US Navy Ships / DDG Arleigh Burke - Class, Seaforces.org Naval Information,"* downloaded 20 July 2010 http://www.seaforces.org/usnships/ddg/Arleigh-Burke-class.htm.

Silva, E., private phone conversation, 30 July, 2010.

Smith, W., private conversation at Smitty's Laundromat – Gas Dryers, 1014 3rd Street, Ferriday, LA, 15 July 2010.

Speed Queen, "*On Premise Single Pocket 50 lb Drying Tumbler Specification*," AO09-203, 2009, downloaded on 1 July 2010 from http://www.speedqueen.com/vend_adv_pdf/ao09-203.pdf.

TurboChef Global Operations, *"C3 Ventless Submittal Information,"* downloaded on 1 July 2010 from http://www.turbochef.com/filemanager/9/C3_Ventless_Submittal_Package.pdf .

U.S. Army Natick Soldier RD&E Center, *"Blodgett Double Stack Combi-Oven,"* downloaded on 1 July 2010 from http://nsrdec.natick.army.mil/media/fact/.

United States Navy, *"Navy and Enlisted Pay, "* downloaded on 5 August 2010 from http://www.Navy.com/Navy/joining/benefits/pay.html.

US Department of Energy, "*E85 emissions*," 8 September 2009, downloaded 5 July 2010 from http://www.afdc.energy.gov/afdc/vehicles/emissions_e85.html.

WATTCO**, "***Duct Heaters/Air Heaters,"* downloaded on 30 August 2010 from http://www.wattco.com/pdf/Duct_Heaters.pdf.

Williamson, R., private conversation at NAVFAC, San Diego, CA, 24 May 2010.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   8725 John J. Kingman Rd. Suite 0944
   Ft. Belvoir, VA 22060-6218

2. Dudley Knox Library
   Naval Postgraduate School,
   411 Dyer Road
   Monterey, CA 93943

3. John Fischer,
   Task Force Energy, OSD
   1400 Defense Pentagon
   Washington, DC, 20301-1400

4. Captain Ricky Williamson
   USN Commanding Officer, Naval Base San Diego
   3455 Senn Rd, San Diego, CA, 92136,

5. Captain Clayton Mitchell
   Naval Facilities Command HQ
   USN 1322 Patterson Avenue SE, Suite 1000
   Washington, DC, 20374-5065

6. Rear Admiral Philip Cullom, USN OPNAV N45
   Building Presidential Top Floor 6
   Arlington, VA, 22202

7. Commander Vincent Garcia
   USN Executive Officer, Naval Base San Diego
   3455 Senn Rd, San Diego, CA, 92136

8. Commander Mathew (Jordy) Harrison
   Commanding Officer, USS HALSEY DDG 97
   3455 Senn Rd, San Diego, CA, 92136

9. Lieutenant Bryan Schneider
   USN Engineering Officer, USS HALSEY DDG 97
   3455 Senn Rd, San Diego, CA, 92136

10. Richard Griggel
    Carderock Division, Naval Surface Warfare Center,
    9500 MacArthur Blvd.,

West Bethesda, MD 20817-5700

11. Dave Gilbert
Surface Warfare Development Group
Naval Amphibious Base Little Creek
Virginia Beach, Va, 23450

12. Fred Tsao
Technical Warrant Holder DDG, NAVSEA 05
1333 Isaac Hull Avenue
Washington Navy Yard, DC 20376-1080

13. Thomas W. Martin
Navy Task Force Energy Surface Ships, NAVSEA 05
1333 Isaac Hull Avenue
Washington Navy Yard, DC 20376-1080

14. Scott Littlefield
Chief Technology Officer
Carderock Division, Naval Surface Warfare Center,
9500 MacArthur Blvd.,
West Bethesda, MD 20817-5700

15. Rich Carlin
Office of Naval Research, Division 333
875 N. Randolph Street, Ste. 1425
Arlington, Va. 22203

16. John Pazik
Office of Naval Research, Division 331
875 N. Randolph Street, Ste. 1425
Arlington, Va. 22203