NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

DETERMINING THE COST AND REDUCTION OF RISK TO FORCE THRESHOLD FOR TRANSITIONING SMALL FORWARD OPERATING BASE POWER GENERATION TO ADVANCED SYSTEMS

by

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December 2020

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

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** December 2020	**3. REPORT TYPE AND DATES COVERED** Master’s thesis

4. TITLE AND SUBTITLE DETERMINING THE COST AND REDUCTION OF RISK TO FORCE THRESHOLD FOR TRANSITIONING SMALL FORWARD OPERATING BASE POWER GENERATION TO ADVANCED SYSTEMS	**5. FUNDING NUMBERS** R8NU8; R8NU8
6. AUTHOR(S) Jason R. Morlan	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research, Arlington, VA 22203-1995; Office of Naval Research Arlington, VA 22203-1995	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

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

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

13. ABSTRACT (maximum 200 words)

Two decades of multi-front conflict in the Middle East have given logisticians and policymakers ample time to evaluate the efficacy of how to resupply and internally sustain forward operating bases (FOB). Specifically, studies have shown that there are manageable connections between the fuel consumed by an FOB, the costs to sustain that FOB with fuel for powering generators, and the potential to reduce the casualties associated with logistics resupply. Considerable research shows that the United States Department of Defense needs to consider alternative methods of power production on FOBs in order to reduce the total ownership costs of operating the FOB and the cost of human life to sustain the FOB that is attributable to logistics resupply missions. This project explores the current costs of sustaining an expeditionary FOB and how the implementation of existing technology could help mitigate those costs. It seeks to establish a potential risk to life savings that could be accomplished by reducing the periodicity of resupply. It is recommended that proof of concept be established for the concept of solar in a box through commercially available systems, such as the system explored in the project.

14. SUBJECT TERMS forward operating base, FOB, fossil fuel, renewable energy, fully burdened cost of fuel, FBCF, logistics, risk to force, signature reduction, microgrid	**15. NUMBER OF PAGES** 67
	16. PRICE CODE

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

NSN 7540-01-280-5500

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

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Two decades of multi-front conflict in the Middle East have given logisticians and policymakers ample time to evaluate the efficacy of how to resupply and internally sustain forward operating bases (FOB). Specifically, studies have shown that there are manageable connections between the fuel consumed by an FOB, the costs to sustain that FOB with fuel for powering generators, and the potential to reduce the casualties associated with logistics resupply. Considerable research shows that the United States Department of Defense needs to consider alternative methods of power production on FOBs in order to reduce the total ownership costs of operating the FOB and the cost of human life to sustain the FOB that is attributable to logistics resupply missions. This project explores the current costs of sustaining an expeditionary FOB and how the implementation of existing technology could help mitigate those costs. It seeks to establish a potential risk to life savings that could be accomplished by reducing the periodicity of resupply. It is recommended that proof of concept be established for the concept of solar in a box through commercially available systems, such as the system explored in the project.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADS	Aerial Delivery System
ALOC	Air Lines of Communication
BESS	Battery Energy Storage System
CESE	Civil Engineering Support Equipment
DLA	Defense Logistics Agency
DOD	Department of Defense
DOTMLPF-P	Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Policy
DZ	Drop Zone
FBCF	Fully Burdened Cost of Fuel
FOB	Forward Operating Base
GLOC	Ground Lines of Communication
JCS	Joint Chiefs of Staff
MHE	Materiel Handling Equipment
MOS	Military Occupational Specialty
MTOE	Modification Table of Organization and Equipment
SiB	Solar in a Box
SLOC	Sea Lines of Communication
SOC	State of Charge
USSOCOM	United States Special Operations Command

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ACKNOWLEDGMENTS

I could not have done this without the support of my family: my parents, Dan and Sharlyn Jackson and Mike and Marylin Morlan, for their support through my career and especially this process. Thank you to Joshua Morlan, my brother, for sitting for hours on a Zoom call trying to help me get through a daunting assignment. Also, to my extended family who made countless treks to come and visit pre- and post-deployment for all my nine deployments: It was truly uplifting and amazing to be able to have everyone together.

Professor Geraldo Ferrer, Dr. Dan Nussbaum, and Mr. Alan Howard: thank you from the bottom of my heart for guiding me. I appreciate your mentorship and patience on my journey through this process.

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I. INTRODUCTION

Unleash us from the tether of fuel.

General James T. Mattis, USMC,
during his 2003 tour as Commanding General
1st Marine Division in Operation Iraqi Freedom
(Joint Chiefs of Staff (JCS), 2019b)

The United States Department of Defense (DOD) may be the largest organizational petroleum consumer globally. It is the major consumer of energy for all federal agencies within the United States government, accounting for 77% of energy consumption within the government agencies (Greenley, 2019). United States military campaigns have doctrinally defined phases. Combat operations and stabilizing operations throughout the various phases of a campaign rely on camps to stage equipment and supplies and for both operational and support personnel to live on to launch combat operations or patrol. Through a distributed network of combat outposts and fire bases (henceforth forward operating base [FOB]) (Joint Chiefs of Staff, 2016), operations and patrols work to either gain ownership of the battlespace or maintain control of the captured space.

Generally, each of these FOBs must generate the power required to sustain it (Department of Defense, 2011*)*. There are times when the local infrastructure can support the FOB by providing shore power. However, as a planning factor, it can never be assumed that the force will be able to sustain the FOB from local infrastructure. Instead, the assumption is that the FOB will generate power using generators and the establishment of a microgrid. The generation of electricity with a generator requires a continual source of fossil fuel, specifically JP8 or equivalent, repair parts, preventive maintenance kits, and troop labor for refueling, service, and maintenance. This requirement for energy sets up a follow-on requirement to establish a robust logistics tail that can keep pace with the consumption of fuel burned by the generators.

Two decades of conflict in the Middle East has given the United States military extended time to evaluate sustainment paradigms. The logistics resupply methodologies to support the FOBs have had ample time to evolve and mature. With this maturity, it has become apparent that logistics resupply is a necessary vulnerability with current fossil fuel-reliant power generation equipment (Army Environmental Policy Institute, 2009). With 50% of fossil fuels consumed at a FOB going toward power generation (Steele, 2015), it is conceivable that removing or reducing consumption could have both cost savings and reduction in lives lost in the pursuit of resupplying FOBs.

Significant risk to force occurs when resupplying FOBs with all classes of supply, but especially fuel for generators. Loss of life for a logistics convoy is estimated at one death for every 24 convoys in Afghanistan (Army Environmental Policy Institute, 2009). Casualties at less than the loss of life have just as much significant impact on operations due to the intensive requirements needed to stabilize, transport, and continue care to the injured. The risk to force is compounded by the amount of fuel consumed, space required to store that fuel, the flammability of the fuel being stored/consumed, and the workforce footprint of these resupply operations. Unless logistics infrastructure can somehow reduce or remove the requirement to resupply fossil fuels specifically for power generation, lives will continue to be risked in the name of logistics rather than in support of operations.

As evidenced by negative public sentiment for the casualties during campaigns such as Vietnam, Operation Iraqi Freedom, and Operation Enduring Freedom, any loss of life, and especially avoidable loss of life, comes with a risk of eroding civilian support and confidence in the mission represented by the various campaigns (Myers & Hayes, 2010). As the public sees the death toll rise, there is associated public fatigue affecting the support for operations, which could impact public support and undermine the overall objective, thereby creating a risk to mission.

Frequent resupply increases the visibility, thereby vulnerability, of a FOB, creating another risk to mission success. With every delivery, airdrop, convoy, or flight, the signature of the FOB increases. This has the negative effect of allowing enemy forces to conduct reconnaissance, which includes developing an understanding of the FOB’s pattern of life. Similarly, if the resupply paradigm includes delivering fuel via Aerial Delivery Systems (ADS), the signature of the FOB, or even the previously unknown presence of the

FOB, can be compromised due to a highly visible resupply paradigm that is discussed in the following analysis.

A. RESEARCH QUESTIONS

This study attempts to answer the question: What are the trade-offs associated with transitioning FOB power supply from legacy energy sources to alternative energy sources? These are the associated questions:

- Can a reduction in risk to force be achieved by transitioning power production or augmenting current production?
- Is there a signature reduction in transitioning to renewable energy?
- What are the intangibles associated with reducing resupply missions?

B. LIMITATIONS

This study has a few limitations that are discussed in the following section, including implications on workforce requirements, potential training changes or additions, and the possibility of contracted fuel delivery.

A full study of the manpower implications of switching sustainment of power generation for a small FOB is beyond the scope of this MBA project. An in-depth study of the specific impacts on manpower and manning requires collaboration between entities that are best studied by the Navy Manpower Analysis Center (NAVMAC). This project will provide the potential for manpower savings, but not with the depth of analysis needed to make informed workforce policy decisions. An in-depth analysis of how a shift in equipment will affect the full spectrum of manpower related pillars of Doctrine, Organization, Training, Materiel, Leadership, and education, Personnel, Facilities, and Policy (DOTMLPF-P) (AcqNotes, 2018) will be required when specific equipment or systems are being evaluated. This study analyzes the baseline, or status quo, cost of utilizing fossil fuel to power the grid.

As new technology is implemented, there is the potential for additional or different training requirements that need to be addressed by the varying Services educational review processes. However, that in-depth DOTMLPF-P level analysis of training requirements is outside the scope of this project. The skill sets to maintain some technology may already reside within a rate or Military Occupational Specialty (MOS).

When deciding whether to align new training and requirements into an existing job specialty or create a completely new one, a detailed analysis of multiple factors must be undertaken. This level of analysis requires subject matter experts from across a wide array of job specialties to weigh in on the holistic impacts that implementation would create. With each of the potential trade-offs/solutions, the total ownership cost of the changes will also be considered.

To relieve the strain on the logistics infrastructure necessary to resupply FOBs with fuel, the delivery of fuel can be contracted out given that the environment and security posture for the operation allows it. Operational and logistics planners plan and then reevaluate each operation as it is foreseen or as it progresses. The dynamic planning factors for each different and often unique set of variables does not allow this project to declare absolutes regarding whether contracted fuel delivery is a viable alternative.

During Phase I, II, and III of operations, resupply is typically considered an organic function. While there are several reasons this is true, the driving factor is the maturity of the theater. Considerations that would eventually allow the Defense Logistics Agency (DLA) or another contracting agency to contract fuel delivery via commercial means include, but are not limited to:

- The availability of contractors with freedom of movement within the battlespace
- Infrastructure sufficiently intact to allow the contractors freedom of movement
- Force protection adequate to be able to screen vendor deliveries
- The ability to adequately vet contractors

It is acknowledged that contracted fuel delivery is a way to reduce the cost of fuel to levels below the Fully Burdened Cost of Fuel (FBCF). It also has the additional benefit of removing service members from harm’s way by shifting the danger of delivering fuel to contractors. However, because contracted fuel delivery is not guaranteed, calculations are based on organic resupply of the FOBs.

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II. LITERATURE REVIEW

A. EMERGING RESEARCH

- Mobile Nuclear Power Plants for Ground Operations

To research alternative methods of power generation to reduce the inherent risk of resupplying FOBs, in 2018 the Department of the Army Deputy Chief of Staff, G-4, commissioned a study to consider the use of mobile nuclear power plants in the sustainment of expeditionary FOBs (Vitali et al., 2018). The report indicated that technically, nuclear power could be used to reduce the number of items required to resupply a FOB by eliminating most of the fuel demand. This would also be in alignment with the U.S. *National Security Strategy* and the *2018 National Defense Strategy* to counter Russia and China (Department of Defense, 2018).

While a mobile nuclear reactor sized for a small FOB does seem like science fiction at this time, with recent advances in technology and the sciences, it is possible, given sufficient resources.

B. SOURCES FOR METHOD USED

1. JASON Report JSR-06-135

The JASON Group includes independent scientists that analyze problem sets that the DOD deems important. Unlike a standing think tank, it meets on an ad hoc basis when specific issues are deemed worthy of analysis (JASON [Advisory Group], 2020).

During the assessment produced by JSR-06-135, the JASON Group identified an upper and lower bound for the FBCF. This analysis is important for any study of whether policies or acquisitions will have a significant effect on overall costs. By acknowledging that a gallon of fuel costs more than just its simple acquisition costs, specifically the additional cost to get to its intended destination, assessments such as this take a holistic look at costs and non-monetary considerations.

Their assessment estimated that the lower limit was $100 per gallon, while the upper limit was $600 per gallon when considering the FBCF (Dimotakis et al., 2006). While this is a significant range, it should not be a surprising result when considering the geographic size of operations and variations on logistical challenges. These considerations cause large variations in costs to deliver fuel.

2. NPS Master's Thesis by Scott Roscoe

The Fully Burdened Cost of Fuel (FBCF) was a heavily researched topic circa 2010-2013. Although the interest in this subject has waned over time, the research that was done is nonetheless significant given the current problem set. Without understanding the price required to get a single gallon of fuel to a remote station, analysts would not be able to compare the benefit of moving to more sustainable technology from the status quo of continuing to deliver fuel to our FOBs.

Roscoe found that there was a disparity across the Services on how they calculated the FBCF (Roscoe, 2010). However, this did not detract from the realization that identifying the minimum and maximum costs to deliver fuel to a FOB is beneficial. This is especially true in the context of determining, from a cost-benefit perspective, whether implementing new technology will have a net reduction in total costs and help to reduce our reliance on fossil fuel. Roscoe (2010) confirms JASON Group's estimate that, when applied to surface resupply, the FBCF remained between $100 and $600 per gallon.

3. Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys

Providing essential resupply to FOBs comes with a measurable amount of risk to force (Army Environmental Policy Institute, 2009). After two decades of conflict in the Middle East, substantial data has been accumulated and then extrapolated to determine the number of casualties that were sustained compared with the number of convoys that occurred. Analysts at the Army Environmental Policy Institute used data derived from the Center for Army Lessons Learned that included resupply of FOBs for all commodities. The resupply missions were then compared to casualties to assess what proportion of the casualties associated with fuel and water. For these convoys, the Headquarters Department of the Army gave estimates for the distribution of 50% fuel, 20% water, and 30% other items (Army Environmental Policy Institute, 2009).

Through its analysis, the Army Environmental Policy Institute calculated a casualty factor of 0.026 for Iraq and 0.042 for Afghanistan to be attributable to logistics convoys (Army Environmental Policy Institute, 2009). For the worst-case scenario (Afghanistan), that equates to one casualty for every 24 convoys. In 2007, an estimated 132 casualties in Iraq and 38 in Afghanistan were attributable to delivering fuel. This was done by taking total fuel compared to casualties associated with logistics convoys and proportioning them out based on the percentage the commodity comprised in a typical convoy (Army Environmental Policy Institute, 2009).

4. Tent Camp Fuel Consumption Calculator

An Excel spreadsheet calculator was produced by the 2nd Naval Construction Battalion Detachment based in Gulfport, MS, to estimate the amount of fuel consumed for each type of equipment on a FOB. According to James Hicks (email to author, May 29, 2020), it calculates aggregated fuel usage for any and all consumers of fuel at a deployed site, including, but not be limited to, support equipment, generators, shower units, and kitchen facilities. However, for the purposes of this project, the 60 kW generator potion was exclusively used. For this project, the basic layout of five generators was used to calculate the number of gallons of fuel used per day, with the exception of reducing the fuel usage per hour. The original calculator utilized a six gallons per hour consumption rate. However, the generator’s technical manual stated 4.8 gallons per hour. Therefore, the technical manual’s figures were used to calculate fuel consumption. The calculator was then modified to provide the number of 55-gallon fuel drums, the number of pallets, and the number of C-130 airdrops that would require over a given amount of time.

5. Joint Publication 4-0 Joint Logistics

Joint Publication 4-0 *Joint Logistics* is the leading joint publication in the J.P. 4-x series that defines doctrinal logistics (JCS, 2019b). It establishes the seven pillars of logistics and the general considerations within those pillars. It provides a common language so that the joint force can communicate with a common understanding, despite Service-specific languages. The pillars, as defined by JP 4-0 *Joint Logistics*, are:

- Deployment and Distribution
- Supply
- Maintenance
- Logistics Services
- Operational Contract Support
- Engineering
- Joint Health Services

Of the seven pillars of logistics, the functional capability of managing supplies falls under the core function of supply (JCS, 2019b). Although other publications better define the bulk petroleum doctrine (JP 4-03), JP 4-0 provides the cornerstone for what is encompassed by and what is included in the term logistics.

6. Joint Publication 4-03 *Joint Bulk Petroleum and Water Doctrine*

Joint Publication 4-03 *Joint Bulk Petroleum and Water Doctrine* is the Department of Defense joint publication aimed at strategic level guidance on bulk petroleum. As with any joint publication, it provides the doctrinal level of understanding of missions in the joint environment.

DLA is the executive agent for bulk petroleum and is responsible for delivering fuel to the point of use by purchasing commercially available fuels and ensuring that the correct additives are in or added to the fuel. However, there are times when DLA cannot contract or does not have the organic capability to deliver the fuel for the last leg of the logistics tail. This occurs in austere environments or during the earliest stages of operations (JCS, 2017).

7. Joint Publication 3-17 *Air Mobility Operations*

Joint Publication 3-17 *Air Mobility Operations* is the doctrinal publication used for air mobility operations (JCS, 2019a). It defines the two methods of aerial delivery as either airland or airdrop. In either method, an aerial platform is utilized to transport the cargo to its intended destination. Generally, the C-130 is the most predominant workhorse for intra-theater airlift. However, C-17s can be utilized for outsized cargo, and when there is enough aggregated cargo to warrant a larger platform.

Airland means the aerial platform designated for delivery of the cargo physically lands on the ground to be offloaded by Materiel Handling Equipment (MHE) (JCS, 2019a). This method of delivery has pros and cons that logistic resupply planners will weigh out when determining the best method of delivery. Some considerations that factor into landing versus not landing are the overall force protection posture of the delivery location, accessibility of an either improvised or improved runway, and whether the equipment exists on site to offload the aircraft.

8. SacTec Solar Product Brochure

In researching already existing technology and systems that could be integrated into a small FOB's microgrid, SacTec Solar emerged as the provider of a system ready for integration(SacTec Solar, 2020). Their system comes packaged in a four-foot-tall standard 20ft by 8ft shipping container, which is half the height of a standard shipping container. This will allow two containers to be stacked on each other for shipment. Each PowerHop System utilizes ten solar arrays for combined production of 23 kW per PowerHop System. A complete analysis of SacTec's capabilities is in the Analysis section.

9. Energy Academic Group (EAG) Developed Optimizer Tool

NPS EAG-sponsored internship program built an optimization tool that allows the manipulation of variables that then outputs the total system cost and time to recoup that additional cost given the savings of fuel. According to the developer Connor Wicker (email to author, October 1, 2020), who is currently studying Nanoengineering with a specialty in Materials Science at the University of California San Diego, the tool is able to process inputs in the fashion discussed throughout this project. The variables that the user can manipulate are:

1. Peak wattage of the system

2a. Size of generators

2b. Number of generators

3. Cost of fuel

4. Dollar per watt of the solar array

5. Days of autonomy needed from the battery energy storage device

6. Allowed DOD for the battery energy storage device

7. Dollars per kW hour for the battery energy storage device

8. Inverter price per kW hour

The tool also outputs a visualization of the expected power consumption compared to the source of power production throughout the day. This is helpful in providing a graphical understanding and summary of the entire microgrid. A complete analysis of the Optimizer Tool and functionality is in the analysis section.

10. Economic Survey of the Monetary Value Placed on Human Life by the Government

Three executive orders have driven the necessity of government agencies to put a value on the loss of life (Silny et al., 2010). These were done to assess the impact of policies, specifically whether implementing the policies would drive cost savings in excess of $100 million. That is, these policies were implemented to test the threshold for whether a policy is economically feasible or not. The case is made that the dollar figures used, implemented in 1978, have not been adjusted for inflation and are critically undervalued. The authors make the case that not adjusting for inflation reduces the actual dollar figure by 2.5 to 3 times (Silny et al., 2010). In the analysis section, the loss of life and the dollar figure we place on that loss of life will be analyzed to determine possible savings.

This article delves into the monetary value of human life. While many that have studied ethics and philosophy could question the ability to assign a dollar figure to human life, it is none-the-less needed to shape current and future policy. Policies that govern our everyday lives are compared to how many lives a given policy may save, or at worst, cause to be terminated. A more thorough analysis of this policy and the implications it has on calculation savings of new technology will be discussed further in the analysis section.

III. METHODOLOGY

To address the questions outlined for the MBA project, an analysis of existing data coupled with original computations will be used to provide recommendations. An analysis of existing FOBs and the support paradigms will set the stage for a computational assessment of fuel consumption in the current environment, aka the status quo. Two sets of computations were developed specifically for this project by an NPS EAG intern and by a company that will represent a notional "solar in a box" or SiB.

The first is an Optimizer Tool, which allows for the dynamic computation of various outputs, given various inputs. As prices of the components in the microgrid, such as battery storage devices, solar panels, and even the FBCF change, the calculations will be updated. The available inputs that will be utilized include:

1. Peak wattage of the system
2a. Size of generators
2b. Number of generators
3. Cost of fuel
4. Dollar per watt of the solar array
5. Days of autonomy needed from the battery energy storage device
6. Allowed DOD for the battery energy storage device
7. Dollars per kW hour for the battery energy storage device
8. Inverter price per kW hour

While the outputs will provide:

1. The total cost of the system
2. Time to recoup the costs through a reduction in fuel usage

The second is a package of set computations provided by the company that designed and built a SiB solution called a PowerHop System. The tools and calculations will be used to identify potential savings that could be realized by supplementing existing microgrids with solar and battery systems.

The information and data provided will be utilized to compare the status quo of current fuel consumption compared to how integrating this already existing system could reduce fuel consumption and thus reduce price and possibly reduce casualties.

IV. ANALYSIS

Through an analysis of a status quo FOB, as compared to the possible reduction in fuel consumption if alternative power production is incorporated, this project will look to bridge the gap between existing systems and emerging technologies.

A. STATUS QUO (A BASELINE FOB)

Two steps were taken in order to establish a baseline or status quo:

- Establish what the general requirements are for a small FOB, which includes a standardized equipment list and typical layouts, and
- Understand how the FOB is resupplied in order to account for resupply missions and understand how the resupply affects the overall signature management of the FOB.

It is acknowledged that many FOBs do not follow a "standard" layout. The electrician on-site may deviate from this layout and utilize techniques to reduce fuel usage such as running dual generator operations, backup generator operations where a second generator only runs during peak operations, or only running the field shower/laundry generator when in active use. However, in order to analyze standardized fuel usage, it was determined that the best approach was to measure fuel consumption for all generators running 24/7.

1. Layout

For the purposes of this study, a standard FOB layout will be used. The layout includes berthing, medical, admin, dining, and a communications tent. It also includes a filled shower and laundry facility. These are very typical requirements for a FOB and, while every installation is unique, and oftentimes small maneuver elements will try to occupy existing structures, this nonetheless gives a good template in which to study average fuel consumption. Regardless of the source of power generation, the overall microgrid will be somewhat similar, except for devices to connect the chosen power generation source to the microgrid.

The standard layout, often called a 50-man camp, can be laid out in a standardized form. Depending on the source of equipment, the layout may vary, but the overall equipment is generally standardized for each provider. Entities like United States Special Operations Command (USSOCOM) components utilize both theaters provided equipment, and they also have their own deployable equipment for loan to subordinate units through the Joint Operational Stock program. There are other programs as well through conventional forces such as Force Provider systems that can be sized in a similar fashion.

Under the 50-man standardized camp construct, the following infrastructure will be supported:

- Seven berthing tents with accompanying environmental control unit
- Medical tent
- Admin tent
- Dining tent
- Communications tent
- Field shower unit
- Laundry unit
- Five 60 kW MEPS generators
- Ancillary cabling that forms the microgrid

A standard generator for small FOBs is an MEP series 60 kW generator. While there are many different configurations of output, from 5 and 10 kW up to 120 kW, the standard for our purposes will be based on the 60-kW generator. All calculations for fuel consumption are based on this.

A 60-kW generator was selected as it is the basis for the microgrid electrical diagram and is the most common generator. There are smaller generators, but with environmental control units requiring a large amount of power when they start up, the smaller generators could get overwhelmed, and the grid becomes more unstable.

2. Personnel Supported

A standard FOB, for this study, is based on a 50-person bare base configuration. This layout will be used as the standard for the theoretical FOB in this project. Because the bulk of the power generated goes to environmental control units, whether there are 30 or 50 personnel, the additional power load is negligible.

3. Support Personnel Requirements

A typical small FOB requires support personnel to maintain the infrastructure and equipment utilized to both sustain the base and to service support and operational motorized equipment. Support personnel is comprised of a cross-section of rates (Navy) or Military Occupational Specialties (MOS) (Army, Air Force, and Marines). The support personnel perform tasks such as service, refuel, and repair generators, maintenance, and repair of tactical and non-tactical vehicles, initial setup, and maintenance of the power grid, along with minor construction and camp improvement projects.

4. Fuel Requirements

To establish fuel requirements, the Fuel Calculator for Civil Engineering Support Equipment (CESE) and Equipment, designed by the 2nd Naval Construction Battalion Detachment Gulfport, was used as a starting point. However, gallons per hour was updated from 6 to 4.8 to account for a 70% load. The assumptions for the calculation of the baseline usage of fuel are that the generator:

- Consumes 4.8 gallons per hour based on a 70% load
- Runs 24 hours per day
- Runs seven days a week
- Runs 365 days a year
- Maintenance downtime is not calculated

- Peak and off-peak are normalized through the gallon per hour constant
- Usage factor is set at 1

Table 1 displays cost per year and cost per month of the standardized FOB, when applying the FBCF to power generation alone. This provides the basis for the status quo fossil fuel consumption and support paradigm.

Table 1. Cost ($M) to Sustain a FOB Utilizing Average Consumption at the FBCF ($/gallon)

	Per year	**Per Month**
FBCF at $100	21	1.8
FBCF at $600	126	10.5

Table 2 displays the available inputs that can drive the calculations. While many of the columns come pre-loaded with common factors, they are editable to accommodate for variations in calculation needs. These pre-loaded columns include:

- Prime Fuel Tank
- Gas/Hour
- Usage Factor
- Hours per shift
- Gallons per shift
- Shifts per day

In the fuel calculation tool, the following user inputs are expected:

Quantity of the generators (the expanded calculator has all equipment that would be expected to be used in a tent camp.

Table 2 displays the variables and the output of fuel needed per year and number of 55-gallon drums utilized per year. Column one is the general name (description of the system used). In this case, it is only the 60kW generators. Column two is the number of equipment (generators in this case) that are utilized to calculate fuel usage. Column three is the size of the fuel tank, which this project is utilizing 55-gallon drums. Column four is the gallons of fuel used per hour. Column five is the usage factor which determines overall consistency of use. Column six is the hours per shift if the day is broken up into shifts. Column seven allows input of shifts per day (in case only partial days are utilized). Column eight is peak days which is used if not all the time being measured is full utilization of the camp. Column nine is the peak fuel which for this project accounts for all 365 days. Column ten is the total fuel requirement which matches the peak fuel requirement because all days were considered peak fuel usage.

Table 2. Status Quo FOB Consumption of Fuel in Gallons and 55-Gallon Drums

SHORT DESC	QUANTITY USED	PRIME FUEL TANK	GALS / HOUR	USAGE FACTOR	HOURS PER SHIFT	GALLONS PER SHIFT	SHIFTS PER DAY	PEAK DAYS	PEAK FUEL	TOTAL FUEL REQUIREMENT
GENERATOR SET 60KW (TQ) DED SKID MTD	5	55	5	1	8	192	3	365	210,240	210,240

GALLONS OF DIESEL or JP-5:	**210,240**
NUMBER OF 55 GALLON DRUMS:	**3,967**

Adapted from: Fuel Calculator For CESE, CEEI, Tent Camp, And Gas Powered Tools provided by James Hicks (email to author, May 29, 2020)

Table 3 utilizes the computations derived from Table 2 to determine the number of 55-gallon drums required per month to sustain a FOB. This requirement is for fuel to support the generator that provides power to the FOB's microgrid. It does not account for any other fuel usage on a FOB such as tactical and non-tactical vehicles or other ancillary fuel usage.

At the standard rate of fuel consumption, a C-130 dropping ADS bundles of palletized fuel drums are required approximately every six days. This requires a significant amount of time and resources to prepare, fly, drop, recover, and then seek the disposition of the required 55-gallon drums.

Table 3. Aerial Delivery Resupply Figures

	55 Gallon Drums Per Month	Pallets Per Month	Flights Needed per Month
55-gallon drums	330.57	82.64	5.17

5. Resupply Methods

Logistics resupply of FOBs utilizes well-established support paradigms through Ground Lines of Communication (GLOC), Sea Lines of communication (SLOC), and Air Lines of Communication (ALOC). Each line offers unique benefits but also comes with inherent limitations.

GLOC is the most stable delivery method, allowing for a larger amount of cargo to be moved with less cost as compared to ALOC. By utilizing convoys, equipment, all classes of supply, and outsized containers can be moved to locations rather efficiently. When establishing a FOB, initial heavy equipment can be line-hauled to the new location in order to establish the infrastructure. Likewise, the resupply of the FOB can utilize GLOC for the delivery of all classes of supply.

GLOC does come with inherent limitations in that it exposes support personnel to the risk of sustaining casualties by opening the opportunity for attack by opposing forces. It also increases the logistics footprint by increasing the necessity for repair capability in a theater. The more motorized assets you have, the more repair capability you will need.

a. Troop Delivery *(GLOC)*

Figure 1 illustrates the level to which logistics resupply (GLOC) missions are exposed to potential threats. While their vehicles do provide some ballistic protection, no level of protection can overcome the fact that they are essentially pulling a large number of combustible materials that could overcome any protection if an Improvised Explosive Device (IED) is detonated near the vehicle.

Source: Franco (2019)

Figure 1. Ground Resupply Mission

During the beginning phases of an operation, troop labor and equipment are utilized for logistics convoys. Units assigned logistics responsibility are outfitted with equipment specifically for the resupply of units or transport of fuel, water, and equipment as part of their Modification Table of Organization and Equipment (MTOE). The MTOE describes the composition and outfitting of a specific unit and modifies the Table of Organization and Equipment (TOE).

While ground resupply through troop labor is a necessary evil during the early stages of operations, it inherently comes with significant risk to force for non-combat operations. With small FOBs spread out, often over formidable terrain, getting fuel to outstations can be a very daunting, time-consuming, resource use intensive, and deadly exercise. It is, however, necessary.

b. Aerial Ground Offload (ALOC)

By landing a tactical resupply aircraft such as a C-130 and subsequently offloading it on the ground, certain advantages, as well as disadvantages, are realized. This method of resupply gains the efficiency of ensuring delivery of product while losing efficiency of ADS.

The multiple benefits of landing to offload resupply items include

1. Reducing the number of outside contractors or foreign nationals that have access to the FOB.
2. Ensuring the product makes it safely to the end-user.
3. Somewhat reducing the overall signature of the base through reducing the number of times parachutes are seen in the sky above the FOB.
4. Offering the ability to retrograde cargo instead of just delivering it.
5. Creating the opportunity to serve as passenger transport.

c. Aerial Delivery System (ALOC)

Aerial delivery of all classes of supply is probably the most rudimentary resupply paradigm available for a logistician. It requires no landing or airstrip, no sustainable GLOC, and no other special requirement outside of the MOSs available on a FOB. Any qualified Joint Tactical Air Controller can control the airspace sufficiently enough to allow an airdrop to occur.

d. Aerial Delivery Systems (ADS)

Riggers (specialists in palletizing and preparing for drop delivery by parachute) are highly trained personnel that identify the cargo to be delivered, the weight and dimensions of the pallets, and how best to prepare the shipment for delivery.

The basic premise of this resupply paradigm is that a class or multiple classes of supply are palletized, rigged, loaded onto a transport (usually a C-130), and then dropped to a designated landing zone or drop zone (D.Z.). The D.Z. size has variables such as wind, drop altitude, humidity, and a multitude of factors that affect how and where the cargo will land.

As you can see in Figure 2, ADS is a very visible method of resupply. Opposing forces can identify the location of drops for miles away. This has a negative effect on both managing the signature of a FOB and in giving away a pattern of life for sustaining the FOB. The negative effect on the signature of a FOB is because of the increase in visibility of the FOB. The pattern of life for the FOB is established by identifying how many times a FOB receives resupply. This pattern of life becomes detrimental for the FOB because adversaries can use the normal rhythm to establish times to strike or establish vulnerable times for other types of subversion.

Source: Walker (2017)

Figure 2. ADS Fuel Delivery

ADS, also known as containerized delivery systems and a host of other programmatic names, offers logistics personnel the ability to be able to resupply FOBs by air without landing (Department of the Army, 2016). This resupply method provides both positive and negative considerations.

One disadvantage is represented in Figure 3. To recover the bundles on target, considerable effort must be applied. The effort comes in both labors to get the bundles ready to load with a forklift and to recover the parachutes and other items that will eventually be retrograded or destroyed.

Source: Walker (2017)

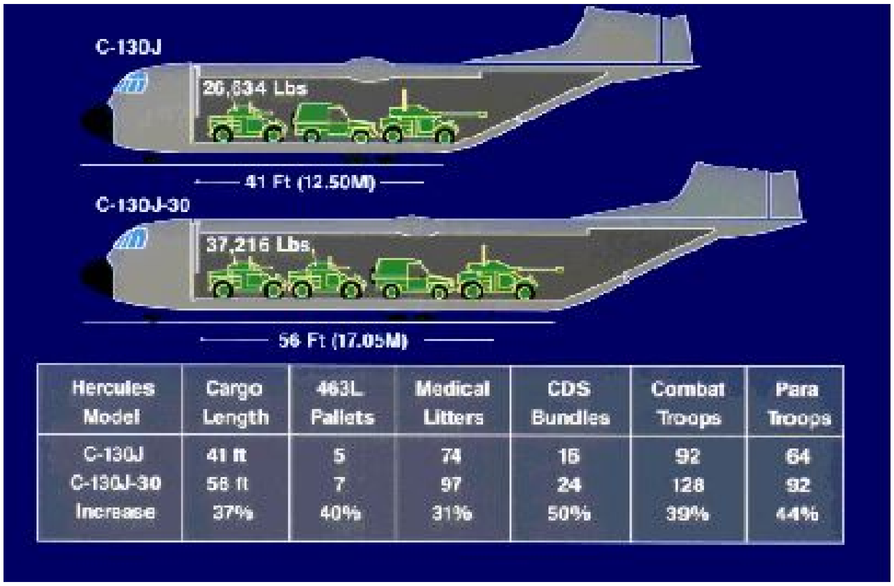
Figure 3. Recovery of ADS Fuel Drop on Target

Another disadvantage is the amount of material that must either be retrograded or destroyed. The first scenario is where material must be retrograded. Considering that approximately 64 barrels of fuel come each week, that material starts to accumulate very quickly. That would require either a logistics convoy to come and pickup retrograde material or for a larger plane to land and load the material. Likewise, 16 parachutes accumulate each week. In the second scenario where you destroy the material, you have to deal with either toxic fumes from burning plastic drums and parachutes or trying to destroy metal drums. Neither of which is desirable considering the sheer volume of equipment.

One advantage is that logistics personnel do not have to travel significant distances by ground and are thus much less likely to experience a troops-in-contact event. This would naturally reduce the exposure to opposing forces while potentially decreasing the number of people killed in a logistics convoy. Because the number of casualties for logistics is directly correlated to the number of resupply convoys (Army Environmental Policy Institute, 2009), a natural reduction in loss of life could occur by reducing the number of resupply convoys, or possibly just in miles traveled.

Another positive is that consistency of resupply could be increased due to the reduction of possible ground hits to convoys.

Figure 4 depicts the overall capacity of a C-130, including the pallet positions required for a CDS, AKA ADS bundle drop. For the purpose of this report, 16 bundle max will be used for all computations to normalize the available positions.



Hercules Model	Cargo Length	463L Pallets	Medical Litters	CDS Bundles	Combat Troops	Para Troops
C-130J	41 ft	5	74	16	92	64
C-130J-30	56 ft	7	97	24	128	92
Increase	37%	40%	31%	50%	39%	44%

Source: Pike (2000)

Figure 4. C-130 Capacity for CDS (ADS) Bundles

e. DLA Contract

Once the battlespace has matured enough, and infrastructure supports contracted delivery of fuel, the Defense Logistics Agency Energy will establish contracts for direct delivery of fuel to a FOB. These contracts substantially reduce the burden on logistics, and they can also actually reduce the overall cost of fuel when considering the Fully Burdened Cost of Fuel (FBCF). However, they also increase the potential for sabotage by allowing continued access to the FOB.

B. ELEMENTS BEING MEASURED

This project's thesis and follow-on questions were designed to determine what the cost is to sustain a small FOB, specifically the fuel used to power the generators that then power the microgrid and the risk to force through sustained casualties. We will measure fuel consumption across a given time frame at a set load factor for the generators that supply power for a small FOB. After establishing the fuel consumption, which will establish a baseline, that number can be used to analyze potential cost and reduction in the risk to force savings that new technology may offer.

We will also measure the fuel use of currently available technology SiB and be able to compare that against the current baseline. This will allow for the comparison of current fuel consumption compared to the implementation of existing technology while also considering the ramifications of reducing the number of resupply missions. The reduction of resupply missions is critical to reducing the risk to force that is inherent in resupply missions.

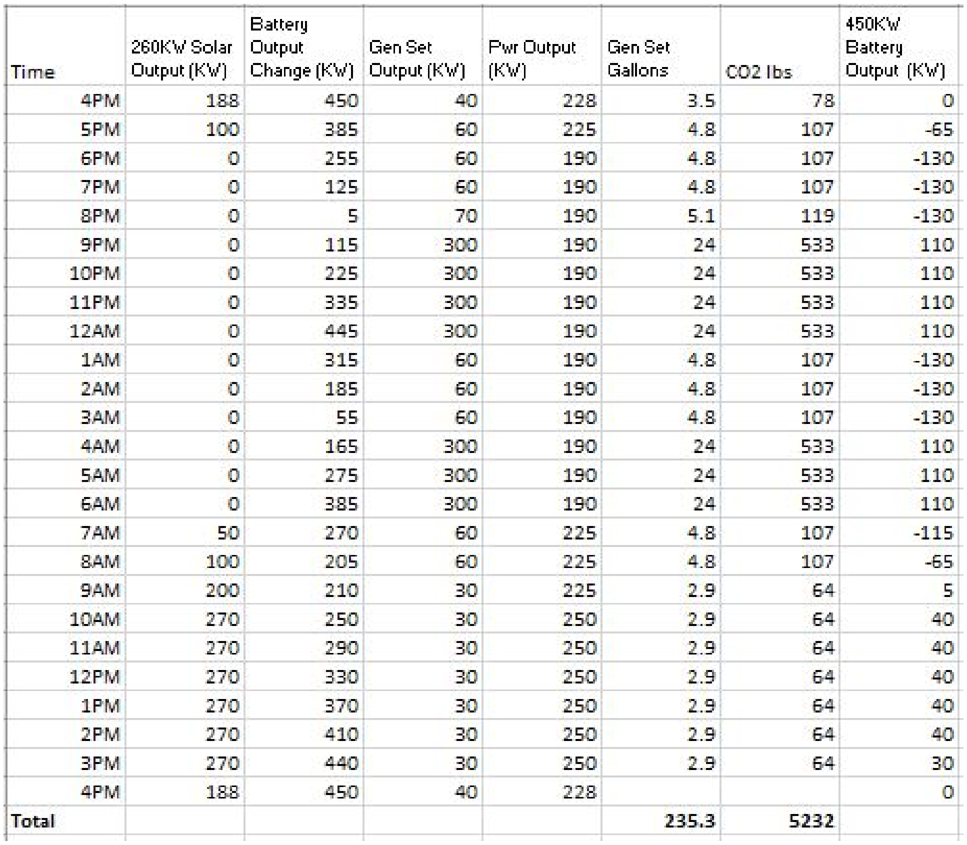
1. Solar in a Box

In researching already existing technology and systems that could be integrated into a small FOB's microgrid, SacTec Solar emerged as a system ready for integration. Their system comes packaged in a ½ tall standard 20ft by 8ft shipping container. Each PowerHop System utilizes ten solar arrays for combined production of 23 kW per PowerHop System.

The standardized FOB in this project is based on 300 kW (five 60kW generators). Therefore, 12 PowerHop Systems are needed to produce the equivalent amount of solar power. However, in collaboration with SacTec engineers, it was determined that the optimal size system to integrate into the FOB is a ten PowerHop System configuration with a 450kW lithium battery storage system. Each power Hop System is currently priced at $250,000 (10 systems at $250,000 equals $2,500,000), and the 450kW lithium battery storage system is priced at $830,000. That combines for a total of $3,330,000. This price does not include an upgrade to mil-spec requirements. The estimated costs were provided during a telephone conversation between SacTec Solar engineers and sales staff, and the author of this project.

Utilizing SacTec Solar data provided the results in Table 4, along with the graphical representation in Figure 5, which displays the usage of power and the production of power throughout a 24-hour time frame.

Table 4. Calculations for PowerHop System Integration



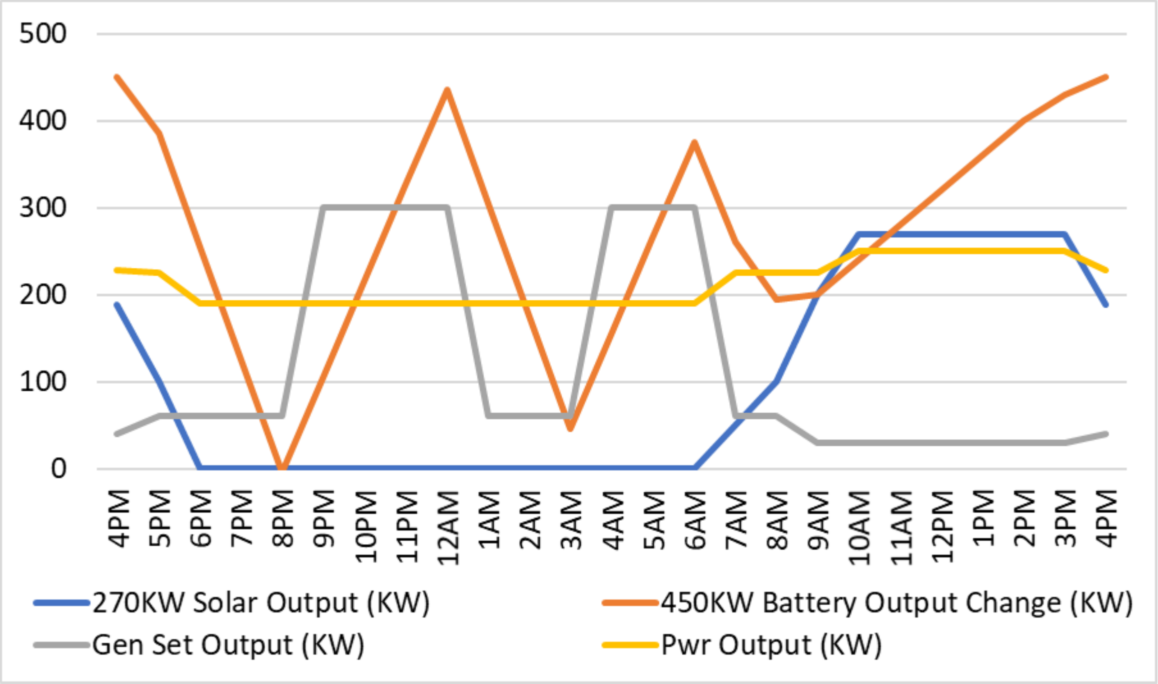
Time	260KW Solar Output (KW)	Battery Output Change (KW)	Gen Set Output (KW)	Pwr Output (KW)	Gen Set Gallons	CO2 lbs	450KW Battery Output (KW)
4PM	188	450	40	228	3.5	78	0
5PM	100	385	60	225	4.8	107	-65
6PM	0	255	60	190	4.8	107	-130
7PM	0	125	60	190	4.8	107	-130
8PM	0	5	70	190	5.1	119	-130
9PM	0	115	300	190	24	533	110
10PM	0	225	300	190	24	533	110
11PM	0	335	300	190	24	533	110
12AM	0	445	300	190	24	533	110
1AM	0	315	60	190	4.8	107	-130
2AM	0	185	60	190	4.8	107	-130
3AM	0	55	60	190	4.8	107	-130
4AM	0	165	300	190	24	533	110
5AM	0	275	300	190	24	533	110
6AM	0	385	300	190	24	533	110
7AM	50	270	60	225	4.8	107	-115
8AM	100	205	60	225	4.8	107	-65
9AM	200	210	30	225	2.9	64	5
10AM	270	250	30	250	2.9	64	40
11AM	270	290	30	250	2.9	64	40
12PM	270	330	30	250	2.9	64	40
1PM	270	370	30	250	2.9	64	40
2PM	270	410	30	250	2.9	64	40
3PM	270	440	30	250	2.9	64	30
4PM	188	450	40	228			0
Total					**235.3**	**5232**	

Source: SacTec, email to author, 14 October 2020

Table 4 shows the usage of power and also the source of power being provided back into battery backup systems throughout a 24-hour period.

- Column 1 (Time) shows the time throughout the day
- Column 2 (260KW Solar Output (KW) shows the production of solar power provided by the PowerHop System
- Column 3 (450KW Battery Output Change (KW) shows the available energy stored in the battery system that is available for discharge
- Column 4 (Gen Set Output (KW) shows the output of power provided by generators on the microgrid
- Column 5 (Pwr Output (KW) shows the holistic power output required by the microgrid
- Column 6 (Gen Set Gallons) shows the number of gallons of fuel estimated to be used during that time
- Column 7 (CO2 LBS) shows carbon emissions per hour. As a side note, this study does not consider carbon emissions.
- Column 8 (450 KW Battery Output (KW) shows the output of the battery system over time. The negative numbers are when the battery system is being charged vice discharged.

Figure 5 displays the usage of power and the production of power throughout a 24-hour-time frame. What is evident in the calculations is that the Gen Set (generators) run time is significantly reduced throughout the day. Without augmenting the current microgrid, Gen Sets run 24/7. After integrating the PowerHop system, the Gen Sets only fully run for nine hours.



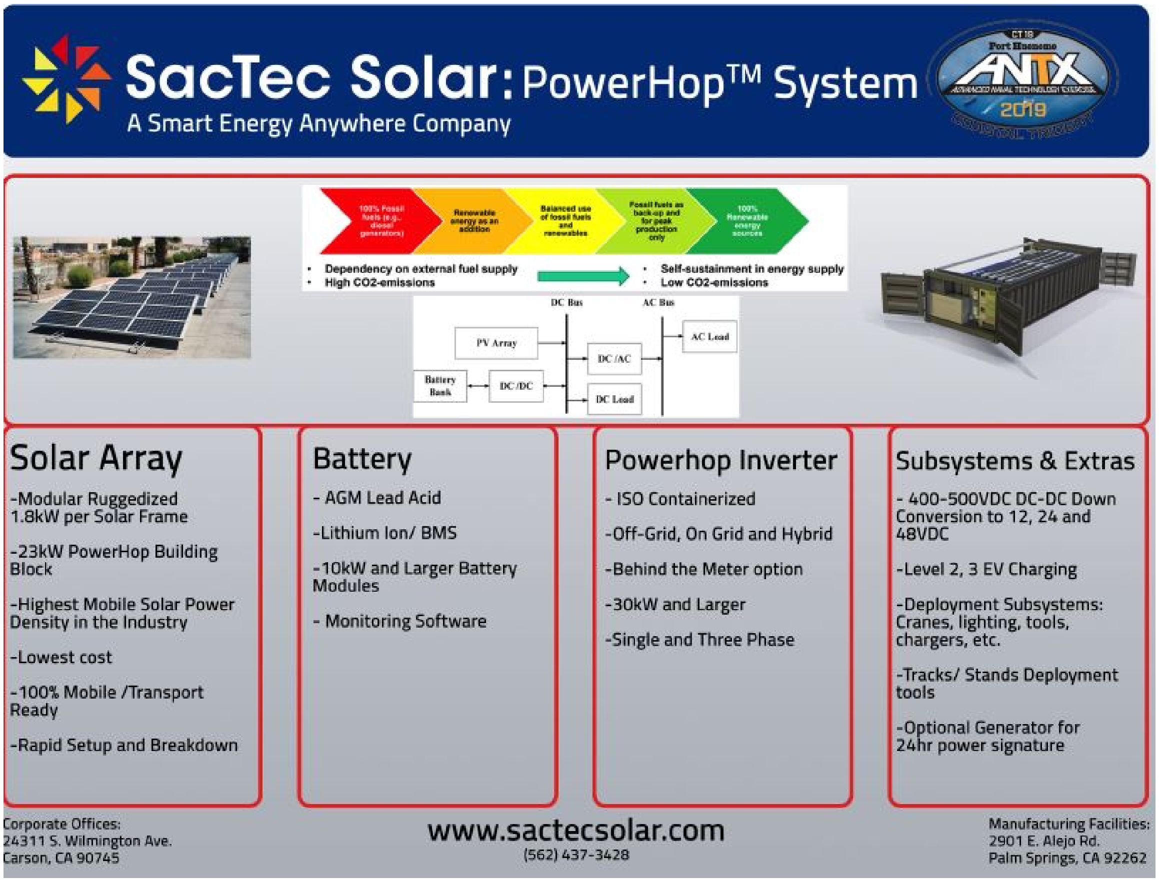
Source: SacTec (email to author, 14 October, 2020)

Figure 5. Power Consumption Throughout the Day

According to the calculations of SacTec engineers, the combined PowerHop Systems and lithium battery storage system could save 280 gallons of fuel per day per system with optimal conditions. The reduction in fuel usage does come at a trade-off in the form of an increase in the footprint, compared to generators, required for power generation.

Each PowerHop System requires 2,000 square feet when used close to the equator. That combines for a total of 20,000 square feet. However, when used farther north or south of the equator, the system's footprint can reach up to 3,200 square feet per system. With the ten systems, that puts the total additional square footage needed at 32,000. That is roughly a 179 ft by 179 ft area, which is 19 feet longer than the width of a standard football field.

Figure 6 illustrates the PowerHop system both in its transportable state illustrated in the upper right-hand picture and its fully deployed state in the upper left-hand picture. The brochure is provided to allow for direct communication with the manufacturer for any detailed questions or further analysis. The utilization of PowerHop as a representation of an already existing and readily deployable system or technology is in no way an endorsement or certification of the system by the author. Any interested party should conduct a full analysis of the system on their own and consider the viability of the insertion of this technology into their existing microgrid.



SacTec Solar: PowerHop™ System

A Smart Energy Anywhere Company

Solar Array

-Modular Ruggedized 1.8kW per Solar Frame

-23kW PowerHop Building Block

-Highest Mobile Solar Power Density in the Industry

-Lowest cost

-100% Mobile /Transport Ready

-Rapid Setup and Breakdown

Battery

- AGM Lead Acid

-Lithium Ion/ BMS

-10kW and Larger Battery Modules

- Monitoring Software

Powerhop Inverter

- ISO Containerized

-Off-Grid, On Grid and Hybrid

-Behind the Meter option

-30kW and Larger

-Single and Three Phase

Subsystems & Extras

- 400-500VDC DC-DC Down Conversion to 12, 24 and 48VDC

-Level 2, 3 EV Charging

-Deployment Subsystems: Cranes, lighting, tools, chargers, etc.

-Tracks/ Stands Deployment tools

-Optional Generator for 24hr power signature

Corporate Offices:
24311 S. Wilmington Ave.
Carson, CA 90745

www.sactecsolar.com
(562) 437-3428

Manufacturing Facilities:
2901 E. Alejo Rd.
Palm Springs, CA 92262

Source: SacTec Solar (2020)

Figure 6. PowerHop System

2. Optimizer Tool

The outputs provide a dynamic product that will allow current and future decision-makers with a quick way to analyze whether cost savings can occur and how long it will take to reap a return on investment in emerging technologies or improvements in the efficiency of existing technologies.

Inputs include:

1. Peak wattage of the system: Max power needed at any point during a day

2a. Size of generators: Size in kW produced as a drop-down menu

2b. Number of generators: Number of generators needed for microgrids

3. Cost of fuel: Total fuel costs which can include delivery

4. Dollar per watt of the solar array: Price expected to acquire a system per watt

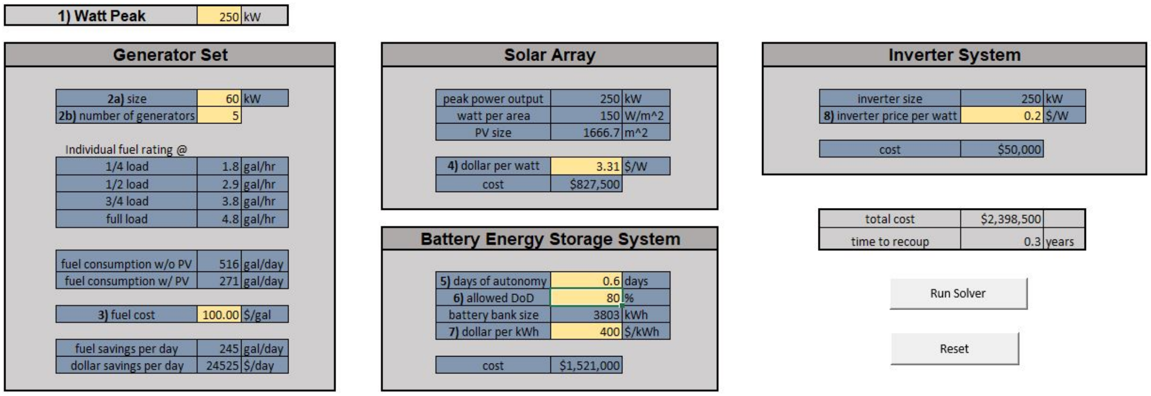
5. Days of autonomy: Amount of time needed from the battery energy storage device which is how long the system will provide power absent means of power production of the generators or solar system.

6. Allowed DOD for the battery energy storage device

7. Dollars per kW hour for the battery energy storage device

8. Inverter price per kW hour

Figure 7 shows the input/output dashboard of the Optimizer Tool, with the user input variables highlighted in yellow.



1) Watt Peak	250	kW

Generator Set

2a) size	60	kW
2b) number of generators	5	

Individual fuel rating @

1/4 load	1.8	gal/hr
1/2 load	2.9	gal/hr
3/4 load	3.8	gal/hr
full load	4.8	gal/hr

fuel consumption w/o PV	516	gal/day
fuel consumption w/ PV	271	gal/day
3) fuel cost	100.00	$/gal
fuel savings per day	245	gal/day
dollar savings per day	24525	$/day

Solar Array

peak power output	250	kW
watt per area	150	W/m^2
PV size	1666.7	m^2
4) dollar per watt	3.31	$/W
cost	$827,500	

Battery Energy Storage System

5) days of autonomy	0.6	days
6) allowed DoD	80	%
battery bank size	3803	kWh
7) dollar per kWh	400	$/kWh
cost	$1,521,000	

Inverter System

inverter size	250	kW
8) inverter price per watt	0.2	$/W
cost	$50,000	

total cost	$2,398,500	
time to recoup	0.3	years

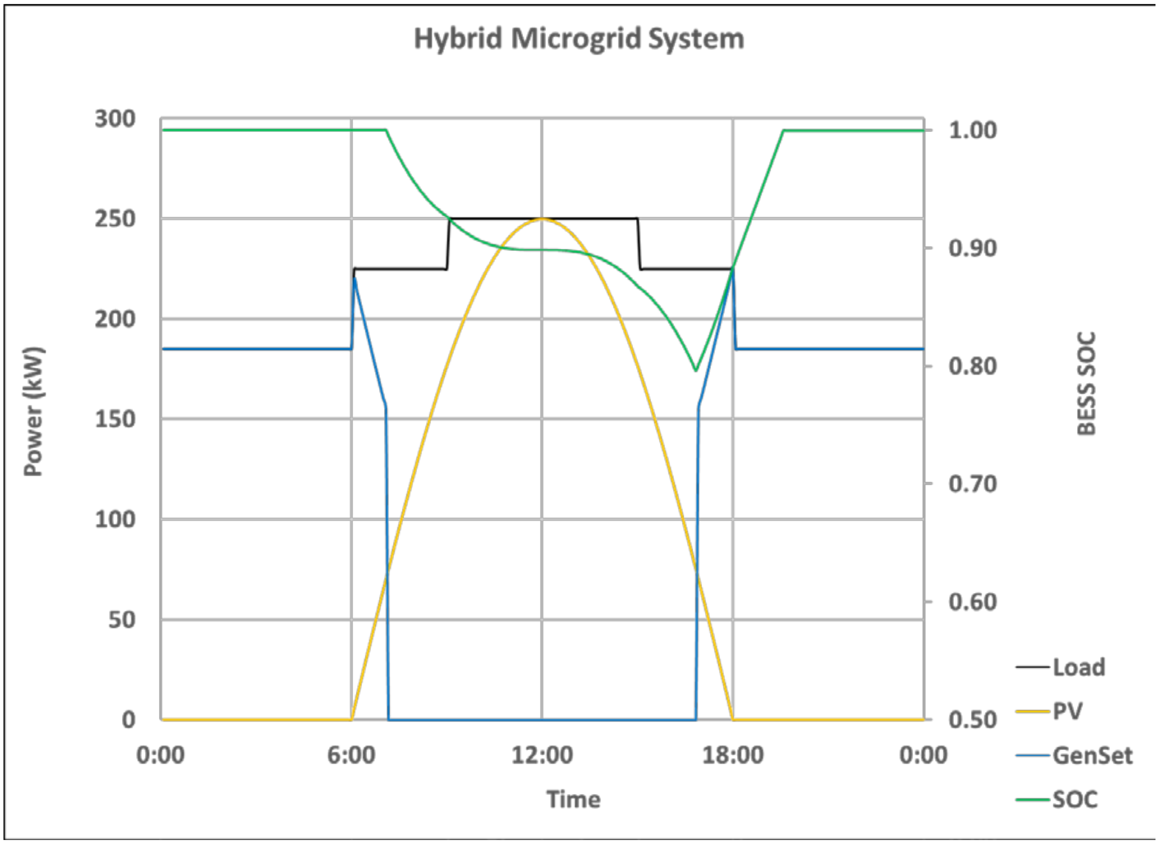
Adapted from: Optimizer Tool provided by Connor Wicker (email to author, October 1, 2020)

Figure 7. Optimizer Tool Inputs/Outputs

For the purpose of this project and the analysis of return on investment, the following inputs were utilized:

1. Peak wattage of the system: 300kW
2a. Size of generators: 60kW
2b. Number of generators : 5
3. Cost of fuel: $100/gallon and $600/gallon
4. Cost per watt of the solar array: $3.31 per watt
5. Days of autonomy needed from the battery energy storage device: .6
6. Allowed DOD for the battery energy storage device: 80%
7. Dollars per kW hour for the battery energy storage device: kept at $400 per kWh
8. Inverter price per kW hour: kept at 20 cents per watt

Figure 8 allows a decision-maker to see where power was produced from during the day. This tool could be used to analyze times of risk during certain times of the day or allow for an understanding of trade-offs that may have to happen. The chart is read by kW hours on the left X-axis and the Battery Energy Storage System State of Charge (BESS SOC) on the right Y-axis. When reading the chart, the green line is read from the right Y-axis while the load, P.V., and Gen Set are read from the left Y-axis.



Adapted from: Optimizer Tool provided by Connor Wicker (email to author, October 1, 2020)

Figure 8. Optimizer Tool Visualization of Power Production Requirements

Figure 8 shows that the load (black line) remains generally constant throughout the evening after 1800 when activities that draw more power, like meal preparation, have begun to wind down and the temperature begins to cool. The cooling off in summertime will mean that the environmental control units (ECUs, that is, large heating and air conditioning units) will begin to have to turn on less often to maintain temperature in the tents. The load will remain constant until early meal preparation begins, and people start waking up at 0600. It is acknowledged that this representation of a load profile is an estimation and may not be representative of all FOBs. In order to get a more accurate load profile, an engineer would need to measure loads for the size of the FOB being constructed and take into account every piece of equipment that would draw power from the grid.

The PV (yellow line) shows that from 1800–0600, no power is generated from the photovoltaic cells. However, at 0600, a gradual increase in power produced ramps up until it peaks at 1200 before gradually decreasing back to zero energy produced at 1800. It is acknowledged that this is an estimation, that actual production will be based on latitude, and that actual times for production and the duration of production will vary.

GenSets (blue line) shows that the generators are running from approximately 1700–0700 while providing some peak power between 0600–0700 and 1700–1800. Through the night, the GenSets utilize excess power produced to recharge the batteries that bridge the gap caused by PV not having reached optimal power production, and when the GenSets turn off in the morning and afternoon.

State of Charge (SOC; green line) graphs the time when the battery system is being used and power depleted from the battery's reserves and when it is being recharged by the generators in the evening. The green line also reveals how far the battery's energy stores are depleted, also known as the state of charge.

Utilizing this tool, it is estimated that the generator usage will decrease from 24 hours to 16 hours if a solar/battery system is implemented. That equates to a reduction in gallons per month used to 220.38, which translates to 55.09 pallets of fuel needed per month, , which equates to 3.44 flights per month. That is a significant reduction in the amount of fuel need to sustain the FOB. With the direct correlation to the reduction of fuel compared to the number of resupply missions, a reduction in the risk to force can be inferred.

3. Waste Stream

While the predominance of this project is focused on the amount of fuel consumed, other considerations play a large part in how to resupply a FOB effectively. Depending on the type of storage for fuel at the FOB, there can be considerably different second-order effects with which to deal.

Fuel storage can be broken down into two categories. The first is bulk storage, which utilizes either tanks or fuel bladders. The second is smaller storage containers like 55-gallon drums. Each comes with a set of pros and cons.

Bulk storage is preferred when the equipment and resupply methodology allow for the delivery of bulk fuel. However, for hard to resupply FOBs where delivery by air is required, it may not make logical sense.

Small storage containers are the predominance of the focus throughout this project. It comes with some unique considerations that must be planned for. Specifically, the waste stream that is produced when sending 55-gallon drums to a location. It creates two scenarios for dealing with the waste stream. The first option is to retrograde all the barrels. The second is to dispose of them on site.

Retrograding the barrels is not ideal because it increases the number of logistics convoys, thus increasing the risk to force. In light of the relatively low cost for the container compared to transport, it generally does not make sense to retrograde.

Since retrograding is not ideal and sometimes impossible due to terrain, disposal on site must be considered. This method of dealing with the waste stream comes with its own unique set of problems.

The 55-gallon drums come in either plastic or metal. With plastic, the destruction of the drums would most likely be achieved by burning them in an open-air burn pit. While an effective way to reduce the drum down to something that can be varied, this method naturally has health concerns. Toxic fumes from burning the barrels make it less than ideal, but necessary.

With metal, it is much harder to destroy the barrels. Digging a pit to bury the barrels whole is one option to dispose of them. Another option is cutting them into pieces and still burying them. The sheer volume of barrels coming in will have the pit size grow rather large, especially if the FOB has an enduring presence.

To understand the sheer volume of waste generated from power generation alone, consider that the status quo requires 331 55-gallon drums per month, or 83 pallets worth of drums.

If SiB is implemented, the waste stream reduction is approximately 50%, which would reduce the monthly use of 55-gallon drums to 165 per month, which is a significant decrease in the overall waste stream that the FOB will have to dispose of. It will also help reduce the overall signature of the FOB through reducing the size of the burial pit, if the drums are metal, or the visibility of the smoke plume from burning, if the drums are plastic. It is also true that plastic drums can be buried or crushed or buried . However, the easiest method of destruction is burning.

4. Casualties

For the discussion of a potential reduction in casualties associated with reducing the resupply periodicity, an acknowledgment of the commonly used phrase that "correlation does not equal causation" must be recognized. This is not to discount the data but merely to acknowledge the potential fallacy of the argument. It appears that the assessment of casualties when overlayed on the amount of fuel delivered and the number of convoys attempted is sound. Thus, this data is used to establish a possible reduction in the risk to force by means of casualty reduction.

At the status quo, with the assumption that one aerial resupply is equivalent to one logistics convoy, there would be one casualty every 144 days. This number was derived from the sustainment periodicity of resupply every six days. Given the casualty factor of one casualty per 24 mission (24 times six) gives the outcome of one casualty every 144 days. Per year, that equates to 2.5 casualties.

5. Cost of Life

The value of a life was obtained by averaging estimates, across multiple government agencies estimates(Silny et al., 2010). This average is $4.5M, with the low value of $3M and the high limit of $6M in unadjusted dollar figures from the 1970s, which have never been adjusted for inflation. Silney et al., acknowledged that there are other figures that are drastically lower and even more drastically higher. However, they focused on the government agencies to establish the value of life, rather than from outside- the-government sources.

While casualties were discussed before, a specific discussion on the effects of the reduction in casualties when compared to different values for the cost of life is important. The following analysis intends to address the variations in casualties per number of convoys as compared to the cost of life at varying levels. As discussed in the Methodology section, there is a range of values associated with the loss of a life. Thus, sensitivity analysis, across a range of values, should be considered in order to make the best recommendation. While the baseline casualty rate was established at one for every 24 resupply missions (Army Environmental Policy Institute, 2009), it is acknowledged that in reality the assessment of potential risk reduction is not a single, fixed number. Rather, it is an intricate problem set that would require an in-depth analysis of how different variables (for example, how reducing periodicity of resupply missions could reduce the exposure to enemy forces, or could reduce the enemy's ability to forecast when a resupply mission will happen, or could allow combat operations more time between resupplies to limit the enemy's effectiveness) could impact the casualty-per-resupply convoy rate.

Table 5 table compares annual cost of logistics resupply mission casualties, for a standard FOB, for three values of life ($3.0M, $4.5M, and $6.5M) in the Status Quo case and in the Solar in a Box (SiB) case. Each cell represents the number of annual casualties multiplied by the cost of life, for the Status Quo or the SiB case. The last row displays the net savings associated with implementing Solar in a Box.

Table 5. Time to Payback Acquisition of Solar in a Box

Cost of Life/Person	**$3M**	**$4.5M**	**$6.5M**
Status Quo	7.60M	11.41M	16.48M
SiB Implemented	3.80	5.70	8.24
Net Savings, Life	**$3.80/year**	**$5.70M/year**	**$8.24M/year**

Table 5 shows the following:

- Implementing Solar in a Box at the lowest estimated cost of life exceeds savings of nearly $700k within the first year ($4M minus the purchase price of $3.3M equals savings of $700k), while continuing to provide a net savings of approximately $4M for follow on years.
- If the average or higher cost of life figure is used, the purchase price of Solar in a Box ($3.3M) is significantly exceeded (actually by a two-three-times factor), as shown in row four, columns three (where the value is 6) and in row four, column four (where the value is 8).

Table 5 shows that implementing SiB makes fiscal sense. While dealing with the cost of life, it is acknowledged that this dollar figure does not capture all of the intangibles associated with losing a service member in a deployed environment. Some of these intangibles include the continuation of erosion of public sentiment for war or contingency environment, emotional damage done to the family and extended family of the service member, and the "bragging rights" that the enemy gets from claiming another enemy killed in action.

Net savings are represented below as the gap between the total cost of casualties between Status Quo and SiB cases. As expected, net savings increase more sharply as the value of life increases.

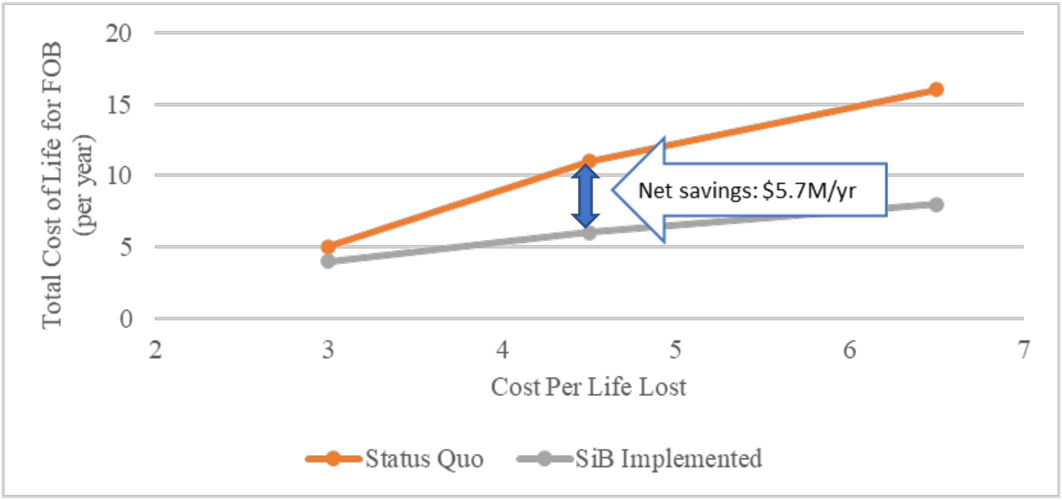


Figure 9. Value of Life for Casualties ($M)

C. FUEL USAGE REDUCTION SAVINGS

While the savings in the cost -of- life- analysis above already validates the purchase of SiB further savings can been achieved through the reduced fuel requirements, when factoring in the Fuel Burdened Cost of Fuel (FBCF). It is understood that in order to reduce the cost of lives lost, the number of resupply convoys must be reduced, and that reduction would result from reducing overall fuel usage.

Another way to do this analysis is through break-even analysis. Table 6 shows the number of days needed to recoup the purchase price of SiB when fuel is valued at three levels of FBCF in the $100-$600 per gallon range. The three levels are the minimum, mean, and maximum provided by the JASON Group's assessment of the FBCF (Dimotakis et al., 2006).

Table 6. Time to Recoup Solar in a Box Investment

FBCF/gallon	Time in Days
100	98
350	28
600	16

Table 6 shows that the break-even point is shortest (under a high FBCF of $600/ gallon) at just over two weeks, and longest (under a lower FBCF of $100) at just over three months. In any of these cases, viewed under break-even analysis, SiB is a very attractive alternative.

In order to visualize the time needed to recoup the initial investment of SiB, Figure 10 shows the time in days to recoup when utilizing the FBCF of $100, $350, and $650 per gallon.

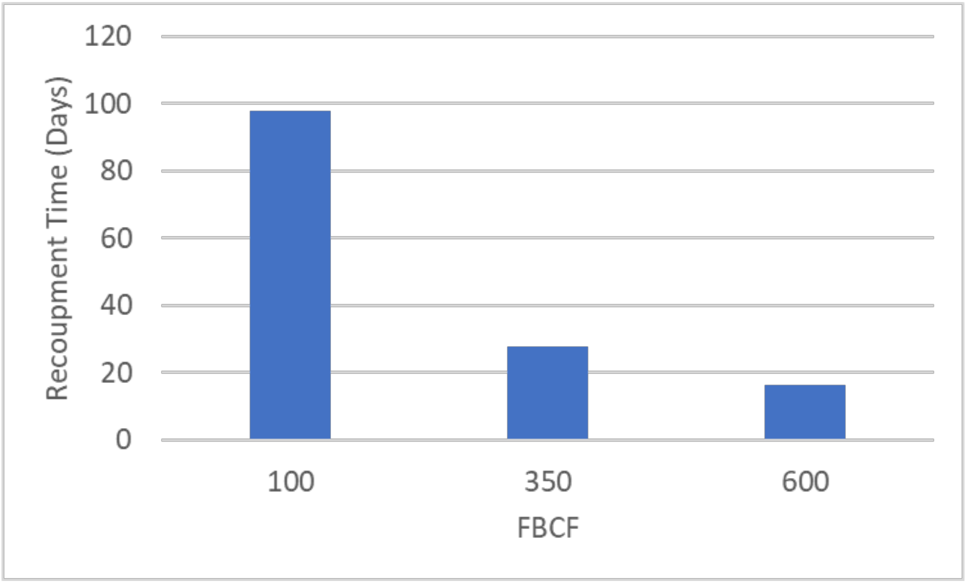


Figure 10. Time to Recoup Investment in SiB

Figure 10 shows the declining days required to recoup the initial investment of SiB when calculated against the minimum, mean, and maximum FBCF. In essence, in the time it takes to get this paper published, this technology could have paid for its initial acquisition costs in FBCF savings alone. That assessment makes a clear statement that implementation should be pursued.

D. RESUPPLY PERIODICITY

Utilizing the consumption rate of fuel established in Table 2, the resupply periodicity of every six days on the status quo FOB was established by taking the amount of fuel consumed (210,240 gallons per year) and dividing that by 53 (number of gallons of fuel in a 55-gallon drum) which gives 3,976 drums per year needed. Since four 55-gallon drums fit on one standard pallet, that equates to 992 pallets per year, or just under 83 pallets per month. With the 16-pallet standard for a C-130 CDS airdrop outlined in this project, that is just over five drops per month, as outlined in Table 3. That means that every six days, the sky near the FOB is littered with 16 parachutes (for fuel for generators alone and not including the food, water, or fuel for other things on the FOB).

However, if SiB is implemented, the total fuel usage for the year drops from 210,240 gallons to 85,885 gallons. This in turn reduces the number of 55-gallon drums used from 3,976 to 1,620. With the 4 drum per pallet standard, that reduces the number of CDS bundles per year from 992 down to 450. In turn, this reduces the number of CDS airdrops from one every 6 days, to one every 12 days, effectively doubling the time between airdrops. By doubling the periodicity between airdrops, that effectively cuts the overall signature of the FOB, when only considering the visibility of airdrops, in half. It is acknowledged that signature management of a facility like a FOB is much more complex than just how many airdrops occur. However, every reduction in the visibility of the FOB from outside the FOB helps, especially in something as visible as airdrops.

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V. OBSERVATIONS

A. STATUS QUO

While it is easy to keep the status quo because the support processes and practices for acquisition of equipment and sustainment of fossil fuels is already in place, that should not deter from seeking a more efficient way of supporting the warfighter. With the casualties attributable to sustaining life on a FOB, it seems intuitive to try to reduce that risk by reducing the cause of the risk. If the predominance of casualties come from sustainment during ground convoys, and 50% of the cargo in a convoy is fuel, then reducing that sustainment periodicity would naturally reduce the casualties associated with the FOB.

B. OPTIMIZER TOOL

The implementation of solar coupled with a battery storage device appears to offer significant cost savings when considering the FBCF, as well as reduction in the risk to force and risk to mission. The Optimizer Tool could be further developed to allow program managers to analyze potential trade-offs for cost savings. With only a few basic inputs, it could be utilized by the customer requesting a governmental contracting action to purchase equipment as a way to establish a government cost estimate.

With the input variables being user -controlled, the tool is flexible enough to be used in tabletop exercises where size of a system, days of autonomy (where the battery system is the only means of providing energy), and varying fuel costs can be war-gamed to establish the best cost benefit tradeoffs. As the price of solar, battery storage, and the inverter change, the input variables can be changed to account for the price fluctuations and thus provide a more real time tabletop exercise.

C. SOLAR IN A BOX

Given the example of PowerHop System from SacTec Solar as a representation of SiB, it seems clear that offsetting fuel consumption with the production of power through both photovoltaic and lithium batteries can save both money and lives.

As an option to test real-world implementation, a combination of PowerHop Systems could be purchased and programed for test and evaluation in a garrison or deployed environment. This would allow us to accumulate actual (rather than estimated) ownership costs of an active FOB. With the system already developed, a test and evaluation cycle of a year could prove beneficial to moving toward the reduction in fuel consumption and the risk to force.

Through calculations made in the analysis chapter, significant savings can be realized by the reduction in the use of fuel alone. With the Powerhop System purchase price being recouped through savings in 16 - 98 days, there is evidence to conclude that a SiB concept is fiscally attractive.

As an extension of the fiscally responsible discussion, when considering the cost of a loss of a life associated with resupplying a FOB, the same conclusion can be made when considering the expected reduction in the loss of life through reducing resupply periodicity. Within a year, even at the lowest dollar figure assigned to value-of-life, the acquisition costs were recouped by reducing the loss of life. As discussed in the analysis, this does not consider intangibles benefits of saving those lives such as the return home of another husband, wife, father, mother, son or daughter.

VI. RECOMMENDATIONS

Implement a Sib-type system to reduce FOB reliance on fossil fuels. Existing technology, detailed in the thesis, in the form of, e.g., a PowerHop System, can reduce the generator run time by at least 50%, which will have the second order effect of reducing periodicity of resupply, which, in turn reduces logistics-linked casualties. The tertiary effects will be reducing overall signature of the FOB and the waste stream associate with the containers necessary to resupply the FOB.

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LIST OF REFERENCES

AcqNotes. (2018). *JCIDS process DOTMLPF-P analysis*. http://acqnotes.com/acqnote/acquisitions/dotmlpf-analysis

Army Environmental Policy Institute. (2009). *Sustain the mission project: Casualty factors for fuel and water resupply convoys*. https://apps.dtic.mil/sti/pdfs/ADB356341.pdf

Department of Defense. (2011). *Energy for the warfighter: Operational energy strategy*.

Department of Defense. (2018). *Summary of the 2018 national defense strategy of the United States of America*. https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf

Department of the Army. (2016). *Aerial Delivery*. https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ATP%204-48%20FINAL%20WEB.pdf

Dimotakis, P., Grober, R., & Lewis, N. (2006). *Reducing DOD fossil-fuel dependence*. Defense Technical Information Center. https://doi.org/10.21236/ADA457233

Franco, N. (2019, April). *Fuel convoy*. https://www.dvidshub.net/image/5852733/fuel-convoy

Greenley, H. L. (2019). *Department of Defense energy management: Background and issues for congress*. Congressional Research Service. https://fas.org/sgp/crs/natsec/R45832.pdf

JASON (advisory group). (2020). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=JASON_(advisory_group)&oldid=971357676

Joint Chiefs of Staff. (2016). *Department of Defense dictionary of military and associated terms (JP 1-02)*. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/dictionary.pdf

Joint Chiefs of Staff. (2017). *Joint bulk petroleum and water doctrine (JP 4-03)*. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp4_03pa.pdf?ver=2018-02-08-091424-107

Joint Chiefs of Staff. (2019a). *Air Mobility Operations (JP 3-17)*. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_17.pdf

Joint Chiefs of Staff. (2019b). *Joint logistics. (JP 4-0)*. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp4_0ch1.pdf?ver=2020-07-20-083800-823

Myers, T. A., & Hayes, A. F. (2010). Reframing the Casualties Hypothesis: (Mis)Perceptions of Troop Loss and Public Opinion about War. *International Journal of Public Opinion Research*, *22*(2), 256–275. https://doi.org/10.1093/ijpor/edp044

Pike, J. (2000). *C-130 Hercules—Military aircraft*. https://fas.org/man/dod-101/sys/ac/c-130.htm

Roscoe, S. A. (2010). *A comparison of the fully burdened cost of fuel methodologies employed across the Department of Defense* [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://apps.dtic.mil/sti/pdfs/ADA531502.pdf

SacTec Solar. (2020). *Mobile Smart Energy, SacTec Solar Brochure*. http://www.sactecsolar.com/contact-us/

Silny, J. F., Little, R. J., & Remer, D. S. (2010). Economic survey of the monetary value placed on human life by government agencies in the United States of America. *Journal of Cost Analysis and Parametrics, 3*(1), 7–39. https://doi.org/10.1080/1941658X.2010.10462226

Steele, D. (2015). Powering soldiers. *Association of the United States Army*. https://www.ausa.org/articles/powering-soldiers

Vitali, J. A., Lamothe, J. G., Toomey, jr, C. J., Peoples, V. O., & Mccabe, K. A. (2018). *Mobile nuclear power plants for ground operations*.

Walker, U. (2017, April). *No roads? No problem with supplies from above*. No roads? No Problem with Supplies from Above

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