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SLB-STO-D ANALYSIS REPORT: MODELING AND SIMULATION ANALYSIS OF FUEL, WATER, AND WASTE REDUCTIONS IN BASE CAMPS: 50, 300, AND 1000 PERSONS

by

Gregg S. Gildea
Paul D. Carpenter
Benjamin J. Campbell
Joseph Quigley
Josue Diaz
Janet Langley

Nathaniel Putnam*
Brendan Hargreaves**
Kate Donahue**
Wayne Lindo**
William F. Harris***
José A. Miletti****

***US Army Corps of Engineers – Engineering Research Development Center –**
Construction Engineering Research Laboratory
Champaign, IL 61826-9005

****Booz Allen Hamilton**
Westborough, MA 01581

*****General Dynamics Information Technology**
Fairfax VA 22030

******Battelle Memorial Institute**
Columbus, OH 43201

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Gregg S. Gildea, Paul D. Carpenter, Benjamin J. Campbell, Joseph Quigley, Josue Diaz, Janet Langley, Nathaniel Putnam*, Brendan Hargreaves**, Kate Donahue**, Wayne Lindo**, William F. Harris***, and José A. Miletti****

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U.S. Army Natick Soldier Research, Development and Engineering Center
ATTN: RDNS-TSI
15 General Greene Avenue, Natick, MA 01760-5000

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*US Army Corps of Engineers - Engineering Research Development Center – Construction Engineering Research Laboratory, 2902 Newmark Drive, Champaign, IL 61826-9005
**Booz Allen Hamilton, 1 Technology Drive, Suite 210, Westborough, MA 01581
***General Dynamics Information Technology, 3211 Jermantown Road, Fairfax, VA 22030
***Battelle Memorial Institute, 505 King Avenue, Columbus, OH 43201

14. ABSTRACT
This report documents the efforts of the U.S. Army Natick Soldier Research, Development and Engineering Center's Sustainability/Logistics-Basing -Science and Technology Objective – Demonstration to analyze the results of modeling and simulation of materiel and non-materiel options to reduce Fuel, Water, and Waste in 50, 300, and 1000 Persons Base Camps. This analysis report captures conclusions, insights, and recommendations to assist the Army Leadership in making informed decisions regarding the implementation of materiel and non-materiel options to save fuel, water, and waste in base camps.

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SAVINGS
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SOLID WASTES
ENVIRONMENTS
WATER QUALITY
ELECTRIC POWER
SUSTAINABILITY
ARMY PERSONNEL
WASTE DISPOSAL
DEMONSTRATIONS
WASTE REDUCTION
RENEWABLE ENERGY
CONTINGENCY BASES
BCIL(BASE CAMP INTEGRATION LABORATORY)
TECD(TECHNOLOGY ENHANCED CAPABILITY DEMONSTRATION)
REDUCED FOOTPRINT
EXPEDIENT SHELTERING
FUEL DEMAND REDUCTION
WATER DEMAND REDUCTION
FORWARD OPERATING BASES
MODELING AND SIMULATION
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EXECUTIVE SUMMARY

The report covers work done for the Sustainability Logistics Basing – Science and Technology Objective – Demonstration (SLB-STO-D) [1] from the period of January 2012 to July 2017.

The SLB-STO-D is an ambitious, highly collaborative Department of the Army-approved program that addresses one of its top challenges: to enable sustainment independence at contingency bases by reducing resupply and backhaul demand. The Army's need to reduce the sustainment demands at base camps is driven by the imperative to minimize the number of resupply convoys and associated ground and air protection. The results will allow contingency base camps to become more efficient with fewer resources needed for sustainment functions with more mission capable Soldiers. The combined fuel and water resupply savings and waste reduction will reduce resupply convoys and keep more troops off the road as a result of fewer convoys, with a significant decrease to Soldier threat hours associated with resupply with the ultimate goal of saving lives. In addition, the rising costs of resupplying expeditionary forces and waste backhaul (i.e., fuel and water consumption and waste generation) will be greatly diminished. Additional information can be accessed at https://www.youtube.com/watch?v=SGDVBDzY3t4.

The interim Army goals (FY12 through FY17) for this effort are to demonstrate the possibilities for optimized integrated non-materiel and technology solution sets to meet the objectives of reducing fuel resupply need by 25%, water resupply need by 75%, and decreasing waste amounts generated by 50%, while maintaining Soldier Operational Quality of Life (QoL(O)) at contingency bases with 50 to 1000 personnel. These programmatic goals are collectively known as fuel, water, and waste (FWW) reductions in base camps. To evaluate the accomplishment of FWW programmatic goals, baselines of fuel and water consumption and wastewater generation were established for the time that the program started in FY12. This resulted in the creation of a FY12 Operationally Relevant Technical Baseline (ORTB), which serves as the basis to compare how potential implementation of post-FY12 materiel and non-materiel solutions contribute to the advancement of the FWW savings goals.

The FY12 ORTB is based on the FY12 base camp equipment used at the inception of the SLB-STO-D program. The SLB-STO-D's problem space was defined in 50, 300, and 1000 personnel (PAX) representative baseline base camps and the applicable operational use-cases. Relevant data and documentation were used to support resource simulation at the three representative baseline base camps in desert, temperate, and tropical expeditionary environments. The FY12 ORTB base camps were simulated and the results, the FWW resources required to operate the FY12 base camps, were published in a report entitled: *Analysis of FY12 Operationally Relevant Technical Baseline* [1].

This report covers the simulation results and analysis of FWW resource optimized 50, 300, and 1000 PAX base camps where numerous integrated materiel and non-materiel solution set options

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[1] Formerly known as Technology-Enabled Capability Demonstration 4a (TECD 4a) Sustainability Logistics-Basing.

are implemented to determine FWW savings as compared to the FY12 ORTB base camps. The majority of the data to support the modeling and simulation for this effort were acquired with the completion of five comprehensive integrated operationally relevant demonstrations in FY15 and FY16 with a total of 37 technologies being demonstrated. The primary purpose of the simulation results and analysis contained in this report is to provide decision-makers with pertinent data concerning potential FWW savings and identifying the impacts of the integration of various materiel and non-materiel solutions into the base camp. The secondary purpose of the analysis is to provide insight from the functional breakdown of the resource usage to guide the development efforts of materiel solutions and the implementation of non-materiel options. The analysis will also assist in identifying functional areas with significant contributions to the overall FWW resource savings of the base camp, which in turn will provide insights into future technology investments.

Key insights of this analysis are:

- Resource reduction at base camps can have a meaningful impact on the safety of Soldiers. An initial operational effectiveness analysis was conducted and showed that meeting (not exceeding) the SLB-STO-D’s target metrics to reduce fuel and water resupply showed a decrease of 39.5% of convoys and 47.8% of transport trucks in convoys. This equated to a 52.8% reduction in threat exposure hours, a reduction of over 489,000 hours over a 180-day period. Including the reductions in solid and liquid waste would provide even greater savings.
- Water is the largest resource transported to a base camp in terms of volume. Solutions that reduce the need for potable water to be transported to and gray and black water transported from the base camp play a significant part in meeting the SLB-STO-D’s overall logistic reduction metrics.
- Materiel solutions play a key role in all integrated solutions that meet the objective measures. Although non-materiel solutions alone can meet the 25% reduction in fuel and 50% reduction in waste water, most have a major negative impact on QoL(O). Non-materiel solutions alone cannot meet the objective metrics related to potable water and solid waste.
- The bulk of the fuel, potable water, and waste reductions were the result of a limited number of technologies: microgrids, gray water recycling, and waste-to-energy converters. These three capabilities played a vital role in the achievement of the SLB-STO-D program objectives and are some opportunities for further development. Note, waste-to-energy converters produce a large continuous power output which must be coupled to a microgrid or very large energy consumer.
- Non-materiel courses of action may not have as great an impact following the implementation of certain technologies. For example, on a base camp with gray water recycling and low-flow showerheads, reducing shower times has a much smaller impact on water savings. Conversely, the resource cost for increased shower times is lessened.
- Power generation is the main driver of fuel consumption, even after optimizing the base camp for resource consumption and production. Options that enable reallocation of power generation to eliminate entire generators have a much larger impact on fuel consumption than those that just reduce overall power demand. In this way, materiel options with lower peak power demands can provide significant fuel savings even if their average

power consumption is equal and the implementation of microgrids can enhance the fuel savings of small power savers. Non-materiel options offer a significant increase in benefit if they enable a reduction in generator count.

- After water saving options are implemented, latrine water usage is reduced considerably, but shower facilities still consume the most potable water of any facility on the base camp. Water consumption by the kitchen and maintenance facilities both increase as a proportion of total water used, making them future areas to target.
- Both waste water and solid waste can be greatly reduced using a single materiel solution each with only a minor impact on the fuel consumption.
- Geographic realities present a significant burden on implementing the minimal number of systems. Microgrids are limited by low power density and geographic sprawl. Water systems are limited by the need to collocate water consumers, waste water producers, and waste water systems. To provide fully integrated water and waste water management at a base camp, careful consideration must be given to system size and the layout of the camp. Oversized systems require the centralization of facilities or the transporting of resources around the camp. Smaller systems enable easier implementation into existing camp designs, but require more equipment.

The SLB-STO-D's objectives are a great start towards achieving the Army's vision of a Net Zero base camp. This analysis showed that to attain self-sustainability, several areas remain to be addressed:

- Army regulations may prove to limit self-sustainability. Doctrine limits gray water recycling systems to recycling 80% of the source water and prohibits the recycling of black water. Water must not be eliminated unnecessarily from the base camp ecosystem. Loosening these regulations and expanding water recycling programs provide an avenue for centralized reduction in potable water consumption and waste production without the need to address the many small consumers and producers on the base camp. As water must be replenished, water collection systems or Water from Air (WFA) will play a key role in regenerating the water supply.
- Noncombustible waste must be addressed at the source. A greater holistic approach could be benefited from by ensuring a sustainable total life cycle management of the source material prior to the material entering the base camp. While waste-to-energy conversion transfers solid waste into a positive resource, its efficiency is highly dependent on the amount of noncombustible waste in the stream. Eliminating this noncombustible waste prior to reaching the base camp will be required.
- Renewable energy can have a meaningful impact on power consumption, but the space required for large scale implementation with current efficiencies reduces its possibility. Technologies that increase efficiencies and the incorporation of renewable energy without requiring additional space, such as through solar shades, can help to achieve self-sufficiency. Because distributed small scale renewable energy systems do not allow for the elimination of generators, their impact on fuel is diminished. Integration of these distributed systems may prove to enable larger fuel savings.
- Energy storage systems will be required to enable renewable energy and further the efficiency of microgrids. Renewable energy is limited to certain times of day—solar panels only produce power when the sun is out, turbines only produce power when there

is wind, etc. For these sources to be fully utilized, energy storage systems sized for base camps must be implemented. The future investments in energy storage systems can continue to address the logistical challenges that come along with those systems, such as weight and safe transportation. Further, the intelligent interaction of energy storage systems and microgrids will enable efficiency features such as peak shaving, load leveling, and the reduction of spinning reserve capacity.

- Black water cannot be eliminated from the base camp ecosystem. Black water is currently an untapped resource on the base camp, with current regulations making it a liability with no potential benefit. Research and development into safe recycling systems for black water combined with identifying safe uses for recycled black water will reduce the demand for water resupply.
- Recycling gray water for potable water may eliminate the need to bring fresh potable water to base camps via convoy or the costly generating of fresh potable water onsite. Current implementations of gray water recycling systems produce non-potable water that is limited to use in facilities such as showers and laundry. Facilities such as dining facilities and aid stations cannot use this recycled water. By developing systems that produce potable water, the product water could be used for all purposes on the base camp.
- Power distribution technology for tactical generators must be improved to fully realize the potential of microgrids. Grid stability and reliability is critical to ensuring mission success when deployed and realizing the full benefits that a microgrid provides. Microgrids are limited by low power density and geographic sprawl, since current power distribution systems (i.e., Power Distribution Illumination Systems, Electrical (PDISEs)) have limited cable lengths over which voltages can be maintained. This is particularly evident when connecting a waste-to-energy converter to a microgrid, because they are typically located away from other camp facilities. To fully utilize a microgrid and minimize the number of microgrids needed, power must be able to be distributed beyond the current capability. Furthermore, intelligent power management and distribution systems could provide a significant impact that would increase security, agility and adaptability of the power systems to enable the Solder to efficiently transmit/transfer power from source capabilities to load requirements.

This report captures a recommendation for the Army to continue to focus on the research and development efforts related to sustainment technologies that demonstrated a large potential impact to reduce FWW to ensure these technologies develop into fielded capabilities.

Moreover, while fuel and water consumption, waste generation, and QoL(O) are key metrics in the design and sustainment of a base camp, several other attributes contribute to the success of base camps. These attributes include reliability, availability, maintainability, cost, manpower, complexity, footprint, and many others. A companion report entitled *Selected Technology Assessment* [1] explores the impact of the aforementioned attributes and the implications of implementing selected technologies in base camps.

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SUSTAINABILITY LOGISTICS-BASING SCIENCE AND TECHNOLOGY OBJECTIVE – DEMONSTRATION

SLB-STO-D ANALYSIS REPORT

MODELING AND SIMULATION ANALYSIS OF FUEL, WATER, AND WASTE REDUCTIONS IN BASE CAMPS: 50, 300 AND 1000 PERSONS

1 INTRODUCTION

The Sustainability Logistics-Basing Science and Technology Objective – Demonstration (SLB-STO-D) objectives are to reduce fuel resupply by 25%, water resupply by 75% and waste generated for backhaul by 50%, while maintaining adequate levels of Operational Quality of Life (QoL(O)). This technical report describes the SLB-STO-D analysis purpose, approach, and methodology used that yielded the modeling results towards the objective goals. The modeling results when compared to the FY12 base camp baselines (50, 300, and 1,000 personnel (PAX)) will show if the generated results achieved the SLB-STO-D's objectives.

Sections 1.1 and **1.2** describe in detail the previously mentioned objectives and the purpose of generating this report.

Chapter 2 describes in detail the analysis purpose and approach used to determine the metrics of fuel and water consumption, waste generation, and QoL(O) that the Targeted Reduction Base Camp will achieve. This chapter also describes the approaches taken to determine which materiel and non-materiel options are to be included in the analysis documentation, data, and the modeling and simulation tools that were used for the analysis.

Chapter 3 identifies the options and categories that could contribute to the SLB-STO-D's program objectives to reduce the need for fuel resupply by 25%, reduce the need for water resupply by 75%, and decrease waste generation/backhaul by 50% while maintaining QoL(O) at the base camp. In this chapter, materiel and non-materiel options were broadly categorized by the three major program objectives: fuel reduction, potable water reduction, and solid and liquid waste reduction. Options were discussed according to their primary function, and also discussed when they overlapped other categories. The holistic approach methodically examined both materiel and non-materiel categories of fielded equipment and Tactics, Techniques, and Procedures (TTP) changes after FY12 and discussed the performance of the individual technologies and the non-materiel solutions.

Chapter 4 investigates how pairs of technologies and/or TTP solutions interact and how their interactions affect base camp resource consumption. It also investigates the effects that the technologies and non-materiel solutions will have in favor or against each other. The chapter also examines the synergistic (i.e., producing greater savings), and antagonistic (i.e., producing less savings) effects the materiel and non-materiel potential solutions have on each other when integrated. Lastly, the chapter goes beyond purely synergistic or antagonistic effects and broadly explores the ways technologies on camp can impact TTP methods of reducing resource usage and the repercussion to QoL(O) and the possible trade-offs.

Chapter 5 investigates resource optimized base camp designs with integrated solution sets of multiple technologies and/or non-materiel solutions to meet program objectives. The chapter examines integrated base camp designs that strive to meet the SLB-STO-D's target reductions. To accomplish these reductions, the base camps were constrained in the same way the FY12 Operationally Relevant Technical Baseline (ORTB) Base Camps were constrained. The camps were structured to meet the SLB-STO-D's use-cases, both the ready state and population variance, to be arranged in an operationally relevant manner, and to meet the same level of services provided at the FY12 ORTB Base Camps.

The report ends with **Chapter 6** focusing on conclusions and insights, and **Chapter 7** covering recommendations. The final chapter is followed by a list of references and a list of acronyms. The report also has four annexes and links to other documents.

1.1 Sustainabilty Logistics Basing-Science and Technology Objective-Demonstration (SLB-STO-D) Program

Contingency bases are highly dependent on resupply, which can be unpredictable, place Soldiers at risk in convoys, and impact mission readiness and execution. It is too costly and labor intensive for a small unit (platoon, company, and battalion) to transport and maintain all required consumables (fuel and water) to last for weeks or months at small base camps. To further compound the problem, Army maneuver units have limited or no organic basing capability and rely on theater-provided support to meet their sustainment requirements. Moreover, except for Force Provider, the preponderance of theater-provided equipment/support is not standardized, integrated, or optimized to be easily deployed, transported, or erected and is inherently inefficient.

The challenges delineated above, the increasing sustainment costs, and hostile threats to resupply convoys compelled the Army to recognize the need to reduce sustainment demands at contingency bases. To this end, in 2011, the US Army, Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology charged the Research, Development and Engineering Command (RDECOM) with conducting a Technology Enabled Capability Demonstration (TECD) 4a – Sustainability Logistics – Basing (SLB) program to develop, collaborate, and execute a program that would address these sustainment challenges. Subsequently, the TECD 4a was reprogrammed and renamed SLB-STO-D. Except for the name change, the scope and integrity of the program remained unaltered.

The following frames the problem statement of the SLB-STO-D program:

> *The Army needs improved capability to enable sustainment independence by reducing resupply and backhaul demand at contingency basecamps. The FY12 to FY17 objective is to reduce the need for fuel resupply by 25%, reduce the need for water resupply by 75%, and decrease waste generation/backhaul by 50%, while*

> *maintaining a Force Provider like Operational Quality of Life (QoL(O)) at these basecamps.*

The statement defines the problem space which forms the basis for the program and lays the foundation for the formulation of the execution plan and resource allocation.

To resolve the challenges of the problem space, the SLB-STO-D formulated a tailored Model-Based Systems Engineering (MBSE) approach for materiel and non-materiel solutions to address Army contingency basing fuel, water, and waste (FWW) reductions as defined in the problem statement. To this end, the SLB-STO-D program uses modeling, simulation, and analysis to demonstrate the stated reduction in FWW. The reductions will be achieved through the implementation of materiel and non-materiel solutions that are compared to an FY12 ORTB Base Camp, which establishes a point of comparison of FWW for 50, 300, and 1,000 personnel base camps. The examined camps are considered small contingency bases and are the focus of the SLB-STO-D program. Additional information can be accessed at https://www.youtube.com/watch?v=SGDVBDzY3t4.

1.2 Report Objectives

The objectives of this report are:

- Demonstrate through modeling and simulation how the Army can achieve the FY12 through FY17 objectives of reducing fuel by 25%, water by 75%, and waste reduction for backhaul by 50%.
- Provide the base camp community with high-level conclusions and insights from the solutions within the Army’s Science and Technology portfolio that contribute to the sustainment and logistical resupply reduction requirements at base camps.
- Show how the SLB-STO-D has met the stated program objectives.
- Enable quantitative comparison of potential materiel and non-materiel base camp solutions.
- Highlight future base camp opportunities for further research and development by identifying potential materiel and non-materiel base camp solutions.
- Communicate the simulation results to a broad base camp community so the results can provide significant insights into efficient base camps outside of the SLB-STO-D program.

2 ANALYSIS PURPOSE AND APPROACH

The analysis purpose and approach determines the goal metrics of fuel and water consumption, waste generation, and QoL(O) that the Targeted Reduction Base Camp[1] will achieve. Additionally, this chapter describes the approaches taken to determine which materiel and non-materiel options are to be included in the Targeted Reduction Base Camp. Furthermore, this chapter reviews how the proposed Targeted Reduction Base Camp was determined and discusses the analysis of deviations from this base camp.

2.1 Analysis Purpose

The purpose of this analysis is to identify an integration of multiple materiel and non-materiel options that when combined achieves the SLB-STO-D's stated reduction goals. To achieve this, the contribution of each individual materiel and non-materiel option towards reducing FWW resupply and backhaul at base camps will also be analyzed. In a complementary analysis, the SLB-STO-D program reviewed the operational acceptability of the current implementations of a subset of these technological capabilities to include an analysis on characteristics such as readiness and maturity, human systems integration, survivability, reliability, availability, maintainability, sustainability, supportability, and force projection. This analysis can be found in the SLB-STO-D's *Selected Technology Assessment* report [1].

The ultimate purpose of this analysis is to define representative Army base camps for 50, 300, and 1000 persons that meet or exceed the SLB-STO-D target FWW reduction metrics. The FWW reductions are in comparison to the FY12 ORTB, which is analyzed in detail in the *Analysis of FY12 Operationally Relevant Technical Baseline: 50, 300 & 1000-Persons Basecamp* [2].

In addition to defining base camps that meet the target FWW reduction metrics, this report will analyze the effect on FWW of various materiel options as well as potential changes to TTPs in isolation to draw conclusions on the potential impact to both FWW reductions and QoL(O).

This report will serve to document a representative base camp that achieves significant FWW reductions using a combination of existing equipment, changes to TTPs, and technologies currently in the RDECOM portfolio without negatively impacting QoL(O). It will also serve as a reference on the impacts of potential FWW reduction techniques on base camps. Finally, this analysis will provide insights into the functional areas that drive fuel and water consumption and waste generation after potential improvements are made to the base camps. The insights will help guide development efforts of materiel and non-materiel solutions to further reduce FWW in base camps.

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[1] The Targeted Reduction Base Camp is defined as a base camp with integrated materiel and non-materiel changes that are designed to reduce 25% of the fuel consumption, 75% of the water consumption, and 50% of the waste generation as compared to the FY12 ORTB Base Camps.

2.2 Analysis Approach and Methodology

In order to achieve the program's resource[2] reduction goals while maintaining the QoL(O) levels of the camp, the SLB-STO-D program defined an Analytical Framework (**Figure 1)** that guided the program towards its goals.

The Analytical Framework provides a high-level visual representation of the SLB-STO-D System Engineering Plan. The Analytical Framework organizes the analysis into a tailored MBSE framework that identifies the relationships between the analytical artifacts and how they systematically fit together to accomplish the SLB-STO-D's objectives. The tailored MBSE application emphasized architecture models and computer-based modeling and simulation of the 50, 300, and 1000 PAX contingency base camps as the primary analytical artifacts supported by technology field demonstrations with empirical data collection that can be used to build, calibrate and validate the models. The implementation of SLB-STO-D's tailored MBSE framework is described in SLB-STO-D's *Model-Based Systems Engineering Implementation Report* [3].

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2 To achieve the program's goals, the SLB-STO-D maintained a wide perspective on potential uses of FWW (solid and liquid) at a base camp, including how each can positively contribute to the base camp ecosystem. Within the context of this report, the term "resource" denotes FWW.

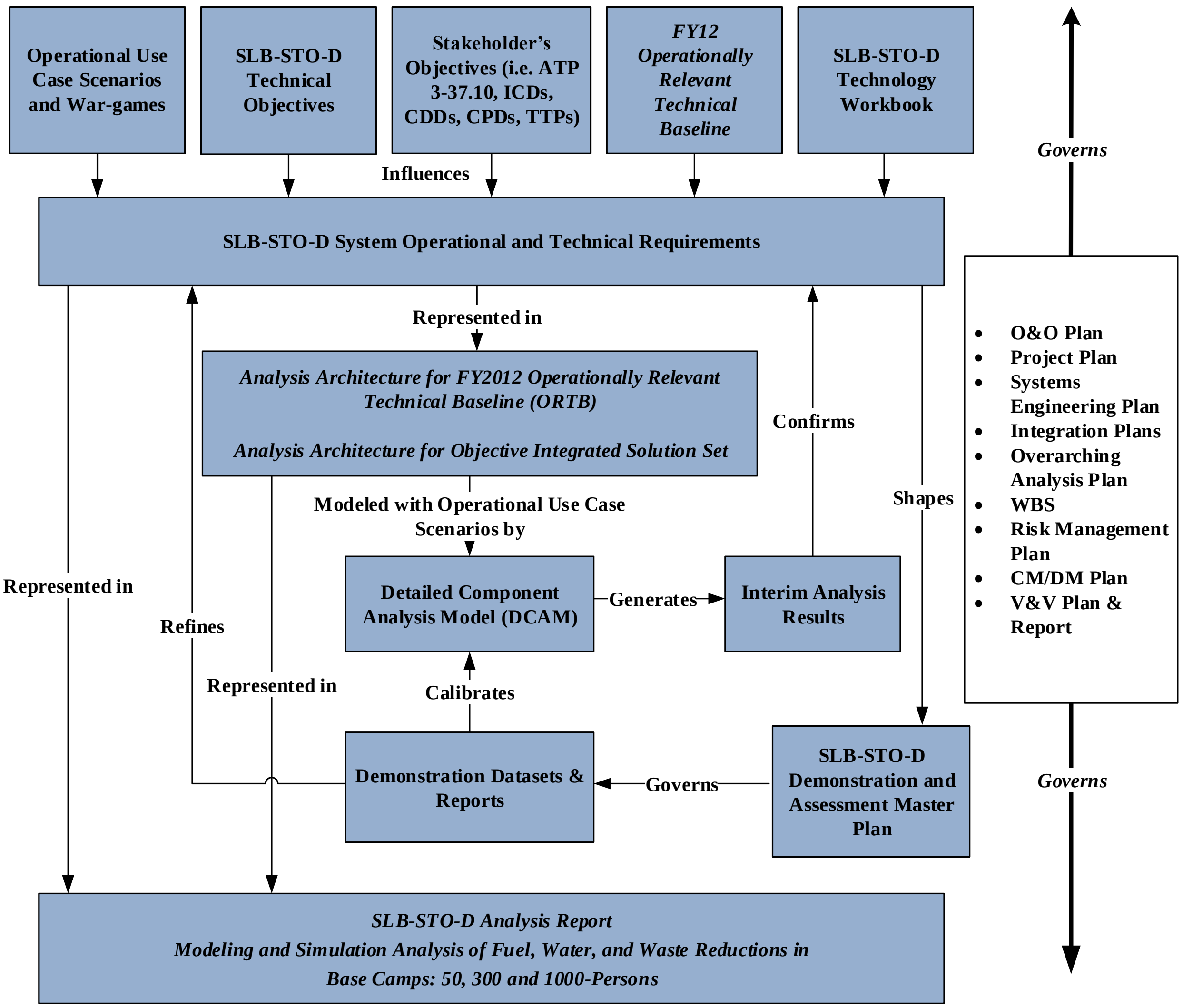


Figure 1. SLB-STO-D Analytical Framework

The analytical process started with defining what a typical base camp in FY12 looked like, which was then transformed into an analysis architecture. The analysis architecture was captured in *Analysis Architecture for FY2012 Operationally Relevant Technical Baseline (ORTB) 50, 300, 1000 Personnel Base Camps* [4].

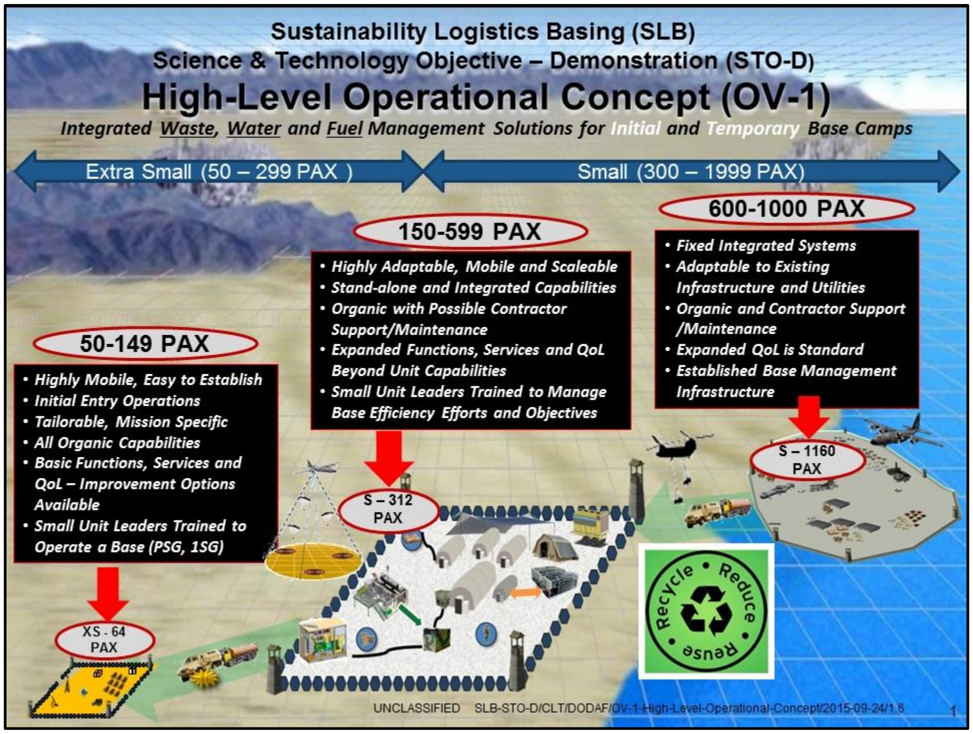
The SLB-STO-D defined the problem space by documenting FY12 50, 300, and 1000 PAX representative baseline base camps (FY12 ORTB Base Camps) and the applicable operational use cases. The FY12 ORTB Base Camps are a characterization of the aggregate or most commonly equipped base camps up to FY12. The FY12 ORTB Base Camp designs were reviewed by stakeholders in the community, approved by Training and Doctrine Command (TRADOC), and agreed to at an O-6 level as being representative of a base camp of that time frame.

The SLB-STO-D acknowledges that base camp designs vary widely and that it would be impossible to analyze all variations; therefore, the SLB-STO-D specified only one camp of each size to serve as the baseline for comparison. A complete listing of the equipment included in the three FY12 ORTB Base Camps is included in **Table 1**. Extensive data and documentation were captured to support resource simulation at the three representative base camps in desert, temperate, and tropical expeditionary environments. These base camps are described in detail in the *FY12 Operationally Relevant Technical Baseline* [5] [6] [7].

Table 1. Equipment List, FY12 ORTB

Name	Quantity		
	50 PAX	300 PAX	1000 PAX
	Provide Electric Power		
30 kW Tactical Quiet Generator (TQG)	6	-	-
30 kW Tactical Quiet Generator (TQG) (Spares, Off)	1	-	-
60 kW Tactical Quiet Generator (TQG)	-	23	73
60 kW Tactical Quiet Generator (TQG) (Spares, Off)	-	3	8
	Enable Command and Control		
AS TEMPER 20x32 (Single-Ply Liner, F100 ECU, MTH150)	-	1	1
B-Hut Shelter (F100 ECU, MTH150)	1	-	2
MILVAN Shelter (COTS ECU)	-	2	9
Meteorological Measuring Set, AN-TMQ-52	-	-	1
Network Communications Hub (F100 ECU)	-	-	1
Satellite Transportable Terminal, AN-TSC-185	-	1	-
	Enable Communications		
MILVAN Shelter (COTS ECU)	-	-	1
	Enable Movement & Maneuver		
AS TEMPER 20x32 (Single-Ply Liner, F100 ECU, MTH150)	-	-	2
	Execute Protection		
Entry Control Point, Unpowered	2	-	-
Entry Control Point with Electric Gate	-	2	2
Guard Tower	-	-	16
Radar Cluster	1	1	2
Radar Set, AN-TPQ-36-V-8	-	-	1
	Provide Access to Maintenance/Repair		
Large Area Maintenance Shelter (LAMS) (2 Large Capacity Field Heaters (LCFH))	-	-	1
Lightweight Maintenance Enclosure (LME) (No ECU)	1	1	4
M7 Forward Repair System	-	1	-
MILVAN Shelter (COTS ECU)	-	1	2
Wash Rack	-	1	2
	Provide Access to Medical & Health Services		
MILVAN Shelter (COTS ECU)	1	1	2
	Provide Access to MWR Services		
AS TEMPER 20x32 (Single-Ply Liner, F100 ECU, MTH150)	-	-	4
Lightweight Maintenance Enclosure (LME) (F100 ECU, MTH150)	-	1	-
MILVAN Shelter (COTS ECU)	-	1	2
	Provide Access to Transportation		
Vehicle Support Set	1	1	1
	Provide Billeting		
AS TEMPER 20x32 (Single-Ply Liner, F100 ECU, MTH150)	6	23	72
AS TEMPER 20x32 (Unoccupied, Off)	-	2	4
Containerized Housing Unit (COTS ECU)	-	-	3
Containerized Housing Unit (Unoccupied, Off)	-	-	2
MILVAN Shelter (COTS ECU)	-	-	4
MILVAN Shelter (Unoccupied, Off)	1	4	4
	Provide Latrine Services		
Burn-Out Latrine	4	-	-
Expeditionary Latrine System (ELS)	-	4	20
	Provide Means to Clean Clothes		
B-Hut Shelter (F100 ECU, MTH150)	-	-	1
Expeditionary Containerized Batch Laundry (ECBL) System	-	-	4
Hand Wash Bucket	1	-	-
MILVAN Shelter (COTS ECU) with COTS Washer and Dryer	-	1	-
	Provide Means to Maintain Personal Hygiene		
AS TEMPER 20x21 (Single-Ply Liner, F100 ECU, MTH150)	-	4	20
Expeditionary Shower System (ESS)	-	4	20
Hand Wash Station	3	-	-
	Provide On-Base Lighting		
Fuel-Powered Light Set	-	1	1
Perimeter Lights	6	24	70
	Provide Subsistence		
AS TEMPER 20x32 (Single-Ply Liner, F100 ECU, MTH150)	1	2	4
Containerized Kitchen System	-	-	2
Expeditionary TRICON Kitchen System (ETKS)	-	2	-
Food Sanitation Center	-	-	2
Multi Temperature Refrigerated Container System (MTRCS)	-	3	7
TRICON Refrigerated Container System (TRCS)	-	2	-
	Warehouse/Store All Supply Classes		
AS TEMPER 20x32 (Single-Ply Liner, F100 ECU, MTH150)	-	-	1
Lightweight Maintenance Enclosure (LME) (No ECU)	-	3	6
MILVAN Shelter (COTS ECU)	-	1	-

Figure 2 shows a High Level Operational Concept (OV-1)[3] for the three representative baseline base camps. The OV-1 provides an overview of each base camp with its high-level capabilities and features. The 50 PAX base camp features highly mobile, entry level organic capabilities that offer basic and limited life support capabilities. The 300 PAX equipment set is mobile with highly adaptable, stand-alone integrated capabilities that offer expanded and scalable life support services beyond the unit's organic capabilities. The 1000 PAX base camp equipment set is made of fixed integrated systems, offering a high level of services, which requires some level of contractor support.


Sustainability Logistics Basing (SLB)
Science & Technology Objective – Demonstration (STO-D)

High-Level Operational Concept (OV-1)

Integrated Waste, Water and Fuel Management Solutions for Initial and Temporary Base Camps

Extra Small (50 – 299 PAX) ⟷ Small (300 – 1999 PAX)

50-149 PAX

- *Highly Mobile, Easy to Establish*
- *Initial Entry Operations*
- *Tailorable, Mission Specific*
- *All Organic Capabilities*
- *Basic Functions, Services and QoL – Improvement Options Available*
- *Small Unit Leaders Trained to Operate a Base (PSG, 1SG)*

150-599 PAX

- *Highly Adaptable, Mobile and Scaleable*
- *Stand-alone and Integrated Capabilities*
- *Organic with Possible Contractor Support/Maintenance*
- *Expanded Functions, Services and QoL Beyond Unit Capabilities*
- *Small Unit Leaders Trained to Manage Base Efficiency Efforts and Objectives*

600-1000 PAX

- *Fixed Integrated Systems*
- *Adaptable to Existing Infrastructure and Utilities*
- *Organic and Contractor Support /Maintenance*
- *Expanded QoL is Standard*
- *Established Base Management Infrastructure*

UNCLASSIFIED SLB-STO-D/CLT/DODAF/OV-1-High-Level-Operational-Concept/2015-09-24/1.6 1

Figure 2. FY12 ORTB High Level Concept

To pursue the SLB-STO-D's goal, potential options to reduce resource consumption and production had to be identified. These potential options were broadly categorized as either materiel or non-materiel with the approach to identifying these options varying between the two categories.

For potential materiel solutions, numerous efforts were identified within the Army's research and development portfolio that might provide technology or systems that would be potential contributors to FWW reductions. In 2011, following the establishment of the potential program challenge statement, the SLB-STO-D reviewed the Army Science and Technology Management Information System (ASTMIS) database and held workshops with representation throughout RDECOM and Engineer Research and Development Center (ERDC) to identify candidate technologies. Technology thrust area leads were identified, with participants from Communications Electronics Research, Development and Engineering Center (CERDEC) (fuel),

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[3] OV-1 is also known as an Operational View-1

the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) (water), and the Natick Soldier Research, Development and Engineering Center (NSRDEC) (waste and fuel), with the responsibility to identify relevant programs in their organizations and throughout the Department of Defense (DoD). Technologies that aligned with the challenge statement and could potentially be demonstrated by FY17 were formally tracked in the SLB-STO-D's *Technology Workbook.*

In the first two years of the program, the SLB-STO-D identified several technology gaps in the portfolio with an objective to seek or promote supplemental funding opportunities to develop technologies to address those gaps. The Rapid Innovation Fund (RIF) was the primary source of such funding. The SLB-STO-D provided topics for three Army RIF and one DoD RIF Broad Agency Announcement solicitations during the period from 2011 to 2014. The call for RIF topics resulted in ten funded technologies, five of which directly participated in the SLB-STO-D integrated demonstrations and were included as part of this analysis.

To ensure the simulations were based on the best available data, the SLB-STO-D planned a series of operationally-relevant demonstration events to collect empirical data on both technologies and baseline equipment. Demonstration candidates were down-selected based on five criteria (schedule, improvement over fielded baseline, contribution to the goals of the SLB-STO-D, innovation, and Technology Readiness Level (TRL)), although ultimately TRL and schedule were the primary focus. Approximately half of the initially identified technologies did not make it on the initial demonstration plans, because they did not meet the entrance criteria of TRL 5. Technology thrust area leads and many of the technology project officers collaborated in a series of workshops to work out the details and plan for the technologies that would be part of each demonstration.

The SLB-STO-D held routine Demonstration Readiness Reviews (DRRs) leading up to each demonstration event. Prior to each DRR, a data call was issued to each technology provider requesting updated documentation that would be used at the DRR and to update the *Technology Workbook.* The DRRs provided a structured venue for discussion and information exchange to track technology development and assure that the demonstration candidate technologies would meet the demonstration entry criteria. These readiness reviews also provided a means to address technology provider responsibilities, integration requirements, and logistical support requirements. For each technology, decisions made as a result of the DRRs included whether to continue as planned, to delay, to reschedule to another demonstration event, or to remove from the candidate list.

The venues for these integrated demonstrations were the Base Camp Integration Laboratory (BCIL) at Fort Devens, MA and the Contingency Basing Integration Technology Evaluation Center (CBITEC) at Fort Leonard Wood, MO. Venues were selected for their ability to replicate operational environments in field contingency bases (e.g., billets, dining facilities, latrines, showers) and their unique instrumentation capabilities which support data acquisition and authentication to enable subsequent analyses. The first demonstration phase consisted of three demonstration events: a 50-person base camp demonstration at the BCIL during September–October 2014 [8], a 1000-person base camp demonstration at CBITEC in April 2015 [9], and a 300-person base camp demonstration at the BCIL in July 2015 [10]. The second demonstration phase consisted of two demonstration events: a 1000-person base camp demonstration at CBITEC in February–March 2016 [11] and a 300-person base camp demonstration at the BCIL in May–June 2016 [12].

Data were collected on systems using electronic instrumentation, automated data acquisition systems, and in some cases manual data collection methods. The data were authenticated using a process modeled after the U.S. Army Test and Evaluation Command data authentication process. The process of authenticating the data consisted of reviewing the data with a Data Authentication Group (DAG) composed of SLB-STO-D team leaders, technology subject matter experts (SMEs), and other SMEs attending the demonstration event. The DAG authenticated the data collected and reduced at the demonstration events for analysis suitability, data completeness, accuracy, consistency, and that it was representative of the evaluated candidate technology and contingency basing activities.

The SLB-STO-D developed a separate non-materiel approach as part of a holistic methodology to achieve its resource reduction objectives. The purpose of the non-materiel approach was to develop non-materiel solutions that supported trade space analysis. The identified non-materiel options were changes to operational behavior and practices (i.e., TTPs) that could be implemented without a technology solution. The implementation of the non-materiel changes was designed to inform leadership of potential changes to TTPs, Soldier behavior, leadership, and/or training that would support a reduction of the base camp resources.

In 2012, the SLB-STO-D conducted a war gaming exercise where changes to TTPs were identified. That exercise elicited TTPs under both normal and stressed operational conditions [13]. The outcome of the war gaming exercise provided the foundation for the development of the SLB-STO-D non-materiel strategy. Following the war gaming exercise, a group of SMEs from the SLB-STO-D, TRADOC and other SMEs performed an assessment of the potential non-materiel solutions to be considered. The group assessed the potential impact of the different proposed non-materiel solutions against the FY12 ORTB Base Camps. The assessment was a subjective look at the non-materiel solutions based on the opinion of the SMEs in terms of how the different solutions would rank as high, medium, low priority or if they had a positive impact, negative impact, or no impact to the area of measurement (**Table 2**).

Table 2. Non-Materiel Solution Prioritization Matrix

Potential Non-Materiel Solution	50 PAX Camp				300 PAX Camp				1000 PAX Camp			
	Contribution to Fuel Efficiency	Contribution to Water Efficiency	Effects on Overall Camp QoL	Effects on Mission Manpower	Contribution to Fuel Efficiency	Contribution to Water Efficiency	Effects on Overall Camp QoL	Effects on Mission Manpower	Contribution to Fuel Efficiency	Contribution to Water Efficiency	Effects on Overall Camp QoL	Effects on Mission Manpower
Consolidate Billeting	H	=	-	+	+	=	-	+	L	=	-	+
Limit HVAC Hours in Billeting	+	=	-	+	+	=	-	+	M/H	=	-	+
Maximize Efficiency of Generator Allocation	+	=	=	+	+	=	=	+	H	=	=	+
Limit Convenience Outlet Usage	+	=	-	+	+	=	-	+	L	=	-	+
Limit HVAC/PWR in Additional Service Spaces	▨	▨	▨	▨	+	=	=	+	L	=	=	+
Restrict Shower Time	▨	▨	▨	▨	+	+	-	-	L	M	-	-
Restrict Shower Temperature	▨	▨	▨	▨	+	=	-	-	L	=	-	-
Limit Latrine Usage	▨	▨	▨	▨	+	+	=	-	L	L/M	=	-
Limit Laundry Functions	▨	▨	▨	▨	+	+	-	-	M	M	-	-
Limit Number of Redundant Systems	▨	▨	▨	▨	+	=	=	+	M	=	=	+

Legend:
H = High Impact
M = Medium Impact
L = Low Impact
+ = Postive Impact
- = Negative Impact
= = No Impact
▨ = Capability not present at the camp

Following the subjective assessment, the SLB-STO-D used the information as the basis for the identification of non-materiel alternatives for both demonstration and modeling. The SLB-STO-D with the assistance of Combined Arms Support Command (CASCOM) and Maneuver Support Center of Excellence (MSCoE) wrote scripts based on the initial alternatives to be used in potential demonstrations and to include as candidates for simulation as part of the modeling effort. The set of non-materiel alternatives was expanded to other categories that the SLB-STO-D modeled (**Table 3**). The categories were then used to model changes to TTPs as explained later in this section.

Table 3. Non-Materiel Categories

Fuel Resupply Reduction	
Power Supply	Generator Reconfiguration
Power Demand	Turn Off Lights Billeting Consolidation Modify Ration Plan Turn Off ECUs ECU Set Points Restrict Use of Convenience Loads
Fuel Consumption	Limit Vehicle Usage
Water Resupply Reduction	
Water Demand	Shower Reductions/No Shower Laundry Reductions/No Laundry Latrine Usage
Waste Generation Reduction	
Waste Reduction	Modify Ration Plan Shower Reductions/No Shower Laundry Reductions/No Laundry Latrine Usage

To quantify the resource consumption of the FY12 ORTB Base Camps and the impact of the various materiel and non-materiel options identified, the SLB-STO-D used the Detailed Component Analysis Model (DCAM) co-developed by the SLB-STO-D and ERDC – Construction Engineering and Research Laboratory (ERDC-CERL). DCAM is a flexible and reconfigurable simulation environment that can be used to simulate base camps that are made up of different types of systems and are configured with various population sizes (see **Section 2.3.1** for a detailed description). To model a base camp in an organized manner, it was first decomposed into functional areas such as *Provide Billeting*, *Provide Latrine Services*, and *Provide Subsistence*. These functional areas were then decomposed into individual facilities, such as billeting tents, latrines, and kitchens. Each facility was then further decomposed into a collection of individual components, such as a shelter, environmental control unit (ECU), and lights.

Numerous models were developed to cover all the identified individual components of the base camp. Each individual component was mapped to a model type as well as the component's respective inputs to the model, the sources of data or information used to define the inputs of the model, and the assumptions and limitations of the component.

The inputs applied for each component were thoroughly researched to determine the best value to be used. In each case, the input used was the best source of data available at the time of development. When available, authenticated data from the integrated demonstrations were analyzed to tune input parameters to models to better match real world performance. When demonstration data were not available, measured data from formal testing, manufacturers' specifications, and SME input were considered. The documentation for each component has full traceability to the inputs and sources, and enables future updates based on availability of new or improved sources of data.

The SLB-STO-D *Models and Simulation Verification and Validation Report* summarizes the modeling and simulation, verification and validation (V&V) methods and provides V&V results documentation formatted in accordance with *MIL-STD-3022 Department of Defense Standard Practice Document of Verification, Validation and Accreditation (VV&A) for Models and Simulation* [14] [15]. This documentation includes the modeling and simulation capabilities, limitations, assumptions, risks, and impacts; identification of unresolved issues associated with V&V implementation; and documentation of lessons learned during the V&V effort.

Simulations were run for a one-year period to ensure all seasonal variations were captured and accounted for across three environments: desert, temperate, and tropical. The representative weather profiles chosen include environments that would significantly stress the cooling and heating systems, as well as a moderate environment which would not require the heating or cooling system to be used as heavily. See **Section 2.3.1.2.3** for a description of the weather profiles used. The FWW results were averaged to a daily usage amount to account for seasonal differences. These mean daily values are used when comparing the results of different simulations.

The SLB-STO-D objective also requires that QoL(O) remain consistent with the FY12 ORTB Base Camps. The QoL(O) for each base camp was assessed using the QoL(O) Tool, developed for the SLB-STO-D program by the Consumer Research Team at NSRDEC (see **Section 2.3.5** for a detailed description). The tool assigned a quantitative value to the ORTB Base Camps based upon the assumptions documented within the ORTB and allowed the SLB-STO-D to quantitatively understand the QoL(O) related impacts of inserting technology or non-materiel changes to a base camp.

The combination of FWW factors from the DCAM simulations and the QoL(O) scores from the QoL(O) Tool provided a complete set of FY12 baseline metrics against which all simulations were compared. These baseline results are presented in detail in the SLB-STO-D's *Analysis of FY12 Operationally Relevant Technical Baseline: 50, 300 & 1000-Persons Basecamp* [2].

The SLB-STO-D approach to determining an integrated base camp that met the objective measures started with analyzing each potential option in isolation to determine its impact on a camp-wide level. These changes were applied against the FY12 ORTB equipment sets described in **Table 1**. DCAM inputs were created incorporating a single change into the ORTB inputs. The analysis of each potential option is discussed in **Chapter 3**. Identifying the impacts of technologies and changes to TTPs in isolation allowed for the identification of options that provide meaningful impact with collateral repercussions to another metric of interest. It further provided visibility into secondary effects of the implementation of certain options. For example, reducing water consumption at the shower facilities meant that the source water tanks had to be filled less often, which resulted in a decrease in vehicle fuel usage. Options were down selected based on their performance against SLB-STO-D metrics. Options that provided a net decrease in QoL(O) were only considered for the final base camp design if a suitable offset could also be included.

In some cases, the SLB-STO-D holistic approach identified multiple systems that had the same or similar capability, though some used a different fundamental technology. For example, four systems that recycle gray water were identified. The number of systems to model and simulate on a base camp level were minimized by analyzing resource flow data and discussing with sponsoring labs which technology was the most promising at the current time. If systems were sized such that competing options were better suited at different base camp sizes, both were modeled.

In the integration of individual potential options, care was taken to ensure assumptions were maintained as consistently as possible between the FY12 ORTB Base Camps and the camp with an integrated option. To achieve this, the FY12 ORTB Base Camp two-dimensional layouts were used as the basis for insertion, with localized changes being made when necessary. In this way, the altered base camps maintained a representative (not optimized) characteristic. Further, assumptions concerning power distribution and generator sizing played a key role in the fuel consumption of the FY12 ORTB Base Camps. The FY12 ORTB Base Camps used a seasonally-adjusted peak connected load[4] to size generators. Since not all equipment on the base camp consumes power at its peak capacity at the same time, this method for sizing generators is very conservative and will overstate the actual requirement. Insertion of resource saving options maintained this method of generator sizing. A non-materiel option of changing this sizing method was also analyzed.

For materiel changes, including the implementation of technologies still under development, certain assumptions as to the fit and maturity of the technologies had to be made. The SLB-STO-D analysis focused on the capability the technology provided as it related to resource consumption and production. The technologies analyzed were at various places in the maturity path and development cycle, with most needing additional development to reach a level of maturity required for fielding. The current operational acceptability of many technologies analyzed is included in the SLB-STO-D's *Selected Technology Assessment* [1]. The SLB-STO-D demonstrated many of the technologies in integrated settings at the CBITEC, Fort Leonard Wood, MO, and the BCIL, Fort Devens, MA. This analysis assumes that fielded implementations of these technologies would behave similarly to those demonstrated.

When applicable, multiple integrations of technologies were examined to determine the impact of integration choices on the SLB-STO-D problem space. For example, the penalty in terms of resource consumption to simplify the implementation was evaluated for many systems. In the case of systems such as gray water recycling, implementations reviewed include using the minimum number of systems required to handle the waste water flow (requires laying out a camp around the technology) as well as using a system near each gray water producing facility (an easier implementation to retrofit). In other cases, such as power generation technologies, the different integrations evaluated included providing power to specific parts of the base camp as well as the base camp as a whole. These implementations informed the final design choices for the Targeted Reduction Base Camp.

Additional consideration was given to power generating technologies. Camp layout plays a critical role in power distribution. While the camp layouts defined in the FY12 ORTB are representative of typical base camps and were used as the insertion point for new technologies, additional analysis was performed on some systems to determine the sensitivity of the results to

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[4] The connected load is the sum of the peak wattage required for all lights and electrical devices in a facility. A seasonal peak was calculated since ECUs and fuel fired heaters would not be operational at the same time.

camp layout. Additional simulations were performed that removed geographical consideration from the analysis and rearranged the base camp facilities to utilize the mathematical minimum number of generators or microgrids required to power the camp. These simulations do not represent an optimal power distribution plan, as there are multiple ways of distributing facilities that achieve this minimal number of generators, but do provide an idea of the penalty in terms of resource consumption for using the chosen layout. A complete redesign of the camp would likely fall between these mathematical minimum scenarios and the geographically constrained scenarios that utilize the base camp layout. Only the scenarios that are geographically constrained to the base camp layout were considered as potential resource saving options in this analysis.

Notably, the designs and assumptions behind the FY12 ORTB Base Camps limited the applicability of some potential materiel solutions. In some cases, the layout of the base camp or the assumed operational environment did not provide circumstances under which to demonstrate the true intentions of an option. For example, man-portable power generation had limited applicability at the FY12 ORTB Base Camps, since the camps were originally designed such that larger generators could be used. At highly mobile base camps of a different design, such a technology could prove to be of great value. Since this analysis focuses on the FWW reductions achieved through various materiel and non-materiel options, options with intentions other than the resource savings may not be shown in their ideal context.

The approach to modeling changes in TTPs (**Figure 3**) was unique. Since the choices of TTP changes are unlimited, discrete options were chosen for each category of change. The specific options to model were chosen using a variety of methods. First, a worst-case scenario was determined for each type of change. This provided an upper bound for the resource savings that could be achieved by making the change. For example, showers were eliminated. This scenario was often the best-case for resource consumption and worst-case for QoL(O) and in many cases well below Army doctrine specified levels of service.

Additional iterations of TTP changes were performed. Some changes had logical progressions (e.g., the number of kitchen meals served per soldier each day was varied from zero to three). Other options were picked based on the attribute levels present in the QoL(O) Tool to provide a measurable QoL difference. Finally, when possible, a doctrinal minimum simulation was performed, providing an upper bound on savings without violating Army doctrine.

The SLB-STO-D use-case designates the camp as an ongoing operation and all considered solutions must be fully implementable at all times going forward. For that reason, courses of action below the doctrinal minimum were not considered for long-term resource savings. These potential TTP changes, however, are common solutions to short-term resource reduction needs, so their analysis was included. Additionally, the elimination of entire base camp services, such as Morale, Welfare, and Recreation (MWR) was not considered a viable resource reduction method, even if their presence was not required by Army doctrine. The FY12 ORTB assumed that these services were present and their elimination would have a negative impact on QoL(O). While these methods were analyzed in isolation, they were not included in the final Targeted Reduction Base Camp.

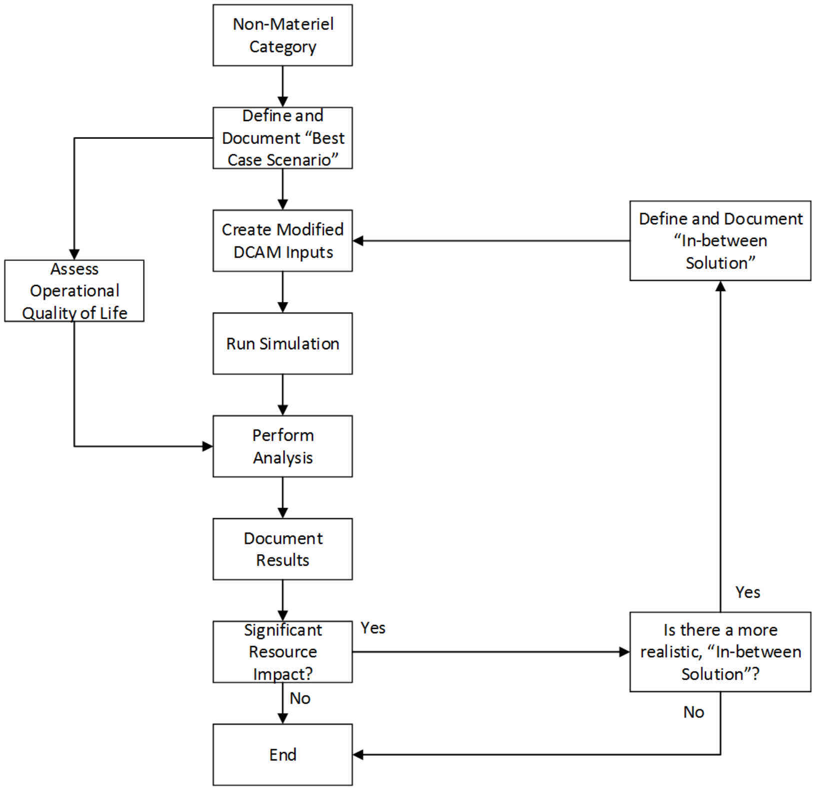

Figure 3. Non-Materiel Process Diagram

Base camp equipment and changes to TTPs do not operate in isolation. A change to one piece of equipment or TTP may have unforeseen impacts on other changes or equipment either upstream or downstream. These relationships can at times be synergistic (resulting in an amplified effect), or antagonistic (resulting in reduced impact). Similarly, the implementation of a new technology simultaneous with a change in TTP can exhibit these interactions. To elicit these second order effects, simulations were performed combining multiple resource saving options. Results from these simulations informed which options compete against each other and potentially obviate the impact of other options, and which are ideally suited to be implemented simultaneously. These second order effects are reviewed in **Chapter 4**.

To achieve the SLB-STO-D goals in resource reduction, numerous technologies and TTPs were integrated together into a base camp designed to meet the target resource reductions (referred to as the Targeted Reduction Base Camps). The options chosen were driven by the individual contributions as well as the second order effects the combinations exhibited. The SLB-STO-D's Targeted Reduction Base Camp is not an optimal design based either on resource consumption and production or QoL(O). The proposed solution set identifies the optimal set of technologies, but does not purposely identify the optimal layout or integration, unless by coincidence. Several factors dictate this disclaimer. First, the basis of the proposed camp designs is the FY12 ORTB Base Camps, which were specified to be typical and representative but not ideal. By using this premise as a starting point and adjusting the layout as opposed to a complete redesign, the proposed base camp designs inherit the same representative characteristic. Furthermore, the DCAM simulation tool was not designed to provide iterative simulations in search of an optimized solution set. The potential solutions simulated were determined outside the DCAM tool by analyzing the simulation results of each individual materiel and non-materiel option. Finally, due to the nature of the modeling and simulation tools employed, no single tool had purview over the entire objective solution space. While the DCAM tool accounts for resource flows, it has limited connectivity to the QoL(O) Tool to determine the impact of resource changes on QoL(O). Analysts could model the same camp using various tools and consider the differences between the results; however, integration of all modeling tools was not in the scope of the SLB-STO-D program. Additionally, not all camp characteristics could be modeled in each tool. For example, the QoL(O) Tool had a discrete value for occupancy of a tent (2, 4, 9, 18) so unless a change of occupancy corresponded to or could be estimated close to these values, the result would not be shown.

Since the Targeted Reduction Base Camp was suboptimal, effort was taken to provide an upper bound on the resource savings that could be achieved using the options identified. Analysis was divided into three parts. First, changes to TTPs were analyzed in an integrated base camp design to determine if resource reduction goals could be met with non-materiel solutions alone if QoL(O) constraints were lifted. Second, a base camp was developed that contained all materiel options for resource reduction, regardless of their impact to camp footprint or QoL(O). Finally, a combination of all TTP and materiel options was developed to determine an absolute best case for resource savings using the options analyzed.

While meeting the resource reduction goals is ideal, implementing the number of changes identified may not prove practical. Further analysis was performed on the Targeted Reduction Base Camp's dependence on key technologies to achieve those reductions, and the impact a very limited number of technologies could have on a base camp. This analysis highlights a smaller set of technologies that can achieve most of the SLB-STO-D's resource reduction goals.

The equipment set of the FY12 ORTB Base Camps overlaps significantly, but several facilities are targeted to specific size base camps. Scalable technologies reduce the number of unique pieces of equipment in the Army catalog and allow for targeted development of single systems that can be used across multiple base camps. The impact of scalable technologies was investigated by identifying a single set of equipment for use at all three base camps. This scenario analyzes the efficiency penalty for using a single system regardless of base camp size. For example, using the same kitchen at both the 300 PAX and 1000 PAX base camps.

As one of the key drivers to reducing resource consumption on contingency base camps is the reduction in threat hours faced by Soldiers in convoys, the SLB-STO-D analyzed the reduction in threat hours faced by Soldiers at base camps that meet the resource reduction goals. This analysis was performed in collaboration with SMEs from the Logistics Innovation Agency (LIA), MSCOE, CASCOM, RDECOM, and ERDC-CERL. The inputs for this analysis were derived from the Unified Challenge FY14 and based on assumptions from Operational Logistics (OPLOG) Planner. LIA used these as inputs into the Fully Burdened Cost Tool (FBCT), producing a cost benefit analysis of operational energy and water technologies using the Unified Challenge theater wide scenario based on the SLB-STO-D base camps. See **Section 2.3.6** for a description of the FBCT.

Finally, while the SLB-STO-D use-case is defined in the FY12 ORTB, a variation on this use-case was analyzed. Since the proximity to water is a key factor in locating contingency base camps, the SLB-STO-D analyzed how the availability of a local water source would change the solution set.

2.3 Modeling and Simulation Tools

The SLB-STO-D analysis relies on numerous modeling and simulation tools developed by the program or by partner organizations. Whenever possible, the SLB-STO-D utilized existing modeling efforts of other organizations, including ERDC-CERL, Army Materiel Systems Analysis Agency/Activity (AMSAA), and LIA. Tools for FWW analysis were enhanced when possible, either by assisting with further development or by providing necessary data to expand modeling efforts. When required, tools were custom-built to bridge gaps in the analysis capabilities. All tools used in this analysis are described in this section.

Moreover, the SLB-STO-D is responsible for the configuration management of the tools, output results, and the supporting documentation. Copies of the supporting documentation, data, and tools used in the analysis effort can be requested using the process described in **Annex B**.

2.3.1 Detailed Component Analysis Model (DCAM)

The SLB-STO-D required a base camp simulation environment that allowed for the quick configuration of various equipment sets, the evaluation of changes in TTPs, and the simulation of various weather profiles. DCAM is a flexible and reconfigurable simulation environment developed by ERDC-CERL with assistance from the SLB-STO-D to incorporate program specific requirements. DCAM can be used to simulate base camps of many different sizes and configurations of different types of systems, which made it ideally suited for the SLB-STO-D requirements, which span three base camp sizes and different equipment sets.

2.3.1.1 Simulation Engine

Where many models are based on facility level consumption, the DCAM base camp model ultimately decomposes the camp into components (i.e., DCAM models a shelter, ECU, lights, and convenience loads, not simply a billeting facility). This granularity allowed for the simulation of many resource savings options quickly and easily. Instead of replacing a shower facility, DCAM allows for the replacement of a showerhead with a low-flow version.

Components in the simulation environment are representations of 29 distinct models. Models range from simple two-mode devices (on or off) to models that incorporate weather parameters, usage events, or the actions of other models. The SLB-STO-D has documented each model used in this analysis, to include a description of how the model manipulates its inputs into its outputs, as well as the assumptions and limitations of the model. Each model has undergone a verification process to ensure it operates as expected. The SLB-STO-D *Models and Simulation Verification and Validation Report* [14] summarizes the modeling and simulation V&V methods and provides V&V results documentation formatted in accordance with *MIL-STD-3022 Department of Defense Standard Practice Document of Verification, Validation and Accreditation (VV&A)*

for Models and Simulation, 05 April 2012 [14] [15]. This documentation includes the modeling and simulation capabilities, limitations, assumptions, risks, and impacts; identification of unresolved issues associated with V&V implementation; and documentation of lessons learned during the V&V effort.

DCAM is a deterministic modeling environment; all simulations for a given set of inputs will produce identical results. There is no stochastic variation in the model. While the lack of variability may limit DCAM's use for some purposes, for the SLB-STO-D, DCAM provided a level playing field for all technologies and non-materiel options and provided comparable results between the options.

DCAM uses an hourly time-step to calculate resource consumption and production. This granular time-step allows for configurable usage schedules for each component modeled. It also allows for the simulator to determine the state of equipment based on triggers from other events (e.g., a waste water treatment system turning on when a source tank reaches a certain level) and to vary resource consumption hourly (e.g., varying power draw of ECUs based on weather parameters). First and foremost, this fidelity in time-step greatly increases the accuracy of fuel consumption predictions of generators. DCAM is capable of tallying hourly power consumption by each piece of equipment attached to a generator and using a fuel curve to calculate a unique fuel consumption each hour.

This hourly time-step limits the effects DCAM can model. For example, transient power spikes due to large motors and compressors turning on are not modeled. While these spikes are not likely to severely impact resource consumption, they are a factor in generator layout. For this reason, care was taken when creating equipment lists to ensure proper power distribution throughout the base camps.

DCAM separates usage assumptions from consumption parameters. Usage assumptions are configured in an Operational View file that defines characteristics such as the number of Soldiers on the base camp, how many times they flush the toilets, and how long their showers take (see **Section 2.3.1.2.2** for a more detailed description). This configurability allowed assumptions to be maintained across simulations, as well as the implementation of TTP changes (e.g., reducing shower times).

Characteristics of component models, such as resource flows and consumption parameters, are stored in a SQLite database known as the Component Database (see **Section 2.3.1.2.4**). Values in this database were fully documented by the SLB-STO-D. The documentation for each component has full traceability to the inputs and sources and enables future updates based on availability of new or improved sources of data.

As weather and environment also influence resource use behavior in various ways, DCAM maps changes in weather to changes in resource use behavior. For example, changes in temperature have a large impact on the power draw requirement of an ECU and the position of the sun and cloudiness in the sky have a significant impact on the performance of solar panels. Additional impacts can be observed using cold weather kits when outdoor temperatures necessitate freeze protection.

The DCAM tool uses numerous input files that include the System Configuration, Equipment List, Operational View, Component Database, and a lookup table database. These inputs are discussed in more detail in **Section 2.3.1.2**. The inputs are defined as follows:

- The System Configuration file documents the base camp's facilities and connections.
- The Equipment List file documents the base camp at the component level instead of the facility level and defines the hourly profile (i.e. hours it is ON or OFF).
- The Operational View file documents the base camp's personnel and the usage events inputs to designated models.
- The Component Database contains the facilities and their defined composition as well as the components and their respective model inputs.
- The lookup database augments the component database by defining the model inputs for components that use an hour-by-hour lookup table for each environment.

The primary outputs of the system model are values of resource consumption and waste production over time. These values are stored in a SQLite database that can be processed and analyzed using various third-party tools. DCAM additionally provides a basic visualization capability for interpreting results. The SLB-STO-D developed extended visualization and analysis capabilities using MATLAB® (see **Section 2.3.4**).

The DCAM simulation engine is a sub-module of the Virtual Forward Operating Base (VFOB) suite of tools. DCAM was co-developed by ERDC-CERL and SLB-STO-D. VFOB is developed and maintained by ERDC-CERL. For more information, the point of contact is Nathan Putnam (nathan.h.putnam@erdc.dren.mil).

2.3.1.2 Simulation Inputs

The DCAM simulation engine uses a variety of configurable inputs. These inputs are a combination of Microsoft Excel workbooks and SQLite databases. By altering these files, the SLB-STO-D simulated various base camp sizes, combinations of equipment sets, and changes to TTPs.

2.3.1.2.1 System Configurations/Equipment Lists

The equipment set of the simulated base camp is specified in two related Microsoft Excel files, which are the System Configuration and the Equipment List.

The System Configuration documents the base camp facilities and the connections between those facilities. It is a higher-level document provided for the convenience of changing simulation inputs and technically is not required to run a simulation. DCAM ingests System Configuration data, decomposes the facilities into individual components based on information in the Component Database, and outputs an Equipment List. The Equipment List documents each individual piece of equipment (component) on the base camp, its connections to other pieces of equipment, and its hourly profile. The Equipment List is the required input to simulate a base camp.

SLB-STO-D standard operating procedure is to configure base camp simulations using System Configurations, when practical. A major advantage of System Configurations is that they are easier to read and update. However, in some specialized cases, only Equipment Lists were created. These cases included changes that were rarely used, such as changing the hourly profiles during a TTP change.

Table 1 (Section 2.2) shows the equipment set for each of the FY12 ORTB Base Camps. Deviations were made from this equipment set to simulate potential resource saving options.

System Configurations (when used) and Equipment List files for all simulations can be requested from the SLB-STO-D. See **Annex B** for information on requesting simulation inputs.

2.3.1.2.2 Operational Views

The Operational View is a Microsoft Excel file that dictates the behavior of usage-based models in the simulation engine. The file lists a series of configurable options. Operational View files were created for each of the FY12 ORTB Base Camps and modified as required to simulate the resource-saving options discussed in **Chapter 3**.

Table 4 shows the configuration options for the FY12 ORTB Base Camps. Assumptions for these configuration options were sourced from the SLB-STO-D FY12 ORTB [5] [6] [7]. Due to the modeling method chosen for some pieces of equipment, the configuration was calculated in concert with other resource flows to result in the consumption assumption made in the ORTB.

Table 4. Operational View, FY12 ORTB, Ready State

Configuration Option*	50 PAX Base Camp	300 PAX Base Camp	1000 PAX Base Camp
Soldiers (male/female)	64/0	312/0	1088/72
Latrine Sink Usage (min)	N/A	2	2
Latrine Toilet Flushes (male/female)	N/A	3/0	3/7
Latrine Urinal Flushes (male/female)	N/A	4/0	4/0
Shower Usage (min)	N/A	10	10
Shower Sink Usage (min)	N/A	2	2
Hand Wash Station Usage (min)	3	N/A	N/A
Aid Station Sink Usage (min) †	0.08	0.05	0.02
Laundry Drying Requirement (lb)	N/A	2.43‡	2.43‡
Laundry Washing Requirement (lb)	0.71§	2.43‡	2.43‡
Kitchen Meals (quantity)	0	2	2
Solid Waste Production (lb)	4.16	9.2	9.2
Noncombustible Waste Production (lb)	0.0	0.0	0.0

* All usage events are per soldier per day

† Calculated to provide total target gal per day per ORTB

‡ Equates to 17 lb per soldier per week

§ Equates to 5 gal of water usage per soldier per week

Operational View files for all simulations can be requested from the SLB-STO-D. See **Annex B** for information on requesting simulation inputs.

2.3.1.2.3 Weather Files

The DCAM simulation engine is configured to accept three weather environments: desert, temperate, and tropical. The weather data are stored in Microsoft Excel spreadsheets and represents a typical year in the given environment. No effort was made to represent extreme conditions, so these weather environments are not representative of equipment design conditions. As the files are pre-defined and no randomness is added to the data, the DCAM simulation is deterministic with respect to weather. The SLB-STO-D environments are represented by actual geographic locations: Kharga, Egypt (desert); Ch'ongjin, North Korea (temperate); and Singapore, Singapore (tropical).

Figure 4 shows the yearly temperature profile of the three simulated environments. Other weather factors are also factored into the DCAM models, including solar insolation and relative humidity.

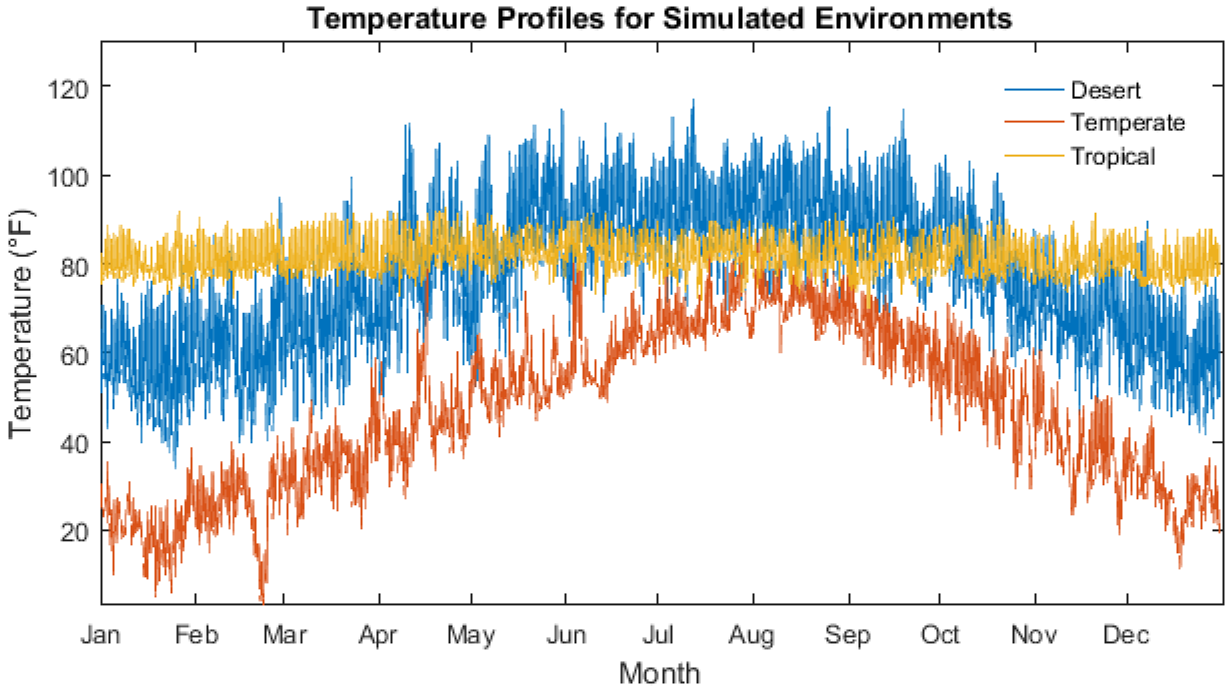

Figure 4. Yearly Temperature Profiles of Simulated Environments

The weather file for the desert environment was derived from up to 21 years (ending in 2003) of weather data provided by the U. S. National Climatic Data Center [16].

Weather files for the temperate and tropical environments are the result of American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Research Project 1015 by Numerical Logics and Bodycote Materials Testing Canada for ASHRAE Technical Committee 4.2 Weather Information [17]. The ASHRAE Research Project 1015 files are derived from up to 18 years of hourly weather data and supplemented by solar radiation estimated on an hourly basis from earth-sun geometry and hourly weather elements.

Weather files for these locations are available for download as part of the U.S. Department of Energy EnergyPlus program [18].

2.3.1.2.4 Component Database

The Component Database contains the facilities and their defined composition as well as the components and their respective model inputs. The lookup database augments the component database by defining the model inputs for components that use an hour-by-hour lookup table for each environment. The lookup database is separated due to file size and contains values from AMSAA Shelter Thermal Energy Model (STEM) simulations for ECUs and shelters of interest to the SLB-STO-D.

Supporting documentation was developed to provide full traceability for the baseline results to the numerous data sources. The SLB-STO-D documented each component (316 total) and facility (160 total) included in the Component Database, mapping each component to a model type, the inputs to the model that determine the resource flows, the sources of data or information used to define the inputs of the model, and the assumptions and limitations of the component. The inputs applied for each component were thoroughly researched to determine the best value to be used. In each case, the input was defined to use the best source of data available at the time of development.

To ensure the simulations were based on the best available data, and to conduct V&V, the SLB-STO-D conducted a series of operationally-relevant demonstration events to collect empirical data on both technologies and baseline equipment. The venues for these events were the BCIL at Fort Devens, MA and the CBITEC at Fort Leonard Wood, MO [8] [11] [10] [9] [12]. Venues were selected for their ability to replicate operational environments in field contingency bases (e.g., billets, dining facilities, latrines, showers) and their unique instrumentation capabilities which support data acquisition and authentication to enable subsequent analyses.

Data were collected on systems using electronic instrumentation, automated data acquisition systems, and in some cases manual data collection methods. Periodic data reviews were conducted by a DAG to ensure the validity and fidelity of the data. The raw data were analyzed by the SLB-STO-D and used to calibrate models to match real world performance.

When demonstration data were not available, measured data from formal testing, manufacturers' specifications, and SME input were considered in the models.

The SLB-STO-D maintains configuration control for the Component Database and lookup database used in this analysis, as well as the specifications that document the model inputs. Additionally, the SLB-STO-D maintains configuration control of the authenticated data sets collected at the SLB-STO-D demonstration events. See **Annex B** for information on requesting simulation inputs, documentation, or demonstration datasets.

2.3.2 Vehicle Fuel Model

The Vehicle Fuel Model is a SLB-STO-D developed MATLAB® model that calculates the estimated vehicle fuel usage on the base camp for the movement of FWW. Based on the resource consumption out of or into each tank, the model calculates the frequency at which a vehicle must visit the tank(s) and the amount of fuel that trip consumes. The model incorporates estimations of the distance between tanks, the co-location of tanks, and the flow rates of pumps. The model assumes the use of a Heavy Expanded Mobility Tactical Truck (HEMTT) M978A4 Fuel Servicing Tanker Truck to refill the fuel tanks and a M1120A4 Load Handling System (LHS) with a LHS Compatible Water Tank Rack (Hippo) to refill potable water tanks. Solid waste is also moved using the M1120A4 LHS. The model incorporates the best available fuel consumption data from specifications, technical manuals, and information provided by Program Executive Office Combat Support & Combat Service Support (PEO CS&CSS).

The Vehicle Fuel Model is developed and maintained by SLB-STO-D. See **Annex B** for information on requesting the model.

2.3.3 AMSAA Shelter Thermal Energy Model (STEM)

STEM was developed by AMSAA as an energy analysis tool to support multiple projects and inform science and technology decision making across the DoD. STEM is a physics-based analysis tool developed in MATLAB® that uses shelter information to estimate the thermal energy demand required to keep a structure at desired internal temperature and humidity settings. By combining the thermal energy demand with ECU models, STEM can estimate electrical power consumption and fuel consumption of fuel fired heaters. Initial models were created using construction information and subsequently tuned using authenticated data obtained from the SLB-STO-D demonstrations, data gathered during field operations, and laboratory thermal chamber environmental testing [19].

When possible, DCAM estimates for shelter heating and cooling electrical demand were obtained from the AMSAA STEM. AMSAA provided simulation outputs for various combinations of shelters and ECUs that were of interest to the SLB-STO-D using assumptions for occupancy and internal electrical dissipation provided by the SLB-STO-D. For the SLB-STO-D simulations, shelters were heated to 68 °F and cooled to 78 °F. The DCAM models utilize a look-up table of these values to obtain estimates on heating and cooling electrical demand based on environmental conditions and shelter construction properties.

AMSAA has verified and validated parts of STEM, depending on the availability of data. All models use the best available data. The SLB-STO-D FY12 ORTB base camps include billeting tents that are Air Supported (AS) Tent, Extendable, Modular, Personnel (TEMPER) 20 ft by 32 ft with a single ply liner and no solar shade, constructed partially elevated off the ground, and using an F100 ECU. This combination has been verified and validated by AMSAA. Other validated STEM models include the Ultra-Lightweight Camouflage-Net System (ULCANS) shade, non-woven liner, Improved Environmental Control Unit (IECU), and other construction levels.

Other AMSAA STEM models were verified using the data obtained from the SLB-STO-D demonstration events including the Barracks Hut (B-Hut), Structural Insulated Panel Hut (SIP-Hut), Rapidly Deployable Shelter (RDS), V1.5 liner with 42k ECU, V1.5 Liner with Shelter Radiant Heating System (SRHS), and the 42k ECU. Data for the fuel fired heater, commercial heat pump, and PowerShade (PShade) models were derived from manufacturer specifications.

The STEM is developed and maintained by AMSAA. For more information, the point of contact is David Carrier (david.a.carrier.civ@mail.mil).

2.3.4 MATLAB® Analysis Tools

The MATLAB® Analysis Tools are an SLB-STO-D developed suite of tools that allow the end user to analyze and visualize the results database output by DCAM. The analysis includes the ability to summarize mean daily values of fuel, power, and potable water consumption and solid and liquid waste generation in tabular and graphical form. The tools further breakdown this summary data by camp level and equipment level functions, and provide a detailed comparison of the differences between selected simulations.

The MATLAB® Analysis Tools are developed and maintained by SLB-STO-D. See **Annex B** for information on requesting the tools.

2.3.5 Operational Quality of Life (QoL(O)) Tool

The SLB-STO-D program objectives require that the Targeted Reduction Base Camp design does not compromise QoL(O). Although there were several DoD efforts researching QoL on base camps, there was not an existing tool that could be used to quantify the QoL(O) impacts as required by the SLB-STO-D program. As a result, the NSRDEC Consumer Research Team developed an analysis methodology and data collection process, administered 1,200 plus Soldier surveys, and developed a customized tool to characterize QoL(O).

This QoL(O) Tool is based on data collected from a survey of approximately 1,200 Soldiers regarding critical aspects of QoL(O) at contingency base camps. Data were collected from July through September 2014 at the following locations: Ft. Polk, Ft. Stewart, Ft. Riley, Joint Base Lewis-McChord, and Camp Edwards [20]. The tool divides QoL(O) into 84 attributes with a total of 306 levels. Based upon a specified size of base camp, composition of Soldiers and officers, and the levels chosen for the attributes, the tool provides a QoL(O) score for each of the seven functional areas: Field Feeding, Hygiene, Billets, MWR, Spiritual/Psychological Support, Personal Security, and Work Area. A complete explanation of the QoL(O) analysis process can be found in *Soldier Quality of Life Assessment: Final Report* [20].

The goal of quantifying QoL(O) is to provide science and technology decision makers the information they need to balance resources (**Figure 5**) with other factors that lead to effective base camps. While the QoL(O) Tool does not evaluate the impact on Soldier readiness, it does focus on the QoL attributes that intuitively have a potential impact on Soldier readiness. A follow-on study is underway which takes the lessons learned from this QoL(O) work and seeks to determine which factors relate most to Soldier readiness.

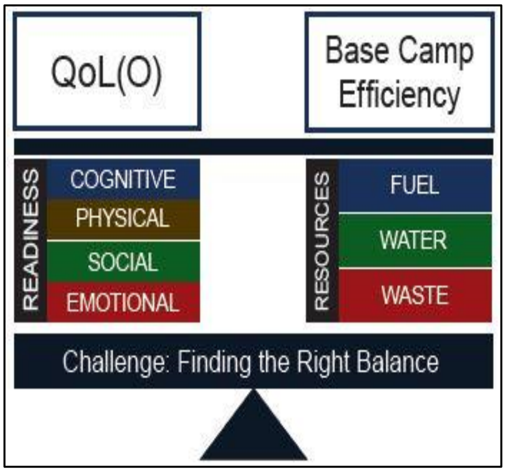

Figure 5. QoL(O) vs. Base Camp Efficiency

The QoL(O) Tool is developed and maintained by the NSRDEC Consumer Research Team. For more information, the point of contact is Justine Federici (justine.federici.civ@mail.mil).

2.3.6 Fully Burdened Cost Tool (FBCT)

The FBCT is a decision support tool for calculating and analyzing the fully burdened costs and benefits of energy and water. The FBCT quantifies the operational, logistical, and economic value added by reducing fuel and water demand. It quantifies value-added in terms of the number of resupply convoys, number of transport trucks, total threat exposure hours, cumulative resupply time, greenhouse gas emissions, fuel and water consumption, as well as the fully burdened cost of water and fuel.

The FBCT allows the user to develop and compare operational scenarios. The SLB-STO-D used the FBCT to compare a baseline operational scenario against an identical scenario where the base camps in the theater reduced fuel usage by 25% and bulk potable water usage by 75%. The fully burdened cost of waste was not considered in the analysis. This analysis provided a quantification of the reduction in threat exposure hours by decreasing resource consumption on the base camp.

The FBCT was developed by the U.S. Army LIA and is maintained by the U.S. Army TARDEC Joint Operational Energy Initiative (JOEI).

2.4 Results Organization and Breakdown

Results will be presented in all chapters for the three base camp sizes of interest: 50 PAX, 300 PAX, and 1000 PAX. Certain options are not applicable to a given base camp size due to its unique layout or equipment set, in which case results will not be presented for that size camp. For all potential base camp designs, simulations were performed across the three environments of interest: desert, temperate, and tropical. In cases where the environment does not have an impact on the analysis of the results, only the desert environment will be shown. Results for other environments can be requested (see **Annex B**). When the environment plays a key role in the analysis, results for all three climatic environments of interest will be shown.

The SLB-STO-D has defined two use-cases upon which to base its integrated solution: Ready State and Population Variance. The Ready State use-case is defined as a base camp that has been fully constructed and operational prior to the start of the simulation. The Population Variance use-case is defined as having a 30% increase in population for up to seven days, thus placing the camp's resources in high demand. All simulation results and analysis detailed in the body of this report are based on the Ready State use-case. The Population Variance use-case was utilized to inform system counts and provide constraints on the base camp designs. For further definition of the FY12 ORTB Operational Use-Cases, please refer to the *FY12 Operationally Relevant Technical Baseline* [5] [6] [7].

The results presented are the result of a simulation of one calendar year. These results are summarized to mean daily values as the consumption values of any particular day of the year may vary. Results are presented both in terms of the absolute resource consumption and the percent difference when compared to the FY12 ORTB Base Camp. Positive percentage differences equate to a positive change on the base camp (e.g., less fuel consumption). Negative percentage differences equate to a negative change on the base camp (e.g., more fuel consumption).

The first results chapter (**Chapter 3**) reviews each individual option identified that could assist in meeting the SLB-STO-D program objectives. Each option, either materiel or non-materiel, is examined in isolation to determine its impact on the program objectives and its potential contribution to an integrated solution that meets the program objectives. These options are compared against other potential solutions that address the same area or facility of the base camp. For example, all options for alternate latrine facilities are analyzed together.

This chapter is further broken down by the three major program objectives: fuel reduction, potable water reduction, and solid and liquid waste reduction. When an option affects more than one resource, it is categorized under its primary function. Sections are further broken down by camp level functions, which are based on Product Director Contingency Basing Infrastructure's (PdD CBI's) Contingency Basing Functional Decomposition [21], followed by equipment level functions. All camp level functions and equipment level functions used in this analysis are listed and described with examples in **Annex D** and are denoted with italics in the report. When an option impacts more than one camp level function, it is listed under its most impactful area on the FY12 ORTB Base Camps. For example, the analysis of shelter technologies is categorized under *Provide Billeting*, since those technologies have the largest impact in that functional area.

The second results chapter (**Chapter 4**) analyzes the combination of two or more options to elicit second-order effects. Resource saving options can interact synergistically, producing greater savings when combined, or antagonistically, producing less savings when combined. In some cases, changes are best made together, while in others they nearly obviate each other. Additionally, certain changes have impacts on QoL(O) that are not immediately apparent. The implementation of certain resource saving options can make the increasing of QoL(O) less costly or make options that decrease QoL(O) less enticing.

The final results chapter (**Chapter 5**) describes an integrated base camp that meets or exceeds the SLB-STO-D program objectives. The choice and integration of technologies into this base camp will be discussed, but not all simulations performed to determine the chosen solution will be presented.

Variations on this equipment set will be investigated to determine the impacts of scalable technologies and reducing the unique technological additions to the base camp. Additional integrated base camp designs will show the potential savings possible when the QoL(O) constraint is removed, both in terms of the reduction of FWW as well the achievable reductions in convoy. Finally, while the SLB-STO-D use-case is defined in the FY12 ORTB, a variation on this use-case to include the availability of a water source will be analyzed.

3 FUEL, WATER, AND WASTE (FWW) REDUCTION OPTIONS

Numerous options were identified that could contribute to the SLB-STO-D program objectives to reduce the need for fuel resupply by 25%, reduce the need for water resupply by 75%, and decrease waste generation/backhaul by 50% while maintaining QoL(O) at the base camp. Options considered were both materiel and non-materiel solutions, incorporating technologies under development by RDECOM and ERDC, equipment fielded after FY12, commercially available items, and changes to TTPs. Each option was examined in isolation to determine its impact on the program objectives and its potential contribution to an integrated solution that meets all the program objectives.

Options are broadly categorized by the three major program objectives: fuel reduction, potable water reduction, and solid and liquid waste reduction. When an option affects more than one resource, it is categorized under its primary function. Report sections are further broken down by camp level functions followed by equipment level functions.

Table 5 show the results of the FY12 ORTB Base Camps across the three environments. The results form the basis of comparison for the savings produced by each option analyzed.

Table 5. Mean Daily Camp Level Summary, FY12 ORTB Base Camps

Environment	Fuel (gal)	Power (kWh)	Potable Water (gal)	Waste Water (gal)	Solid Waste (lb)
			50 PAX Camp		
Desert	215	1007	75	27	266
Temperate	219	661	75	27	266
Tropical	212	951	75	27	266
			300 PAX Camp		
Desert	1042	5108	8723	8529	2870
Temperate	1096	4091	8723	8529	2870
Tropical	1023	4806	8723	8529	2870
			1000 PAX Camp		
Desert	3376	17580	31305	31153	10672
Temperate	3654	14751	31305	31153	10672
Tropical	3301	16463	31305	31153	10672

3.1 Fuel Reduction

The SLB-STO-D’s objective is to reduce fuel usage by 25%. In the FY12 ORTB Base Camps, 82.3–90.1% of all fuel was used to provide electric power. As a result, electric power must be addressed for this objective to be met. The two methods of reducing fuel use related to electric power generation are to either produce electric power more efficiently or to reduce the amount of electric power demanded. **Table 6** shows the mean daily fuel breakdown in the Desert camp.

Table 6. Mean Daily Fuel Breakdown by Camp Level Function, Desert

	50 PAX		300 PAX		1000 PAX	
Functional Area	gal	%	gal	%	gal	%
Provide Electric Power	177	82.3%	937	89.9%	3042	90.1%
Provide Access to Transportation	5	2.3%	59	5.7%	182	5.4%
Provide Subsistence	0	0.0%	0	0.0%	45	1.3%
Provide Means to Maintain Personal Hygiene	0	0.0%	12	1.2%	44	1.3%
Provide On-Base Lighting	0	0.0%	3	0.3%	28	0.8%
Execute Protection	13	6.0%	13	1.2%	26	0.8%
Provide Access to Maintenance Repair	0	0.0%	18	1.7%	9	0.3%
Provide Latrine Services	20	9.3%	0	0.0%	0	0.0%
TOTAL	215	100.0%	1042	100.0%	3376	100.0%

Note: Values may not sum to total due to rounding

For the first method, producing more electric power with less fuel can be achieved by either using more efficient generators or by placing the generators in a more efficient arrangement. For the second option of reducing power demand, it is helpful to examine **Table 7**, which shows power demand by camp level function.

Table 7. Mean Daily Power Breakdown by Camp Level Function, Desert

	50 PAX		300 PAX		1000 PAX	
Functional Area	kWh	%	kWh	%	kWh	%
Provide Billeting	624	62.0%	2402	47.0%	7626	43.4%
Enable Command and Control	231	22.9%	554	10.8%	2326	13.2%
Provide Means to Maintain Personal Hygiene	0	0.0%	428	8.4%	2100	11.9%
Provide Access to MWR Services	0	0.0%	302	5.9%	1697	9.7%
Provide Subsistence	118	11.7%	913	17.9%	1425	8.1%
Provide Means to Clean Clothes	0	0.0%	207	4.1%	816	4.6%
Provide On-Base Lighting	0	0.0%	144	2.8%	420	2.4%
Provide Latrine Services	0	0.0%	90	1.8%	438	2.5%
Execute Protection	8	0.8%	14	0.3%	263	1.5%
Enable Movement and Maneuver	0	0.0%	0	0.0%	203	1.2%
Warehouse Store all Supply Classes	0	0.0%	13	0.3%	117	0.7%
Provide Access to Maintenance Repair	5	0.5%	22	0.4%	101	0.6%
Provide Access to Medical & Health Services	21	2.1%	21	0.4%	43	0.2%
Enable Communications	0	0.0%	0	0.0%	4	0.0%
TOTAL	1007	100.0%	5108	100.0%	17580	100.0%

Note: Values may not sum to total due to rounding

Reducing power demand does reduce fuel usage, but is not a linear relationship: a 25% reduction in power demand would produce a reduction in fuel usage substantially lower than 25%. However, understanding the power breakdown is still helpful in targeting areas for demand reduction. An examination of **Table 7** indicates that *Provide Billeting* is the single largest consumer of power, ranging from 43.4%–62.0% depending on the base camp size. *Enable Command and Control* as well as *Provide Subsistence* are also leading consumers of power and likely targets for demand reduction.

Figure 6 depicts a summary of the fuel reduction options reviewed in this chapter. Many of the potential solutions for fuel reduction require trade-offs between QoL(O), water consumption, and waste reduction. These trade-offs are discussed in this section.

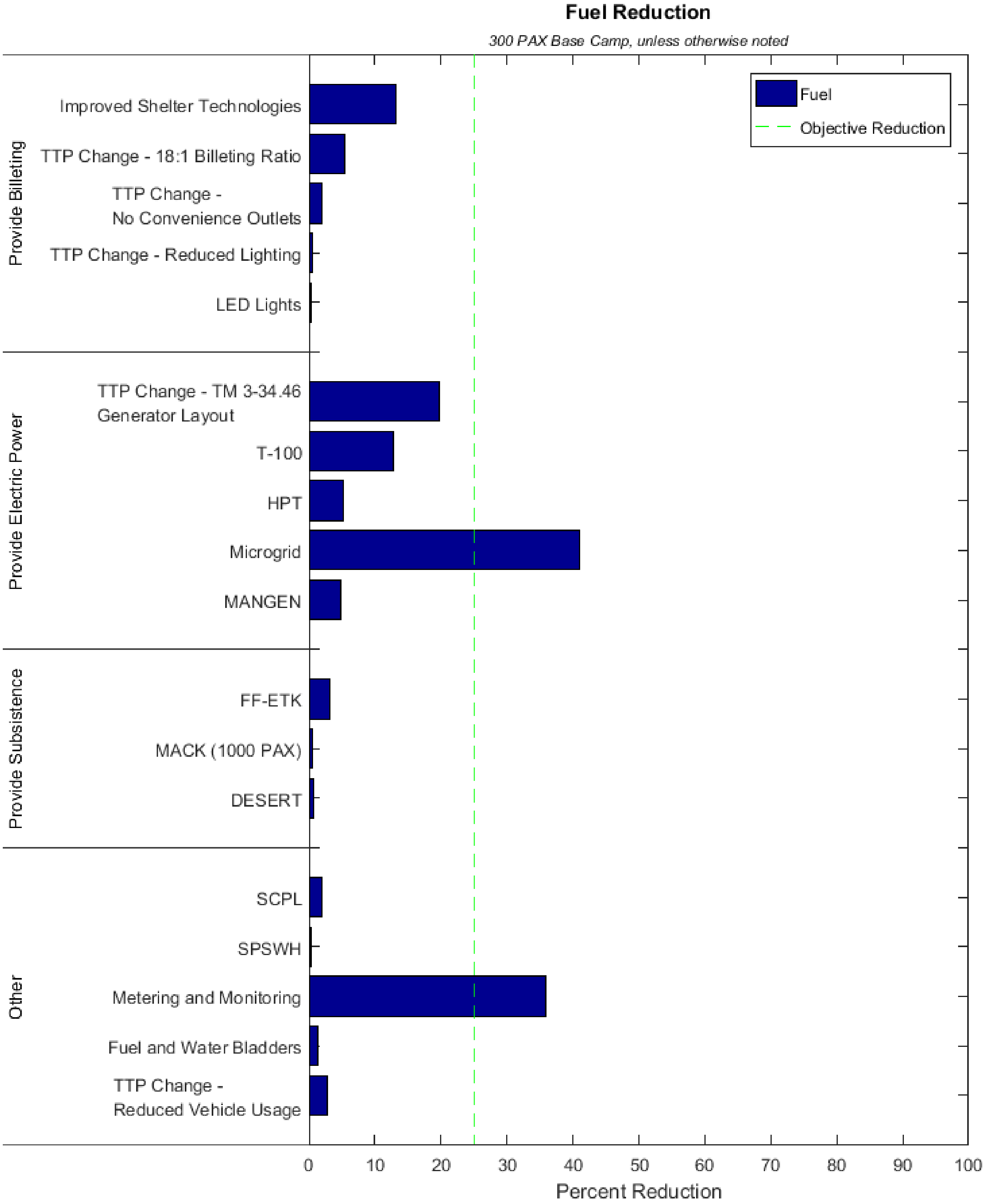

Figure 6. Fuel Reduction

3.1.1 Provide Billeting

Across all the FY12 ORTB camps, *Provide Electrical Power* is the largest consumer of fuel, and *Provide Billeting* is the largest power demand. This indicates that solutions addressing billeting might have a sizeable impact on overall fuel usage. Addressing billeting power demand will be instrumental in meeting the SLB-STO-D's objective of reducing fuel resupply by 25%.

Several types of shelters at the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps fulfill the base camp level function of *Provide Billeting* and other base camp services. The most common billeting structure by far is the AS TEMPER Tent 20 ft by 32 ft. Per the SLB-STO-D FY12 ORTB, the AS TEMPER 20 ft by 32 ft tent is outfitted with bunked cots, a limited number of convenience outlets, fluorescent lighting, an ECU, and a single ply liner (standard issue with the AS TEMPER tent in FY12). The baseline AS TEMPER tent has no vestibule, no solar shade, and is built on a platform partially elevated off the ground.

Other common shelters in the FY12 ORTB Base Camps are the B-Hut and the Military Van (MILVAN) Container. The B-Hut structure houses the Tactical Command Center at the FY12 ORTB 50 and 1000 PAX Base Camps. B-Huts are plywood structures built onsite, with a peaked roof and a footprint of approximately 18 ft by 32 ft. B-Huts include lighting, outlets, and an ECU. MILVAN structures are used to provide billeting and other camp functions across the FY12 ORTB Base Camps. MILVANs are converted shipping containers outfitted with minimal insulation, lighting, outlets, and an ECU. There are several technological methods to reduce power and fuel consumed by *Providing Billeting*: improving shelter structure and insulation (**Section 3.1.1.1**), improving the ECU (**Section 3.1.1.2**), replacing shelters and integrated shelter systems (**Section 3.1.1.3**), and changing lighting (**Section 3.1.1.6**). Additionally, this section examines potential non-materiel solutions or TTP changes, including billeting consolidation (**Section 3.1.1.4**) and convenience load reduction (**Section 3.1.1.5**). The combined application of all selected *Provide Billeting* technologies, potential non-materiel, and TTPs is discussed in **Section 3.1.1.7**. In total, 21 technologies and three potential non-materiel solutions or changes to TTPs were investigated for their suitability in contributing to the SLB-STO-D's target of reducing fuel resupply by 25%.

3.1.1.1 Shelter Improvements

The most common shelter on the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps is the 20 ft by 32 ft AS TEMPER Tent. Improvements can be made to the energy efficiency of the AS TEMPER tents by increasing the insulation value of the tent, thus reducing the rate of energy transfer into and out of the tent. The FY12 baseline tent is equipped with a single ply liner, which can be removed and replaced with an alternative liner. Additionally, a solar shade can be raised over the roof of the tent, reducing both solar load and wind speed. This section focuses on the different tent liners and solar shades available for integration in the FY12 AS TEMPER tent.

Four technologies were investigated for their suitability in contributing to the reduction of shelter thermal energy demand. The FY12 ORTB baseline equipment is also described below as well. For complete descriptions of the technologies, see **Annex C**. These technologies were grouped into two sections, liners and shades, and included the following:

Liners:

- Single Ply Liner (FY12 ORTB baseline equipment) – A currently-fielded liner that consists of lightweight woven polyester fabric coated in vinyl. It is included in the standard parts set associated with the AS TEMPER tent.
- Non-Woven Composite Insulation Liner (Non-Woven Liner) – A currently-fielded liner for the AS TEMPER tent that consists of a non-woven composite insulation, which provides a higher level of thermal insulation than the Single Ply Liner. The non-woven liner was fielded post-FY12 and is considered a materiel solution for SLB-STO-D purposes.
- V1.5 Liner – A prototype liner for AS TEMPER tents that integrates a radiant liner with fabric insulation, a dropped ceiling, insulated ducting, and a built-in plenum for soft distribution of conditioned air.

Shades:

- ULCANS shade – A currently-fielded solar shade that can be erected over an AS TEMPER tent to block a portion of solar radiation from the roof and sides of the AS TEMPER tent, as well as reducing wind speed experienced by the tent.
- PShade – A commercially available solar shade with 3.6 kW flexible photovoltaic (PV) array integrated into the shade materiel that can be erected over an AS TEMPER tent to block a portion of solar radiation from the roof and sides, as well as reduce wind speeds experienced by the tent.

All four technologies reviewed were sponsored by NSRDEC along with Program Manager Force Sustainment Systems (PM FSS). The Non-Woven Liner, ULCANS, and V1.5 Liner were demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA. The V1.5 Liner was also demonstrated by the SLB-STO-D at the CBITEC at Fort Leonard Wood, MO. The Single Ply-Liner, the FY12 ORTB TEMPER tent liner, was also demonstrated by the SLB-STO-D to support modeling and simulation of all the legacy FY12 TEMPER tents. Data collected at the demonstrations were used by AMSAA to support the STEM [22] [23].

To compare these technologies, the thermal energy demand of the shelter measured in kBTU was analyzed. In this section, the thermal energy demand describes the energy required to either heat the shelters to 65 °F or cool the shelters to 78 °F [24]. Energy loss from door openings is not considered. Note that the thermal energy demand of the shelter is not equivalent to the ECU power demand.

Comparisons of the thermal energy demand for the various liner and shade technologies are included in **Table 8** and **Table 9**, respectively. Shelter thermal demand was estimated by the AMSAA using the STEM [19]. Details of the data sources and validation and verification are available in *Shelter Thermal Energy Model: Sustainability and Logistics Basing-Science & Technology Objective-Demonstration Model Developments* [25].

Table 8. Comparison of Mean Daily Thermal Demand, Tent Liner Technologies

	Partially Elevated/ Single-Ply Liner/ No Shade		Partially Elevated/ Non-Woven Liner/ No Shade		Partially Elevated/ V1.5 Liner/ No Shade	
Environment	kBTU*	Δ	kBTU*	Δ	kBTU*	Δ
Desert	386	-	264	31.6%	156	59.5%
Temperate	404	-	270	33.0%	183	54.8%
Tropical	341	-	257	24.8%	199	41.6%

[*] Based on AMSAA STEM simulations of AS TEMPER 20 ft by 32 ft tents with 0.288 kW of internal load and nine persons at rest

Table 9. Comparison of Mean Daily Thermal Demand, Shelter Shade Technologies

	Partially Elevated/ Single-Ply Liner/ No Shade		Partially Elevated/ Single-Ply Liner/ ULCANS Shade		Partially Elevated/ Single-Ply Liner/ PShade	
Environment	kBTU*	Δ	kBTU*	Δ	kBTU*	Δ
Desert	386	-	348	9.8%	276	24.4%
Temperate†	404	-	388	4.0%	373	7.7%
Tropical	341	-	303	11.3%	231	32.5%

[*] Based on AMSAA STEM simulations of AS TEMPER 20 ft by 32 ft tents with 0.288 kW of internal load and nine persons at rest.

[†] Shades are assumed to be removed during the winter

Both tent liner and shelter shade technologies showed a significant reduction in shelter thermal energy demand. Tent liners were effective similarly across all environments, proving least effective in the most consistently hot climate, which is the tropical environment. Conversely, shelter shades were most effective in the tropical environment, but significantly less effective in the colder temperate environment. Across all environments, the V1.5 Liner and the PShade showed significantly more savings than their currently-fielded counterparts.

Liner and shading technologies, while reducing shelter thermal demand individually, can be integrated together in a single tent. While all combinations of liners and shades were simulated using AMSAA STEM and analyzed by SLB-STO-D, two illustrative combinations are presented: the Non-Woven Liner with the ULCANS shade (a currently-fielded combination) and the V1.5 liner with the PShade (a combination of promising technologies). **Table 10** shows the combined effects of liner and shade technologies.

Table 10. Comparison of Mean Daily Thermal Demand, Combined Liner and Shade Technologies

	Partially Elevated/ Single-Ply Liner/ No Shade		Partially Elevated/ Non-Woven Liner/ ULCANS Shade		Partially Elevated/ V1.5 Liner/PShade	
Environment	kBTU*	Δ	kBTU*	Δ	kBTU*	Δ
Desert	386	-	243	36.9%	136	64.5%
Temperate†	404	-	261	35.3%	186	54.0%
Tropical	341	-	235	31.1%	178	47.8%

[*] Based on AMSAA STEM simulations of AS TEMPER 20 ft by 32 ft tents with 0.288 kW of internal load and nine persons at rest.

[†] Shades are assumed to be removed during the winter due to snow loads

Both combinations presented showed significant reductions in shelter thermal energy demand. The combination of a V1.5 Liner and PShade showed an additional reduction of 16.7–27.6% over the Non-Woven Liner and ULCANS Shade across the three environments. While neither combination of liner and shade technologies provided an additive reduction in shelter thermal energy demand, the combinations proved more effective than either individually.

Of all liner and shade combinations analyzed, the pairing of a V1.5 Liner and PShade proved most effective at reducing shelter thermal energy demand of AS TEMPER 20 ft by 32 ft tents across all environments. An analysis of the STEM model outputs was also conducted for AS TEMPER 20 ft by 21 ft tents, used for shower changing tents. The V1.5 Liner and PShade was identified as the best liner and shade combination and provided a similar reduction in shelter thermal energy demand for these tents.

In addition to the energy savings provided by its shading capability, the PShade has a 3.6 kW PV array mounted on top of the shade material. Combined with energy storage, the power generated by this PV array is used locally in each tent to power loads. Two integration scenarios were simulated to determine the fuel savings associated with the PShade's power generation capability. In the first scenario, the PShade is limited to only savings from its shading capability. In the second scenario, the PV array provides shade and also generates electricity.

Table 11 shows the simulation result of the integration scenarios across the different base camp sizes in the desert environment. Under both scenarios, all AS TEMPER tents were integrated with the V1.5 Liner and 42 k ECU (see **Section 3.1.1.2** for analysis of ECU technologies). Therefore, the total power savings cannot be attributed solely to the PShade, but the additional power savings from the addition of the PV array is entirely due to the power generation capability of the PShade.

Table 11. Mean Daily Camp Level Summary, Shading Technologies, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	Gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lbs.	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Shade Only[*]	190	11.6%	556	44.8%	75	0.0%	27	0.0%	266	0.0%
Shade and PV Array[*]	187	13.0%	501	50.3%	75	0.0%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Shade Only[*]	951	8.7%	3381	33.8%	8723	0.0%	8529	0.0%	2870	0.0%
Shade and PV Array[*]	919	11.8%	2800	45.2%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Shade Only[*]	3092	8.4%	11071	32.8%	31305	0.0%	31153	0.0%	10672	0.0%
Shade and PV Array[*]	3014	10.7%	9756	40.7%	31305	0.0%	31153	0.0%	10672	0.0%

[*] AS TEMPER tents with V1.5 Liner, 42 k ECU, and PShade

Utilizing the PV array of the PShade on all TEMPER tents provided up to 11.4% power savings over just the shading capability in the desert environment. This resulted in an additional reduction in fuel consumption of 1.4%, 3.1%, and 2.3%, respectively, across the 50 PAX, 300 PAX, and 1000 PAX base camps in the desert environment. While the PShade provided significant power savings, the use of this power locally limited its impact on fuel savings since no generators could be shut down. Integration of this renewable energy source into a grid may prove more effective at reducing fuel consumption. Nevertheless, the unique integration of a flexible PV array into a shade proved valuable since it provides an extra power savings at no additional footprint cost.

In general, shade and liner technologies enable significant fuel savings by reducing the thermal demands of the AS TEMPER tent. While the combination of the Non-Woven Liner and ULCANS Shade provided significant reductions in both fuel and shelter thermal energy demand, the V1.5 Liner and PShade provided a larger reduction. The combination of the V1.5 Liner and PShade shows the best promise in contributing to the SLB-STO-D objective resource reductions.

3.1.1.2 Environmental Control Units (ECUs)

Several ECUs are part of the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps. The ECUs fulfill the requirement of maintaining interior temperatures between 68 °F to 78 °F [26]. ECUs common in the FY12 ORTB are the F100 ECU and MTH150 fuel fired heater, as well as smaller commercial units. The MTH150 is the heating source during the winter months for AS TEMPER tents in the temperate environment only. Power and fuel demand for each ECU was estimated by the AMSAA STEM [22] [23]. Each ECU has a power and fuel demand, matching to a specific shelter, under specific conditions and environment. The ECU demand profile translates to a specific shelter's thermal energy demand, which corresponds to a demand of power and fuel.

In general, the ECUs discussed below have three modes of operation: heating, ventilation, and cooling. The ECUs in FY12 ORTB provide heating through electric heating elements and cooling through traditional air conditioning technology. Ventilation is provided by a large fan used to circulate both hot and cooled air. The MTH150 fuel fired heater provides only heat by directly burning fuel with additional power consumption to power fans and control circuitry. All ECUs modeled are considered thermostatically controlled with the ability to monitor the temperature inside the tent.

Seven ECU technologies were investigated for their suitability in contributing to the SLB-STO-D's target fuel savings of 25%. The FY12 ORTB ECU and fuel fired heater are also included in the descriptions below for comparison purposes. For complete system descriptions of the technologies, see **Annex C**. These technologies included the following:

- F100 (FY12 ORTB baseline equipment) – A currently-fielded ECU that provides 60 kBTU of air conditioning and 10 kW of heat.
- MTH150 (FY12 ORTB baseline equipment) – A currently-fielded fuel-fired heater that provides 120 kBTU of heat and requires electrical power to operate.
- 42k ECU – A prototype ECU that uses variable speed motors and a variable frequency drive compressor to provide 42 kBTU of air conditioning and 6.6 kW of heat.
- 60k IECU – A currently-fielded ECU that provides 60 kBTU of air conditioning and 10 kW of heat. The IECU was fielded post-FY12 and is considered a materiel solution for SLB-STO-D purposes.

- Improved F100 (IF100) – An upgraded F100 with improved efficiency through the incorporation of a variable speed fan and compressor that provides 60 kBTU of air conditioning and 10 kW of heat.
- 60k Innovative Cooling Equipment ECU (60k ICE ECU) – A prototype ECU that provides 60 kBTU of air conditioning and 10 kW of heat.
- SRHS – A prototype radiant floor heating system for AS TEMPER tents that is intended for cold climates and utilizes the same electrical interfaces as other ECUs. The SRHS only provides heat.
- 22k Heat Pump – A commercially available ECU that provides 22 kBTU of air conditioning and 23 kBTU of heat. The 22k Heat Pump has a much smaller heating and cooling capacity than other ECUs analyzed.
- 18k Energy Efficient ECU (18k EEECU) – A prototype ECU that provides 18 kBTU of air conditioning and 4 kW of heat.

The F100, the FY12 ORTB AS TEMPER ECU, was demonstrated by the SLB-STO-D to support modeling and simulation.

Four of the seven technologies reviewed (IF100, 42k ECU, 18k EEECU, and SRHS) were sponsored by NSRDEC along with PM FSS. The 42k ECU and SRHS were demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA and CBITEC at Fort Leonard Wood, MO, respectively. The 42k ECU provided identical heating capacity to the baseline F100, but only 70% of the cooling capacity. While undersized for the baseline shelters, when paired with improved shelter technologies, the 42k ECU provides enough cooling capacity. Data were collected on the IF100 outside of the SLB-STO-D program. The IF100 incorporated incremental improvements through variable speed fans and compressors that increased efficiency over the baseline F100. Performance data were not available on the 18k EEECU, so it was not included in this analysis.

One technology reviewed (60k ICE ECU) was sponsored by CERDEC. The 60k ICE ECU was demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA.

The IECU is currently-fielded equipment. The IECU was demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA. The 22k Heat Pump was modeled from manufacturer specifications.

Estimates of ECU power and fuel consumption were provided by AMSAA STEM [19]. Data collected on the ECUs at the SLB-STO-D demonstrations were used by AMSAA to support the STEM model [22] [23]. The ECU technologies were evaluated against the AS TEMPER tent with the V1.5 Liner and PShade (see **Section 3.1.1.1**). The STEM results were based on the requirement to either heat the shelters to 65 °F or cool the shelters to 78 °F [24]. Energy loss from door openings was not considered. Analysis of STEM results was used to down-select the number of ECUs to model based on their performance against SLB-STO-D program goals and their applicability to the SLB-STO-D base camp [27].

The ECU and tent combinations were examined for cooling and heating overload, which are periods of time when the ECU is unable to keep up with heating or cooling demands to maintain temperatures between 68 °F and 78 °F. All combinations of tent, liner, shade, and ECU were analyzed. The F100 ECU in the FY12 ORTB AS TEMPER tent with Single Ply Liner and no shade was overloaded 1.4% of the year in cooling mode in the desert environment [27]. However, the F100 was able to maintain the temperature in both the tropical and temperate environments. In the temperate environment, the MTH150 was required. Without the fuel fired heater, the F100 would have been overloaded in heating mode 14.3% of the year. The improved AS TEMPER with V1.5 Liner, PShade, and 42k ECU had no instances of heating or cooling overloading in any environment [27]. Additionally, for billeting tents, the MTH150 would not be required to maintain the temperature in the temperate winter (for empty tents, it would still be required to prevent overloading 2.0% of the year). Because the MTH150 more efficiently produces heat, it was retained as the preferred heating option. The AS TEMPER with V1.5 Liner and PShade had a significantly reduced shelter thermal energy demand, allowing for the smaller capacity 42k ECU to be used. The 42k ECU was identified as using the least amount of power to provide the necessary heating and cooling.

The SRHS was investigated as a potential replacement for the MTH150. While analysis of STEM results showed the SRHS can provide the required heat, the system required over double the electrical energy of the 42k ECU and MTH150 combination to maintain the heat required in the billeting tents. This tradeoff of power for fuel may prove valuable, especially at base camps where host nation power is available. As this did not align with the FY12 ORTB, the MTH150 was kept as the heat source for the temperate winters.

Table 12 shows the yearly power and fuel demand of the FY12 ORTB shelter with F100 and MTH150 compared to the AS TEMPER tent with V1.5 Liner, PShade, 42k ECU, and MTH150. Fuel consumption is only present in the temperate environment, as the MTH150 is only used in that climate during the winter.

Table 12. Comparison of Yearly Power and Fuel Demand, ECU Technologies

	Partially Elevated/Single-Ply Liner/No Shade/F100 & MTH-150				Partially Elevated/V1.5 Liner/PShade[*]/42k ECU & MTH-150			
	Power[†]		Fuel[†]		Power[†]		Fuel[†]	
Environment	kWh	Δ	gal	Δ	kWh	Δ	gal	Δ
Desert	34,392	-	0	-	6,978	79.7%	0	0.0%
Temperate[‡]	18,839	-	1,162	-	9,229	51.0%	605	47.9%
Tropical	31,230	-	0	-	3,895	87.5%	0	0.0%

[*] Power generated by PShade is not included.

[†] Based on AMSAA STEM simulations of AS TEMPER 20 ft by 32 ft tents with 0.288 kw of internal load and nine persons at rest.

[‡] Shades are assumed to be removed during the winter

The combination of the AS TEMPER V1.5 Liner, PShade, and 42k ECU reduced ECU power demand across the desert, temperate, and tropical environments by 79.7%, 51.0%, and 87.5%, respectively. **Table 12** does not account for the PShade ability to generate power, which would reduce the net power consumption of the shelter even further. See **Table 11** for the base camp level effect of PShade power generation.

The 42k ECU proved to be the right-sized ECU, given the reduction in thermal energy demand with the implementation of the V1.5 Liner and PShade. The 42k ECU provided the largest reduction in the power required by the ECU across all environments investigated. This ECU, paired with the V1.5 Liner and PShade, will form the basis for shelter improvements.

3.1.1.3 Replacement Shelters and Integrated Shelter Systems

Several shelters that were developed for an alternative concept of operations or that provide different capabilities than the FY12 ORTB tent were identified. Several of these technologies were developed for a small shipping cube and quick set-up and tear-down of the system. Other systems were developed with energy efficiency prioritized, allowing for a larger shipping cube and longer set-up and tear-down.

Nine technologies were investigated for their suitability in contributing to the SLB-STO-D's target fuel savings of 25%. For complete system descriptions of the technologies, see **Annex C**. These technologies included the following:

- SIP-Hut – A pre-fabricated structure that is assembled onsite. The SIP-Hut panels are highly insulated and include lighting, outlets, and ECU interfaces.
- Energy Efficiency (E2) Optimization of Combat Outpost/Patrol Base Shelters to Reduce Fuel Consumption – The E2 prototype reduced fuel consumption through demand control management, battery storage, improved electrical component design, a new ECU, and energy efficient shelter improvements. The E2 prototype components include the V1.5 Liner (see **Section 3.1.1.1**) and 42k ECU (see **Section 3.1.1.2**).
- Energy Efficient Rigid Wall Module (E2RWM) Billeting Shelter – A shelter that provides billeting within an expandable container structure and includes built-in insulation, lighting, outlets, and ECU interfaces.
- E2RWM with Energy Storage (E2RWM - E3) – A variant of the E2RWM with integrated solar panels and power storage,
- Rapidly Deployable Lightweight Shelters for Austere Environments (RDS) – A prototype shelter that provides billeting within a modular pallet based footprint and includes rigid panels and a fabric roof.
- Self-Sustaining Living Module (SLIM) – A prototype shelter that includes power generation, power storage, and a billeting structure. The power generation and storage is provided by a 10 kW generator, batteries, and ground-based PV array. The SLIM structure includes built-in insulation, lighting, outlets, ECU interfaces, and ECU.
- Advanced Energy Efficient Shelter Systems (AEESS) – A prototype shelter that reduces fuel through demand control management, battery storage, use of DC power, improved electrical component design and, energy efficient shelter improvements. The AEESS program focused on optimized fuel consumption and reduction in manpower requirements.
- Expeditionary Mobile Base Camp Demo – Small Unit Sustainment System (SUSS) – A prototype shelter that reduces manpower requirements by speeding the set-up, resulting in more Warfighters available for mission operations. The SUSS program focused on optimized manpower requirements and reduction in fuel consumption.
- Smart Energy Efficient Deployable Shelters (SEEDS) – A prototype shelter that minimizes shelter energy losses using advanced insulation and improvements to the

shelter skin, shelter fly, and high performance computational modeling for optimized design. The SEEDS program focused on minimization of shelter energy losses.

Six of the nine technologies reviewed (SLIM, E2, AEESS, SUSS, SEEDS, and RDS) were sponsored by NSRDEC. SLIM and E2 were demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA. RDS was demonstrated at CBITEC at Fort Leonard Wood, MO.

The SLIM proved immature at demonstrations; therefore, it was not analyzed in this report. The components of the E2 system were analyzed separately: the V1.5 Liner is discussed in **Section 3.1.1.1** and the 42k ECU is discussed in **Section 3.1.1.2**. Since the SUSS and AEESS were designed to fill a capability gap for short missions that require self-sustainability, it did not fit well with the SLB-STO-D use case and would result in lower QoL(O) on the base camp. For this reason, it was not included in this analysis.

Collected demonstration data for the RDS supported AMSAA STEM model development. The RDS system was designed for austere environments and supports four Soldiers per shelter. Due to the large difference in shelter size, many more RDS systems would be required than 20 ft by 32 ft TEMPER tents. An analysis of AMSAA STEM results shows that an RDS with a heat pump is a viable alternative to the FY12 ORTB shelters based on energy demands in the desert and tropical environments. However, billeting Soldiers with RDS systems would require significantly more power than the baseline system in the temperate environment. Due to the large difference in design size, the RDS was not considered a viable candidate to replace the 20 ft by 32 ft TEMPER tents.

The E2RWM Billeting Shelters and E2RWM - E3 are being evaluated by PM FSS. While data have been collected, a verified shelter model was not available at the time of analysis. For this reason, it was not included in the simulations.

The SEEDS shelter, sponsored by ERDC-CERL attempted to maximize shelter thermal efficiency to increase the overall R-value of the shelter envelope and reduce the energy needed for cooling and heating. Technologies incorporated included a vestibule, two radiant barriers, the elimination of windows, and a multilayered soft door. The effort concluded that the SEEDS shelter decreased energy use by 30.6% under cold weather conditions and 34.5% for warm weather conditions when compared to a baseline Utilis TM60 shelter [28]. Since a comparable shelter model was not available at the time of analysis, it was no included in the simulations.

The SLB-STO-D demonstrated various SIP-Hut technologies at CBITEC at Fort Leonard Wood, MO. Data collected at demonstration supported the development of a model using the AMSAA STEM. SIP-Huts were considered a potential replacement shelter for the existing rigid wall shelters on the base camp, B-Huts. This was the only replacement shelter system identified that aligned with the SLB-STO-D use-case.

Estimates of ECU power and fuel consumption were provided by AMSAA STEM [19]. An analysis of the power and fuel required by the SIP-Hut compared to the baseline B-HUT was conducted based on the STEM outputs [27]. Three variants of the SIP-Hut were demonstrated by the SLB-STO-D, all of which were modeled using the AMSAA STEM. Due to limited data availability, only one variant was considered for analysis—the Type 1 SIP-Hut with camouflage shade. The SIP-Hut was evaluated against the available ECUs. Because of the very low energy demand, the 22k Heat Pump was selected as the right-sized ECU for the SIP-Hut.

Table 13 shows the comparison of the FY12 ORTB B-Hut with F100 ECU and MTH150 and the SIP-Hut with 22k Heat Pump ECU. Fuel consumption is only present in the temperate environment, as the MTH150 is only used in that climate during the winter.

Table 13. Comparison of Yearly Power Demand, Replacement Shelter Technologies

	Elevated/B-Hut/No Shade F100 & MTH150				Elevated/SIP-Hut/Camouflage Shade 22k Heat Pump			
	Power		Fuel		Power		Fuel	
Environment	kWh*	Δ	gal*	Δ	kWh*	Δ	gal*	Δ
Desert	28,433.0	-	0.0	-	1915.0	93.3%	0.0	0.0%
Temperate	15,612.4	-	1,156.5	-	3378.9	78.4%	0.0	100.0%
Tropical	28,982.0	-	0.0	-	1,504.5	94.8%	0.0	0.0%

* Based on AMSAA STEM simulations with 0.0 kW of internal load and no occupants.

The combination of the SIP-Hut and 22k Heat Pump reduced ECU power demand across all three environments by 85.2–92.3%. Additionally, the SIP-Hut did not require a fuel fired heater in the temperate climate, eliminating 1,156.5 gal of fuel demand. The elimination of MTH150s would have the additional benefit of a reduced equipment set and a concomitant reduction in maintenance, as well as a reduction in manpower and fuel costs to refuel the tanks.

The SIP-Hut with 22k Heat Pump showed a significant reduction in both fuel and power compared to the B-Hut shelters. This combination shows promise in contributing to the SLB-STO-D objective resource reductions.

3.1.1.4 Billeting Consolidation

Billeting consolidation aims to increase the number of personnel in each active billeting structure, thereby reducing the number of billeting structures on camp that consume resources. Existing billeting guidance reference minimum allowable space as 72 sq ft per soldier and 55 sq ft per soldier during surge and mobilization [29]. During emergencies and surges of less than 72 h, 40 sq ft per soldier may be allocated [29]. The FY12 ORTB Base Camps do not meet the guidance of providing 72 sq ft per soldier, though they are representative of base camps in 2012.

One change to TTP was investigated for its suitability in contributing to the SLB-STO-D's target fuel savings of 25%. This option was the following:

- Change in TTP – A change in TTP to consolidate billeting shelters at a ratio of approximately 18 people per AS TEMPER 20 ft by 32 ft tent.

A potential TTP change scenario was analyzed in which personnel were consolidated into billeting structures at a ratio of approximately 18 people per AS TEMPER 20 ft by 32 ft tent. The number of Soldiers per billet was chosen to be 18 because this was the initial assumption in the FY12 ORTB Base Camp configurations, based on an occupancy of up to two 9-person squads per billet. This scenario provides 36 sq ft per soldier, which is approximately half of what is required by current Army guidance [29]. The shelters removed from operation were chosen to maximize the number of generators that could be shut off as a result. As convenience loads are associated with personnel and not the tents, the loads moved with the personnel, effectively increasing the convenience loads in each remaining tent.

The FY12 ORTB 50 PAX Base Camp, which has a total population of 64 personnel, averages 11 personnel per tent or 58 sq ft per soldier across the six AS TEMPER 20 ft by 32 ft tents. At the 50 PAX base camp, the population was consolidated into four tents. Two tents were removed from the power grid, which allowed one generator to be turned off. Billeting consolidation at the 50 PAX camp resulted in the camp averaging 16 personnel per tent or 40 sq ft per person.

The FY12 ORTB 300 PAX camp, which has a total population of 312, averages 13.5 personnel per tent or 47 sq ft per person across the 23 AS TEMPER 20 ft by 32 ft tents. At the 300 PAX base camp, the population was consolidated into 18 tents. Five tents were removed from the power grid, which in turn allowed one generator to be turned off. Billeting consolidation resulted in the 300 PAX base camp averaging 18 personnel per tent or 38 sq ft per person.

The FY12 ORTB 1000 PAX camp, which has a total population of 1,160 personnel, averages 16 persons per tent or 41 sq ft per person across 74 AS TEMPER 20 ft by 32 ft tents, three Containerized Housing Units (CHUs) and four MILVANS. At the 1000 PAX base camp, the population was consolidated into 65 tents. Seven tents and four MILVANS were removed from the power grid, which in turn allowed two generators to be turned off. Billeting consolidation resulted in the 1000 PAX camp averaging 18 personnel per tent or 38 sq ft per person.

Table 14 shows the results of the simulation of the billeting consolidation scenario across the different base camp sizes in the desert environment.

Table 14. Mean Daily Camp Level Summary, Billeting Consolidation, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Billeting Consolidation, 18:1	183	14.9%	804	20.2%	75	0.0%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Billeting Consolidation, 18:1	986	5.4%	4603	9.9%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Billeting Consolidation, 18:1	3275	3.0%	16789	4.5%	31305	0.0%	31153	0.0%	10672	0.0%

Billeting consolidation showed a significant decrease in power consumption with a lesser, albeit still significant, decrease in fuel consumption. The decrease in fuel consumption was largely attributable to savings in the *Provide Electric Power* functional area, with a small amount of savings in the *Provide Access to Transportation* functional area due to fewer fuel tanks being refueled. In the temperate environment, there were additional savings in the *Shelter Heating and Cooling* functional area from the reduction in fuel fired heaters.

The fuel savings in *Provide Electric Power* was split between several factors: lowering the demand by shutting down billeting facilities, reducing the number of generators, and producing power more efficiently by increasing the load on the remaining generators (i.e., the marginal cost of a kW decreases under higher loads). Shutting down generators proved the most impactful factor in reducing fuel consumption. A generator running idle (its lowest fuel consumption) consumed 9.4%, 2.8%, and 0.9% of fuel at the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps, respectively. One generator was shut down at the 50 PAX and 300 PAX base camps and two generators were shut down at the 1000 PAX base camp. This equates to 51.8–63.0% of the reduction in fuel consumption in the desert environment being attributable to just shutting down generators. The most fuel savings result from removing billeting facilities from the power grid, as to enable shut-down of generators.

While billeting consolidation reduced the base camp fuel demand, this reduction came at a cost of QoL(O). The number of people in each living space was identified as the fifth most impactful attribute to QoL(O) [20]. The QoL(O) Tool can model the effect of the number of personnel in a living space only at four discrete levels: 2, 4, 9, and 18 personnel per living space [20]. The personnel per living space ratio at the FY12 ORTB Base Camps varies between the 9 personnel and 18 personnel per living space. To keep the QoL(O) score conservative, values were rounded up to 18 personnel per space. Therefore, while the QoL(O) Tool does not have the fidelity to quantify the impact of the billeting consolidation scenario, the trend is clear—increasing the number of personnel in a living space decreases QoL(O). Since the SLB-STO-D's goal is to maintain the QoL at the base camps, billeting consolidation is not a candidate TTP solution to achieve the stated resource reduction goals.

3.1.1.5 Convenience Loads

Outlets across each base camp allow personnel to power personal electronics (e.g., televisions, cell phones, electric razors). These personal electronics are collectively referred to as convenience loads. Mission equipment is not considered personal electronics; therefore, only non-mission-critical changes will be discussed in this section. Existing guidance recommends that all facilities used for housing or office space and other areas that require the use of electronic devices be supplied with sufficient fixed electrical outlets [26]. The magnitude of power used by convenience loads is largely driven by the personnel living on the base camp. Reducing this demand would require the enforcement of a TTP change.

One change to TTP was investigated for its suitability in contributing to the SLB-STO-D's target fuel savings of 25%. This option was the following:

- Change in TTP – A change in TTP to eliminate all convenience loads across the base camp.

A single scenario was simulated to determine the impact of reducing convenience loads on fuel consumption. In this scenario, all convenience loads were eliminated. This included convenience loads in the billeting tents, dining facilities, MWR, and command facilities (convenience loads in command facilities are nonessential loads, not mission equipment). This scenario would be considered a best-case scenario from a power reduction standpoint. However, a realistic scenario would likely fall between eliminating all convenience loads and the scenario depicted in the baseline.

Table 15 shows the results for the simulation of the elimination of convenience loads across the different base camp sizes in the desert environment.

Table 15. Mean Daily Camp Level Summary, Convenience Loads, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
No Convenience Loads	213	0.9%	960	4.7%	75	0.0%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
No Convenience Loads	1022	1.9%	4743	7.2%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
No Convenience Loads	3284	2.7%	15876	9.7%	31305	0.0%	31153	0.0%	10672	0.0%

Eliminating convenience loads moderately reduced power demand across the three base camps, but had a very limited impact on fuel consumption, reducing fuel consumption at the 50, 300, and 1000 PAX base camps by 1.1%, 1.9%, and 2.7%, respectively. The impact on fuel reduction is limited, as the elimination of convenience loads reduced power by a small amount at almost every shelter, but did not lower power consumption enough to eliminate any generators.

Additionally, eliminating convenience loads negatively impacts QoL(O). **Table 16** shows the QoL(O) scores of the simulated camp with no convenience loads in comparison to the FY12 ORTB Base Camps.

Table 16. Comparison of QoL(O) Scores, Convenience Loads

	QoL	
Simulation Description	Score	Δ
	50 PAX Camp	
FY12 Baseline	31.3	-
No Convenience Loads	25.6	-5.7
	300 PAX Camp	
FY12 Baseline	65.3	-
No Convenience Loads	54.8	-10.5
	1000 PAX Camp	
FY12 Baseline	67.0	-
No Convenience Loads	56.1	-10.9

The elimination of convenience loads reduced QoL(O) by up to 10.9 points across the three base camps. This score reduction was exacerbated by the number of QoL(O) attributes tied to the presence of convenience loads. For example, eliminating these convenience loads also eliminated access to televisions, DVD players, and gaming consoles. Each of these incrementally reduced QoL(O) on the base camps. The FY12 ORTB 300 PAX and 1000 PAX Base Camps, which have a higher level of baseline service, experienced a higher drop in QoL(O) score compared to the most austere 50 PAX base camps.

While the elimination of convenience loads did provide fuel savings, these savings came at a significant cost to QoL(O). Since it is the SLB-STO-D goal to maintain the QoL at the base camps, removal of convenience loads is not a candidate solution to achieve the stated resource reduction goals.

3.1.1.6 Lighting

The *Lighting* equipment level function power demand is largely contributed to by two components: general purpose shelter lighting (i.e., the fluorescent lights used in many facilities) and exterior lighting (i.e., perimeter flood lights). This section focuses on the interior lighting used in facilities such as billeting. Each individual fluorescent light does not draw a significant amount of power, but because there are a significant number of fluorescent lights across the base camp, the total power demand is relatively large. Replacing these lights with more efficient versions would result in a significant reduction in power demand, as would reducing the number of hours the lights are used. These two factors, lighting efficiency and usage schedule, were both analyzed for their base camp level impact.

One technology and two potential changes to TTPs were investigated for their suitability in contributing to the SLB-STO-D target fuel savings of 25%. The FY12 ORTB fluorescent lights are also included in the descriptions below for comparison purposes. For complete system descriptions of the technologies, see **Annex C**.

- Ruggedized fluorescent lights (FY12 ORTB baseline equipment) – Currently-fielded, commercially available fluorescent lights that provide general purpose lighting in shelters.
- Ruggedized Light Emitting Diode (LED) lights – Commercially available energy efficient LED lights that are a 1:1 replacement for the legacy fluorescent lights.
- Change in TTP – A change in TTP to eliminate the use of non-essential lighting.
- Change in TTP – A change in TTP to restrict the use of non-essential lighting by approximately 50%.

Three scenarios were simulated. In the first scenario, all ruggedized fluorescent lights were replaced with their LED counterparts. The LED lights are capable of multiple levels of brightness. These lights were set to provide equivalent lighting to the baseline fluorescent lights.

In the second scenario, a TTP change was implemented to eliminate the use of non-essential lighting. While this scenario is unrealistic, it provides an upper bound for the savings that can be achieved by reducing lighting; any realistic reduction in lighting use will result in lesser savings. All light fixtures were shut-off except for the lights in the tactical operations centers (TOCs), tactical action centers (TACs), and command posts (CPs), where the use of these lights was reduced from 24 h a day to 8 h at night. Perimeter and outdoor lighting was not impacted as it was deemed essential to soldier safety.

In the third scenario, a TTP change was implemented to enforce the selective use of nonessential lighting. While lighting was allowed at all hours, only half of all lights could be used (i.e., only four of eight fluorescent lights in each billeting tent were operational). The exception to this was lights in the TOCs and TACs, where the use of lights was unrestricted. Perimeter and outdoor lighting was not impacted as it was deemed essential to soldier safety.

Table 17 shows the results of the implementation of the LED lights and the two TTPs restricting lighting use across the different base camp sizes in the desert environment.

Table 17. Mean Daily Camp Level Summary, Lighting, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Essential Lighting Only	212	1.4%	946	6.1%	75	0.0%	27	0.0%	266	0.0%
Lighting Use Restricted 50%	214	0.5%	978	2.9%	75	0.0%	27	0.0%	266	0.0%
LED Lights	215	0.0%	991	1.6%	75	0.0%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Essential Lighting Only	1043	1.3%	4857	4.9%	8723	0.0%	8529	0.0%	2870	0.0%
Lighting Use Restricted 50%	1044	0.6%	4988	2.4%	8723	0.0%	8529	0.0%	2870	0.0%
LED Lights	1039	0.3%	5051	1.1%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Essential Lighting Only	3379	1.5%	16635	5.4%	31305	0.0%	31153	0.0%	10672	0.0%
Lighting Use Restricted 50%	3385	0.7%	17126	2.6%	31305	0.0%	31153	0.0%	10672	0.0%
LED Lights	3365	0.3%	17370	1.2%	31305	0.0%	31153	0.0%	10672	0.0%

Eliminating non-essential lighting minimally reduced power demand across the three base camps. The in-between case of restricting lighting by 50% produced approximately half the savings. Neither option had a significant impact on fuel consumption, with a fuel reduction of 1.3–1.5% across the three base camps in the desert environment.

The implementation of LED lights had a negligible impact on the base camps' fuel consumption: it reduced fuel consumption by 0.0–0.3% in the desert environment. While the impact on a camp-wide level was minimal, LED lights did provide a 14.5–25.0% reduction in power consumption in the *Lighting* functional area. Their potential for resource reduction may not warrant immediate upgrade of existing facilities; however, the incremental replacement of fluorescent lights with LED lights provides a small but relatively inexpensive savings. Additional benefits may also be seen from their ability to be dimmed, which would further save power.

Restricting the use of lighting also negatively impact QoL(O) on the base camps. **Table 18** shows the QoL(O) scores of the camp in comparison to the FY12 ORTB Base Camps. At all three base camps, the elimination of non-essential lighting results in a net decrease of QoL(O) by 2.2 points. While the QoL(O) Tool does not provide the fidelity to measure the impact of restricting lighting by 50%, it is assumed that this change in TTP would also decrease QoL(O).

Table 18. Comparison of QoL(O) Scores, Lighting

Simulation Description	QoL Score	QoL Δ
	50 PAX Camp	
FY12 Baseline	31.3	-
Essential Lighting Only	29.1	-2.2
	300 PAX Camp	
FY12 Baseline	65.3	-
Essential Lighting Only	63.1	-2.2
	1000 PAX Camp	
FY12 Baseline	67.0	-
Essential Lighting Only	65.3	-2.2

Since it is the SLB-STO-D goal to maintain the QoL at the base camps, restricting non-essential lighting is not considered a candidate solution to achieve the stated resource reduction goals. However, since LED lights do not impact QoL(O), LED lights will be considered as a potential solution.

3.1.1.7 Combined Effect of Billeting Technologies

A total of 21 billeting technologies and three TTPs were considered for integration into the 50, 300, and 1000 PAX base camps. Because the performance of ECUs is highly dependent on other shelter technologies (i.e., liner and shades), the performance of shelter technologies is best analyzed as an integrated system. While technologies and TTP changes were analyzed in the context of billeting shelters, similar equipment sets are used across the base camp allowing billeting technologies to be integrated into a significant number of facilities in addition to billeting structures.

Of the 21 technologies analyzed, 6 were considered potential solutions to achieve resource reduction goals: LED lights, V1.5 Liner, PShade, 42k ECU, SIP-Hut, and 22k Heat Pump ECU. Three TTPs were considered for integration: consolidation of billeting shelters, elimination of convenience loads, and reduction of non-essential lighting. Since all three resulted in a decrease of QoL(O), none were considered candidates to achieve the SLB-STO-D objective resource reductions.

A single scenario was simulated to investigate the combined impact of shelter technologies. The V1.5 Liner and PShade were integrated on each AS TEMPER tent, including both 20 ft by 32 ft and 20 ft by 21 ft tents. All F100 ECUs were replaced with 42k ECUs, but MTH150 fuel-fired heaters continued to be used to provide heat in the temperate environment during the winter season. All B-Huts with their associated F100 ECU and MTH150 were replaced with SIP-Huts with 22k Heat Pump ECUs. Because lighting acts independently of other shelter technologies, it was not included in the integrated simulation.

The individual effect of each of these technologies is available in the following sections: *Shelter Improvements* (**Section 3.1.1.1**)*, Environmental Control Units (ECUs)* (**Section 3.1.1.2**), *Replacement Shelters and Integrated Shelter Systems (***Section 3.1.1.3**), and *Lighting* (**Section 3.1.1.6**).

Table 19 shows the results for the simulation of the integrated shelter technologies across the different base camp sizes in the three environments. Because shelters are greatly impacted by the climate, the results of all three environments are included.

Table 19. Mean Daily Camp Level Summary, Provide Billeting Technologies

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	Gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
50 PAX Camp										
Desert Environment										
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Improved Shelters	178	17.2%	342	66.0%	75	0.0%	27	0.0%	266	0.0%
Temperate Environment										
FY12 Baseline	219	-	661	-	75	-	27	-	266	-
Improved Shelters	193	11.9%	412	37.7%	75	0.0%	27	0.0%	266	0.0%
Tropical Environment										
FY12 Baseline	212	-	951	-	75	-	27	-	266	-
Improved Shelters	174	17.9%	278	70.8%	75	0.0%	27	0.0%	266	0.0%
300 PAX Camp										
Desert Environment										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Improved Shelters	905	13.2%	2528	50.5%	8723	0.0%	8529	0.0%	2870	0.0%
Temperate Environment										
FY12 Baseline	1096	-	4091	-	8723	-	8529	-	2870	-
Improved Shelters	1001	8.7%	3173	22.4%	8723	0.0%	8529	0.0%	2870	0.0%
Tropical Environment										
FY12 Baseline	1023	-	4806	-	8723	-	8529	-	2870	-
Improved Shelters	888	13.2%	2240	53.4%	8723	0.0%	8529	0.0%	2870	0.0%
1000 PAX Camp										
Desert Environment										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Improved Shelters	2916	13.6%	8878	49.5%	31305	0.0%	31153	0.0%	10672	0.0%
Temperate Environment										
FY12 Baseline	3654	-	14751	-	31305	-	31153	-	10672	-
Improved Shelters	3329	8.9%	11628	21.2%	31305	0.0%	31153	0.0%	10672	0.0%
Tropical Environment										
FY12 Baseline	3301	-	16463	-	31305	-	31153	-	10672	-
Improved Shelters	2841	13.9%	7750	52.9%	31305	0.0%	31153	0.0%	10672	0.0%

The combination of the V1.5 Liner, PShade, 42K ECU, and SIP-Hut with 22k Heat Pump ECU reduced power demand by 22.4–70.8% across the three base camp sizes. These savings were concentrated in the *Shelter Heating and Cooling* functional area, which saw reductions in power consumption of up to 83.4%. Power reductions were less in the temperate environment due to the use of MTH150 fuel-fired heaters. During the winter months when the MTH150s are in use, any requirement for heat results in a constant power draw. This power draw is the same regardless of whether the improved shelters require less heat.

These power savings resulted in a reduction in fuel demand of 8.7–17.9% across the base camps. The difference in fuel savings and power savings is a reminder that power savings does not equate to a proportional fuel savings. To fully capitalize on the reduction in power demand, electrical loads should be consolidated to fewer generators, turning off unnecessary power generation assets.

By downsizing the ECU to the 42k ECU, the peak power draw of the ECU is reduced from the baseline F100’s 11.55 kW to 7.3 kW. This reduction in peak power consumption allowed for localized generator reallocation to be performed. At the 50 PAX base camp, loads could be rebalanced to eliminate one generator. At the 1000 PAX base camp, five billeting shelters could be allocated to each 60 kW TQG instead of only three using the baseline equipment. This eliminated five generators from the equipment set. At the 300 PAX base camp, no generator reallocation was possible due to the unique geographic layout of that base camp. The combination of a basic generator reallocation, V1.5 Liner, PShade, 42k ECU, and SIP-Hut reduced fuel demand at the 50 PAX and 1000 PAX base camps by 27.0% and 18.0% in the desert environment, respectively. For more information on generator reallocation see the discussion in Camp Wide Power Generation, **Section 3.1.2.1.**

The shelter and ECU technologies analyzed have a significant impact on fuel reduction by insulating and shading shelters and sizing ECUs to the thermal demand of a structure. Shelter shade and liner technologies enable smaller ECUs to be used, which not only reduces power consumption, but enables more shelters to be placed on a single generator. Since the elimination of power generation equipment provides a significant fuel consumption reduction, care must be taken in sizing generators to these reduced electrical loads. These findings support the previous recommendation of the Smart and Green Energy (SAGE) program that steps be taken to "[r]eplace poorly or un-insulated tents with insulated, energy efficient shelters featuring rightsized high-efficiency ECUs" [30].

The *Provide Billeting* functional area is the single largest consumer of power at the FY12 ORTB Base Camps. The use of shelter technologies to reduce fuel and power demand in this area will be key in meeting the SLB-STO-D goal of 25% fuel demand reduction, since all changes to TTPs that achieved resource reductions proved detrimental to QoL(O). The combination of V1.5 Liner, PShade, and 42k ECU showed the highest savings for TEMPER tents, while the SIP-Hut with 22k Heat Pump ECU proved most efficient for rigid wall shelters. LED lights are applicable across all shelters and will also be considered. In general, improved shelter technologies reduced the thermal demand of shelters, and right-sized ECUs to the new thermal energy demand. The ECUs selected had comparatively smaller peak power draws that allowed for a reduction in generators. Each of these effects have a synergistic effect that results in a greater fuel savings than the individual technologies alone.

3.1.2 Provide Electric Power

On each FY12 ORTB Base Camp, 71.8–90.3% of all fuel is used to provide electric power, depending on the environment and camp size. If the SLB-STO-D fuel reduction goal is going to be met, the efficiency of electric power production must be addressed. This section discusses the *Provide Electric Power* functional area, whether by camp-wide power generation (**Section 3.1.2.1**), man-portable spot generation (**Section 3.1.2.2**), or through renewable energy sources (**Section 3.1.2.3**).

A few general principles guide selection of power generation technologies. First, fuel consumption is typically not linear: the fuel required to produce a kW of power varies, according to each generator's specific fuel-to-power curve. Additionally, consumption differs between different sized generators when providing the same amount of power. A generator producing 30 kW of power uses less fuel, sometimes a lot less, than two generators each producing 15 kW. More efficient generator-loading techniques can produce fuel savings.

Secondly, the geographical layout of the base camp can play a large role in its overall fuel consumption. Generators can only supply power to devices that are located physically close to them. As will be discussed in **Section 3.1.2.1,** generators are limited in their geographic span by the effect of voltage loss due to cable length and the distance power cables are able to reach. In general, a base camp that is more compact requires fewer generators (and therefore less fuel) than one that is more spread out. The FY12 ORTB Base Camps were designed based on input from SMEs, as discussed in **Section 2.2**. Care was taken to ensure that the base camp layout would be a representative example of actual base camps in FY12—not an optimized ideal. After a layout had been decided, generators and other power-generation technologies were placed on the camp to address power demand.

Thirdly, the number of loads connected to a generator is limited by their peak power requirement. The FY12 ORTB allocated loads to generators based on seasonally-adjusted peak connected loads (i.e., the peak wattage required for all electrical devices in a facility, adjusted to account for only the ECU or fuel-fired heater). This method provides a conservative allocation, resulting in more generators than would likely be required. Other methods of generator allocation exist, including *TM 3-34.46* [31], which will be discussed in **Section 3.1.2.1**. Different allocation strategies can produce different results, so the impact of these options will be investigated.

Finally, power can also be generated without the use of fuel through renewable sources of energy, such as wind and solar, as discussed in **Section 3.1.2.3**. Renewable power generation saves fuel both by reducing the amount of power required to be supplied by the generators and by reducing the peaks of certain technologies, allowing their remaining power demand to be addressed more efficiently, as well as by reducing the amount of fuel used in convoys to resupply fuel to the base camp.

Because of the complex and transitory nature of base camps, it is unrealistic to assume that base camps will be perfectly optimized to achieve the minimum possible fuel consumption. Instead, this section will focus on simulating bounding runs and simulating technologies in different configurations and locations to get the most complete information on the relative performance of various technologies.

3.1.2.1 Camp-Wide Power Generation

Power at the FY12 ORTB Base Camps is provided by mobile electric generators. The DoD uses a family of generator sets to produce the electrical power needed by military field units. At the FY12 ORTB Base Camps, only a single type of generator set is used at each camp – 30 kW TQGs at the 50 PAX base camp and 60 kW TQGs at the 300 PAX and 1000 PAX base camps. This section focuses on augmenting or replacing these TQGs to enhance the base camp’s capability to provide power. This contrasts with **Section 3.1.2.2**, which focuses on small, man-portable generators that are not sufficiently sized to provide power to the entire base camp.

At all of the FY12 ORTB Base Camps, the *Power Generation* functional area is the largest consumer of fuel, accounting for 71.8–90.3% of the overall fuel consumption depending on the environment and camp size. For this reason, reducing the amount of fuel consumed to generate power at the base camps is key to meeting the SLB-STO-D's goal of a 25% reduction in fuel consumption. Fuel use related to electric power generation can be reduced two ways: producing electric power more efficiently or reducing the amount of electric power demanded. This section focuses on to what extent technologies and non-materiel solutions in this functional area can contribute to fuel savings when integrated into the FY12 ORTB Base Camps.

The options analyzed can be sorted into three broad categories: generator allocation methods, island power generation, and grid power generation. Generator allocation focuses on the decision process by which electrical loads are paired with a particular power source. Variations in methods and camp layout have a potentially large impact on power distribution, which in turn impacts fuel consumption. Island generation and microgrids are alternative power production and distribution methods. Island generation uses standalone generators to power specific facilities. All generators act independently of each other. This is the scheme used to power the FY12 ORTB Base Camps. In a microgrid configuration, multiple generators are interconnected to act as a single unit using a control algorithm.

The physical layout of each baseline camp has a significant impact on generator allocation both in terms of the presence of physical impediments and in terms of the effect of voltage loss due to cable length. According to *TM 9-6150-226-13 Operator and Field Maintenance Manual for Power Distribution Illumination Systems, Electrical (PDISE)*, the maximum cable length to prevent unacceptable voltages losses under maximum load is 300 ft [32]. As a design factor for this analysis, a conservative 200 ft straight line distance from the generator was used to determine if a structure was close enough to be powered by the generator asset. This factor allowed for an extra 100 ft of slack to account for running cables around structures of moving power generation assets to more convenient locations (e.g., by a nearby road).

To assess the impact of this constraint, scenarios were developed where camp power consumers were assigned to the fewest number of generators possible. These simulations no longer reflect an operationally relevant layout and are referred to as "Mathematical Minimum" simulations. The purpose of these analyses scenarios is to establish an upper limit of on-base fuel savings for a given power distribution method. This scenario represents a best-case, when and if a base camp were set up perfectly to facilitate the fewest number of generators required to provide power.

3.1.2.1.1 Generator Allocation Methods

Generator allocation focuses on the decision process by which electrical loads are paired with a particular power source. Variations in methods and camp layout have a potentially large impact on the number of generators required and the power distribution, which in turn impacts fuel consumption. Right-sizing power generation equipment with loads will result in more efficiently produced power and therefore fuel savings.

One change to TTP was investigated for its suitability in contributing to the SLB-STO-D's target fuel savings of 25%. The FY12 ORTB generator allocation method is also included in the descriptions below for comparison purposes. These options included the following:

- Seasonally-adjusted Connected Loads (FY12 Baseline method) – A method of allocating generators based on the peak wattage required for all electrical devices in a facility, adjusted to account for only the ECU or fuel-fired heater.
- Change in TTP – A change in TTP to reallocate generators according to *TM 3-34.46, Theater of Operations Electrical Systems* [31].

The FY12 ORTB method of using connected loads was considered the most operationally relevant method at the time, although the partial peak method is defined in an Army technical manual (*TM 3-34.46)* and could be considered equally relevant. Sizing generators by connected loads is straightforward: system peak power numbers are aggregated and assigned to different generator sets, which are limited by their continuous power rating. If the total peak power of systems assigned to a generator does not exceed the capacity of the generator, it is considered valid. The FY12 ORTB Base Camp layouts were designed by base camp SMEs and generators were allocated to maintain the constraints on generator capacity and the physical layout of the camp. This method is conservative, ensuring that the base camp power generation capacity can meet the demand of all systems on the base camp while drawing the maximum wattage simultaneously.

The *TM 3-34.46* power distribution method takes the connected loads and scales them down based on a variety of factors. This method uses demand factor coefficients between zero and one to scale down the connected load to account for the fact that all equipment in a facility does not operate at the same time. Further scaling accounts for the diversity of loads (e.g., the kitchen facilities consume a lot of power, but during set time-periods). Ultimately, in many cases, the sizing of generators is based on a fraction of the connected load. This allows more power consumers per generator and thus in turn reduces the number of generators.

Three scenarios were simulated to determine the impact of changing the generator allocation method.

In the first scenario, generators were reallocated according to demand loads derived from *TM 3-34.46* in an operationally relevant environment, maintaining constraints on the physical layout and geometry of the camp itself, which includes cable lengths and physical impediments. As compared with the FY12 ORTB Base Camps, this method allowed for the elimination of 1, 7 and 26 generators at the 50, 300, and 1000 PAX base camps, respectively.

Since generator allocation methods are constrained by the geographic layout, inefficiencies in layout are inherent to the base camp, and not due to the allocation method. Two scenarios investigated this impact. In both scenarios, the constraint of geography was removed, allowing for the mathematical minimum number of generators to be used. In one scenario, the FY12 ORTB method of generator allocation was used, and the *TM 3-34.46* method was used in the other.

Using the minimum number of generators and the FY12 ORTB method of generator allocation allows for the elimination of 8 and 19 generators at the 300 PAX and 1000 PAX base camps, respectively. The 50 PAX base camp is identical to using the *TM 3-34.46* allocation method, eliminating one generator.

Using the minimum number of generators and the *TM 3-34.46* method of generator allocation allows for the elimination of 10 and 28 generators at the 300 PAX and 1000 PAX base camps, respectively. The 50 PAX base camp is identical to using the *TM 3-34.46* allocation method, requiring five generators.

Table 20 shows the results of the simulations of the TTP change scenarios across the different base camp sizes in the desert environment. Additional scenarios in combination with changes to power generation equipment are discussed in **Section 3.1.2.1.2** and **Section 3.1.2.1.3**. For each scenario presented, the same simulations were completed for each environment, but the results for the temperate and tropical environments are essentially the same as the desert[5], and are therefore omitted from this report. Although power, water, solid waste, and liquid waste metrics were calculated as part of each simulation, these numbers were omitted from the report because there was no change from the baseline.

Table 20. Mean Daily Fuel Usage, Generator Allocation Methods, Desert

Simulation Description	Fuel (gal/day)	Δ
	50 PAX Camp	
FY12 Baseline	215	-
TM 3-34.46	195	9.3%
	300 PAX Camp	
FY12 Baseline	1042	-
TM 3-34.46	837	19.7%
Mathematical Minimum TQGs	835	19.9%
Mathematical Minimum TQGs with TM 3-34.46	780	25.1%
	1000 PAX Camp	
FY12 Baseline	3376	-
TM 3-34.46	2625	22.3%
Mathematical Minimum TQGs	2704	19.9%
Mathematical Minimum TQGs with TM 3-34.46	2517	25.4%

By utilizing the *TM 3-34.46* generator reallocation method, a base camp can save a significant amount of fuel in comparison to the FY12 ORTB baseline. The fuel reduction was different across the three base camp sizes. In the desert environment, the 50 PAX base camp saw a 9.3% reduction in fuel consumption, but the 300 PAX and 1000 PAX base camps exhibited a 19.7% and 22.3% reduction, respectively. While there appears to be a trend of larger savings at larger camps, the fuel savings more closely aligns with the percentage of power generation equipment eliminated.

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[5] The SLB-STO-D generator model does not take into account environmental factors (e.g., ambient temperature, fuel temperature, and altitude) that can affect generator efficiency. Data was not available to quantify the impact of these variables in the model.

To illustrate this, consider the extreme scenario of a base camp that is powered entirely by one large generator. If loads were reallocated based on *TM 3-34.46*, the camp would see no fuel savings since power demand stayed constant and the total number of generators would not be reduced. At base camps with many smaller generators, the percent reduction in generators would be similar to the percent reduction to the calculated connected load. At the FY12 ORTB 50 PAX Base Camp, six 30 kW TQGs at baseline are reduced to only five generators using the *TM 3-34.46* method, a 16.7% reduction in on-base generator capacity. At the 300 PAX and 1000 PAX base camps, there are 7 generators (30.4%) and 26 generators (35.6%) reductions, respectively. The percent reduction in fuel at any camp using a different generator allocation method is directly related to reduction in active generators, and this relationship is reflected in simulation results across each camp.

The purpose of the mathematical minimum scenarios, although likely unrealistic in practice, is to measure the extent to which layout affects overall base camp power generation efficiency and what would be theoretically possible if this constraint was relaxed in the context of a particular generator allocation method. The FY12 ORTB Base Camps are representative designs. As such, deviations on this design could be just as operationally relevant and even small changes to facilities could cascade larger changes to generator allocation. In this case, both the seasonally-adjusted connected load approach utilized in the FY12 ORTB and the *TM 3-34.46* method were assessed.

In the case of the 50 PAX base camp, there was no difference when the layout constraint was relaxed. Utilizing the *TM 3-34.46* generator allocation alone will generate the best outcome without a change in the camp equipment set.

At the 300 PAX base camp, allocating generators using the FY12 ORTB method and using the mathematical minimum number of 60 kW TQGs required yielded a fuel savings of 19.9% in the desert environment, which is only a 0.2% increase in savings over an operationally relevant *TM 3-34.46* allocation. This 0.2% decrease amounted to an approximately 2 gal average daily fuel reduction. The total reduction in generator count is the same in both the mathematical minimum scenario using the baseline method and the operationally relevant scenario using the *TM 3-34.46* method. Thus, a difference in load profile and how it is distributed to the camp's generators proved the true source of the difference between the two scenarios. Since camp power load cannot be predicted beforehand to determine load difference, for all intents and purposes these methods should be considered equally effective at the 300 PAX base camp. The only method to achieve more fuel savings is to utilize both *TM 3-34.46* and mathematical minimum layout simultaneously. In this case, the total average daily fuel savings is 25.1% in the desert environment. What this shows is that if the operational considerations were removed when designing the camp layout, camp equipment could be set up in a way that minimizes the total number of generators as its primary purpose. There would be an additional 5.2% fuel savings in comparison to a base camp set up operationally with the *TM 3-34.46*. While 5.2% may represent a significant amount of fuel, this number represents the maximum fuel savings possible when all non-materiel courses of action are considered given a particular base camp layout, equipment set, and equipment usage profile.

The 1000 PAX base camp showed a result that is unlike the smaller base camps, which indicates a difference in the relative importance of generator allocation method and layout constraints. In the case of the 1000 PAX base camp, utilizing the mathematical minimum number of generators and FY12 ORTB method of allocation created a lower percentage fuel savings than using *TM 3-34.46* in an operational base camp configuration. At the 1000 PAX base camp, the aggregate camp power is a greater constraint than the layout of the camp itself. In fact, when the mathematical minimum number of generators are used with the *TM 3-34.46* method, the total average daily fuel savings was 25.4%. This represents an additional 5.5% savings over the mathematical minimum number of generators using the FY12 ORTB method and a 3.1% additional fuel savings over the *TM 3-34.46* method alone.

These results do not provide clear insight into whether generator loading method or geographical constraints are consistently the more important factor in generator efficiency. However, there are a few trends that were observed and should be considered. When using larger generators, especially when those generators each represent a large percentage of the total required power capacity of the camp, utilizing different generator allocation methods may not yield a significant difference. In some cases, it will not make a difference at all. In cases where camps are powered by large numbers of small generators, using an appropriate allocation method proves more important. For an operational base camp, unlikely to prioritize operational energy as its primary goal, utilizing the *TM 3-34.46* method of generator allocation will provide most of the savings, with designing the base camp to minimize the generator count producing only incremental gains. Although the number of data points is somewhat limited since only three base camps were assessed against a baseline, the difference between an operational layout and the mathematical minimum number of generators was only a 0.0% to 5.2% reduction in fuel.

3.1.2.1.2 Island Power Generation

Using standalone generators to power specific facilities is referred to as island power generation. In this configuration, all generators act independently of each other, with no awareness to the generators around them. This is the scheme used to power the FY12 ORTB Base Camps, which use a single type of generator set at each camp—30 kW TQGs at the 50 PAX base camp and 60 kW TQGs at the 300 PAX and 1000 PAX base camps.

Increased efficiencies when utilizing island power generation can be achieved in several different ways. These methods include increasing the fuel efficiency of the generators themselves and generator right-sizing methods. Right-sizing methods include multiple techniques. Determining generator allocations based on different connected load calculations is discussed in **Section 3.1.2.1.1**. This section will discuss the possibility of substituting baseline generators for those with a different electrical capacity.

While the impact on changing island generator capacity will be analyzed, all assessments are based on a single type of generator set being used at the base camp. Mixed equipment sets of different generators for a highly optimized allocation were not assessed due to the complexity of the problem space and the capabilities of the modeling environment being used. While DCAM does have the ability to simulate any generator asset in its database, equipment set variations are manually entered, making iterative analysis in search of an optimized power layout impractical.

Four technologies were investigated for their suitability in contributing to the SLB-STO-D's target fuel savings of 25%. The FY12 ORTB generators are also included in the descriptions below for comparison purposes. For complete descriptions of the technologies, see **Annex C**. These options included the following:

- 30 kW TQG (FY12 ORTB baseline equipment) – A currently-fielded, skid-mounted generator that provides up to 30 kW of power with improved performance over the legacy standard family of DoD generators.
- 60 kW TQG (FY12 ORTB baseline equipment) – A currently-fielded, skid-mounted generator that provides up to 60 kW of power with improved performance over the legacy Standard Family of DoD Generators.
- Hybrid Power Trailer (HPT) – A prototype hybrid power system consisting of a 15 kW TQG coupled with 80 kWh of battery storage mounted on a trailer. The battery is used as the main power source to the load, and the onboard generator is run to recharge the battery as required.
- T-100 High Mobility Multipurpose Wheeled Vehicle (HMMWV) Towable Generator (T-100) – A prototype generator that provides up to 80 kW of continuous power (100 kW instantaneous) which can be towed behind a HMMWV or Joint Light Tactical Vehicle (JLTV). The T-100 features load-following technology that varies the generator engine speed to match the power demand.
- Advanced Nanogrid Power Management – A prototype power distribution and management system that automatically shifts electrical loads between different phases to balance the three phases.
- Single Common Powertrain Lubricant (SCPL) – A developmental, fully synthetic, multipurpose, heavy-duty diesel engine oil that provides a reduction in fuel consumption, maintenance of component durability, multifunctional performance (e.g., engine, transmission, hydraulic systems), and a reduction in maintenance compared to existing engine oils.

Numerous analysis scenarios were simulated to determine the impact of various island generator configurations. Additional scenarios were developed to measure the impact of design assumptions and constraints.

The FY12 ORTB 50 PAX base camp is unique in its use of 30 kW TQGs, where the 300 PAX and 1000 PAX base camps both use 60 kW TQGs. Since both sizes of generators would be equally operationally relevant at the 50 PAX base camp, the larger generators could have been used. By replacing the 30 kW TQGs with 60 kW TQGs, the number of power generation assets was cut in half. Since the base camp was so small, no facilities would have to be moved to accommodate the change. This change in equipment set demonstrates the results sensitivity to the assumed use of 30 kW TQGs.

The T-100, sponsored by CERDEC and demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA, is a lightweight generator prototype that provides up to 80 kW of continuous power. Data collected at the demonstration were used by CERDEC and SLB-STO-D to generate a fuel curve for the T-100. While the T-100 includes variable-speed technology designed to increase efficiency, the primary objective of the program was to increase the generator capacity that can be towed behind a HMMWV or JLTV. As such, design decisions favored weight over fuel consumption. The unique capacity of the generator limited its impact at the FY12 ORTB Base Camps. When developing the FY12 ORTB Base Camps, a large amount of effort went into creating an operationally relevant layout that was shaped in part by the Army's current suite of generators, more specifically the 30 kW and 60 kW TQGs. Having additional power capacity in a base camp, especially one that is not a multiple of 30 or 60 kW, made developing a layout challenging. If the T-100 generator was introduced during design and setup, the camp itself could look different.

To address this issue, the analysis approach taken was to develop bounds for the fuel savings, since developing new base camp layouts designed around the new generator would have been extremely complex and likely would have eliminated some of the inefficiencies inherent in the FY12 ORTB layouts. Two scenarios were investigated. The lower bound for fuel savings is based on a one-to-one drop-in replacement for the TQGs (not optimizing the base camp for the increase in capacity). An upper bound for fuel savings is based on a best-case scenario using the mathematical minimum number of T-100s. This reduced the number of generators to 2 (from 6), 13 (from 24), and 38 (from 75) at the 50, 300, and 1000 PAX base camps, respectively.

Variations of the T-100 integration scenarios were analyzed assuming the T-100 uses SCPL. SCPL technology is under development by TARDEC. A primary motivation for investigating this technology is to reduce the logistical difficulties associated with using multiple lubricants for the variety of technologies and environments where base camps operate. The candidate technology generally exhibits another beneficial effect: lower viscosity, which enables greater fuel efficiency through reduction in energy lost to friction and other imperfections of engine performance. While additional testing remains to be done on SCPL's long-term impact, limited testing has been conducted. Comparing the SCPL against the Army's standard lubricant. Further testing may be pursued with generator manufacturers to qualify SCPL.

The Advanced Nanogrid Power Management, under development by NSRDEC, is a prototype power distribution and management system that automatically shifts electrical loads between different phases to balance the three phases. This will eliminate the need to shed loads or maintain load prioritization databases. The DCAM simulation environment assumes loads are balanced across the electrical phases, so the performance of the system could not be included in this analysis.

The HPT, under development by ERDC-CERL, was demonstrated by the SLB-STO-D at CBITEC at Fort Leonard Wood, MO. The system model is based on empirical data collected by ERDC at the Experimental Forward Operating Base (ExFOB). The HPT is unique in that the system attempts to power loads using battery power, starting the generator only to recharge the battery or to handle surges in power demand that the battery cannot handle. This allows the attached generator to be shut-down instead of idling at all times. One challenge associated with integrating the HPT in the configuration in which it was demonstrated was finding opportunities for relevant implementation at the FY12 ORTB Base Camps. The HPT utilized a 15 kW TQG as its power generation source and an 80 kWh battery. The system can only guarantee a capability to power a 15 kW load, assuming the battery is completely discharged. In reality, the HPT has an additional capability of shedding non-priority loads to prevent overloading. However, this capability is not present in the model.

One scenario was identified for this configuration: using the HPT to power the entry control points (ECPs) at the 300 PAX base camp. The ECPs at the 50 PAX camp do not require power, and the ECPs at the 1000 PAX camp are near other systems and thus share access to another generator set, the total peak of which is greater than what would be appropriate for the HPT.

The HPT is limited by the requirement to be trailer-mounted; there is nothing intrinsic to the hybrid power technology that limits the generator size to 15 kW. To better analyze the potential impact of hybrid technologies as a concept, a second scenario was investigated that used the same energy storage subsystem as the HPT, but replaced the small generator with 30 kW or 60 kW TQGs (i.e., the same generators as the FY12 ORTB Base Camps). These systems could act as drop-in replacements for the baseline's current generator sets and give a better representation of the hybrid power technology area. Using the FY12 ORTB generators was a conservative design choice, based on the documented peak power draws of the connected loads. Although it is unlikely that all the peaks for a given set of connected systems would occur simultaneously, what is not clear is what a reasonable observable peak might be. The DCAM simulation software runs at a 1-h time step, which means that any observed "peak" would in effect be the maximum 1-h average power draw. It is unlikely that the observed hourly average power draw is actually true peak power, and therefore it would be inappropriate to utilize it as a design parameter.

Table 21 shows the results of the simulation of the scenarios across the different base camp sizes in the desert environment. For each scenario presented, the same simulations were completed for each environment, but the results for the temperate and tropical environments are essentially the same as the desert[6], and therefore omitted from this report. Although power, water, solid waste, and liquid waste metrics were calculated as part of each simulation, these numbers were omitted from the report since there is no change from the baseline. The only exception is the small increase in power associated with HPT since the system is not assumed to have a 100% round trip efficiency, due to both inverter and converter losses as well as current leakage in the battery.

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[6] The SLB-STO-D generator model does not take into account environmental factors (e.g., ambient temperature, fuel temperature, and altitude) that can affect generator efficiency. Data were not available to quantify the impact of these variables in the model.

Table 21. Mean Daily Fuel Usage, Island Power Generation, Desert

	Without SCPL		With SCPL	
Simulation Description	Fuel (gal/day)	Δ	Fuel (gal/day)	Δ
	50 PAX Camp			
FY12 Baseline	215	-	212	1.4%
All 60 kW TQG	177	17.7%	-	-
1-1 T-100 Swap	224	-4.2%	220	-2.3%
Mathematical Minimum T-100s	145	32.6%	143	33.5%
HPT for all TQGs	161	25.1%	-	-
	300 PAX Camp			
FY12 Baseline	1042	-	1023	1.8%
T-100 Swap	909	12.8%	891	14.5%
Mathematical Minimum T-100s	710	31.9%	698	33.0%
HPTs for all TQGs	724	30.5%	-	-
HPTs for ECPs	988	5.2%	-	-
	1000 PAX Camp			
FY12 Baseline	3376	-	3315	1.8%
1-1 T-100 Swap	2977	11.8%	2919	13.5%
Mathematical Minimum T-100s	2259	33.1%	2220	34.2%
HPTs for all TQGs	2455	27.3%	-	-

At the 50 PAX base camp, the use of 60 kW TQGs instead of 30 kW TQGs resulted in a 17.7% reduction in fuel consumption in the desert environment. In this scenario, the generator capacity remained the same, since the six 30 kW TQGs were replaced with three 60 kW TQGs. Thus, unlike non-materiel courses of action to reduce numbers of generators (see **Section 3.1.2.1.1**), fuel savings were realized while providing the same power generation capacity (i.e., capability) without any right-sizing.

The implementation of T-100s on a one-to-one basis was the only scenario that resulted in a negative impact to fuel consumption at the 50 PAX base camp, with a 4.2% increase in fuel usage. This is not surprising given that 80 kW generators are replacing 30 kW generators on a one-to-one basis. The scenario with only the minimum number of T-100 generators (i.e., two generators), resulted in a 32.6% fuel reduction in the desert environment. This scenario can also be constrained to the camp's layout given its very small size (i.e., cables can stretch across the entire base camp without voltage drop concerns).

What is furthermore interesting is that the savings from powering the base camp with only two T-100s is nearly double the 17.7% fuel savings realized by replacing the 30 kW TQGs with 60 kW TQGs on a one-to-one basis. The scenario using 60 kW units was not assessed with the assumption of utilizing the mathematical minimum number of generators, because it has no impact on the generator count required. Even using the alternate generator allocation method documented in *TM 3-34.46* (see **Section 3.1.2.1.1**) in addition to the mathematical minimum does not reduce the number of generators required. Therefore, using the minimum required number of T-100s on the 50 PAX base camp will save nearly twice as much fuel as using the minimum number of 60 kW TQGs.

Determining and understanding the baseline of comparison is critical to understanding the fuel savings potential for any technology. In the case of the 50 PAX base camp, if the baseline camp used 60 kW TQGs instead of 30 kW TQGs, the realized fuel savings of implementing T-100s would only be 14.9%. The difference between a 14.9% and a 32.6% projected savings was in effect decided based on the determination of the baseline itself. In either case, the T-100 generator provided a rather sizable fuel savings in comparison to legacy generator sets.

The swapping of T-100s on a one-to-one basis with 60 kW TQGs resulted in a fuel savings of 12.8% and 11.8% on average per day in the desert environment at the 300 PAX and 1000 PAX base camp, respectively. Unlike the 50 PAX base camp, there is a net decrease in fuel; however, this outcome can be predicted in both cases by examining the generator fuel consumption curve for all three generators (**Figure 7**). Compared to the 30 kW TQG, the T-100 consumes more fuel under all conditions except very small loads, where it performs only marginally better than the 30 kW TQG. In comparison to the 60 kW TQG, however, the T-100 is more efficient except at loads above 50 kW. Loads that high are the exception at the FY12 ORTB Base Camps.

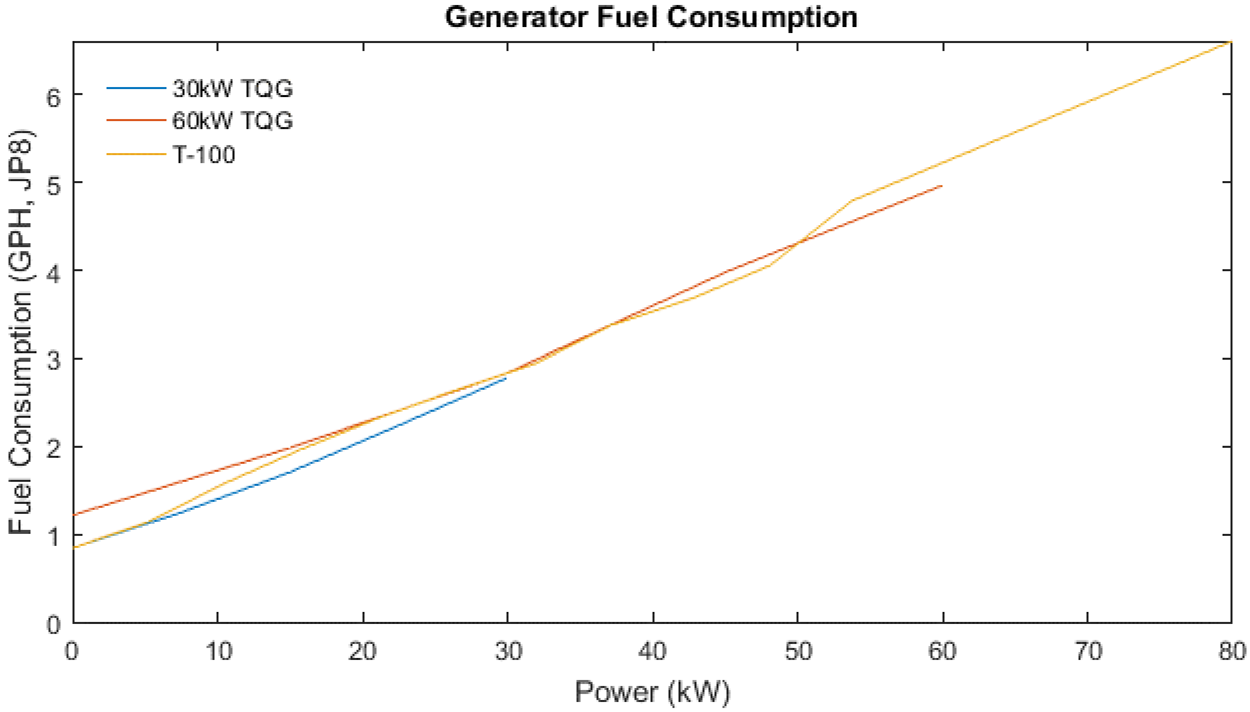

Figure 7. Generator Fuel Consumption

What was not predicable was how similar the fuel savings would be when implementing the mathematical minimum number of T-100 generators on the 300 PAX and 1000 PAX base camps. The projected average fuel savings were 31.9% and 33.1% at the 300 PAX and 1000 PAX base camps, respectively. The similarity in fuel savings between the two base camps is likely not a coincidence—both camps utilize a very similar equipment set and are powered by the same generator in their baseline.

If the impact of SCPL in generators was isolated, it would yield a 1.8% reduction in fuel at the 300 PAX base camp using the baseline 60 kW TQGs. Of this, the majority is due to the efficiency increases in the generators with a small savings associated with reduced usage of on-camp logistics vehicles to refuel the generators. This amounts to savings of approximately 20 gal of jet propulsion fuel, type 8 (JP-8) per day on average, which is rather impressive considering that is all due to an oil change. Although SCPL projects fuel savings, reduced maintenance requirements, and reduced oil change frequency, further testing is still required to substantiate these projections. To qualify the SCPL, further testing may be pursued with generator manufacturers. Similar results are shown when combining SCPL and T-100 generators.

At the 300 PAX base camp, the HPT was sized appropriately to power the ECPs. In this scenario, a 5.2% reduction in daily average fuel consumption was observed. This is a result of replacing two 60 kW TQGs, one at each ECP. At the FY12 ORTB Base Camps, the HPT in the configuration demonstrated had this single application, but if the baseline camps were different there may have been other integration opportunities, and therefore a larger potential for fuel savings. Small-scale power generation systems, such as the demonstrated HPT, have niche applications that are not necessarily tied to a particular base camp size, but rather to unique aspects of a camp’s layout.

To assess the potential hybrid power generation, scenarios were assessed that used the HPT’s energy storage system combined with the FY12 ORTB generators. This allowed for a one-to-one augmentation of each baseline TQG with a hybrid battery system.

At the 50 PAX base camp, the fuel savings from implementing the 30 kW HPT was 25.1% on average in the desert environment. Although this is a large percentage of fuel savings, it does fall short of using only two T-100s to power the base camp. The trend continues at the 300 PAX and 1000 PAX camps, with the projected fuel savings similar across base camp sizes. The daily average fuel savings in the desert environment is 30.5% and 27.3% at the 300 PAX and 1000 PAX base camps, respectively. If 60 kW HPT systems were implemented at the 50 PAX base camp, the savings would exceed the 25.1% number projected for the 30 kW HPT units. This has to do with the relative efficiency of the two TQGs under peak load conditions. The extent of the savings is not known. With such a high capacity for savings in a trailer mounted system, hybrid power systems are an area with a lot of potential for further research and analysis.

Although hybrid power systems showed a strong contribution to fuel savings, there are limitations to the analysis. While the model takes into account inverter and converter efficiency losses as well as temporal losses in the battery, the impact of climate on battery performance was not analyzed, as system performance in severe heat and cold was assumed to be the same. This may not accurately reflect the performance of the system in the real world. Additionally, the system was assumed to be able to handle all loads at the base camps. Equipment with a large power surge, such as large laundry systems or ECUs with no soft start or variable speed compressors, may overwhelm the hybrid power system’s battery. These variables were not assessed during demonstration, and so were not included in this analysis. Further research and development may be required to assess these potential areas of concern. As such, the scenario presented is to be interpreted as a best-case scenario that illustrates the potential for fuel savings of hybrid technology as a whole and not necessarily an evaluation of a single implementation or system.

Increasing the efficiency of island power generators resulted in significant fuel savings. Both technologies analyzed, the HPT and the T-100, showed potential savings using very different methods. The T-100 uses a variable speed generator that matches engine speed to the load required, thereby increasing efficiency under most load conditions. The HPT uses a hybrid battery-generator combination to power loads, shutting down the generator when not needed and running the generator at peak load (i.e., when it is most efficient) to charge the battery. Both technologies provide unique integration opportunities due to their capacity.

3.1.2.1.3 Grid Power Generation

Microgrids allow for the integration of multiple generators to act as one, intelligent whole. While algorithms and capabilities vary, microgrids generally intelligently turn individual power generation assets on and off to supply the demanded power load and provide overhead capacity for increases in loads.

Three technologies were investigated for their suitability in contributing to the SLB-STO-D's target fuel savings of 25%. The FY12 ORTB generators are also included in the descriptions below for comparison purposes. For complete descriptions of the technologies, see **Annex C**. These options included the following:

- 30 kW TQG (FY12 ORTB baseline equipment) – A currently-fielded, skid-mounted generator that provides up to 30 kW of power with improved performance over the legacy Standard Family of DoD Generators.
- 60 kW TQG (FY12 ORTB baseline equipment) – A currently-fielded, skid-mounted generator that provides up to 60 kW of power with improved performance over the legacy Standard Family of DoD Generators.
- Energy Informed Operations (EIO) – A developmental intelligent power system interface standard for an intelligent microgrid and associated applications that allows optimization of power and energy resources.
- Vehicle-to-Grid/Vehicle-to-Vehicle (V2G/V2V) Power System – A prototype bi-directional power/communications management and grid service that uses a vehicle-based, fast-forming, ad-hoc aggregated power network.
- SCPL – A developmental, fully synthetic, multipurpose, heavy-duty diesel engine oil that provides a reduction in fuel consumption, maintenance of component durability, multifunctional performance (e.g., engine, transmission, hydraulic systems), and a reduction in maintenance compared to existing engine oils.

EIO, sponsored by CERDEC and demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA, is a developmental interface standard that aims to allow both power generators and loads to interact in an intelligent microgrid. As demonstrated, the EIO microgrid can utilize different sized generators simultaneously and incorporate the intelligent use of energy storage. Microgrids respond to changing loads on a second-by-second basis by adjusting available capacity or intelligently shedding loads. Since the DCAM simulation environment uses an hourly time step, modeling the EIO microgrid precisely was not possible. Instead, a generic implementation of a microgrid based on the generator control algorithm used by EIO was implemented. This generic microgrid is a simplification of EIO's capabilities. The results do not necessarily reflect all the benefits of the EIO implementation.

Variations of the microgrid integration scenarios were analyzed with the assumption that the generators use SCPL. SCPL technologies are under development by TARDEC. A primary motivation for investigating this technology is to reduce logistical difficulties associated with using multiple lubricants for the variety of technologies and environments where base camps operate. The candidate technologies generally exhibit another beneficial effect: lower viscosity, which enables greater fuel efficiency through reduction in energy lost to friction and other imperfections of engine performance. Further testing is required to understand SCPL's long-term impact, additionally generator manufacturers to qualify SCPL.

The V2G/V2V Power System, sponsored by TARDEC, is a prototype microgrid designed to use tactical vehicles as ad-hoc power generators. The system was demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA, where it proved effective at powering base camp facilities. Because the V2G/V2V Power System is designed for highly mobile environments that would benefit from ad-hoc microgrid formation, it was not analyzed in this report [33].

No other technology demonstrated or analyzed in this report has a higher fuel savings potential than microgrids. As a result, integration scenarios were designed to enable analysis on many different aspects of microgrid technology and implementation choices.

Determining the absolute best mix of generators varies by base camp design and is not something that could be determined by this analysis. Only three base camps were analyzed, each utilizing a very similar equipment set. The best generator mix will ultimately be determined by a base camp's power profile, and the best configuration for the FY12 ORTB Base Camps may not be the best configuration elsewhere. However, numerous configurations of microgrids were investigated to determine the impact of constituent generators on efficiency.

Figure 8 shows the fuel consumption curves for four different microgrids alongside a histogram of 300 PAX base camp average hourly power draw per microgrid. This histogram of average power loads is based on the implementation of four operationally relevant microgrids in the desert environment and provides context to the amount of power required from the microgrid. For example, even though the microgrids can provide up to 360 kW, the average hourly power draw never approaches that level.

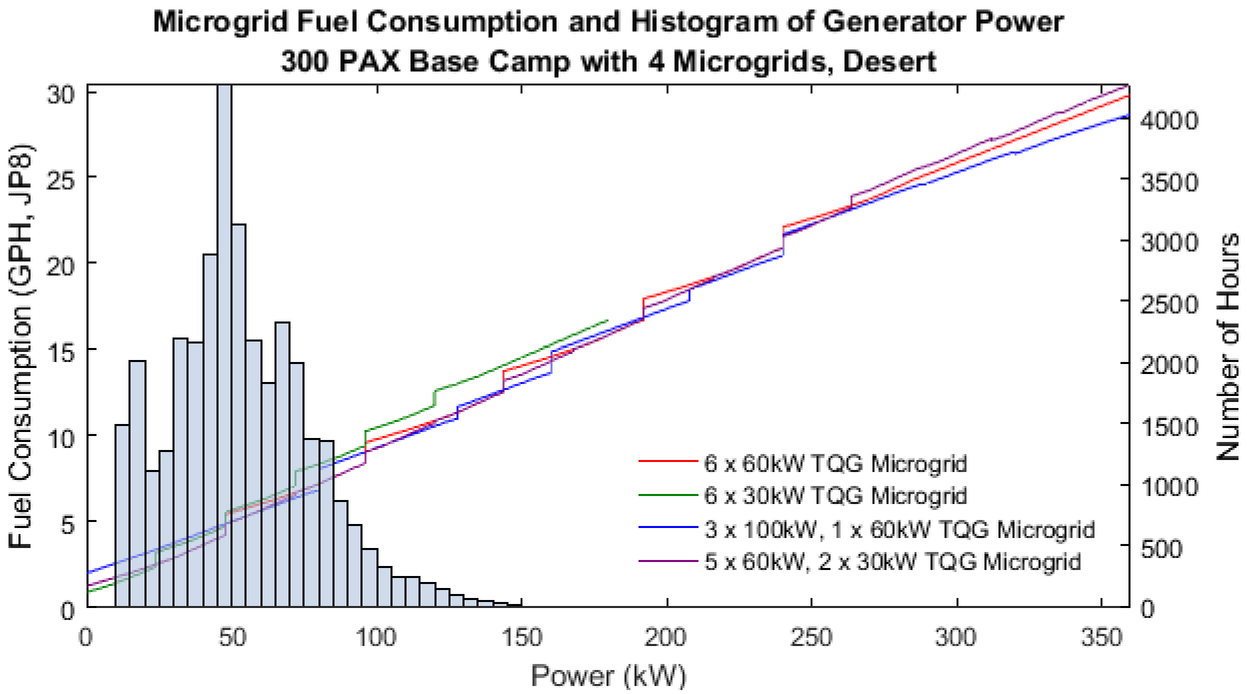

Figure 8. Microgrid Generator Configurations

Figure 8 shows four different microgrids with four different configurations, including two grids with a mix of different sized generators. For a single microgrid configuration to achieve the most fuel savings regardless of the power profile, its fuel consumption would have to be less than all the others—without intersection and across the entire capacity. In fact, what an analysis of the microgrid fuel curves reveals is that even with these four different microgrid configurations, each grid has intervals where it is the most efficient (or tied for most efficient). In the lowest power draw interval of the histogram, the grid with six 30 kW TQGs is the most efficient. In the next interval, there is a tie between the six 60 kW TQG grid and the five 60 kW TQG/two 30 kW TQG grid for most efficiency, followed by the three 100 kW TQG/one 60 kW TQG grid. Each of these grid configurations is very close in terms of potential savings, although there are some configurations that are clear improvements over the others. Ultimately, a decision was made to only pursue grids with one single generator type because the options for customization were high, and the simulation tools available did not have the capability to calculate the optimal configuration that not only considers fuel savings, but grid stability, and ultimately operational relevance. Since microgrids utilizing a single type of generator have been successfully demonstrated in the past, a decision was made to constrain the analysis to only two configurations: the six 60 kW TQG and six 30 kW TQG microgrids.

The first two integration scenarios aim to represent realistic implementations of microgrids at the FY12 ORTB Base Camps. The purpose of these scenarios is to assess the impact of a microgrid in the most realistic scenario possible, a part of which is taking an operational layout into consideration. While the maximum cable length to prevent unacceptable voltage losses under maximum load is 300 ft [32, pp. 0001-3], a design factor of a conservative 200 ft straight line distance from the generator was used to determine if a structure was close enough to be powered by the asset. This factor allowed for an extra 100 ft of slack to account for running cables around structures of moving power generation assets to more convenient locations (e.g., by a nearby road).

In the first scenario, a single microgrid consisting of six 30 kW TQGs was implemented to power the 50 PAX base camp. This grid could utilize the existing generators in the FY12 ORTB equipment set. In the second scenario, many microgrids containing six 60 kW TQGs were implemented at each base camp. This requires 1, 4, and 11 microgrids at the 50, 300, and 1000 PAX base camps, respectively. At the 50 PAX base camp, this would require the replacement of the baseline 30 kW TQGs with 60 kW TQGs. At the 300 PAX base camp, due to the grids containing six TQGs each, an operationally relevant layout would require one more generator than the baseline camp. At the 1000 PAX base camp, microgrids allow for the elimination of eight generators from the equipment set. Note that because the TQGs are gridded, not all the available generators are on at any given point in time.

From an operational standpoint, a base camp may not be in a stable configuration throughout its life cycle. In some cases, as its mission changes and remains in operation for a longer period of time, its population may grow. This may include the addition of new base camp systems to support the new population. This characteristic makes designing optimized base camps difficult. When a base camp is first built, a designer with the proper training can design a fuel-efficient base camp with the right power generation assets and distribution equipment. As the base camp expands and transforms over time, the base camp of the future may not be as optimal. In the case where microgrids are widely used, having a camp with several smaller grids that were set up at different points in the base camp’s lifecycle is potentially more realistic. While this is almost certainly not the optimal configuration, it begs the question of what the most efficient grid configuration looks like, assuming the generator equipment set does not change.

To investigate the potential efficiency losses due to non-optimal power distribution, an additional integration scenario was developed that removed the constraint of base camp layout. This scenario used the mathematical minimum number of microgrids at each base camp. At the 300 PAX base camp, instead of four of the six 60 kW TQG microgrids and one islanded generator in the realistic grid scenario, power generation assets were reduced to three grids only. The 1000 PAX base camp saw similar reduction, decreasing the number of grids from 11 to 8, and eliminating the sole islanded generator. Since a single grid can power the 50 PAX base camp even when constrained to layout, no microgrids could be consolidated at that base camp.

The final microgrid characteristic analyzed is the grid’s overall capacity, which was thus far assumed to be six generator sets. The final analysis scenario is focused on measuring the potential benefit of powering the entire camp on one large grid. No microgrid product like this exists, and making a 60 kW TQG grid of this size may not be feasible from a technical standpoint, the intent is to determine a best-case upper bound for microgrid consolidation. This analysis also aims to assess the value of having scalable grid architecture beyond the 6 x 60 kW TQG use case.

Several aspects of large-scale grids using small tactical generators must be considered in a real-world implementation that could not be factored in to the simulation. Grid stability may prove an issue. As grids become larger, the noise in power demand increases relative to the capacity of a given generator. It is unknown whether the percentage of spinning reserve for a smaller six-generator grid can be held with larger grids that have more generators. There may also be operational concerns—in an environment with a high threat level it may not be wise to rely on a power distribution system with a single point of failure. On the other hand, there may be situations where a single large grid could be very beneficial, such as a back-up to a base camp that has access to host nation power. Regardless of the circumstances or potential barriers that need to be addressed, this scenario is a valid upper bound on best-case grid consolidation.

Not all factors worth analyzing were able to be considered, but their analysis could prove fruitful by future programs. The first is the potential for the microgrid to shed power loads or fail. This analysis does not consider system failure modes or features (e.g., load prioritization) or situations where power generation and distribution systems do not meet demand. Secondly, sub-hourly time step behavior is not captured in the model. While in reality there may be circumstances on a second or minute time step that may cause an additional generator to turn on or off over the course of an hour, for the purposes of this analysis, microgrid fuel consumption is calculated based on an hourly time step from the aggregated hourly average power draw of the power consumers to which it is connected. The last potentially major variable not analyzed is the spinning reserve. The spinning reserve is the amount of excess capacity that a microgrid maintains to absorb power demand increases while another generator is started and synced to the microgrid. This value dictates when additional generators are turned on as loads increase and when generators are turned off as loads decrease. For this analysis, the spinning reserve is held constant at 20% of the current power demand.

Table 22 shows the results of the simulation of the scenarios across the different base camp sizes in the desert environment. For each scenario presented, the same simulations were completed for each environment, but the results for the temperate and tropical environments are essentially the same as the desert[7], and are therefore omitted from this report. Although power, water, solid waste, and liquid waste metrics were calculated as part of each simulation, these numbers were omitted from the report because there is no change from the baseline.

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[7] The SLB-STO-D generator model does not take into account environmental factors (e.g., ambient temperature, fuel temperature, and altitude) that can affect generator efficiency. Data was not available to quantify the impact of these variables in the model.

Table 22. Mean Daily Fuel Usage, Grid Power Generation, Desert

	Without SCPL		With SCPL	
Simulation Description	Fuel (gal/day)	Δ	Fuel (gal/day)	Δ
	50 PAX Camp			
FY12 Baseline	215	-	212	1.4%
30 kW Grid	144	33.0%	142	34.0%
60 kW Grid	131	39.1%	129	40.0%
	300 PAX Camp			
FY12 Baseline	1042	-	1023	1.8%
Realistic Grids	614	41.1%	604	42.0%
Mathematical Minimum Grids	577	44.6%	567	45.6%
One Big Grid	550	47.2%	541	48.1%
	1000 PAX Camp			
FY12 Baseline	3376	-	3315	1.8%
Realistic Grids	1968	41.7%	1936	42.7%
Mathematical Minimum Grids	1935	42.7%	1902	43.7%
One Big Grid	1836	45.6%	1805	46.5%

Although the 50 PAX base camp could be modeled with a 60 kW TQG grid only, the fuel savings would include savings because of two different variables. It would include the savings inherent to the microgrid technology combined with the savings associated with using 60 kW TQG, a larger and more fuel-efficient generator. To isolate the impact of the microgrid from the change in generator size, two integration scenarios were developed for the 50 PAX base camp: one using a six 30 kW TQG microgrid and one using a six 60 kW TQG microgrid. The fuel savings attained using a 30 kW TQG grid in the desert environment was 33.0%, which surpasses the fuel savings of any island power generation scheme analyzed (see **Section 3.1.2.1.2**). The only course of action with greater fuel savings was the 60 kW TQG grid that achieved a 39.1% fuel savings, a full 6.1% over the 30 kW TQG configuration.

The realistic implementation of the six 60 kW TQG microgrids resulted in a fuel savings of 41.1% and 41.7% at the 300 PAX and 1000 PAX base camps, respectively. This estimate is slightly higher than the SAGE project predicted fuel savings of up to 34% annually when a microgrid was implemented in isolation [30]. Although this scenario projected the lowest fuel savings of the microgrid scenarios, it was the most realistic scenario, and it produced a dramatic increase in fuel savings over all other technologies and non-materiel solutions analyzed. The largest fuel savings in island power generation was achieved using an idealized scenario of the mathematically minimum number of T-100 generators (see **Section 3.1.2.1.2**). Microgrids, even when constrained to a non-optimal layout, resulted in a 9.2% and 8.6% increase in fuel savings over the best island power generation scenario at the 300 PAX and 1000 PAX base camps, respectively.

When the constraints of the base camp layout were removed, there was additional fuel savings potential for the six 60 kW TQG grid at both the 300 PAX and 100 PAX base camps. The impact proved relatively small. The mathematical minimum grid simulation at the 300 PAX and 1000 PAX base camps produced a fuel savings of 44.6% and 42.7%, respectively. Ultimately this represents an improvement in fuel savings on each respective camp of 3.6% and 1.0%, which in the context of the total savings is not that significant. This fuel reduction is a result of microgrid consolidation. When two or more microgrids are consolidated, it is possible that under certain load conditions the base camp as a whole will require fewer generator-hours to operate. This is analogous to generator reallocation and consolidation methods discussed **Section 3.1.2.1.1**. By consolidating generators on a base camp, the total amount of generator-hours decreases, resulting in lower fuel consumption. With microgrids, however, the opportunity to reduce generator-hours occurs on an hour-by-hour basis instead of requiring the complete elimination of a generator like in island power generation. In other words, the same number of generators are required to account for peak load conditions, but on average fewer generators will be operational at any point in time. While a base camp layout is a key operational aspect of a base camp and there may be perception that it is a significant hindrance to designing an efficient camp, the fuel consumption was only slightly affected by the constraint of a non-optimal layout.

The implementation of a single large microgrid provided a fuel savings of 47.2% and 45.6% at the 300 PAX and 1000 PAX base camps, respectively. This amounted to an additional 2.6% and 2.9% fuel savings over the mathematical minimum number of grids and an additional 6.1% and 3.9% fuel savings over the realistic grid scenario at the 300 PAX and 1000 PAX base camps, respectively. This gap between one large microgrid and several smaller grids is quite large, considering the large grid is still using 60 kW TQGs and a larger grid could be even more efficient with the use of larger, and therefore more efficient, generators. Although outside the scope of this analysis, opportunities to analyze microgrid configurations with larger generator assets as part of larger grid capacities would be worthwhile avenues for future research. While this may seem contradictory to the decision to only analyze grids containing 30 kW and 60 kW TQGs, the load profile of the camp in question and the characteristics of the power demand histogram must be considered. The histogram in **Figure 9** shows the average load profile when four microgrids power the base camp. If all four microgrids were consolidated, the same grid performance step function would continue with the same pattern, only the power demand histogram would shift to the right. Additionally, in the case of a larger grid it may be possible to have a larger spinning reserve coefficient, further reducing the number of generators active at any one time.

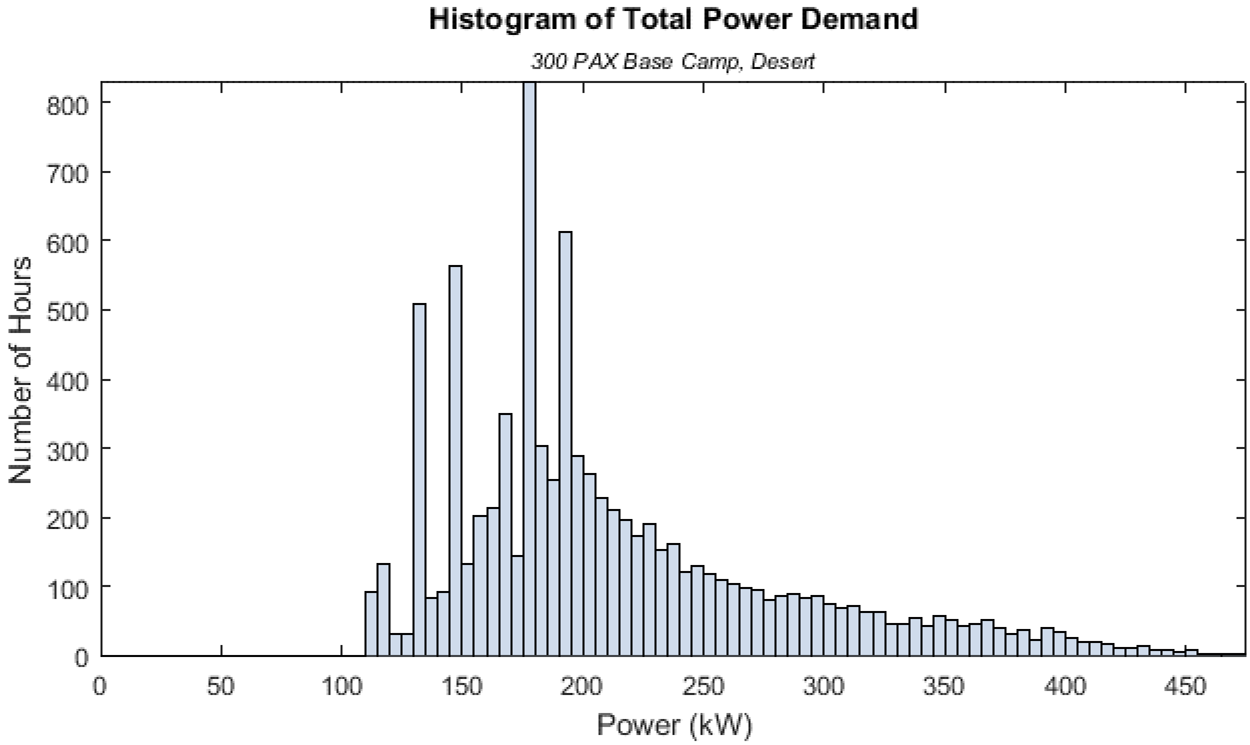

Figure 9. **Histogram of Total Power Demand, 300 PAX Base Camp, Desert**

The addition of SCPL to microgrids showed savings of approximately 1% in all cases. This savings was lower than the implementation of SCPL in island generators. This is due to the decrease in generator-hours after the implementation of microgrids. With generators on for fewer hours, the overall fuel saving opportunities for SCPL are reduced. Given the potential ease of implementation on the base camp, assuming SCPL is qualified for use in generators, the 1% fuel savings would essentially be free.

Regardless of the implementation, no other technology had a larger fuel savings potential than the microgrid. Based on analysis of the three FY12 ORTB Base Camps, the fuel savings from implementing the microgrid is not that sensitive to any of the defining characteristics analyzed. In fact, the variation in fuel savings between the different microgrid scenarios in this analysis is smaller than the difference between the most conservative microgrid implementation modeled and the second most impactful technology.

3.1.2.1.4 Summary of Camp-Wide Power Generation

At all of the FY12 ORTB Base Camps, the *Power Generation* functional area is the largest consumer of fuel. The options analyzed to reduce fuel consumption in this functional area can be sorted into three broad categories: generator allocation methods, island power generation, and grid power generation.

All scenarios analyzed in **Section 3.1.2.1** are summarized in **Table 23**. The table simplifies the comparisons of different simulation runs by identifying the generator asset utilized and operational relevance of the layout simulated. Additionally, it notes both the number of generators present on the camp simulated and the number of generators utilized. For scenarios that do not include a microgrid, the number of generators in the equipment set is equal to the number used, unless there are extras present that are not utilized. At the 300 PAX and 1000 PAX base camps, the billeting and transients and VIP visits are assumed to be rare. The generators powering those facilities are present, but kept off. In addition to using more efficient power generation technology, such as the case with the T-100, the ability to reduce the number of generators in use is a major contributor to fuel savings.

Table 23. Summary of Integration Scenarios, Camp-Wide Power Generation

Simulation Description[*]	Operation 2D Layout	Power Generation Asset	No. in Equipment Set[†]	No. Used[‡]
		50 PAX Camp		
FY12 Baseline	Yes	30 kW TQG	6	6
TM 3-34.46	Yes	30 kW TQG	5	5
All 60 kW TQG	Yes	60 kW TQG	3	3
30 kW Grid	Yes	30 kW TQG	6	5
60 kW Grid	Yes	60 kW TQG	6	3
1-1 T-100 Swap	Yes	T-100	6	6
Mathematical Minimum T-100s	Yes	T-100	2	2
HPT for all TQGs	Yes	HPT with 30 kW TQG	6	6
		300 PAX Camp		
FY12 Baseline	Yes	60 kW TQG	24	23
TM 3-34.46	Yes	60 kW TQG	17	16
Mathematical Minimum TQGs	No	60 kW TQG	17	16
Mathematical Minimum TQGs with TM 3-34.46	No	60 kW TQG	14	14
Realistic Grids[§]	Yes	60 kW TQG	25	14
Mathematical Minimum Grids	No	60 kW TQG	18	12
One Big Grid	No	60 kW TQG	N/A	10
1-1 T-100 Swap	Yes	T-100	24	23
Mathematical Minimum T-100s	No	T-100	13	13
HPTs for all TQGs	Yes	HPT with 60 kW TQG	24	23
HPTs for ECPs	Yes	HPT with 15 kW TQG	2	2
		60 kW TQG	22	21
		1000 PAX Camp		
FY12 Baseline	Yes	60 kW TQG	75	73
TM 3-34.46	Yes	60 kW TQG	49	47
Mathematical Minimum TQGs	No	60 kW TQG	50	50
Mathematical Minimum TQGs with TM 3-34.46	No	60 kW TQG	45	43
Realistic Grids[¶]	Yes	60 kW TQG	67	41
Mathematical Minimum Grids	No	60 kW TQG	48	39
One Big Grid	No	60 kW TQG	N/A	35
1-1 T-100 Swap	Yes	T-100	75	73
Mathematical Minimum T-100s	No	T-100	38	37
HPTs for all TQGs	Yes	HPT with 60 kW TQG	75	73

[*] Generators are sized according to seasonally-adjusted peak connected loads, unless otherwise noted to be sized according to TM 3-34.46.

[†] Does not include backup generators.

[‡] Maximum number of generators used in any environment. Generators are not considered used if all connected facilities are unused (e.g., transient billeting).

[§] Four microgrids and one island generator due to geographic constraints.

[¶] Eleven microgrids and one island generator due to geographic constraints.

The resulting fuel savings for the runs described above are shown in **Table 24**. For each scenario presented, the same simulations were completed for each environment, but the results for the temperate and tropical environments are essentially the same as the desert, and are therefore omitted from this report. Although power, water, solid waste, and liquid waste metrics were calculated as part of each simulation, these numbers were omitted from the report since there is no change as a result of integrating them into the baseline. The only exception is the small increase in power associated with HPT since the system is not assumed to be 100% round trip efficient due to inverter and converter losses as well as current leakage in the batteries.

Table 24. Mean Daily Fuel Usage, Camp-wide Power Generation, Desert

	Without SCPL		With SCPL	
Simulation Description	Fuel (gal/day)	Δ	Fuel (gal/day)	Δ
	50 PAX Camp			
FY12 Baseline	215	-	-	-
TM 3-34.46	195	9.3%	-	-
All 60 kW TQG	177	17.7%	-	-
30 kW Grid	144	33.0%	142	34.0%
60 kW Grid	131	39.1%	129	40.0%
1-1 T-100 Swap	224	-4.2%	220	-2.3%
Mathematical Minimum T-100s	145	32.6%	143	33.5%
HPT for all TQGs	161	25.1%	-	-
	300 PAX Camp			
FY12 Baseline	1042	-	-	-
TM 3-34.46	837	19.7%	-	-
Mathematical Minimum TQGs	835	19.9%	-	-
Mathematical Minimum TQGs with TM 3-34.46	780	25.1%	-	-
Realistic Grids	614	41.1%	604	42.0%
Mathematical Minimum Grids	577	44.6%	567	45.6%
One Big Grid	550	47.2%	541	48.1%
T-100 Swap	909	12.8%	891	14.5%
Mathematical Minimum T-100s	710	31.9%	698	33.0%
HPTs for all TQGs	724	30.5%	-	-
HPTs for ECPs	988	5.2%	-	-
	1000 PAX Camp			
FY12 Baseline	3376	-	-	-
TM 3-34.46	2625	22.3%	-	-
Mathematical Minimum TQGs	2704	19.9%	-	-
Mathematical Minimum TQGs with TM 3-34.46	2517	25.4%	-	-
Realistic Grids	1968	41.7%	1936	42.7%
Mathematical Minimum Grids	1935	42.7%	1902	43.7%
One Big Grid	1836	45.6%	1805	46.5%
1-1 T-100 Swap	2977	11.8%	2919	13.5%
Mathematical Minimum T-100s	2259	33.1%	2220	34.2%
HPTs for all TQGs	2455	27.3%	-	-

Generator allocation focuses on the decision process by which electrical loads are paired with a particular power source. Two methods were analyzed: using seasonally-adjusted connected loads (the FY12 ORTB method) and using *TM 3-34.46*. Additional analysis focused on the penalty of geographical constraints in loading generators. The results showed that utilizing the *TM 3-34.46* method of generator allocation will provide most of the savings achievable by proper generator allocation, with designing the base camp to minimize the generator count producing only incremental gains.

The FY12 ORTB Base Camps use island power generators. Increasing the efficiency of island power generators resulted in significant fuel savings. Both technologies analyzed, the HPT and the T-100, showed potential savings, and both technologies provide unique integration opportunities at the FY12 ORTB Base Camps due to their capacity. The HPT proved limited in its demonstrated configuration, but when paired with a larger generator, produced savings in excess of minimizing the number of TQGs on the base camp. Since minimizing the number of generators may prove operationally unrealistic, hybrid power may enable those savings without significant reconfiguration of base camps.

Microgrids proved to be the single most effective means of reducing fuel consumption. Additionally, the fuel savings from implementing the microgrid is not that sensitive to any of the defining characteristics analyzed, making any microgrid an excellent choice for fuel savings.

Each technology analyzed provides capabilities that others do not, and there will always be tradeoffs involving other factors that go beyond fuel savings in identifying the ideal equipment set for a particular application or mission. While microgrids proved the most efficient overall at the FY12 ORTB Base Camps, they may not prove the most efficient in every implementation scenario.

3.1.2.2 Man-Portable Power Generation

Man-portable power generation assets aim to enable islanded power generation at a physical size and weight that can be safely transported by hand. These generators are typically small in electrical power generation capacity, ranging from 1–2 kW. Currently-fielded power generation assets providing 2 kW of power are heavy; the Mobile Electric Power (MEP)-501A weighs 123 lb [34]. While various sizes of generators are available in the Army inventory ranging from 2 kW to 100 kW in capacity, only one size of generator is used at each FY12 ORTB Base Camp—30 kW TQGs at the 50 PAX base camp and 60 kW TQGs at the 300 PAX and 1000 PAX base camps. Smaller, man-portable options may prove better sized to handle certain loads. Properly sizing power generation assets to their loads (i.e., right-sizing) results in power being produced more efficiently.

At all of the FY12 ORTB Base Camps, the *Power Generation* functional area is the largest consumer of fuel, accounting for 71.8–90.3% of the overall fuel consumption depending on the environment and camp size. Reducing the amount of fuel consumed to generate power at the base camps is key to meeting the SLB-STO-D’s goal of a 25% reduction in fuel consumption. This section focuses on to what extent man-portable generators can contribute to fuel savings when integrated into the FY12 ORTB Base Camps.

Three technologies were investigated for their suitability in contributing to the SLB-STO-D’s target fuel savings of 25%. For complete descriptions of the technologies, see **Annex C.** These technologies included the following:

- 1 kW Man-Portable Generator (MANGEN) – A prototype generator that provides up to 1 kW of electrical power in a man-portable package. The MANGEN has the capability to operate in parallel with a second MANGEN and provide a total of 2 kW.
- Quiet, Multi-Fuel Migrating Combustion Chamber Engine & Generator (QMEG) – A prototype generator that is multi-fuel capable (JP-8 and diesel fuel) and provides up to 2 kW of electrical power in a man-portable package.
- SCPL – A developmental, multipurpose, heavy-duty diesel engine oil that provides a reduction in fuel consumption, maintenance of component durability, multifunctional performance (e.g., engine, transmission, hydraulic systems), and a reduction in maintenance compared to existing engine oils.

MANGEN was sponsored by CERDEC and demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA. The MANGEN is a prototype adaptation of a commercial generator that enables the use of JP-8 as a fuel in addition to diesel fuel. It has a 1 kW capacity, but can be connected in parallel with a second MANGEN to double the capacity to 2 kW. Data collected at the demonstration was used by CERDEC and SLB-STO-D to generate a fuel curve for the MANGEN.

QMEG, sponsored by CERDEC, aims to produce a soldier-portable generator that can efficiently use JP-8 and alternate fuels. As a 2 kW, man-portable generator, the QMEG could be integrated in place of the MANGEN in any scenario that requires parallel MANGENs. This would have the added benefit of reducing power generation assets to a single piece of equipment. This project was not sufficiently mature to be considered for inclusion in this report.

SCPL technologies are under development by TARDEC. A primary motivation for investigating this technology is to reduce logistical difficulties associated with using multiple lubricants for the variety of technologies and environments where base camps operate. The candidate technologies generally exhibit another beneficial effect: lower viscosity, which enables greater fuel efficiency through reduction in energy lost to friction and other imperfections of engine performance. Additional testing remains to be done on SCPL’s long-term impact in generators.

Assumptions concerning base camp layout as well as the assumed usage characteristics can play a large part in the assessment of a fuel reduction technology. Many variables affect how base camps are structured and how power is provided to on-camp systems; therefore, opportunities to utilize man-portable generators for base camp sustainment will vary by base camp. Identifying operationally relevant applications for a small power producer that also supported the SLB-STO-D’s fuel savings objective proved challenging at the FY12 ORTB Base Camps. The FY12 ORTB Base Camp layouts were developed by base camp SMEs with power distribution designed around using either 30 kW or 60 kW TQGs for power generation. As such, the potential integration opportunities of smaller power generation assets were limited. This analysis report focuses on the fuel reduction capabilities of technologies as they related to the FY12 ORTB Base Camps. The analysis may not translate directly to other base camps, as relevant applications for small power producers vary across base camps.

At the 50 PAX base camp, no appropriate integration for the MANGEN was identified. The small size of the base camp dictates that facilities are closer together, enabling facilities to be connected to fewer, larger power generation assets. Isolated facilities such as ECPs and guard towers are unpowered. The lack of an application at the FY12 ORTB 50 PAX Base Camp should not be generalized to all base camps of that size, only that there was a lack of operationally relevant applications for the MANGEN at the FY12 ORTB 50 PAX Base Camp, specifically.

At the 300 PAX base camp, two scenarios were simulated to investigate the impact of the MANGEN. At the 300 PAX base camp, two MANGENs were paired for parallel operation and used to replace a 60 kW TQG at each ECP. The paralleled MANGENs were first simulated with only their onboard fuel tanks and then simulated with a 5-gal military fuel can (Jerry can) acting as an additional external fuel tank. Additionally, both scenarios were repeated but with SCPL used in the MANGEN.

At the 1000 PAX base camp, three scenarios were investigated. In the first scenario, geographically isolated guard towers were powered by the MANGEN (one MANGEN per guard tower). While these guard towers are located far from power sources at the FY12 ORTB 1000 PAX Base Camp, they were assumed to draw power from the closest 60 kW TQG. As all the 60 kW TQGs powering the guard towers were also powering other base camp systems, none of the TQGs could be turned off. In the second scenario, all guard towers were powered with a single MANGEN unit, regardless of proximity to existing generators. This scenario also did not enable any TQGs to be shut off. The third scenario furthered the concept of powering all guard towers with MANGENs by simulating the MANGEN with a 5-gal military fuel can acting as an external fuel tank. Additionally, all scenarios were repeated but with SCPL used in the MANGEN.

The integration scenarios presented were selected based on the feasibility and operational relevance of utilizing MANGENs in single as well as parallel configurations. The unique design of each of the FY12 ORTB Base Camps did not enable similar integrations. The guard towers at the 300 PAX base camp are unpowered; thus, a scenario using MANGENs to power guard towers was not possible. The ECPs at the 1000 PAX base camp share a generator with other loads. Adding an additional MANGEN to power only the ECP would result in more fuel consumption than the FY12 ORTB Base Camp.

Table 25 shows the results of the simulation of the integration scenarios across the different base camp sizes in the desert environment. Since the MANGEN was only used to power loads that did not vary with climate, the results did not vary by climate. Although power, potable water, waste water, and solid waste metrics were calculated as part of each simulation, these numbers were omitted from the report because the integration of the MANGEN has no impact on the baseline values.

Table 25. Mean Daily Fuel Usage, Man-Portable Power Generation, Desert

	Without SCPL		With SCPL	
Simulation Description	Fuel (gal/day)	Δ	Fuel (gal/day)	Δ
	300 PAX Camp			
FY12 Baseline	1042	-	-	-
Two MANGENs at each ECP	995	4.5%	995	4.5%
Two MANGENs at each ECP with fuel can	992	4.8%	992	4.8%
	1000 PAX Camp			
FY12 Baseline	3376	-	-	-
MANGEN at isolated guard towers	3392	-0.5%	3391	-0.4%
MANGEN at every guard tower	3438	-1.8%	3437	-1.8%
MANGEN at every guard tower with fuel can	3386	-0.3%	3386	-0.3%

At the 300 PAX base camp, the use of parallel MANGENs instead of 60 kW TQGs at the ECPs showed a sizable fuel savings, even before the addition of a fuel can as an external fuel tank. This simple drop in replacement yielded a fuel savings of 4.5%. This fuel savings is directly attributable to shutting off two 60 kW TQGs. The two pairs of paralleled MANGENs consumed part of the fuel diverted from the 60 kW TQGs that were shut off. An additional 0.3% savings was achieved by increasing the fuel tank size with an external fuel can. By increasing the fuel tank size, the tank had to be refilled less often, resulting in a small savings from reduced vehicle usage.

From a maintenance standpoint, using MANGENs at the 300 PAX base camp could potentially be beneficial. The 60 kW TQGs replaced in the 300 PAX base camp scenario are used solely to provide power to ECPs. These TQGS are severely under-loaded and vulnerable to damage from wet stacking. The smaller MANGEN would not be as susceptible to this problem.

At the 1000 PAX base camp, the first scenario utilized MANGENs only at guard towers that are isolated from base camp power infrastructure. This yielded a small increase in fuel consumption, on average 16 gal per day. This fuel increase trend continues when the implementation of MANGENs expands to all guard towers, increasing the total base camp fuel demand by 62 gal per day (or 1.8%).

Most of this increase in fuel is not related to the MANGEN’s fuel consumption, but rather the increase in fuel required for on-camp logistics vehicles to keep each MANGEN’s fuel tank full. As discussed in **Sections 2.3.2** and **3.1.4.3**, the Vehicle Fuel Model assumes that on-base vehicles are used to refill or empty all tanks as needed. In a case like the MANGEN where the tanks are very small, this results in a tank being refilled multiple times a day, making this assumption unrealistic. When 5-gal fuel cans are included to expand the fuel tank size of each MANGEN at every guard tower, only a 10 gal or 0.3% increase in fuel usage over the baseline was observed. Without the fuel cans, the increase in fuel was 62 gal a day, meaning that 52 gal of fuel a day was used by vehicles to refill the MANGENs. The utilization of 5-gal fuel cans as expanded fuel tanks had a significant impact on base camp fuel consumption.

Each integration scenario was also investigated with SCPL used in the MANGEN. Although SCPL is a promising technology, test results at this point are still preliminary, and the lubricant has never been demonstrated in a MANGEN unit. The feasibility of using SCPL is other generators has been demonstrated, however. Analysis of the possible fuel savings attributed to SCPL is discussed in greater length in **Section 3.1.2.1**.

SCPL is estimated to reduce generator fuel consumption by 2%. The lack of observable fuel reduction at the 300 PAX base camp is the result of rounding the results data to the nearest whole gallon. This savings is to some extent noticeable when looking at the results for the 1000 PAX base camp scenarios, but is more evident when working with larger volumes of fuel. See **Section 3.1.2.1** for details on the use of SCPL in different applications.

Although it may be possible to utilize man-portable generators in other scenarios on other base camps, the SLB-STO-D analysis showed mixed results when implemented on the FY12 ORTB Base Camps. These results were largely due to the power distribution assumptions at the FY12 ORTB Base Camps and the limited applicability of a small generator at the camps. In general, using the MANGEN to replace a larger power generator that is severely under-loaded will reduce fuel consumption at the base camp. This concept is generically known as right-sizing, or pairing an electrical load to an appropriately sized power source. Implementing MANGEN in a manner that does not shut down other power sources will not result in a fuel savings; however, there are other benefits to this scenario. Utilizing a man-portable generator allows Soldiers the flexibility to provide power when and where they need it, without the material handling equipment required to move a larger and heavier power producer.

3.1.2.3 Renewable Energy

Renewable energy is power generated from resources that are constantly replenished and will never run out. While the nature of base camps may not lend itself to all forms of renewable energy for reasons such as mobility, many forms of renewable energy scale well to a base camp size.

At all of the FY12 ORTB Base Camps, the *Power Generation* functional area is the largest consumer of fuel accounting for 71.8–90.3% of the overall fuel consumption depending on the environment and camp size. Reducing the amount of fuel consumed to generate power at the base camps is key to meeting the SLB-STO-D goal of a 25% reduction in fuel consumption. Options for fuel reduction in *Power* Generation can be addressed on both the demand and supply side by reducing power consumption or by more efficiently producing power. This section focuses on the use of renewable energy to meet power demands.

Six technologies were investigated for their suitability in contributing to the SLB-STO-D's target fuel savings of 25%. For complete descriptions of the technologies, see **Annex C.** These technologies included the following:

- Solar Panels – Commercially available systems that harness the power of the sun to generate electricity.
- Nanoparticle-Polymer Composite PV Films – Prototype films applied to PV films using nano-enhanced power/energy-harvesting technology that will provide more power/energy than traditional PV films, including in low-light conditions at dusk and dawn.

- Wind Acceleration Module (WAM) – A commercial technology that passively accelerates wind to increase energy density and provides a continuous renewable energy source that can operate 24 h a day.
- Energy Storage Systems (ESS) – Commercially available battery storage systems used to store power created by renewable resources prior to use.
- Renewable Energy for Distributed Under-supplied Command Environments (REDUCE) – A prototype hybrid energy system mounted on a towable trailer consisting of an onboard diesel generator, solar panels, wind turbines, and an energy storage capability.
- Scorpion Energy Hunter Renewable Energy System – A commercially-available hybrid power system with an integrated 5 kW solar array, 30 kW generator, and 105 kWh of battery storage
- Solar Powered Shelter System (SPSS) – A commercially-available, hybrid power system with an integrated solar array, battery, and control system designed to mount to the top of standard ISO containers.

Solar panels, a commercially available item, come in many styles. Solar panels incorporated into this analysis come in two distinct formats: flexible and rigid. Since solar panels are often an augmentation to a technology rather than its primary function, analysis of the impact of renewable energy on these systems is discussed with the system itself. The impact of solar panels in isolation, such as with a dedicated solar array, was not analyzed, since the impact is highly sensitive to assumptions about the size of the array. If enough space is dedicated to install solar panels and energy storage, nearly any base camp could eventually be self-sustaining. Further, as higher efficiency solar panels are produced, the area required to install the panels will decrease. Previous demonstrations at the BCIL in Fort Devens, MA showed that a 12.9 kW solar array produced up to 12% of a 150 PAX base camp's daily energy needs [30].

For modeling purposes, solar panels were classified in three arrangements: horizontal, tilted, or tracking. Horizontal solar panels lay flat and collect Global Horizontal Irradiance, which includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DIF). While not ideal from an energy collection perspective, the horizontal arrangement is common in that panels can be laid flat on the ground or mounted directly atop existing flat-roofed structures such as containers. The optimum tilt for solar panels varies throughout the year. It was deemed unlikely that much effort would be spent in routinely moving the panels, so the angle of all tilted panels was set at the latitude of the base camp, which is generally considered an optimum angle if not adjusting seasonally. Finally, tracking panels use a variety of methods to always track the sun. These panels collect only DNI.

Figure 10 shows the power production potential of the three different solar panel arrangements in the desert environment. Solar panels that track with the movement of the sun consistently produce the highest power output. These panels come with the added complexity of tracking equipment. Panels tilted at the angle of latitude perform consistently well, but performance drops during the summer months. During these months, the sun is overhead, allowing horizontal panels to collect more solar irradiance than the tilted panels. Horizontal panels perform well during the summer months, but performance is significantly lower at all other times of the year.

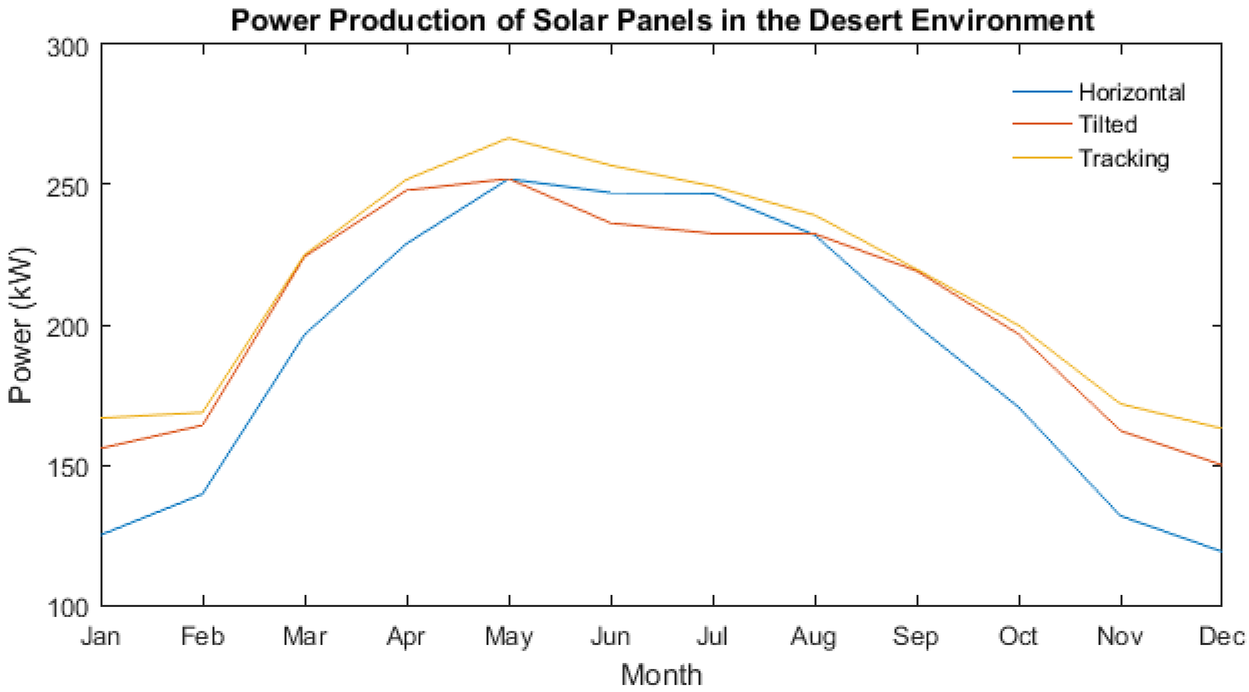

Figure 10. Power Production of Solar Panels, Desert

Rigid solar panels have a higher efficiency than flexible panels at the expense of portability and storage size. Flexible solar panels have the advantage of being foldable, making them more portable. They can also be incorporated into a variety of shelters and structures, reducing the need for dedicated space to house solar arrays. This convenience comes at the expense of efficiency, with flexible panels generally being less efficient than rigid panels. Additionally, unless placed over a rigid structure, flexible panels are difficult to arrange at optimal angles. For example, a solar shade with integrated flexible panels has panels pointing in numerous directions. For the purposes of this analysis, flexible panels are assumed to be to be oriented in the same fashion as rigid panels (i.e., in a single plane), though with reduced efficiency.

Nanoparticle-Polymer Composite PV Films, being investigated by NSRDEC, aim to boost their efficiency. The films use nano-enhanced power/energy-harvesting technology that provides more power/energy than traditional PV films, including in low-light conditions at dusk and dawn. These improvements may enable Soldiers to reduce the number of batteries to support equipment by enabling them to recharge batteries in the field. Though predicted to have power densities twice that of the commercially available flexible panel solutions, the technology was not matured enough to include in this analysis.

Several technologies reviewed in this report include solar panels:

- PShade (see **Section 3.1.1**) – A commercially available solar shade with 3.6 kW of flexible PVs integrated into the shade materiel that can be erected over an AS TEMPER tent to block a portion of solar radiation from the roof and sides, as well as reduce wind speeds experienced by the tent.

- Desert Environment Sustainable Efficient Refrigeration Technology (DESERT) High Efficiency-Multi Temperature Refrigeration Container System (HE-MTRCS) (see **Section 3.1.3.2**) – A prototype refrigerated container based on the fielded MTRCS system that contains an improved refrigeration unit that is both more energy efficient and reliable, as well as upgrades to the container itself to increase efficiency and performance.
- Minimized Logistic TRICON Integrated Latrine (MIL-TOILAT) (see **Section 3.3.1**) – A prototype latrine system designed for up to 50 users that includes water reduction technologies such as sink water recycling, waterless urinals, dual flush toilets, and an incinerator to eliminate all latrine black water. The system is designed with the capability to operate off-grid, with an integral reverse osmosis system for purifying water and an on-board generator.
- Replacement Shelters and Integrated Shelter Systems (see **Section 3.1.1.3**) – Numerous integrated shelter systems reviewed utilize solar arrays to supplement grid-provided power.

The energy harvested by solar panels does not necessarily need to be transformed into power. Solar water heaters capture the sun’s energy and convert it directly to heat for heating water. A single technology analyzed in this report uses renewable energy to produce heat:

- Self-Powered Solar Water Heater (SPSWH) (see **Section 3.1.4.1**) – A prototype technology that focuses energy from sunlight and converts it into heat for water heating, while storing excess heat in a metallic phase-change material contained within it.

Wind provides another renewable resource at base camps with which to generate power. Power generation from wind has the advantage of not being limited to daylight hours, as wind is present through the night as well. WAMs, a commercial technology being investigated by NSRDEC for its potential use at base camps, accelerates ambient wind, thereby increasing the power density of the arrays. WAMs are not included in this analysis due to lack of performance data at the time of publication.

ESS are a critical component to using renewable energy efficiently. Renewable energy production is often inconsistent or time limited (e.g., solar panels only produce power during daylight hours), resulting in overproduction during certain hours and underproduction during others. Energy storage allows the time shifting of this power.

The SLB-STO-D analyzed energy storage in the context of each system into which it was integrated. Most technologies analyzed contained a combination of a charge controller, battery, and inverter system. Each individual system was modeled along with the power generation equipment (e.g., solar panels), with the efficiency of the energy storage system offsetting power produced by the panel. Larger scale energy storage was also analyzed in the context of alternative energy; a 60 kW energy storage system was paired with the Waste to Energy Converter (WEC) (see **Section 3.3.4**). The WEC experienced similar issues to renewable energy, with power production being uneven and overproduction occurring during certain hours.

The REDUCE is a self-contained system that includes solar power, wind generation, and an energy storage system, combined with an onboard generator. The REDUCE was demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA, where it proved capable of powering select equipment on the base camp. Because of the small capacity of the system (the onboard generator is 3.8 kW) the REDUCE had few applications at the FY12 ORTB Base Camps, which were designed with 30 and 60 kW TQGs. For this reason, it was not included in this analysis.

The Scorpion Energy Hunter Renewable Energy System is a commercial system demonstrated at the BCIL at Fort Devens, MA and is being evaluated by PM FSS. The system is a hybrid power system with an integrated 5 kW solar array, 30 kW generator, and 105 kWh of battery storage. The Scorpion Energy Hunter Renewable Energy System was not included in this analysis due to lack of performance data at the time of publication.

The SPSS, under evaluation by PM FSS, was demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA. The system is designed to fit atop standard ISO containers and integrates a solar array and battery storage to supplement generator power. The FY12 ORTB Base Camps are primarily soft-wall configurations, limiting the applicability of the SPSS. Therefore, the SPSS is not analyzed in this report. The PShade (see **Section 3.1.1.1**) provides a similar power generation capability for AS TEMPER tents.

Renewable energy will play a key role in the development of self-sustaining base camps. The technologies analyzed show the incremental gains that can already be achieved through the integration of renewable energy and, given careful design, can have minimal to no impact on camp footprint.

3.1.3 Provide Subsistence

The *Provide Subsistence* functional area encompasses field feeding and is unique in that it directly impacts every resource type on the base camp: consuming power, fuel, and potable water and producing waste water and solid waste. This section focuses on options within *Provide Subsistence* that impact the consumption of power and fuel. Options that impact the production of waste are discussed in **Section 3.3.2**. Fuel and power demand in this functional area can be addressed by augmenting or replacing field feeding equipment.

The ability to provide subsistence is a critical base camp life support capability as it is essential for sustaining Soldiers and enabling them to complete their mission. The ration mix differs between baseline camps due to the camp population and field feeding equipment available. Due to its small size and more expeditionary mission, there is no field subsistence equipment present on the FY12 ORTB 50 PAX Base Camp; Soldiers have a ration mix consisting of two Meals, Ready to Eat (MREs) and one Unitized Group Ration – Express (UGR-E) per day. Both meals do not require fuel to prepare, and the amount of water required to activate the flameless ration heater is negligible. The FY12 ORTB 300 PAX and 1000 PAX base camps provide two UGR-A rations and one MRE per day, which requires onsite field kitchens, sanitation, and refrigeration assets [7].

The *Provide Subsistence* functional area represents a relatively small consumer of fuel and power on the FY12 ORTB Base Camps. Since the 50 PAX base camp does not include kitchens, this functional area consumes no fuel. While the 300 PAX base camp does have kitchens, they do not consume fuel directly. *Provide Subsistence* accounted for 11.7%, 17.9% and 8.1% of total power consumed at the 50, 300, and 1000 PAX base camps in the desert environment, respectively.

3.1.3.1 Food Preparation and Cleaning

The Army has a set of fielding feeding platforms designed to provide variable number of UGR-A rations and provide required field sanitation. At the FY12 ORTB 300 PAX Base Camp, the capability to provide UGR-A rations and conduct field sanitation is provided by the Force Provider Expeditionary TRICON Kitchen (ETK). The system contains both a suite of commercial kitchen appliances for cooking and a three-sink sanitation center for the cleaning and sanitation of kitchenware. At the FY12 ORTB 1000 PAX Base Camp, there are two Containerized Kitchens (CK), which are designed with a capacity to produce 800 UGR-A meals per meal period. Unlike the ETK, the CK does not have an onboard sanitation capability and thus each CK is accompanied by a Food Sanitation Center - 2s (FSC-2). The FY12 ORTB 50 PAX Base Camp does not provide UGR-A rations and therefore is not discussed in this section.

The proportion of energy required for field feeding is relatively small in comparison to other sustainment capabilities. At the FY12 ORTB 300 PAX Base Camp, food preparation and sanitation consumes 282 kWh or 6–7% of the camp’s electrical energy per day depending on the climate. At the 1000 PAX Base Camp, food preparation and sanitation requires both electrical power and fuel because the CK and FSC-2 utilize fuel-fired burners for kitchen appliances and three-sink sanitation. Unlike the ETK, which utilizes all-electric commercial appliances, cooking energy is distributed between electric power and JP-8 fuel burned directly by integral burners. Food preparation and sanitation at the 1000 PAX base camp consumes 1.5–1.8% of the base camp’s electric power and 1.2–1.4% of the fuel on average per day, depending on the environment.

Two technologies were investigated for their suitability in contributing to the SLB-STO-D’s target fuel savings of 25%. For complete descriptions of the technologies, see **Annex C**. These technologies included the following:

- Fuel-fired Expeditionary TRICON Kitchen (FF-ETK) – A prototype field kitchen and integral appliance suite that leverages appliance technologies developed under the Modular Appliances for Configurable Kitchens (MACK) program. The FF-ETK is a drop-in replacement for the all-electric ETK at the FY12 ORTB 300 PAX Base Camp.
- MACK – A prototype fuel-fired appliance suite that is efficient, man-portable, and configurable for integration into each of the Army’s maneuver field feeding platforms: the Assault Kitchen (AK), Battlefield Kitchen (BK), and CK. This appliance suite was demonstrated as part of a prototype Containerized Kitchen – Improved platform (CK-I), which is a drop-in replacement for the CK at the FY12 ORTB 1000 PAX Base Camp.

Implementation of more efficient technologies can yield energy savings in two different ways. First, it could provide the same capability or service at a lower energy cost than the baseline system. Second, it could reduce system peak power to the point that fewer or smaller tactical power generation assets are required to be kept operational on the base camp. Integration scenarios were developed to investigate both possibilities.

The FF-ETK and CK-I were integrated into the 300 PAX and 1000 PAX base camps respectively, in a one-to-one swap of the existing baseline equipment. The FF-ETK has a reduced peak power in comparison to the baseline ETK, allowing for fewer generators to be used to power the field feeding facilities. Two scenarios were simulated for the FF-ETK, one without generator reallocation and one with generator reallocation. The CK-I, which includes the MACK appliances, has the same peak power as the baseline CK. No generators could be shut off when the CK-I was implemented at the 1000 PAX base camp, so only one scenario was simulated.

Table 26 shows the results of the simulation of the integration scenarios across the different base camp sizes in the desert environment. The results in temperate and tropical climates are similar.

Table 26. Mean Daily Camp Level Summary, Food Preparation and Cleaning, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
FF-ETK, No Generator Reallocation	1040	0.2%	4876	4.5%	8799	-0.9%	8605	-0.9%	2870	0.0%
FF-ETK, Generator Reallocation	1010	3.1%	4876	4.5%	8799	-0.9%	8605	-0.9%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
CK-I	3359	0.5%	17414	0.9%	31305	0.0%	31153	0.0%	10672	0.0%

At the 300 PAX base camp, the impact of the FF-ETK on potable and waste water metrics are slight and indicate that the FF-ETK may require more potable water for meal preparation. The FF-ETK has a different appliance suite than the ETK, with more cooking capacity, which reduces meal preparation time. One reason for that increase in cooking capacity is the inclusion of an 11-gal tilt skillet in the FF-ETK that replaces the 10-qt steam jacketed kettle in the legacy ETK. The tilt skillet can be used to cook boil-in-a-bag ration components, and many UGR-A components can be prepared with this cooking method. The model's data rely on a limited dataset based on only two trial meal preparations for each kitchen. While more data are required to show a definitive and quantifiable difference in water consumption, based on the characteristics of the kitchen itself, it is reasonable to assume the trend is a small increase in potable water demand over the legacy system.

Examining power and fuel demand, a key difference between the FF-ETK and the ETK is that the baseline ETK has electric appliances, while the FF-ETK replaces them with fuel-fired appliances. Switching to the fuel-fired suite of appliances means that the thermal energy used for cooking is no longer produced by electric power, but instead by burning fuel directly within the appliances themselves. This introduces a new fuel-consuming system, but since fuel-fired heating is more efficient than generating electric power and converting it into thermal energy, there is a net reduction of 0.2% in the fuel demand.

As previously mentioned, in the case of the FF-ETK, generator reallocation is possible. Comparing the FF-ETK simulations without generator reallocation and with generator reallocation shows the reductions in power draw are the same, decreasing the average daily power demand by 4.5–5.7% depending on the environment. However, reallocating generators increases fuel savings by, on average, from 1.9–2.9% to 2.8–3.1%.

At the 1000 PAX base camp, the integration of a CK-I with onboard MACK appliances suite has a minimal impact on camp resource consumption. By replacing two legacy CKs with CK-Is, power consumption was reduced by 0.9–1.1% and fuel reduced by 0.5–0.6%. In the case of the CK-I, more efficient fuel-fired appliances are replacing legacy fuel-fired appliances in the CK. As result, the power reduction is small, because the appliances in the CK are already fairly efficient.

The power reduction at the 1000 PAX base camp has less to do with the appliances and more to do with other changes to the kitchen platform. One of the major contributors is the absence of the ECU on the CK-I. Unlike the CK, which has an onboard ECU, the CK-I uses several fans. Soldier feedback from a demonstration at CBITEC confirmed that the switch to fans did not downgrade workspace comfort [9]. Unlike the legacy appliances in the CK that utilize open combustion heating, the CK-I appliances use a closed heat exchanger inside the appliance itself. This concept enables the combustion gases and excess heat to be vented out of the workspace, dramatically reducing the temperature inside the kitchen. This combination of venting and fans is more effective at cooling the workspace, since the cooling capacity of the legacy CK’s ECU is exceeded by the heat generated by the platform’s open combustion appliances.

In comparing the CK-I resource savings with the FF-ETK, there are some other differences, mainly as a result of the methodology used. Unlike the comparative demonstrations that were executed to measure the differences between the FF-ETK and baseline ETK, the CK-I was demonstrated but the baseline CK was not. In place of a full-scale demonstration of the CK, a best estimate of its resource consumption was modeled. The fuel, power, water, and waste water model inputs for the CK were based on SME input and component-level performance metrics. Although not ideal, the resources to demonstrate the CK and CK-I comparatively were not available. Based on these SME assumptions and component level data sets, it is clear that the CK-I appliances will be more fuel efficient, and based on the systems within each, the power consumption of the CK-I will consume less power than the baseline CK. In terms of water and waste water, there is no technical reason to assume that the CK-I suite of appliances would require more water and/or produce more waste water than the legacy suite, so the CK and CK-I models share the same assumptions and values for the system-level performance.

Another aspect of this analysis to be considered is the resource savings difference between replacing electric appliances, like the ETK, with closed-combustion fuel-fired ones, like the CK-I. While it may be tempting, these numbers are not directly comparable for a number of reasons. These include differences in baseline camp size, baseline equipment set, the set of appliances in each suite, and the fact that the ETK has onboard sanitation while the CK relies on being paired with a FSC-2 to provide this capability.

Overall, simulations show that swapping out the ETK for the FF-ETK at the FY12 ORTB 300 PAX Base Camp produces savings in fuel consumption and increased consumption and production of potable water and waste water, respectively. Additionally, swapping out the CK for the CK-I shows smaller fuel savings and no change in any other resource. These conclusions are made less clear by the limited availability of demonstration data for these technologies, particularly with respect to potable water and waste water. However, both swaps discussed result in fuel savings. In addition, there are other capabilities and benefits to the Army not captured as part of this analysis. More information is provided in a companion report entitled *Selected Technology Assessment* [1].

3.1.3.2 Refrigeration

The ability to prepare UGR-A rations on a base camp requires access to refrigeration for the preservation of perishable food items. As defined by the FY12 ORTB, cold storage for perishable food items is provided by a combination of Tri-Cold containers, MTRCS, and commercial 20-ft refrigerated containers. Because UGR-A rations are consumed at the FY12 ORTB 300 PAX and 1000 PAX Base Camps but not the FY12 ORTB 50 PAX Base Camp, only the larger camp sizes will be discussed in this section.

Camp refrigeration consumes 5.8–8.2% of the daily average electrical energy at the 300 PAX base camp, depending on the environment. At the 1000 PAX base camp, this percentage is lower across the board, about 2.0–4.0%. Understanding the overall level of power demand associated with refrigeration creates an upper bound for base-wide percentage reduction possible with the implementation of more efficient refrigeration technology. Lowering power consumption leads to less fuel required to generate power, which could assist in meeting the SLB-STO-D goal of reducing fuel consumption by 25%.

The FY12 ORTB 300 PAX Base Camp uses two Tri-Cold containers and three 20-ft commercial refrigerated containers, while the FY12 ORTB 1000 PAX Base Camp uses two MTRCS and five 20-ft commercial refrigerated containers. The rationale for determining the amount of required refrigeration space is discussed in detail within the Field Feeding appendix of the FY12 ORTB [6] [7]. While distinguishing between a MTRCS and a commercial container serves no purpose in the context of this analysis, it was a point of emphasis with the program’s stakeholders that the Army may not have enough MTRCS systems to supply all base camps, and a representative base camp may not include that equipment. As a result, the baseline camp includes commercial units that are assumed to have the same level of energy performance as a MTRCS. This assumption allows for an evaluation of improved refrigeration technology in principle against older, commercially-available refrigeration technology (e.g., the MTRCS refrigeration unit).

Two technologies were investigated for their suitability in contributing to the SLB-STO-D target of fuel savings of 25%. For complete descriptions of the technologies, see **Annex C**. These technologies included the following:

- MTRCS (FY12 ORTB baseline equipment) – A currently-fielded, refrigerated container, transportable by a Palletized Loading System vehicle. The MTRCS has an internal partition, allowing for maintaining two separate temperatures.

- DESERT HE-MTRCS – A prototype refrigerated container based on the fielded MTRCS system that contains an improved refrigeration unit that is both more energy efficient and reliable, as well as upgrades to the container itself to increase efficiency and performance.
- Desert Power 2 (DP2) Solar Array – A standard Solar System I shade shelter modified by the inclusion of 2 kW of flexible solar panels.

The DESERT HE-MTRCS unit includes a number of upgrades over the legacy MTRCS. These upgrades include modifications to the refrigeration unit to improve energy consumption and system reliability and to increase the insulation in the container itself. Additionally, the modified refrigeration unit is capable of directly accepting electrical power from solar panels. The refrigerated container model takes into account the ambient environmental temperature as well as the desired internal temperature in each of the container's partitioned zones. The electrical power required is based on an hourly average. The refrigeration power model assumes that the containers are in steady-state and does not account for the effect of door openings or the temperature of the container's contents. Other environmental considerations that affect a refrigeration system's energy demand such as humidity, solar radiation, heat transfer from the ground, and wind speed/direction were not included in the model. The inclusion of these factors was not pursued due to the lack of supporting data, the resources required to calibrate the model for an increased number of input variables, and the relatively small impact it would have on model accuracy.

Several integration scenarios were investigated. In the first scenario, the DESERT HE-MTRCS was swapped out as a one-to-one replacement of all 20-ft baseline refrigerated containers on both the 300 PAX and 1000 PAX base camps. In the second scenario, the DESERT HE-MTRCS was integrated into the 300 PAX and 1000 PAX base camps in combination with the DP2 Solar Array, which is a 2 kW tilted array. When the DP2 solar array is simulated, one solar panel array is joined with each DESERT HE-MTRCS unit. The TriCold systems were not modified for either scenario.

Efficiency gains and the capability of the DESERT HE-MTRCS to directly interface with the DP2 solar panels both allow reductions in power demand. Another opportunity for energy reduction enabled by the DESERT HE-MTRCS is generator reallocation due to the reduction in system peak power. When sizing tactical power generation assets, peak power of the connected systems is the main variable to consider. A reduction in peak power demand of a piece of equipment may enable fewer power generation assets to be used. In this particular scenario, generator reallocation was only possible at the 1000 PAX base camp. Due to the physical layout of the refrigeration units and other systems on the 300 PAX camp, there were no opportunities for generator reallocation. For a more detailed discussion of power generation modeling, see **Section 3.1.2**.

The two integration scenarios described above were repeated at the 1000 PAX base camp, but including generator reallocation. In each case, a single 60 kW TQG could be eliminated.

Table 27 shows the results of the simulation of the integration scenarios across the different base camp sizes and environments.

Table 27. Mean Daily Camp Level Summary, Refrigeration

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
Desert Environment										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
DESERT HE-MTRCS	1036	0.6%	5001	2.1%	8723	0.0%	8529	0.0%	2870	0.0%
DESERT HE-MTRCS, DP2	1034	0.8%	4963	2.8%	8723	0.0%	8529	0.0%	2870	0.0%
Temperate Environment										
FY12 Baseline	1096	-	4091	-	8723	-	8529	-	2870	-
DESERT HE-MTRCS	1094	0.2%	4045	1.1%	8723	0.0%	8529	0.0%	2870	0.0%
DESERT HE-MTRCS, DP2	1093	0.3%	4031	1.5%	8723	0.0%	8529	0.0%	2870	0.0%
Tropical Environment										
FY12 Baseline	1023	-	4806	-	8723	-	8529	-	2870	-
DESERT HE-MTRCS	1017	0.6%	4691	2.4%	8723	0.0%	8529	0.0%	2870	0.0%
DESERT HE-MTRCS, DP2	1016	0.7%	4681	2.6%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
Desert Environment										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
DESERT HE-MTRCS	3363	0.4%	17334	1.4%	31305	0.0%	31153	0.0%	10672	0.0%
DESERT HE-MTRCS, DP2	3359	0.5%	17242	1.9%	31305	0.0%	31153	0.0%	10672	0.0%
DESERT HE-MTRCS, Generator Reallocation	3334	1.2%	17334	1.4%	31305	0.0%	31153	0.0%	10672	0.0%
DESERT HE-MTRCS, DP2, Generator Reallocation	3329	1.4%	17242	1.9%	31305	0.0%	31153	0.0%	10672	0.0%
Temperate Environment										
FY12 Baseline	3654	-	14751	-	31305	-	31153	-	10672	-
DESERT HE-MTRCS	3649	0.1%	14643	0.7%	31305	0.0%	31153	0.0%	10672	0.0%
DESERT HE-MTRCS, DP2	3647	0.2%	14608	1.0%	31305	0.0%	31153	0.0%	10672	0.0%
DESERT HE-MTRCS, Generator Reallocation	3619	0.7%	14643	0.7%	31305	0.0%	31153	0.0%	10672	0.0%
DESERT HE-MTRCS, DP2, Generator Reallocation	3617	1.0%	14608	1.0%	31305	0.0%	31153	0.0%	10672	0.0%
Tropical Environment										
FY12 Baseline	3301	-	16463	-	31305	-	31153	-	10672	-
DESERT HE-MTRCS	3287	0.4%	16200	1.6%	31305	0.0%	31153	0.0%	10672	0.0%
DESERT HE-MTRCS, DP2	3286	0.5%	16175	1.8%	31305	0.0%	31153	0.0%	10672	0.0%
DESERT HE-MTRCS, Generator Reallocation	3258	1.3%	16200	1.6%	31305	0.0%	31153	0.0%	10672	0.0%
DESERT HE-MTRCS, DP2, Generator Reallocation	3256	1.4%	16175	1.8%	31305	0.0%	31153	0.0%	10672	0.0%

At the 300 PAX base camp, implementing the DESERT HE-MTRCS resulted in power savings of 1.1–2.4% and fuel savings of 0.2–0.6%. At the 1000 PAX base camp, power savings were 0.7–1.6% and fuel savings were 0.1–0.4%. What is immediately noticeable is the difference in percentage power reduction compared to percentage fuel reduction. This discrepancy is caused by two different aspects of the camp. First is the presence of camp systems that consume fuel directly, such as the fuel-fired shelters and water heaters, the CK (1000 PAX base camp only), and on-base vehicles. Because power generation is not the only consumer of fuel, any reduction in power demand will necessarily have a smaller impact on fuel resource savings than power resource savings. The other contributing factor to the discrepancy has to do with the fuel consumption characteristics of the TQGs powering the camp. As discussed in **Section 3.1.2**, the fuel efficiency as a function of kW demand is nonlinear. Therefore, a proportional reduction of power does not imply an equal proportion of fuel reduction.

The next simulation involves the addition of the DP2 Solar Array. The impact of adding the array at the 300 PAX base camp results in a 0.2–0.7% reduction in electrical energy consumption and a 0.1–0.2% reduction in fuel in comparison to the HE-MTRCS alone. The difference at the 1000 PAX base camp is similar. The dissimilarities in energy consumption in various environments is a result of differences in both climate and latitude. The power produced by the DP2 Solar Array is directly related to the camp's latitude.

When generator reallocation is performed to take advantage of the lower peak power of the DESERT HE-MTRCS, a further reduction in fuel demand of 0.6–0.9% depending on climate is observed. The lower peak power associated with the DESERT HE-MTRCS system has a greater impact on fuel reduction than the increase in system efficiency and addition of solar panels combined, by a factor of more than 2. It is notable that technologies with lower peak power than their legacy counterparts may create opportunities for increased fuel savings. When the DP2 Solar Array is included with generator reallocation, the combination results in a fuel savings of 0.8–0.9%, slightly greater than in the generator reallocation simulation without the DP2 solar panels.

Both the DESERT HE-MTRCS and DP2 Solar Array technologies show savings in power demand and fuel consumption within the *Provide Subsistence* functional area, especially when combined with generator reallocation. Both of these technologies will be considered as a potential solution to achieve the SLB-STO-D's resource reduction goals.

3.1.3.3 Ice Production

Potable ice is used in field kitchens and dining facilities to chill perishable food and beverages as well as to chill bulk and bottled water prior to consumption. Ice is also used for medical and mortuary affairs at the base camp. Additionally, the presence of ice at the base camp can increase morale. At the FY12 ORTB Base Camps, ice is not produced organically. Base camps are dependent on truck convoys to import ice to the camp.

As representations of typical base camps of their era, the FY12 ORTB Base Camps do not possess the capability to organically produce ice. In fact, only the FY12 1000 PAX Base Camp is assumed to have access to ice. Since ice is not currently produced on the base camp, adding ice making equipment, while increasing the QoL(O) of the base camp, will result in a net increase in fuel and water consumption. Producing ice organically is moving the resource consumption from off base to on base. For this reason, ice production was not considered a viable candidate to help achieve the SLB-STO-D program objective resource reduction. Since ice plays a key role in base camps, however, its impact is analyzed in isolation.

One technology and one commercial item were investigated for their suitability in producing ice organically at a base camp. For complete descriptions of the technology options—see **Annex C**. These options included the following:

- Containerized Ice Making Technologies (CIMT) – A prototype ice making technology that produces more ice and uses less power and fuel than currently deployed and near-term solutions.

- Containerized Ice Making System (CIMS) – A commercial, containerized ice production system that makes ice, bags the ice, seals the bags, and stores the bags in an internal freezer.

Planning factors for potable ice vary from 2 to 6 lb per soldier per day, depending on the climate [35]. At the FY12 ORTB Base Camp, the planning factor chosen was 2 lb per soldier per day across all climates [7]. Using this planning factor, approximately 25% of the space in one MTRCS freezer must be dedicated to ice storage. Since the freezers required for field feeding had spare space, no additional freezer space was added to account for ice storage. Similarly, producing ice on base would utilize this same storage space with no net change to the camp footprint.

Quantifying the impact of producing ice organically on a base camp is a difficult problem. The resources consumed to transport ice via convoy are sensitive to a variety of factors that vary from camp to camp. Notably, these include the quantity of ice needed, ambient temperature, and convoy travel time.

The FY12 ORTB specifies a planning factor of 2 lb of ice per soldier per day at the 1000 PAX base camp. Based on the number of Soldiers at the base camp, a 3-day resupply frequency would require 6,960 lb of ice to be delivered every 3 days. According to NSRDEC's SMEs, ice deliveries in the Combined Joint Operations Afghanistan contained 1,500 lb of ice per pallet. This would equate to a requirement of five pallets of ice per resupply.

The SLB-STO-D's use-case assumes that cargo and bulk potable water are transported by an M1120 HEMTT LHS with a M1076 Palletized Load System trailer (carrying HIPPOs for water transport). The logical extension of the use case is to use the same truck and trailers with MTRCS freezers. Since a MTRCS can hold eight pallets, the ice required at the 1000 PAX Base Camp would require 62.5% of the space in one MTRCS.

Alternatively to trucking the ice, the convoy could be altered to include additional potable water, so that potable ice could be produced at the base camp. Ice machines reject a small amount of high mineral content water in the production of ice. The CIMT, a technology being reviewed by NSRDEC as part of the CIMS program, indicates a rejection rate of approximately 15 gal per day to generate 3,600 lb of ice. This equates to approximately 12.4 gal of water being required to produce 100 lb of ice. This is in line with the usage rate specified in commercially available equipment [36]. Based on this, approximately 866 gal of potable water would be required to produce 3 days' worth of ice. This equates to 43.2% of a HIPPO.

Since convoys can contain supplies for numerous base camps, it is impossible to quantify the impact of the increased truck utilization without making assumptions about the entire theater of operations. In the case of a direct convoy carrying a single camp's supplies, either method of ice production would require a single truck (or trailer). However, in the case of multiple camp resupply, transporting ice would allow only enough ice to supply 3.2 1000 PAX base camps to be transported on a single truck and trailer versus transporting potable water, which could supply ice making capabilities to 4.6 camps using the same truck and trailer.

Truck utilization may also play a factor in climates that require larger quantities of ice. A single HIPPO can hold enough water to produce up to 4.6 lb per soldier per day of ice for the FY12 ORTB 1000 PAX Base Camp. A single MTRCS can only deliver 3.4 lb per soldier per day of ice.

Regardless of truck count, the convoy faces another cost for transporting ice over water: fuel to power MTRCS freezers. The amount of fuel required to maintain the freezers is highly sensitive to ambient temperature as well as the convoy travel time. Convoy travel time depends heavily on the arrangement of base camps, how far down stream of the Sustainment Brigade a camp is located, the travel conditions and terrain to get to the base camp, and the amount of time to unload the convoy trucks (since the MTRCS cannot be shut down until unloaded).

Figure 11 depicts the notional support operations in a developed theater of operations [37]. Based on this, two notional flows of materiel were developed. In the first, the convoy went from a Combat Sustainment Support Battalion (CSSB) to another CSSB before arriving at a base camp. In the second option, a Brigade Support Battalion (BSB) Distribution Company carried the ice further into theater to a Forward Support Company (FSC). Notably, any number of stops could be possible, which will have a large impact on convoy travel time.

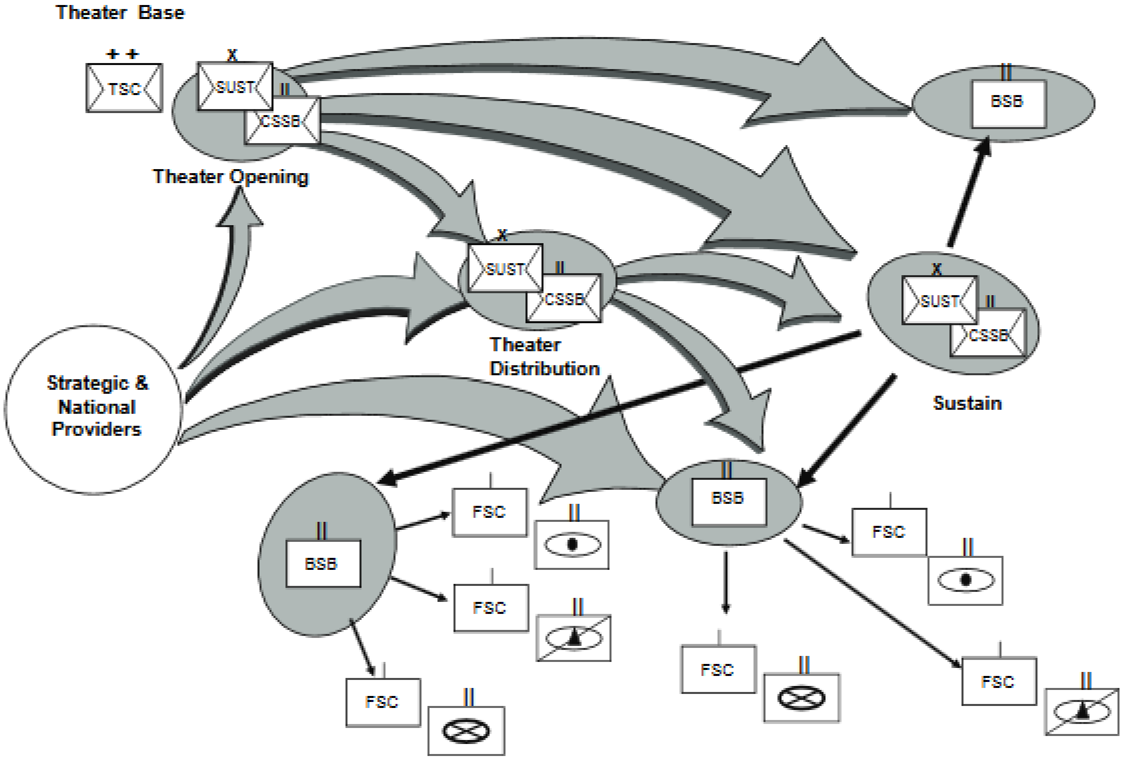

Figure 11. Notional Support Operations in a Developed Theater of Operations.

Reprinted from FMI 4-93.2, *The Sustainment Brigade*

Distances between the CSSBs, BSBs, and FSCs were varied according to FMI 4-93.2. The recommended distance between a Sustainment Brigade and the BSBs it supports is from 60 to

175 km. The BSBs should be from 30 km to 45 km from the FSCs [37]. The terrain type was assumed to get progressively worse farther into theater, starting with primary roads between CSSBs to cross country roads between BSBs and FSCs. Travel speed was dictated by the road conditions (28.29 mph on primary roads, 23.89 mph on secondary roads, and 12.90 mph on cross country roads).

Table 28 shows the average fuel consumption of the MTRCS freezer when used to transport ice from the CSSB to its destination during average temperature conditions in each environment. Since the fuel consumption is highly correlated to time to delivery (which in turn is dictated by distance travelled), the best-case scenario includes bases that are closest together.

Table 28. Fuel Consumption for Ice Delivery

	Distance (km)			Time to Delivery*	MTRCS Fuel Consumption† (gal)		
Scenario	To CSSB	To BSB	To FSC	(h)	Desert	Temperate	Tropical
BSB Best Case	60	60	-	8.9	4.5	2.1	4.9
BSB Worst Case	175	175	-	14.4	7.2	3.4	8.0
FSC Best Case	60	60	30	11.9	6.0	2.8	6.6
FSC Worst Case	175	175	45	19.6	9.8	4.7	10.8

[*] Includes 3 h of unload time per stop

[†] Based on average temperature in the given environment

Producing ice at the base camp also has a fuel cost. The stated power consumption of the CIMT is 5.85 kW (the average power consumption for the CIMS was unavailable at the time of publication). To produce enough ice for the FY12 ORTB 1000 PAX Base Camp, the system would need to operate for approximately 15.5 h per day. Since the power draw of the CIMT is relatively low and the generators on the FY12 ORTB Base Camps are generally underutilized, it is likely that the CIMT would be attached to an existing generator. Additional fuel consumption to power the generator would be approximately 6.1 gal per day (or 18.3 gal per 3-day resupply period). This fuel consumption is higher than the delivery fuel consumption under average conditions.

Given that the MTRCS fuel consumption is highly sensitive to ambient temperature, there may be situations where delivering ice costs more fuel. **Figure 12** depicts the fuel consumption of the MTRCS to the two delivery sites across a range of temperatures. The temperatures chosen correspond to the minimum, maximum, and average temperatures seen in the three SLB-STO-D environments. As shown, in cold temperatures, the fuel consumption of the MTRCS is very low, even when travelling long distances. At higher temperatures, however, fuel consumption surpasses 21 gal per MTRCS container when delivering ice to the farthest FSC at the peak of the summer desert. Ice production at base camps during summer months will likely consume less fuel than importing ice via convoy.

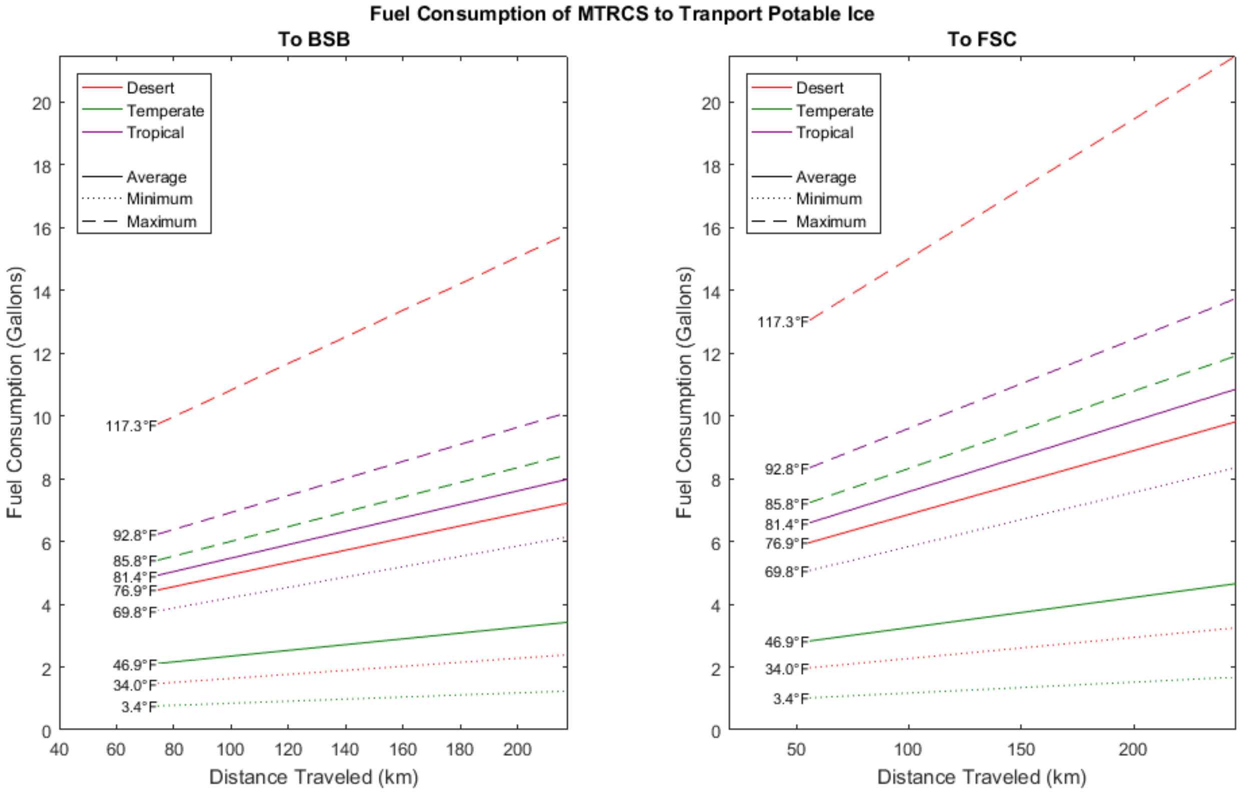

Figure 12. Fuel Consumption for Ice Delivery

In the select temperature and operational conditions, namely hot environments and distant base camps, potable ice production on the base camp may directly save fuel over transporting ice to the base camp. While this analysis focused on the FY12 ORTB 1000 PAX Base Camp, smaller base camps may be located downstream and require longer resupply routes. Organic ice production may allow for ice availability at locations that would otherwise be too costly to resupply via convoy. Additional consideration should also be given for the requirement to store ice in transit, at intermediary destinations, and at the final base camp. The final base camp is required to have enough freezer space for the full 3-day resupply quantity. While this does not impact the FY12 ORTB 1000 PAX Base Camp, the lack of impact was a consequence of coincidence, not design. Potable water storage, on the other hand, has a near negligible cost in all but the coldest of temperatures, where cold weather kits must keep it from freezing (and ice is less likely a desired resource). The storage of potable water has the additional advantage in that there is no requirement that the water be used for making ice. It provides options to base camp commanders to direct potable water where required at a particular time and in a particular situation.

In addition to potential fuel savings, organic production of ice can facilitate an increase in QoL(O). The ability to cool drinking water is the second most influential attribute in the *Field Feeding* functional area. Additionally, access to ice for cooling beverages has an additional impact on QoL(O). Cooling drinking water could be accomplished via refrigeration, which may require additional equipment to support the additional refrigeration requirement or via ice, which would necessitate ice being brought into the camp via convoy or produced organically.

Beverages are often required to stay cool when conducting missions launched from the base camp, and utilizing ice is a common means to keep beverages cooled.

While producing ice organically will not help achieve resource reduction at the FY12 ORTB Base Camps, localized ice production could have a large impact on theater-wide fuel usage in convoys. This impact depends heavily on the environment and the distance ice must travel to reach its final destination. Additionally, given the expense of transporting ice, organic production may allow for ice at base camps not currently serviced today.

3.1.4 Other

Some options for resource reduction at the FY12 ORTB Base Camps target particular equipment level functions or cut across several camp level functions. These options include the heating of water, options to reduce on-base vehicle usage, and the utilization of metering and monitoring technologies to achieve added efficiencies. This section reviews the impact of these options on resource consumption.

3.1.4.1 Water Heating

In the FY12 ORTB 300 PAX and 1000 PAX Base Camps, daily showers are offered. Because the baseline QoL standards at these camps allow Soldiers to have control over the temperature of the water in their shower, this requires that the potable water be heated. The heating process is a direct consumer of fuel as well as power. An option to reduce resource usage includes a solar water heater, which relies on energy provided by the sun to reduce the frequency with which the fuel water heater needs to be used.

Water heating is a comparatively small consumer of fuel at the base camps, responsible for about 1% of all fuel consumption. However, it is also one of the only direct sources of fuel consumption. Much of the other fuel draws are to supply generators to produce power. Reducing fuel used for power generation requires either reducing the power demand or generating power more efficiently. These options will be discussed in **Section 3.1.2**. By contrast, examining water heating makes it possible to have a direct impact on the amount of fuel consumed.

One technology was investigated for its suitability in contributing to the SLB-STO-D target fuel savings of 25%. For a complete description of this technology, see **Annex C**. This technology was the following:

- Solar Water Heater - A device that focuses energy from sunlight and converts it into heat for water heating.

The solar water heater in this analysis is a simplified model based on the SPSWH under development by NSRDEC. The SPSWH tracks the sun over the course of the day to maintain optimal positioning to collect direct solar insolation. This solar insolation is converted to heat, which is used to preheat water on the base camp. The key difference between the solar water heater as modeled and the SPSWH is that the latter includes a Thermal Storage Device (TSD) while the model does not. The TSD stores energy by heating a metallic phase-change material contained within it. Later, this material is used to turn water into steam, which heats the remainder of the water. Solar water heaters can only collect heat during the sunlit hours, so the TSD enables heat to be stored into the night, extending the effectiveness of the SPSWH. The TSD is omitted in DCAM due to the complexity of modeling it. Including it would have improved the overall performance of the solar water heater, a fact which will be discussed later in this section.

Solar water heaters can be used anywhere hot water is required on the base camp. At the FY12 ORTB Base Camps, hot water is generated using a WH-400 for the shower facilities and using Modern Burner Units (MBUs) in the FSC-2. The SPSWH was demonstrated by the SLB-STO-D in an integration with shower facilities, so the WH-400 was the chosen integration for simulations. Two integration scenarios were simulated. In the first scenario, three units were provided next to each pair of showers. This matches the planned number of units per 150 soldier modules of the SPSWH. The baseline WH-400 was retained within the shower system to heat water during hours when the solar water heater is not sufficient. As a variation, an additional simulation was run where there are six solar water heaters per pair of showers. This helps determine the marginal improvement of including greater numbers of solar water heaters. The FY12 ORTB 50 PAX Base Camp does not have showers, so is not modeled here.

Table 29 shows the results of the simulation of the integration scenarios across the different base camp sizes in the desert environment.

Table 29. Mean Daily Camp Level Summary, Solar Water Heater, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
3 Solar Water Heaters per Shower	1038	0.4%	5105	0.1%	8723	0.0%	8529	0.0%	2870	0.0%
6 Solar Water Heaters per Shower	1038	0.4%	5105	0.1%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
3 Solar Water Heaters per Shower	3362	0.4%	17567	0.1%	31305	0.0%	31153	0.0%	10672	0.0%
6 Solar Water Heaters per Shower	3360	0.5%	17566	0.1%	31305	0.0%	31153	0.0%	10672	0.0%

Overall, implementing three solar water heaters per pair of showers saves about 0.4% of fuel and reduces power demand by 0.1%. This relatively modest overall savings somewhat obscures the overall efficacy of the solar water heater. Looking at the *Water Heating* equipment level function, including the solar water heater reduces fuel usage by 30.0–31.6% and reduces power demand by 5.9–7.1%, a very substantial resource savings level. The reduction in power demand comes about because when less fuel is used, less fuel needs to be pumped, a process which uses electric power. However, the *Water Heating* equipment level function only accounts for 1.0–1.1% of overall fuel consumption and 0.9–1.2% of power demand. In general, the solar water heater is very effective at reducing the fuel needed in the category of water heating. However, because water heating is responsible for such a small portion of overall fuel usage on camp, the impact on overall fuel usage is relatively small.

Expanding to six solar water heaters per pair of showers saves about 0.4–0.5% of fuel and 0.1% of power. For the *Water Heating* equipment level, this scenario reduced fuel demand by 33.6–34.5% and power demand by 6.5–7.9%. Note that doubling the number of solar water heaters does not double the amount of resource savings. This is because, without a TSD, solar water heaters can only provide hot water during hours with sunlight. In the desert environment, for example, there is no direct normal irradiation present 52.5% of the time, meaning that no matter how many solar water heaters are included, the fuel fired water heater would still be required during more than half of the hours in the year.

Even though a TSD was not directly modeled in DCAM, a model of the thermal requirements to heat water can give estimates for the performance of the full SPSWH in terms of heat energy. Without the TSD, a solar water heater would provide on average 30.9% of the yearly heat energy required to heat water. With the TSD, it would provide 78.0% of yearly heat for hot water—more than double. As a result, including the TSD would be expected to have a significant positive impact on the fuel savings within the *Water Heating* equipment level function.

In summary, the solar water heater is a technology that reduces fuel needed for water heating by focusing solar rays. This reduces how often and how intensely the fuel fired water heater in the showers is required, bringing an overall drop in fuel usage and power demand for pumping fuel. The solar water heater brings about a large reduction in the amount of fuel required for water heating, and would bring about even more savings if it were implemented as it currently exists with the TSD. However, because *Water Heating* is such a small proportion of overall fuel usage, the impact of the solar water heater on overall fuel demand was quite small.

3.1.4.2 Metering and Monitoring

Metering and monitoring technologies use various sensors, either centrally located or distributed across the camp, to collect and analyze local data to inform decision makers. These data can assist with the optimal use of equipment, with identifying potential issues such as malfunctions or leaks, or with identifying resource intensive items and potential mitigation strategies. While metering and monitoring solutions can potentially measure all resources at a base camp, their insight into power consumption is likely most significant.

The *Power Generation* functional area is the largest single consumer of fuel at the FY12 ORTB Base Camps across all environments, accounting for 71.8–90.3% of the fuel consumed. More efficiently using equipment, sizing generators, and allocating loads could all assist with achieving the SLB-STO-D goal of a 50% reduction in fuel usage.

Two technologies were investigated for their suitability in contributing to the SLB-STO-D's target fuel savings of 50%. For complete descriptions of the technologies, see **Annex C**. These technologies included the following:

- Nonintrusive Load Monitoring (NILM) – A process to disaggregate appliance-level power information from a centralized sensor package located at the generator or panel that allows for accountability of devices consuming power, condition-based management, and inference of human activity from electrical activity.

- Deployable Metering and Monitoring System (DMMS) – A prototype monitoring suite that uses commercially available sensors to measure power values and other parameters of interest such as temperature, liquid level, and pressure to provide an updated view of utilities being used at a base camp and to allow local commanders to make energy informed decisions.

NILM, a technology reviewed by PM FSS, uses centralized sensors located at main power panels or generators paired with disaggregation algorithms to analyze electrical data and determine which loads are operational at which times and infer human activity from those loads. A NILM sensor package was installed at the BCIL in September 2013. Further demonstrations of the same equipment were held at Ft. Polk, LA in 2014. The NILM package could distinguish between mission critical loads, QoL loads, expendable loads, and wasteful loads. By understanding the behavior of various loads on the base camp, cost can be quantified, and mitigation steps can be taken to lower those costs. The demonstration at the BCIL showed a possible 14% power savings over a 48 h period by only taking freeze prevention measures in facilities with water pipes and not heating unoccupied shelters while the unit was offline. This equated to a 60 gal savings of diesel fuel over that period [38, p. 81].

DMMS, developed by the U.S. Army Corps of Engineers ERDC-CERL, has been demonstrated several times, including by the SLB-STO-D in 2015 [9]. Unlike the centralized electrical sensors of NILM, DMMS uses sensors located throughout the base camp that connect to an open architecture dashboard to facilitate informed decision making. Sensors can measure both supply and demand side power as well as fuel and temperature status.

While both systems have demonstrated a potential fuel savings by informing local decision makers about the costs of particular actions or equipment, their impact on resource consumption in that regard depends on altering human behavior. In this sense, both solutions are enablers of non-materiel solutions, such as the following:

- Limiting convenience loads (see **Section 3.1.1.5**)
- Reducing facility light usage (see **Section 3.1.1.6**)

Additionally, both systems provide the capability to determine actual power usage by downstream loads. This information could be used to influence generator layout and right-size loads to a generator's output and potentially decrease the number of generators necessary.

One simulation scenario was chosen to model this potential. The scenario was designed to provide an upper bound to power and fuel savings by matching loads to generators to maximize loading and minimize the number of generators. The SLB-STO-D simulation is based on an hourly time step with resource consumption values being an hourly average. The peak hourly average power consumption for each facility was used to size the generators. Since the simulator does not model the impacts of short term or transient spikes in power usage, such a generator layout in real life would likely lead to short term brown or blackouts as high-power equipment turned on and off and power usage spiked for short periods. Additionally, loads were not allocated in a geographically relevant manner, but rather to optimize loading. **Table 30** shows the number of generators used in the ORTB and the reduced number needed when sized for the loads experienced by the simulator. The simulation shows a potential upper bound of designing a generator layout based on the loads a camp is experiencing versus a method based on specification peak loads.

Table 30. Total Generators, ORTB vs. Load Optimized Layout

Base Camp	ORTB	Optimized	Δ
50 PAX Base Camp	6	4	-33.3%
300 PAX Base Camp	23*	10	-58.3%
1000 PAX Base Camp	73*	32	-56.2%

* Exclusive of generators that were always off during the simulation

Table 31 shows the results of the simulation across the different base camp sizes in the desert environment. The fuel changes seen are entirely attributable to a reduction in total generator hours to supply the same load.

Table 31. Mean Daily Camp Level Summary, Metering and Monitoring, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Metering and Monitoring	175	18.6%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
ORTB, Min. Gensets	215	0.0%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
TM 3-34.46, Min. Gensets	195	9.3%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Metering and Monitoring	668	35.9%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
ORTB, Min. Gensets	835	19.9%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
TM 3-34.46, Min. Gensets	780	25.1%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Metering and Monitoring	2215	34.4%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%
ORTB, Min. Gensets	2704	19.9%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%
TM 3-34.46, Min. Gensets	2517	25.4%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%

The ORTB generators are sized to handle the peak loads of each facility and connected in an operationally relevant and geographically constrained manner. Optimizing generator layout based on measured loads at the base camp without regard to these additional constraints showed savings of up to 18.6%, 35.9%, and 34.4% are achievable at the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps, respectively. These savings were similar across all three environments. While real life savings would likely be lower when factoring in geographic constraints and the need for some overhead to absorb short term spikes in power draw, the results demonstrate the potential cost of inefficient generator usage.

The savings seen are largely dependent on the inefficiencies in generator layout at the FY12 ORTB Base Camps. To isolate the impact of the generator sizing factor on the fuel cost, the simulation results can be compared against generator allocation methodologies where the geographic and operationally relevant constraints were eliminated (see **Section 3.1.2.1** for further analysis of these results). Sizing generators based on experienced loads showed a potential savings of 14.5–18.6% over a sizing method based on peak loads and an approximately 10% savings over generators sized according to *Technical Manual 3-34.46, Theater of Operations*

Electrical Systems across the three base camp sizes in the desert environment. This savings is entirely attributable to the sizing factors on which the number of generators depended.

The metering and monitoring of power and other usage factors at a base camp can lead to optimizations in equipment usage. These optimizations will vary in impact and largely depend on the particular camp at which they are employed. One key area these devices could affect is generator layout. Doctrinal methods of sizing and allocating loads of generators are necessarily conservative to be applicable across the spectrum of base camps. By having more information available about the local use and power draw of individual pieces of equipment, power distribution can be optimized to a particular camp, which can greatly increase the camp's fuel efficiency.

3.1.4.3 On-Base Vehicles

The FY12 ORTB Base Camps have many vehicles, which are generally used to transport materials, such as fuel and water, throughout the camp, as well as transporting goods and personnel across the camp. A HEMTT M978A4 Fuel Servicing Tanker Truck is used to refill the fuel tanks and a M1120A4 LHS with a HIPPO is used to refill potable water tanks. Using these vehicles to transport resources is a large consumer of fuel, so this section examines ways to reduce fuel consumption by vehicles.

The *On Camp Vehicles* functional area is the second largest consumer of fuel behind *Power Generation* in the desert and tropical environments and third behind *Shelter Heating and Cooling* in the temperate environment. Approximately half of this functional area is due to transporting fuel, water, and solid waste around the camp. Reducing the vehicle fuel consumption would help achieve the SLB-STO-D goal of a 50% reduction in fuel usage.

Four courses of action were investigated for their suitability in contributing to the SLB-STO-D's target fuel savings of 50%. These options included the following:

- Increased fuel tank size – Using existing, fielded equipment such as 1,000 gal fuel bladders and additional military fuel cans (jerry cans), increase the net tank size of key fuel consumers.
- Increased water tank size – Using existing, fielded equipment such as 3,000 gal collapsible, fabric tanks, increase the net source tank size of key potable water consumers.
- Change in TTP – A change in TTP to restrict the use of on-base vehicles solely to refilling fuel and water tanks.
- SCPL – A developmental, multipurpose, heavy-duty diesel engine oil that provides a reduction in fuel consumption, maintenance of component durability, multifunctional performance (e.g., engine, transmission, hydraulic systems), and a reduction in maintenance compared to existing engine oils.

Table 32 shows the fuel tanks across the three ORTB Base Camps and the frequency each is refilled. The tanks identified as candidates for replacement with larger bladders were those that have external fuel interfaces that could be collocated as well as the facilities that used jerry cans to supply fuel, such as the CK and wash racks.

Table 32. Fuel Tank Refill Frequency

		Quantity		
Equipment	Refill Frequency	50 PAX	300 PAX	1000 PAX
Radar Cluster Generator	4 times per day	1	1	2
CK	2 times per day	-	-	2
Large Capacity Field Heater, LCFH Type II	2 times per day	-	-	2
TQG	1-2 times per day	6	24	75
M7 Forward Maintenance Assembly	1 time per day	-	1	-
Wash Rack	Every other day	-	1	2
Food Sanitation Center	Every other day	-	-	2
Military Tactical Heater, MTH150	Every 4-5 days	8	33	111
Fuel-powered Lights	Every 5 days	-	-	8
Water Heater, WH-400	Every 7-9 days	-	4	20

Since the generators and Large Capacity Field Heaters both contain external fuel connections, they were connected to 1,000 gal fuel bladders that were added in geographically relevant locations that logically grouped three to four pieces of equipment per bladder. Generators located near the ECPs were not connected to fuel bladders, since SMEs noted that large fuel quantities would not be placed near the entrances in the field.

Each of the items that was fueled by military fuel cans (the CK, Food Sanitation Center, and wash rack) had the number of cans doubled. Items that did not have an external fuel connection, such as the M7 Forward Maintenance Assembly and fuel-powered lights, were not changed. The MTH150s, while having an external fuel connection, were not connected to larger bladders; they were unlikely to be able to be easily collocated around a larger bladder. The WH-400 water heaters were already connected to a 55-gal drum in the baseline camps. Following these changes, no fuel tank on the camp was visited more than once per day.

In addition to increasing fuel storage, the refill frequency of potable water tanks was investigated. The most frequently refilled tanks belonged to the shower facilities, which were refilled daily at the FY12 ORTB 300 PAX Base Camp and every other day at the FY12 ORTB 1000 PAX Base Camp. The potable water source tanks for the laundry facilities were only refilled every 2 to 3 days at the two base camps. Additional 3,000 gal collapsible, fabric water tanks were added to both the potable water source and the gray water output of the showers. This effectively doubled the input and output tanks.

Reducing Vehicle Usage is a TTP solution that restricts use of vehicles only to cases where it is necessary to refill and empty FWW tanks. Typically, vehicles are additionally used for delivering MREs, mail, transportation of Soldiers, and (in the case of forklifts) repositioning structures within the camp. In this TTP, these would be eliminated, likely necessitating human transport of smaller materials and eliminating the movement of larger systems. Exact measurements of the impact of this on QoL(O) are unfortunately not available, but it appears clear that this would have a negative impact, given the increase in workload manual movement of these materials would require. On the positive side, this solution can be implemented without any changes to technology present on a base camp and for as long or short a period as necessary.

At the 50 PAX base camp, vehicles are only used to refill and empty tanks; therefore, this option was not modeled at that base camp.

SCPL technologies are under development by TARDEC. A primary motivation for investigating this technology is to reduce logistical difficulties associated with using multiple lubricants for the variety of technologies and environments where base camps operate. The candidate technologies generally exhibit another beneficial effect: lower viscosity, which enables greater fuel efficiency through reduction in energy lost to friction and other imperfections of engine performance. SCPL technology in this simulation is modeled only in use for vehicles.

Table 33 shows the results of the simulations of increasing fuel and water tank sizes, reducing fuel usage, and implementing SCPL across the different base camp sizes in the desert environment.

Table 33. Mean Daily Camp Level Summary, Fuel and Water Bladders, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
50 PAX Camp										
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Fuel Tanks Only	211	1.9%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
SCPL	215	0.0%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
300 PAX Camp										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Fuel Tanks Only	1031	1.1%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
Fuel and Water Tanks	1028	1.3%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
Reduced Vehicle Usage	1014	2.7%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
SCPL	1041	0.1%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
1000 PAX Camp										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Fuel Tanks Only	3338	1.1%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%
Fuel and Water Tanks	3336	1.2%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%
Reduced Vehicle Usage	3289	2.6%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%
SCPL	3373	0.1%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%

Due to the FY12 ORTB 50 PAX Base Camp not having shower facilities, only the impact of adding fuel bladders was simulated at that camp size. Attaching the generators to fuel bladders showed a fuel savings of 1.8–2.4% across the three environments. While the percent savings varied, the whole gallons savings was between 4 and 5 gal per day.

Both the FY12 ORTB 300 PAX and 1000 PAX Base Camps showed a 1.1–1.2% fuel savings across the three environments after implementing fuel bladders. Implementing larger water tanks at the shower facilities at the FY12 ORTB 300 PAX Base Camp increased fuel savings by 0.2% across all three environments. Implementing the same increase at the FY12 ORTB 1000 PAX Base Camp showed a less than 0.1% increase in fuel savings. This lower savings is due to those tanks being refilled only every other day in the baseline scenario compared to daily at the FY12 ORTB 300 PAX Base Camp.

Reducing Vehicle Usage showed by far the greatest fuel savings, decreasing fuel usage by about 3% at both the FY12 ORTB 300 PAX and 1000 PAX Base camps. However, as discussed before, this is also the option that likely has the largest negative impact on QoL(O), reducing the likelihood that it would ever be implemented.

SCPL, by contrast, has the most model fuel savings: about 0.1% or less of total fuel usage. At the 50 PAX, for example, the percentage of fuel saved rounds to 0.0% over the course of a year. However, implementing SCPL has benefits outside of fuel savings, such as reducing the logistical burden of maintaining multiple lubricants. This would likely make SCPL the solution with the smallest logistical burden on the base camp out of all the options discussed here.

While the camp-level impact of the changes appeared small, implementing the increase in tank sizes reduced the fuel consumption in the *On Camp Vehicles* functional area by 23.7–24.4% and 22.0–23.2% at the FY12 ORTB 300 PAX and FY12 ORTB 1000 PAX, respectively. This reduction comes at minimal expense, mostly in planning and laying out a base camp to accommodate the increased tank sizes. The TTP solution of Reduce Vehicle Usage fared even better, reducing fuel consumption in the *On Camp Vehicles* functional area by 46.3–47.8% in the FY12 ORTB 300 PAX and FY12 ORTB 1000 PAX, respectively. However, as noted above, this TTP solution would likely have a negative impact on QoL(O). SCPL for vehicles had the most modest impact on fuel savings in the *On Camp Vehicles* functional area of 2.0% savings across all FY12 ORTB Base Camp sizes.

Even after the decreases considered here, the *On Camp Vehicles* functional area still remains one of the highest consumers of fuel on the base camp, indicating that it could be a fruitful target for further reductions. Note, however, that since this functional area only represents about 2% of fuel usage at the FY12 ORTB 50 PAX camp and about 5% at the FY12 ORTB 300 PAX and 1000 PAX camps, the overall fuel usages from the functional area is capped at relatively modest levels.

3.2 Potable Water Reduction

One of the SLB-STO-D's objectives is to reduce bulk potable water resupply by 75%. There are three primary methods for reducing potable water resupply to the base camp: produce bulk potable water onsite, reduce the demand for potable water, and reuse or recycle waste water in place of fresh potable water. The last two of these methods have an additional benefit of decreasing the amount of waste water for disposal. The first two options are discussed in this section, while the possibility of reusing or recycling waste water is discussed in **Section 3.3.3**.

Table 34 shows the breakdown of water consumption at the FY12 ORTB base camps by camp level function. For the SLB-STO-D to meet its potable water resupply reduction objective of 75% through reduced demand, the *Provide Means to Maintain Personal Hygiene* functional area (i.e., shower facilities and hand wash stations) must be addressed at all base camps. At the FY12 ORTB 50 PAX Base Camp, this functional area accounts for 26% of potable water usage. At both the FY12 ORTB 300 PAX and 1000 PAX Base Camps it accounts for over 56% of all potable water usage. In addition, the *Provide Latrine Services* functional area, which consumes over 26% of all potable water at the two larger camps, will have to be addressed as well. This is discussed with the potential for latrine systems to reduce waste in **Section 3.3.1**. At the FY12

ORTB 50 PAX Base Camp, the *Provide Means to Clean Clothes* functional area will also need to be addressed.

Table 34. Mean Daily Potable Water Breakdown by Camp Level Function

	50 PAX		300 PAX		1000 PAX	
Functional Area	gal	%	gal	%	gal	%
Provide Means to Maintain Personal Hygiene	27	36.0%	4961	56.9%	18444	58.9%
Provide Latrine Services	0	0.0%	2321	26.6%	8855	28.3%
Provide Means to Clean Clothes	46	61.3%	751	8.6%	2712	8.7%
Provide Subsistence	0	0.0%	370	4.2%	654	2.1%
Provide Access to Maintenance Repair	0	0.0%	312	3.6%	624	2.0%
Provide Access to Medical & Health Services	3	4.0%	8	0.1%	17	0.1%
TOTAL	75	100.0%	8723	100.0%	31305	100.0%

Note: Values may not sum to total due to rounding

Alternatively, instead of reducing demand, potable water could be produced onsite, which would result in a resupply reduction. While the SLB-STO-D use case does not include having a water source such as a lake or well nearby, the potential impact of water filtration will be discussed since other base camps may have access to such a water source. Further, the ability to produce potable water from moisture content in the air, which could apply to any base camp, will be discussed.

Figure 13 depicts a summary of the potable water resupply reduction options reviewed in this section. Many of the potential solutions for potable water resupply reduction require trade-offs between QoL(O), fuel consumption, and potable water reduction. These trade-offs are discussed in this section.

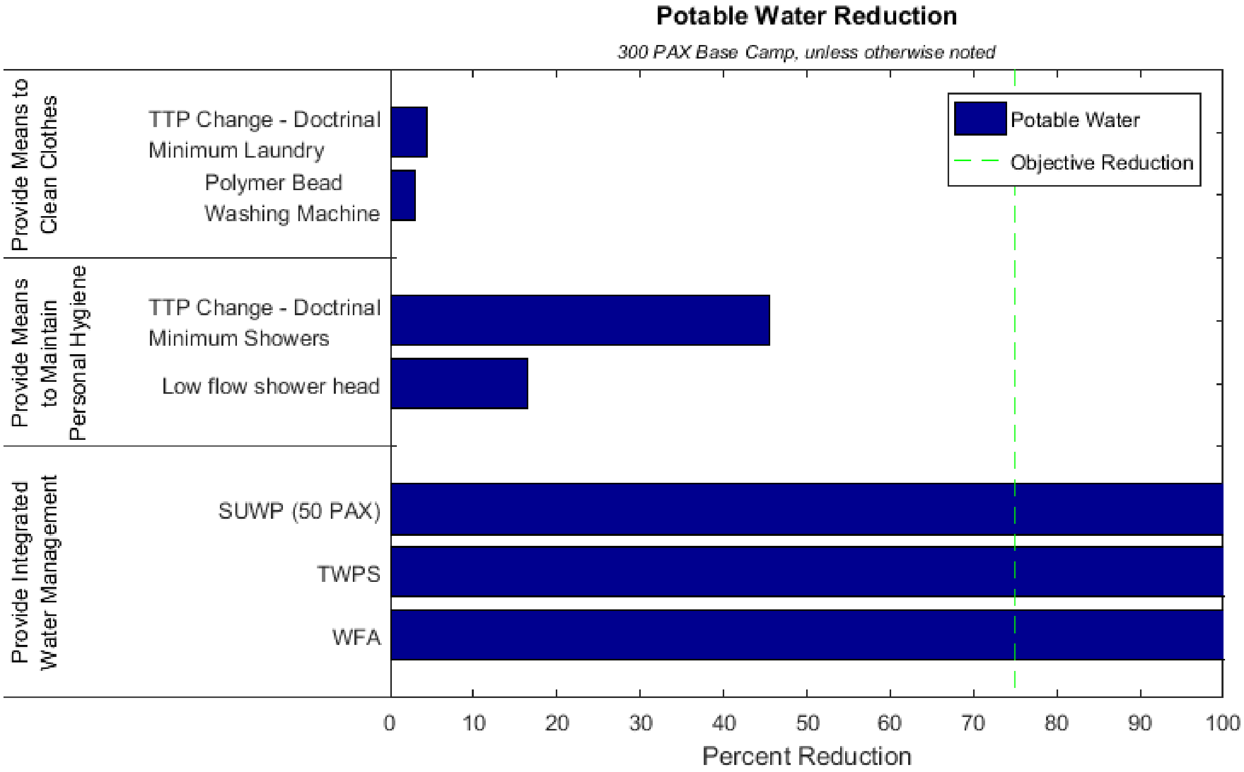

Figure 13. Potable Water Reduction

3.2.1 Provide Means to Clean Clothing

Providing the means to clean clothes is one of the many functions a base camp must fulfill. The equipment that serves this function at the FY12 ORTB Base Camps is different for each of the base camp sizes. All of these pieces of equipment produce waste water while consuming potable water and small amounts of power. Options to reduce resource usage include providing less frequent laundry service and using more efficient equipment to clean clothes.

At the FY12 ORTB 50 PAX Base Camp, laundry is done individually in a hand wash bucket with the waste water disposed of onsite. At the FY12 ORTB 300 PAX Base Camp, laundry is also done individually by the Soldiers, but is done in 20-lb commercial washers. At the FY12 ORTB 1000 PAX Base Camp, laundry turn-in service is provided using Expeditionary Containerized Batch Laundry Systems (ECBLS) containing 50-lb washing machines (clothing for approximately three Soldiers is washed per load).

At the FY12 ORTB 50 PAX Base Camp, the *Provide Means to Clean Clothing* functional area represents approximately 61% of the total potable water usage. At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, the same functional area represents approximately 9% of potable water consumption and 9% of waste water production. The large disparity in proportion of resource usage between camp sizes is due to the lack of showers, latrines with running water, and kitchens at the FY12 ORTB 50 PAX Base Camp, making laundry water usage a larger percentage overall. Even at the FY12 ORTB 300 PAX and 1000 PAX Base Camps, the *Provide Means to Clean Clothing* functional area represents the third largest consumer of potable water and producer of waste water, indicating that it could be a fruitful area to focus on.

One technology and one change to TTP were investigated for their suitability in contributing to the SLB-STO-D target potable water savings of 75% and waste water savings of 50%. For complete descriptions of the technologies, see **Annex C**. These options included the following:

- Change in TTP – A change in TTP to modify the amount of laundry that each soldier is allowed to do per week.
- Polymer bead washing machine – A commercially available washing machine that uses less water than a traditional washing machine through the use of nylon polymer beads to absorb stains.

The first option is to reduce laundry frequency, thereby reducing the total volume of laundry cleaned and the resources needed. The FY12 ORTB specifies an allowance of 17 lb per person per week of laundry at the 300 PAX and 1000 PAX base camps. For the larger camps, the 17-lb allowance approximately matches the maximum each soldier is authorized to turn in each, which is equivalent to three battle dress uniforms [39]. Doctrinal minimum is 7.2 lb per person per week [40]. At the FY12 ORTB 50 PAX Base Camp, each soldier is given 5 gal of water a week to hand wash laundry and is allowed to wash as much laundry as they prefer with that amount of water.

The amount of laundry was varied across the following options: baseline, ½ of baseline, ⅓ of baseline, ¼ of baseline, and no laundry at all. Note that all but the first two options listed are below doctrinal minimums, so are not considered potential options to meet the SLB-STO-D objective resource reductions. However, they are included here to illustrate the potential savings of a short-term variation in laundry frequency.

The polymer bead washing machine is a commercial item being reviewed by NSRDEC that uses polymer beads to reduce water consumption, slightly increasing power consumption as a side effect. The washing machine has been neither ruggedized for military use nor tested completely. It is sized identically to the commercial washer included in the ECBLS, which makes it simple to integrate into the 1000 PAX base camp by swapping out one piece of equipment for another. Using the polymer bead washing machine at the 300 PAX base camp would mean that multiple Soldiers would need to consolidate their garments to do one load of their weekly laundry, which would be a change in camp function. As a result, this technology was only simulated at the 1000 PAX base camp.

Table 35 shows the results of the simulation of the resource-saving options across the different base camp sizes in the desert environment.

Table 35. Mean Daily Camp Level Summary, Provide Means to Clean Clothes, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
½ Baseline Laundry	215	0.0%	1007	0.0%	52	30.7%	27	0.0%	266	0.0%
⅓ Baseline Laundry	215	0.0%	1007	0.0%	45	40.0%	27	0.0%	266	0.0%
¼ Baseline Laundry	215	0.0%	1007	0.0%	41	45.3%	27	0.0%	266	0.0%
No Laundry	215	0.0%	1007	0.0%	29	61.3%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
½ Baseline Laundry	1036	0.6%	5007	2.0%	8348	4.3%	8154	4.4%	2870	0.0%
⅓ Baseline Laundry	1034	0.8%	4973	2.6%	8223	5.7%	8029	5.9%	2870	0.0%
¼ Baseline Laundry	1033	0.9%	4956	3.0%	8160	6.5%	7966	6.6%	2870	0.0%
No Laundry	1029	1.3%	4902	4.0%	7973	8.6%	7778	8.8%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
½ Baseline Laundry	3355	0.6%	17220	2.1%	29949	4.3%	29797	4.4%	10672	0.0%
⅓ Baseline Laundry	3349	0.8%	17100	2.7%	29497	5.8%	29345	5.8%	10672	0.0%
¼ Baseline Laundry	3344	1.0%	17040	3.1%	29271	6.5%	29119	6.5%	10672	0.0%
No Laundry	3329	1.4%	16764	4.6%	28593	8.7%	28441	8.7%	10672	0.0%
Polymer bead washer	3378	-0.1%	17624	-0.3%	30395	2.9%	30243	2.9%	10672	0.0%

Note: The FY12 ORTB specifies a laundry allowance of 5 gal of water per week at the 50 PAX base camp and 17 lb per soldier per week at the 300 PAX and 1000 PAX base camps.

Table 35 shows the dramatic effect that reducing laundry frequency can have on water usage at the 50 PAX base camp, an effect that increases with each reduction in laundry frequency. While the percent savings are considerable, the total gallons saved is less than 50 gal per day even when laundry is completely eliminated. Laundry frequency has no impact on any resource flow besides potable water usage because the hand wash laundry bucket consumes no power or fuel and the waste water it generates is assumed to be disposed of onsite.

In contrast, at the 300 PAX base camp, laundry influences waste water, fuel, and power usage as well as potable water consumption. Note that even the most draconian option of eliminating laundry altogether at the 300 PAX base camp elicits less than 10% savings in water usage and waste water generation. This is due to the fact that the laundry facilities are a much smaller proportion of overall water use at the larger base camps.

The impact of laundry frequency modifications on the 1000 PAX base camp is highly similar to the 300 PAX base camp. The 1000 PAX base camp differs in that it includes analysis of the polymer bead washer, which produces savings of approximately 2.9% in potable water consumption and waste water production while prompting an increase of 0.1% in fuel usage. Note that the water savings associated with the polymer bead washer are smaller than those associated with even the mildest TTP modification of ½ baseline every week. However, the polymer bead washer is assumed to have no impact on QoL(O), whereas the TTP modifications would negatively impact QoL(O).

Laundry systems contribute to a moderate amount of potable water usage at the FY12 ORTB Base Camps, which prompted consideration of both materiel and TTP changes to reduce consumption. Reduction in laundry frequency produced substantial potable water savings at the 50 PAX base camp of 30.7–61.3%. Potable water and waste water savings at the 300 PAX and 1000 PAX base camps were more moderate at 4.3–8.7% for laundry reduction, with additional fuel savings of about 1%. The polymer bead washer had smaller potable and waste water savings of about 2.9% with fuel increases of less than 1%. The SLB-STO-D will consider the TTP solution of the doctrinal minimum amount of laundry done per week (approximately ½ baseline laundry) as well as the implementation of polymer bead washers to achieve the objective resource reductions.

3.2.2 Provide Means to Maintain Personal Hygiene

The *Provide Means to Maintain Personal Hygiene* functional area includes the base camps' shower facilities. The showers produce large amounts of waste water and consume large amounts of potable water and small amounts of power and fuel. Resource reductions can be brought about by either reducing usage or improving shower technology to consume less water. Note that the FY12 ORTB 50 PAX Base Camp does not have showers and therefore is not discussed in this section.

Showers are a very important consumer of water, representing 51.1–53.0% of potable water usage and 52.3–53.3% of waste water production at the FY12 ORTB 300 PAX and 1000 PAX base camps. Consequentially, to meet the SLB-STO-D's resource savings of 75% for potable water and 50% for waste water, it is essential to address the showers. Additionally, showers are an important driver of QoL; shower frequency and shower duration are responsible for over 2.5 and 1.3 QoL(O) points respectively. Shower frequency is more important than any QoL attribute aside from the need to wear body armor and the type of bed available [20].

One technology and one change to TTP were investigated for their suitability in contributing to the SLB-STO-D's target for potable water savings of 75% and waste water savings of 50%. For complete descriptions of the technologies, see **Annex C**. These options included the following:

- Change in TTP – A change in TTP to modify the shower duration and frequency.

- Low-flow showerheads – A commercially available low-flow showerhead that decreases the flow rate of water while showering.

Six shower duration scenarios were explored: no showers, the doctrinal minimum number and length of showers, 2 min showers daily, 5 min showers daily, 10 min showers daily (baseline), and 15 min showers daily. Doctrinal minimum is one 7-min shower [39] and one "field expedient" (approximately 45 s) shower weekly [40]. Note that the complete elimination of showers is below the doctrinal minimum. Consequently, it is not considered a potential option to meet the SLB-STO-D objective resource reductions. However, it is included here to illustrate the potential savings of a short-term variation in frequency.

The low-flow showerheads are commercially available. For simulation purposes, they are integrated into the baseline shower facilities, the Expeditionary Shower System. The showerheads reduce the water necessary for showers of any length. The baseline showerhead uses 1.43 gal of potable water per shower min, while the proposed low-flow showerhead uses 0.97 gal per min, a 32% reduction in water demand [41]. Every gallon of potable water used by the shower is assumed to correspond directly to a gallon of waste water produced. Common concerns about low-flow showerheads are that they clean less thoroughly and that users might take longer showers that partially negate the effect of the low-flow showerhead. The showerheads were demonstrated in a SLB-STO-D demonstration at the BCIL to investigate their performance at eliminating dirt and oil, which determined that the low-flow showerhead selected did a better job of cleaning than the baseline showerhead [41]. Additionally, an analysis of showerhead usage at the BCIL indicates that Soldiers using a low-flow showerhead actually take slightly shorter showers than those using a baseline showerhead [42]. This analysis relies on a limited amount of data collected at a training base camp. While more data would be required to definitely assess that low-flow showerheads decrease shower times across a range of conditions, this analysis supports that, at the very least, the implementation of low-flow showerheads did not result in longer showers that would offset the water savings. This analysis combined with performance testing indicate that the low-flow showerheads would perform as desired under actual implementation.

Table 36 shows the results for a 300 PAX and 1000 PAX base camp in the desert environment (other environments show similar patterns). **Figure 14** displays potable water savings for each value of shower length, as well as potable water savings associated with a low-flow showerhead used for 10 min showers.

Table 36. Mean Daily Camp Level Summary, Provide Means to Maintain Personal Hygiene, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
300 PAX Camp										
No Showers	1022	1.9%	5082	0.5%	4262	51.1%	4067	52.3%	2870	0.0%
Doctrinal minimum*	1024	1.7%	5085	0.5%	4755	45.5%	4560	46.5%	2870	0.0%
2 min daily showers	1025	1.6%	5087	0.4%	5154	40.9%	4960	41.9%	2870	0.0%
5 min daily showers	1031	1.1%	5095	0.3%	6493	25.6%	6298	26.2%	2870	0.0%
FY12 Baseline†	1042	-	5108	-	8723	-	8529	-	2870	-
15 min daily showers	1050	-0.8%	5122	-0.3%	10954	-25.6%	10760	-26.2%	2870	0.0%
Low-flow showerheads	1034	0.8%	5100	0.2%	7288	16.5%	7094	16.8%	2870	0.0%
1000 PAX Camp										
No Showers	3308	2.0%	17482	0.6%	14717	53.0%	14565	53.3%	10672	0.0%
Doctrinal minimum*	3315	1.8%	17493	0.5%	16550	47.1%	16398	47.4%	10672	0.0%
2 min daily showers	3321	1.6%	17502	0.4%	18035	42.4%	17883	42.6%	10672	0.0%
5 min daily showers	3341	1.0%	17531	0.3%	23011	26.5%	22859	26.6%	10672	0.0%
FY12 Baseline†	3376	-	17580	-	31305	-	31153	-	10672	-
15 min daily showers	3419	-1.3%	17629	-0.3%	39599	-26.5%	39447	-26.6%	10672	0.0%
Low-flow showerheads	3354	0.7%	17549	0.2%	25969	17.1%	25817	17.1%	10672	0.0%

* One 7 min shower and one "field expedient" (approximately 45 s) shower per week

† 10 min daily showers

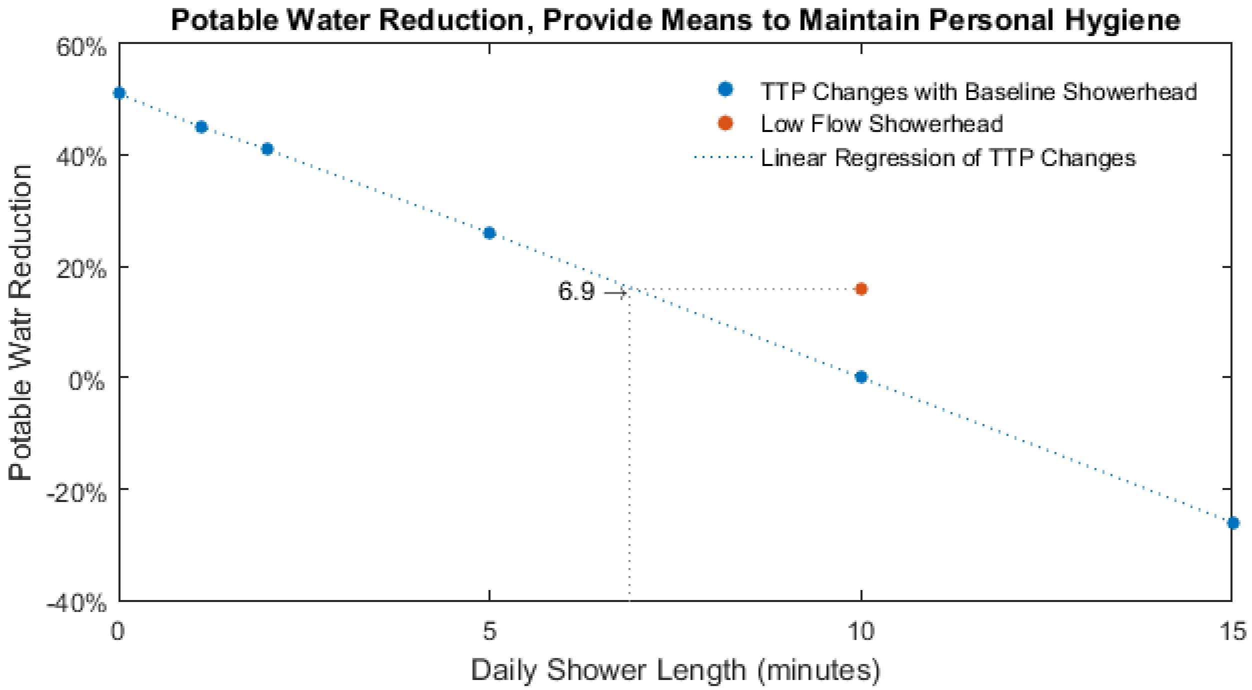

Figure 14. Potable Water Savings from Shower Technologies, 300 PAX Base Camp

The magnitude of the impact of shower lengths on potable water consumption is quite large. Going to doctrinal minimums saves 46–47% of overall potable water usage, while increasing shower lengths to 15 min results in an increase in water usage of 26–27%. The relationship between shower length and potable water reduction is linear; the savings for any shower length can be interpolated from the lengths chosen. The impact on fuel usage is comparatively small, from about a 0.8% increase when extending shower times to a 2.0% savings when eliminating showers entirely. This fuel consumption variation results from variation in pumping, water heating, and vehicle fuel usage to refill tanks.

Reducing showers to the doctrinal minimum shower lengths and frequencies would bring about a 1.4 points reduction in QoL(O) at 300 PAX and 1000 PAX base camps. On the other hand, increasing shower lengths to 15 min daily would increase QoL(O) by less than 0.1 points at the 300 PAX and 1000 PAX base camps [20].

When a low-flow showerhead is added to the base camp and a shower length of 10 min per person per day is implemented, it results in potable waters savings of approximately 16% and waste water savings of approximately 17%. The fuel and power savings are positive but quite small. As shown in **Figure 14**, the savings associated with low-flow showerhead usage is approximately equal to the predicted savings associated with 6.9 min showers. This corresponds closely with the 32% reduction in potable water usage that the low-flow showerhead provides compared to the baseline. This indicates that this technology allows for substantial water savings at no expected impact on QoL(O), a strong benefit.

The consumption of potable water and production of waste water by the shower facilities must be addressed to meet the SLB-STO-D's goals for resource savings. Changing shower length and frequency, a TTP modification, as well as improved technologies in the form of low-flow showerheads are both options to address this challenge. Shower length modifications allow for substantial resource savings in potable water and waste water production, though they negatively impact QoL(O). Low-flow showerheads have more moderate savings, but have no impact on QoL(O). Going forward, the main options that will be considered are the doctrinal minimum of shower frequency as well as 15 min daily showers, an option that increases QoL. Additionally, the low-flow showerheads will be considered as a materiel option.

3.2.3 Provide Integrated Water Management

Sections 3.2.1 and **3.2.2** discussed potable water demand reduction through the lens of reducing potable water use in a particular functional area. However, this is not the only way to reduce the amount of potable water transported to the base camp. It is also possible to use water available onsite, either present in the air as humidity or in liquid form such as a lake or well. These sources are discussed in **Sections 3.2.3.2** and **3.2.3.3**, respectively. Using onsite water can reduce the amount of potable water that needs to be trucked to base camps without requiring changes in equipment sets or TTPs specific to any functional area. However, to ensure sanitary requirements are met, water quality monitoring tools are required. Specifically, in the case where water is purified or generated onsite in large quantities, water quality must be checked frequently and with a high degree of accuracy. Technologies for ensuring the quality of water are discussed in **Section 3.2.3.1**.

3.2.3.1 Water Quality Monitoring

Water quality monitoring denotes the capability to confirm that a bulk unit of water meets Army water quality standards. Two areas are of primary concern: the raw water source and the product water source. Raw source water is source water found at the surface (e.g., lakes, rivers, and ponds) or ground water (e.g., underground streams and wells). Product water is the water produced onsite through different water treatment methods [43]. The goal of the SLB-STO-D is to reduce bulk potable water resupply by 75%. While water quality monitoring technologies are capable of monitoring both raw and product water, their contribution to the SLB-STO-D goals is based on their ability to monitor product water from water systems that directly reduce water resupply.

The capability of water quality monitoring does not directly reduce potable water usage; however, it does provide data on the quality and potability of water and enables the certification of bulk water. It also gives an indication of the health of the water system and how well the system is processing the product water. Each of the water quality monitoring technologies monitors or senses certain chemical and biological aspects of water. The water quality monitoring technologies discussed in this section not only enable the safe consumption of bulk potable water brought in by convoy, but also mitigate risks associate with gray water recycling (see **Section 3.3.3.1**), waste water treatment (see **Section 3.3.3.2**), and water purification (see **Section 3.3.3.3**). This capability of monitoring the water quality of the water systems will have a positive indirect effect on the SLB-STO-D's goals.

Three technologies were investigated for their suitability to contribute to the SLB-STO-D program objectives. For a complete description of these technologies, see **Annex C**. These technologies included the following:

- SafePort – A prototype portable water analysis system that uses microfluidic chips to allow for rapid chemical analysis in the field by Soldiers with minimal technical background.
- Microfluidic Sensors for In-line Water Monitoring – A prototype inline water monitoring kit intended to replace the Water Quality Analysis Set: Purification (WQAS-P) that uses microfluidic sensors to transmit monitoring data to a smart phone or other device.
- Handheld Toxin and Pathogen Detector – A prototype pathogen detection device consisting of a cellphone, detection devices, and sampling titrators that can detect common contaminants of gray water recycling processes.

The DoD has specified Military Field Water Standards for long-term use and considers the consumption of water that does not meet these standards [44] a significant operational risk. Additionally, Army Public Health Command provides guidance on water characteristics for different classifications of source waters to include ground water, surface water, and treated waste water [45].

The currently-fielded water quality testing kit, the WQAS-P, is intended to be operated by a water treatment specialist (MOS 92W) [46]. Other water sampling and bacteriological analysis requires a Preventative Medicine Specialist (MOS 68S) [47]. Notably, current Army standards require that preventative medicine personnel certify that the quality of recycled gray water for shower use meets specified standards [48]. Specialized Soldiers are in limited supply, especially at smaller base camps, leading to long sampling intervals and increased risks.

Enhancements to water quality monitoring technologies aim to mitigate risk by making water quality monitoring portable, instantaneous, and easier to be performed by Soldiers without a technical background. SafePort, developed by ERDC-CERL, consists of a reusable hardware unit that accepts interchangeable microfluidic chips that can be chosen by the end user. These chips allow for the rapid detection and quantification of chemical and toxic contaminants [49]. Microfluidic Sensors for In-line Water Monitoring, developed by TARDEC, consists of a suite of sensors to provide quality assurance information and enable the performance optimization of water treatment equipment. The system was demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA in July of 2015. The Handheld Toxin and Pathogen Detector, also developed by TARDEC, allows for pathogen detection in less than an hour, compared to the current 24 h incubation period. The system was demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA in June of 2016.

Since the power draw, water consumed, and waste created by these systems is almost negligible, they were not modeled for simulation purposes. However, water quality monitoring plays a vital role in the enabling of many water technologies that are key to the SLB-STO-D meeting its objective resource reductions.

3.2.3.2 Water from Other Sources

Potable water can be created at or near a contingency base camp, which decreases (or eliminates) the need to transport bulk potable water by convoy and thereby decreases soldier threat hours spent outside the wire. When a bulk water source is available, such as a lake or well, water purification can be used to sanitize the water to ensure the health/safety of personnel (see **Section 3.2.3.3**). When a bulk water source is not available, other sources may be tapped to generate water. Notably, water can be condensed from the air to provide a safe means of producing potable water when other options are limited.

At the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps, respectively, 75, 8,723 and 31,305 gal per day of bulk potable water are consumed[8] on the base camp. The SLB-STO-D goal is to reduce the bulk potable water resupply requirement by 75%. One option to reduce the resupply requirement is to generate potable water onsite. The tradeoff between onsite potable water production and the fuel necessary to accomplish that production is examined below.

One technology was investigated for its suitability in contributing to the SLB-STO-D target potable water savings of 75%. For a complete description of the technology, see **Annex C**. This technology was the following:

- Water from Air (WFA) – A prototype system that utilizes a unique solid desiccant wheel technology to draw and condense water out of the air over the entire military climatic operating range.

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[8] The SLB-STO-D objectives do not include potable water required for hydration (i.e., drinking water).

The WFA technology is sponsored by TARDEC. The WFA technology has been demonstrated several times, including in 2015 by the SLB-STO-D [10]. The SLB-STO-D analyzed data collected during 2015 climatic chamber testing to create an empirical model of the WFA [50]. This analysis found that for the limited number of data points available there was a high correlation between water production and relative humidity. While an adequate model for the purposes of SLB-STO-D was created using only relative humidity as a weather parameter, the model is entirely empirically-based and not based on the physics that drive the WFA processes. The system may not entirely operate in a theoretically predictable way due to some characteristics of the system's design, which may explain the unexpected correlation to relative humidity over the theoretically predicted temperature and absolute humidity. New data sources could lead to further refinement of the model.

Discussions with an SME from TARDEC concluded that the empirical model developed by the SLB-STO-D model adequately represented the system’s capabilities for the purposes of the SLB-STO-D effort, given the available data. The SME further noted that the SLB-STO-D model would predict lower water production in the desert environment and higher water production in the temperate environment, compared to what would be found with a strictly physics-based model. This difference in predicted water output is due to not directly taking temperature into account. The SLB-STO-D WFA model will equate the performance in the two environments when the relative humidity is the same, but a physics-based model would show the desert should be better than the temperate for the same temperature and humidity.

A single integration scenario was chosen for simulation. This scenario involved placing enough WFA units to generate 100% of the camp’s bulk potable water. Since the WFA is powered using an internal generator, the units could be placed anywhere on the camp without regard to integrating with other systems. While a single integration scenario was chosen, the WFA’s dependence on the environment resulted in significantly different system counts and usage schedules across the three environments. **Table 37** shows the system counts across the three base camp sizes and environments. The usage schedules were chosen to coincide with the most ideal operating hours based on water production in each environment. The schedule of the units was varied to target 100% potable water production.

Table 37. System Counts, Water from Other Sources

Base Camp	Desert	Temperate	Tropical
FY12 ORTB 50 PAX Camp	1	1	1
FY12 ORTB 300 PAX Camp	24	24	20
FY12 ORTB 1000 PAX Camp	80	84	72

Table 38 shows the results of the simulation of the WFA technology across the different base camp sizes and across the different environments. Since the WFA systems are sized to produce at least 100% of the potable water required on the base camp, the overall result is a slight negative potable water consumption (i.e., net production). This overproduction was minimized by varying the usage schedules of the WFA systems. Due to the use of a single WFA system on the 50 PAX Base Camp and the simulator having an hourly time step, the overproduction was more significant than at the larger camps.

Table 38. Mean Daily Camp Level Summary, Water from Other Sources

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
Desert Environment										
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
WFA	234	-8.8%	1007	0.0%	-5	106.7%	27	0.0%	266	0.0%
Temperate Environment										
FY12 Baseline	219	-	661	-	75	-	27	-	266	-
WFA	237	-8.2%	661	0.0%	-13	117.3%	27	0.0%	266	0.0%
Tropical Environment										
FY12 Baseline	212	-	951	-	75	-	27	-	266	-
WFA	230	-8.5%	951	0.0%	-22	129.3%	27	0.0%	266	0.0%
					300 PAX Camp					
Desert Environment										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
WFA	3179	-205.1%	5108	0.0%	-57	100.7%	8529	0.0%	2870	0.0%
Temperate Environment										
FY12 Baseline	1096	-	4091	-	8723	-	8529	-	2870	-
WFA	2794	-154.9%	4091	0.0%	-42	100.5%	8529	0.0%	2870	0.0%
Tropical Environment										
FY12 Baseline	1023	-	4806	-	8723	-	8529	-	2870	-
WFA	2631	-157.2%	4806	0.0%	-32	100.4%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
Desert Environment										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
WFA	11095	-228.6%	17580	0.0%	-25	100.1%	31153	0.0%	10672	0.0%
Temperate Environment										
FY12 Baseline	3654	-	14751	-	31305	-	31153 -		10672	-
WFA	9743	-166.6%	14751	0.0%	-72	100.2%	31153	0.0%	10672	0.0%
Tropical Environment										
FY12 Baseline	3301	-	16463	-	31305	-	31153	-	10672	-
WFA	9062	-174.5%	16463	0.0%	-64	100.2%	31153	0.0%	10672	0.0%

Based on the results, implementing WFA at a small base camp (e.g., FY12 ORTB 50 PAX Base Camp) requires little additional fuel. The WFA technology met the 50 PAX camp's bulk potable water needs with a fuel cost of less than 9% across all environments. This fuel cost was mostly attributable to direct consumption by the WFA system, with a small additional cost in vehicle fuel to transport fuel to the system. This production was achieved with a single unit running only 4 to 5 h per day. Moreover, the FY12 ORTB 50 PAX Base Camp has a significantly lower level of service than the larger base camps, utilizing burn-out latrines and having no shower or laundry facilities.

However, the scenario chosen is unlikely to be realistic at a base camp with a similar equipment set and level of service as the FY12 ORTB 300 PAX and 1000 PAX Base Camps, where the fuel usage increased by a minimum 154.9%. Both camps have full-service latrines, showers, and laundry. It is likely that at any base camp of this size that is generating water using WFA would take extra measures to reduce the amount of potable water being used. These measures may include TTP changes (e.g., decreased shower times or laundry) or materiel changes (e.g., water saving measures or recycling systems). **Section 5.2** discusses the impact of implementing WFA on a base camp with other water saving measures in place.

Fuel consumption varied considerably by environment. This was largely attributable to the variation in humidity levels across the three climates.

Figure 15 shows a histogram of relative humidity across the three environments. As shown, the desert environment is generally a low humidity environment and the tropical environment is generally high humidity. The temperate environment is more variable. On the basis of a whole gallon of fuel, the tropical environment proved to be the least costly environment to operate the WFA, followed by the temperate environment, and finally the desert. This correlates with the relative humidity of each climate.

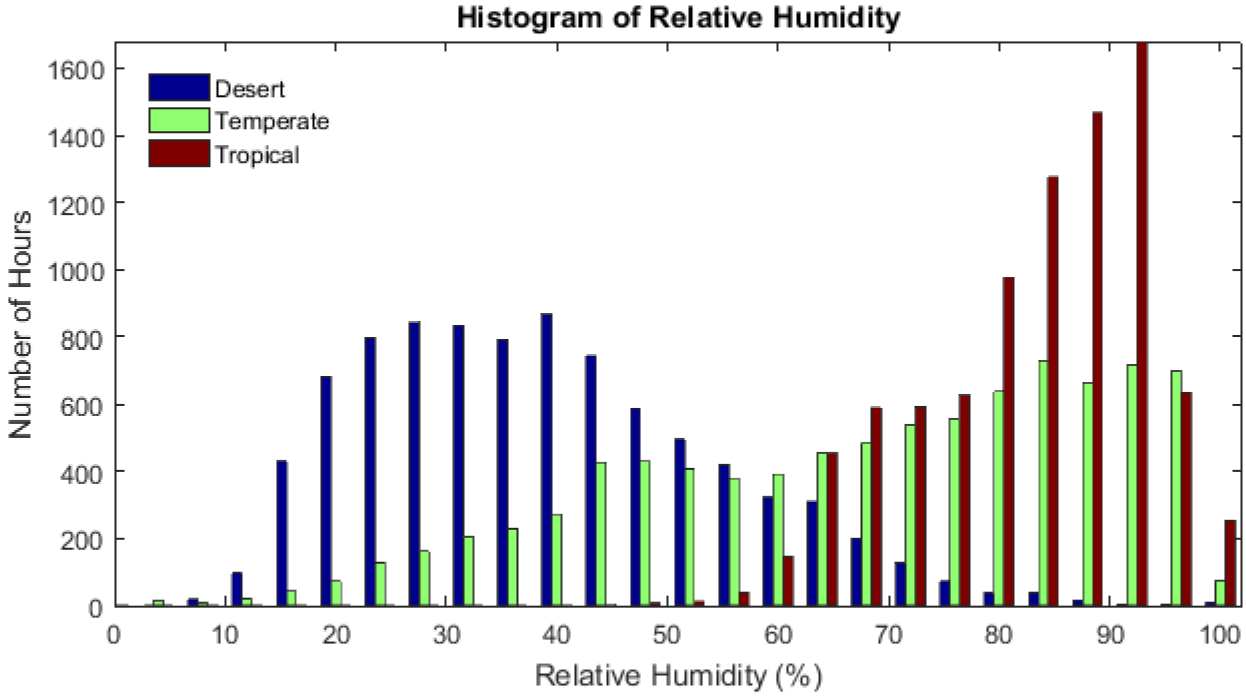

Figure 15. Histogram of Relative Humidity

Although more systems are required to be run for longer hours in the temperate environment, the fuel increase in the temperate environment was found to be significantly less than in the desert environment and only marginally more than in the tropical environment. This is due to the WFA's freeze protection feature, which shuts down the system when the dew point falls below 20 °F. Therefore, the net hours of operation in the temperate environment is less than in the desert.

This freeze protection capability has an additional implication; water production in the temperate environment showed much more seasonal variation than in the other two climates. The WFA system counts and hours of operation were designed so that that the daily average water production over the year was enough to meet the daily average water consumption. **Figure 16** shows the water production of the WFA units at the 300 PAX Base Camp by month, along with the bulk potable water consumed by the FY12 ORTB 300 PAX Base Camp for that month. As shown, water production in the tropical environment was very consistent for the entire year. Water production in the desert was fairly consistent, with peak production occurring in the winter months. While production dipped below the requirement in the summer, a combination of storing excess water during the more productive times and increasing the number of hours the existing systems were running during the less productive times would likely make up the deficit.

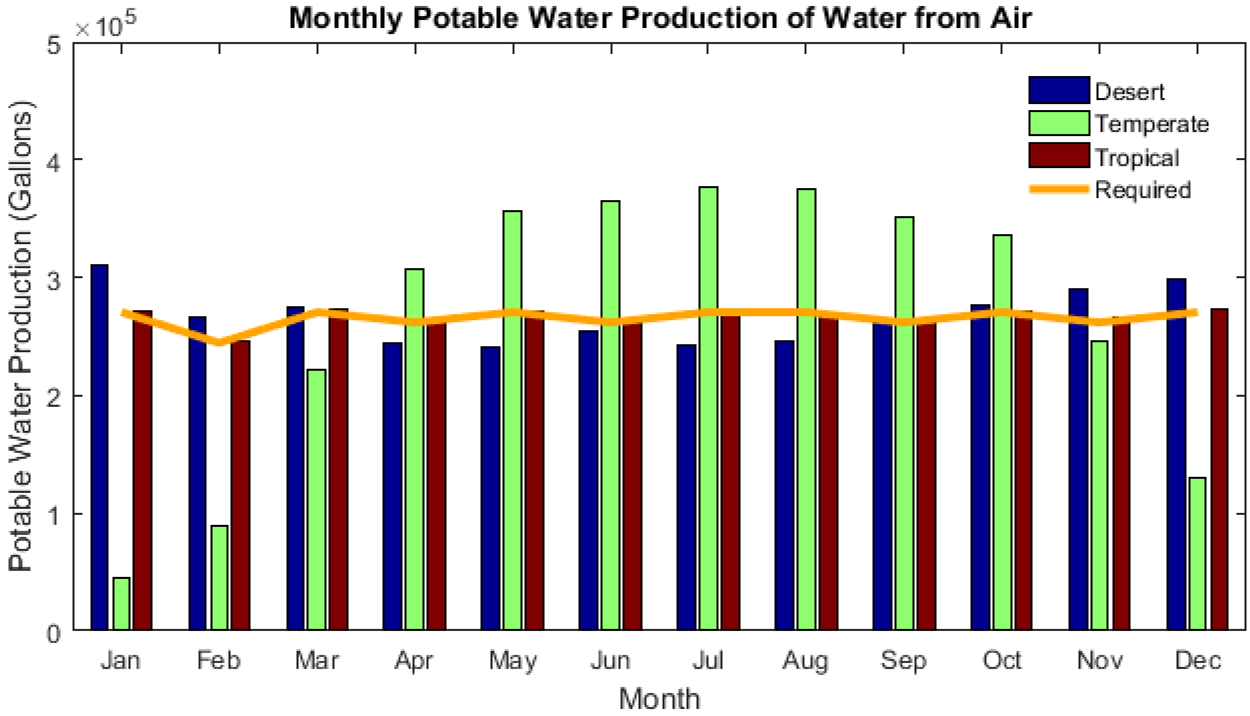

Figure 16. Potable Water Production of WFA by Month

In the temperate environment, however, water production was significantly less than required in the winter months. This is due to the large number of hours below the freeze protection threshold of the WFA. This deficit is too large to meet using the existing number of units. To survive the winter with only water produced from WFA systems, significant changes to reduce potable water demand at the base camp would need to be made or a large increase in the number of WFA systems would be required.

The usage schedule of the WFA was defined to operate the system during the best-case hours in each environment. While these hours could be calculated from any historical weather source, to test the sensitivity of the simulation results to the usage schedule chosen, simulations were run operating the WFA at the worst-case hours. **Table 39** shows the efficiency of the WFA system (gallons of water produced per gallon of fuel consumed) at the 300 PAX Base Camp under both usage schedules.

Table 39. WFA Efficiency Across Environments, 300 PAX Base Camp

	Gallons of Water per Gallon of Fuel		
Environment	Best Hours	Worst Hours	Δ
Desert	4.1	3.9	0.1%
Temperate	5.2	5.2	0.0%
Tropical	5.4	5.3	0.0%

As shown in the table above, the usage schedule had little to no impact in the temperate or tropical environments. This is due to the high humidity at all hours in the tropical environment and the fact that the least productive hours in the temperate environment tended to be the coldest, when the WFA shut itself down. The desert, already found to be the most expensive environment in which to operate the WFA, showed the highest sensitivity to schedule. This was likely due to the desert having larger swings in humidity in any given day.

Overall, while the WFA system proved capable of meeting the water demand of the three base camps given enough systems and hours of operation, the quantity of systems required at base camps with high levels of services may prove unrealistic. The WFA proved unique compared to most technologies analyzed, in that use of the system, including the number of systems and hours of operation, had to be highly customized to the environment. Schedule management was exceedingly important in the desert environment, where system efficiency varied the most with schedule. This potential issue can be mitigated by automating system performance based on locally measured humidity levels.

WFA demonstrates a direct tradeoff between fuel consumption and potable water production. Its role in contributing to the SLB-STO-D's objectives will be considered in that light. At base camps with low water consumption, such as the FY12 ORTB 50 PAX Base Camp, WFA may prove a reasonable tradeoff to eliminate the need to resupply bulk water. Additionally, as base camps approach Net Zero[9] [51], WFA may prove valuable in replacing water that must be removed from the base camp for safety reasons, such as the byproduct from gray water recycling systems.

3.2.3.3 Water Purification

Potable water demand can be addressed by bringing in bulk potable water by convoy or by onsite generation. Onsite generation through condensing air humidity into water is discussed in **Section 3.2.3.2**. This section will consider the case where natural sources of water, such as a lake or well, are available.

The FY12 ORTB does not specify that a water source is available at each of the base camps. Options discussed in this section will necessary deviate from the FY12 ORTB and therefore will not be considered as viable solutions to meet the SLB-STO-D objective resource savings. However, since the presence of water plays a key role in the location of base camps, the contribution of water filtration technologies to resource savings may prove valuable in other circumstances. To that end, **Section 5.4** discusses an alternate use-case where multiple technologies improve resource consumption in a situation with natural access to water.

At the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps, 75, 8,723 and 31,305 gal per day of bulk potable water are consumed, respectively. The SLB-STO-D's goal is to reduce

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[9] The Net Zero initiative is an Army program that addresses sustainability and security challenges in installations. The program focuses on the critical areas of energy, water, and waste as it attempts to implement measures for installations to consume only as much energy or water as it produces over the year (i.e., Net Zero) and/or eliminating waste.

the bulk potable water resupply requirement by 75%. One option to reduce the resupply requirement is to generate potable water onsite. The tradeoff between onsite potable water production and the fuel necessary to accomplish that production is examined below.

Three technologies were investigated for their suitability to contribute to the SLB-STO-D's target potable water savings of 75%. For a complete description of the technologies, see **Annex C**. The technologies included the following:

- Tactical Water Purification System (TWPS) – A fully contained mobile water purification system capable of purifying, storing, and dispensing water meeting Military Field Water Standards for long-term consumption at up to 1,500 gal per h.
- Small Unit Water Purifier (SUWP) – A developmental man-portable water purifier capable of producing up to 20 gal per h of filtered water.
- Accelerated Vapor Recompression Water Purifier – A prototype adaptation of a commercially-available oil field water purifier using advanced distillation technology; capable of producing up to 125 gal per h of filtered water.
- Mobile Water Purification System (MWPS) with Adaptive Armament Reactive Interface Domains (AARID) Filter – A commercially available water filtration system outfitted with a prototype filter created from a government proprietary, visible light activated, PV material that can deactivate contaminants without the use of chemicals and is infinitely renewable without cost or human intervention.

The TWPS is a currently-fielded system that exists in two versions: one for the Army and one for the Marine Corps. Performance modeling was based on the equipment associated with the Army TWPS. The TWPS performance varies based on the temperature and contamination level of the input water. This analysis assumes a conservative production rate of cold water with high salinity. A cleaner water source would produce more water and consume less fuel. The TWPS ships with its own generator and a cold weather module which assists in maintaining performance in below-freezing conditions.

The SUWP is a technology in development designed to fill a capability gap for a system designed to purify water to support a squad (12 Marines) to platoon (40 Marines) [52]. Its performance is assumed to be identical to that of the TWPS except for its capacity, which is reduced to 20 gal per h for the conservative test case of cold water with high salinity. Because it is much smaller than the TWPS, it is assumed that in cold weather it could be brought inside a heated tent, eliminating the need for a cold weather module.

Accelerated Vapor Recompression is an adaptation to suit military needs of existing technology used in the oil industry. The project, supported by TARDEC, differs from the other purification processes discussed in this section in that it involves distillation rather than filters. The important innovations lie in increases in efficiency and reductions in size that make it more easily deployable. This technology was not included in the analysis because of lack of information on its performance.

The AARID materiel, under development by the U.S. Army Armament Research, Development, and Engineering Center (ARDEC), enables sanitation of not only water, but also materials such as walls, tables, and food service equipment. A current prototype system demonstrated the capability of applying the material to a filter in a commercially available water filtration system. Future research, in conjunction with NSRDEC, will focus on applying the AARID technology to address a key technology gap for sanitation alternatives that enhance food safety as well as a possible technology insertion for self-sanitizing coatings on field kitchen surfaces and individual foodservice equipment. Performance data on the MWPS with AARID filter were not available under similar climatic and contaminant conditions as the TWPS. Because the performance of these technologies is not directly comparable, the AARID was not considered in this analysis.

This section investigates the impact of supplying all of a base camp's bulk potable water demand[10] using these water treatment systems. In this scenario, it is assumed that there are no limits on either the overall amount of natural water that is accessible to the base camp or the amount of this water that can be withdrawn each hour. Given that the 1000 PAX ORTB base camp will consume over 11 million gal of potable water a year, these assumptions may not hold true under all operational scenarios.

Assuming sufficient natural water, at the 50 PAX base camp, one SUWP running for 4 h daily is sufficient to supply all necessary potable water. At the 300 PAX base camp, one TWPS running for 8 h is necessary, while at the 1000 PAX base camp, two TWPS running for 13 h a day each is required. The SUWP is powered by an existing generator, while the TWPS each require their own generators and are generally placed on the edge of camp along with bladders to hold necessary inputs and outputs to the systems.

Table 40 discusses the results of the scenarios discussed above. Because the SUWP and TWPS are sized to produce at least 100% of the potable water required on the base camp, the overall result is a slight negative potable water consumption (i.e., net production). Due to the hourly schedule of the simulator, the degree of overproduction varies depending on how closely the potable water requirements of the camp fall to a multiple of the SUWP or TWPS hourly production. In actual usage, the technologies could be left turned on for shorter periods than an hour, eliminating overproduction.

Table 40. Mean Daily Camp Level Summary, Water Purification, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY 12 Baseline	215	-	1007	-	75	-	27	-	266	-
One SUWP, 4 h daily	216	-0.5%	1009	-0.2%	-5	106.7%	27	0.0%	266	0.0%
					300 PAX Camp					
FY 12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
One TWPS, 8 h daily	1096	-5.2%	5397	-5.7%	-1149	113.2%	8532	0.0%	2870	0.0%
					1000 PAX Camp					
FY 12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Two TWPS, 13 h daily	3505	-3.8%	18517	-5.3%	-779	102.5%	31163	0.0%	10672	0.0%

Table 40 shows that all potable water demand can be addressed with only minimal increases in fuel usage, between 0.5% and 5.2% in the desert environment. The TWPS has slightly greater

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[10] The SLB-STO-D objectives do not include potable water required for hydration (i.e., drinking water).

fuel demand in the temperate environment due to the cold weather module, bringing the fuel increase to 5.9% at the 300 PAX base camp and 4.2% at the 1000 PAX base camp. This scenario assumes the worst-case for a natural water source (i.e., cold, high salinity water) and actual performance could be substantially better. As opposed to the WFA discussed in **Section 3.2.3.2**, the quantities of systems and increase in fuel required are quite reasonable: one SUWP at the 50 PAX base camp, one TWPS at the 300 PAX base camp, and two TWPS at the 1000 PAX base camp. In fact, if a 13.2% reduction in potable water demand was achieved through other means, only one TWPS would be required at the 1000 PAX base camp.

Overall, the addition of one to two water purification devices per base camp enables onsite production of sufficient water to meet demand with only modest increases in fuel usage. This analysis was done assuming the most conservative estimates for the quality of natural water available, so actual performance could be even better. However, water purification requires a natural water source, which in general cannot be guaranteed. Given these results, water purification is the best option for base camps where a source of water is available, implying that sighting camps near water sources would have a dramatic impact on resupply convoys. Since the FY12 ORTB does not specify the availability of a natural source of water, water purification will not be considered as part of a potential solution to the SLB-STO-D problem statement.

3.3 Solid and Liquid Waste Reduction

One of the SLB-STO-D's objectives is to reduce waste generation and backhaul by 50%. Waste is generally separated into two categories: solid waste and waste water. The SLB-STO-D goal is to reduce each category of waste by 50% compared to the FY12 ORTB Base Camps.

There are three primary methods of reducing waste water on a base camp: reducing potable water consumption by waste generating facilities, reusing waste water, and treating waste water for onsite disposal. The first two of these methods have the added benefit of decreasing the potable water consumption of the camp in addition to reducing the amount of waste water that must be disposed. Reducing potable water consumption by waste generating facilities is discussed in **Section 3.2**, while options for reusing or recycling waste water and treatment for onsite disposal are discussed in this section.

Table 41 shows the breakdown of waste water production at the FY12 ORTB base camps by camp level function. For the SLB-STO-D to meet its waste water reduction objective of 50%, the *Provide Means to Maintain Personal Hygiene* functional area (e.g., shower facilities and hand wash stations) must be addressed at all base camps. At the FY12 ORTB 50 PAX Base Camp, this functional area accounts for 100% of waste water. At both the FY12 ORTB 300 PAX and 1000 PAX Base Camps it accounts for over 58% of all waste water generation. In addition, the *Provide Latrine Services* functional area, which produces over 28% of all waste water at the two larger camps, is a target for reduction as well.

Table 41. Mean Daily Waste Water Breakdown by Camp Level Function

	50 PAX		300 PAX		1000 PAX	
Functional Area	gal	%	gal	%	gal	%
Provide Means to Maintain Personal Hygiene	27	100.0%	4961	58.2%	18444	59.2%
Provide Latrine Services	0	0.0%	2447	28.7%	9327	29.9%
Provide Means to Clean Clothes	0	0.0%	751	8.8%	2712	8.7%
Provide Subsistence	0	0.0%	370	4.3%	654	2.1%
Provide Access to Medical & Health Services	0	0.0%	0	0.0%	17	0.1%
TOTAL	27	100.0%	8529	100.0%	31153	100.0%

Note: Values may not sum to total due to rounding

Similar to waste water, solid waste can be reduced through two methods: reducing the sources of solid waste generation or reducing the need for back-haul by utilizing methods for onsite disposal. Both options are discussed in this section.

Table 42 shows the breakdown of solid waste at each of the FY12 ORTB base camps. Solid waste at the FY12 ORTB 50 PAX Base Camp is generated at a rate of 4.16 lb per person per day. At the FY12 ORTB 300 PAX and 1000 PAX Base Camps the rate is higher at 9.2 lb per person per day. This rate of solid waste production is based on two factors: the field feeding plan and the other services that are provided at the base camp. Since the level of service provided at the base camp must remain consistent across possible solution sets, only the waste from field feeding can be readily addressed. Field feeding accounts for 100% of the solid waste at the FY12 ORTB 50 PAX Base Camp and 54.1% of the solid waste generated on the FY12 ORTB 300 PAX and 1000 PAX Base Camps.

Table 42. Mean Daily Solid Waste Breakdown by Source

	50 PAX		300 PAX		1000 PAX	
Source	lb	%	lb	%	lb	%
Field Feeding	266	100.0%	1554	54.1%	5777	54.1%
Other Sources	0	0.0%	1317	45.9%	4895	45.9%
TOTAL	266	100.0%	2870	100.0%	10672	100.0%

Note: Values may not sum to total due to rounding

Figure 17 depicts a summary of the waste reduction options reviewed in this section. Many of the potential solutions for waste reduction require trade-offs between QoL(O), fuel consumption, and waste reduction. These trade-offs are discussed in this section.

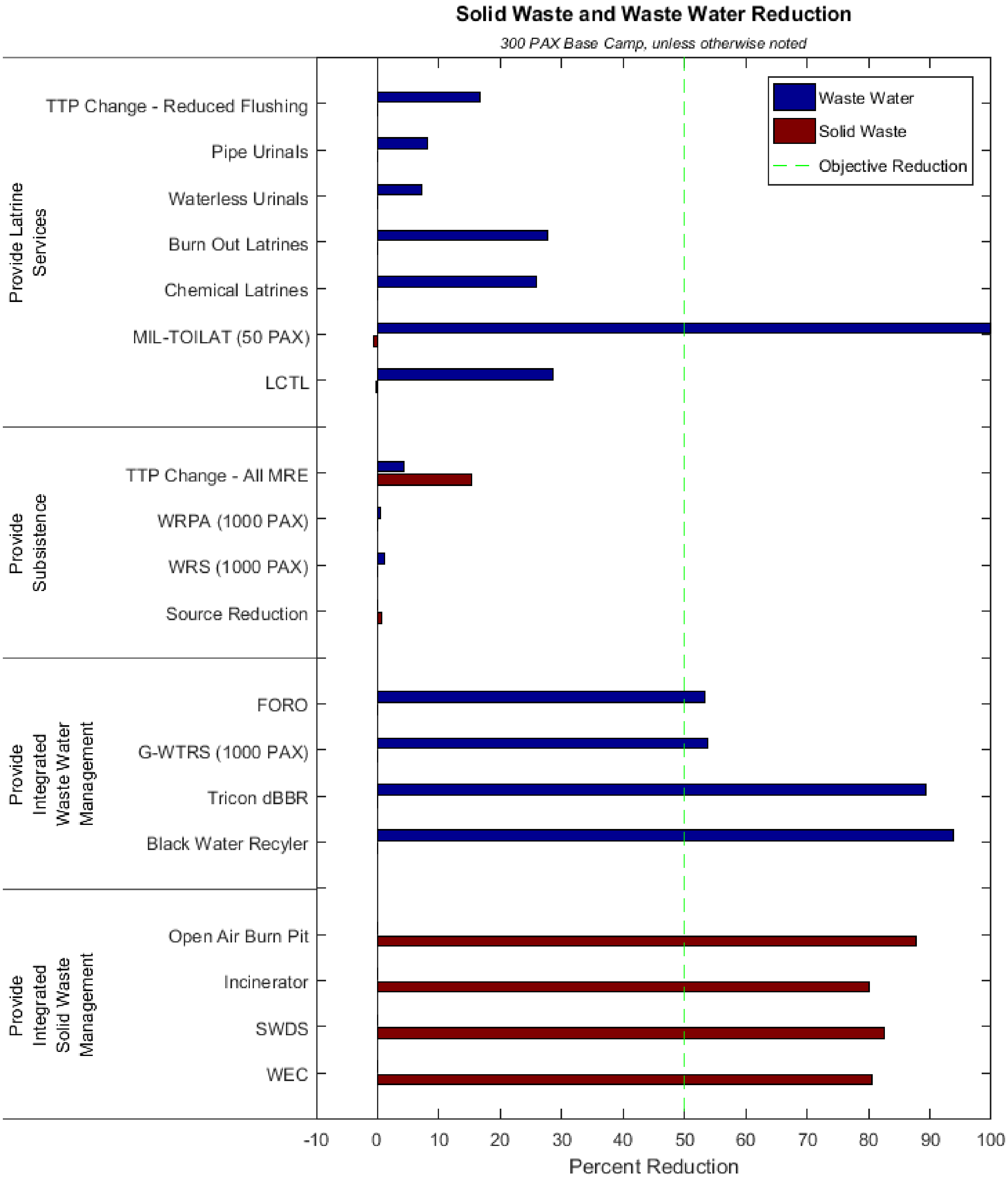

Figure 17. Solid Waste and Waste Water Reduction

3.3.1 Provide Latrine Services

Latrine facilities use a variety of technologies and processes to reduce the amount of water required to operate the systems and the amount of waste water they generate. These facilities vary significantly in their design and the level of QoL offered to the users. Options range from field expedient latrines made of materials available onsite to containerized systems that provide a higher level of service.

At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, respectively, 8,529 and 31,153 gal per day of waste water are generated. Of that, 22.8% of waste water on the FY12 ORTB 300 PAX and 29.9% of waste water on the FY12 ORTB 1000 PAX Base Camps is generated by the latrine facilities. Since the FY12 ORTB 50 PAX Base Camp uses burn-out latrines, no waste water is generated by the latrines at that base camp. Reducing the logistical burden of removing this liquid waste from the base camp is key to meeting the SLB-STO-D goal of a 50% reduction in waste generation/backhaul. Options for waste water reduction within this functional area include source reduction (e.g., low-flow toilets or waterless urinals) or waste water treatment for onsite disposal (see **Section 3.3.3.2).**

Additionally, at both the FY12 ORTB 300 PAX and 1000 PAX Base Camps, the latrine facilities consume over 25% of the total potable water. Therefore, the amount of potable water consumed by the latrines must necessarily be addressed to meet the SLB-STO-D objective of a 75% reduction in potable water usage. The tradeoffs between potable water reduction, waste water reduction, and fuel necessary for the process to accomplish that reduction is examined below.

Three technologies, two commercially available solutions, two field expedient methods, and one change to TTP were investigated for their suitability in contributing to the SLB-STO-D target waste water savings of 50% and potable water savings of 75%. For complete descriptions of the technologies, see **Annex C**. These options included the following:

- Change in TTP – A change in TTP to instruct Soldiers not to flush urinals and to selectively flush the latrine toilet only after defecation and not after urination.
- Burn-Out Latrines – A field expedient latrine consisting of a 55-gal drum, cut in half, with an improvised wooden seat, where the latrine waste is incinerated using available fuel (such as JP8) as an accelerant.
- E2RWM Hygiene Complex – A hard-side, expandable containerized shelter designed for energy efficiency that contains five toilets and five showers.
- Pipe Urinals – A field expedient urinal system consisting of pipes directed into soakage pits.
- Chemical Latrines – A commercially available, portable unit that collects latrine waste in a holding tank and uses chemicals to minimize odors. The contents of these systems must be pumped out for disposal in an Army-approved manner, likely by a contractor.
- Waterless Urinals – A commercially available technology that can be integrated into a larger latrine system (such as a containerized system) that drains via gravity instead of flushing into the existing waste collection system.
- Low Cost TRICON Latrine (LCTL) – A prototype latrine system designed for up to 150 users that includes water reduction technologies such as sink water recycling, waterless urinals, and dual flush toilets and an incinerator to eliminate all latrine black water.
- MIL-TOILAT – A prototype latrine system designed for up to 50 users that includes water reduction technologies such as sink water recycling, waterless urinals and dual flush toilets and an incinerator to eliminate all latrine black water. The system is designed

with the capability to operate off-grid, with an integral reverse osmosis system for purifying water and an on-board generator.

Several integration scenarios were simulated to determine the impact of the various latrine options.

The TTP change was implemented using existing latrine facilities. Since the FY12 ORTB 50 PAX Base Camp does not have flushable urinals or latrines, the TTP change would have no impact at that base camp. At both the FY12 ORTB 300 PAX and 1000 PAX Base Camps, the TTP change was implemented while the camps used their baseline equipment set, which in both cases consisted of several Expeditionary Latrine Systems (ELS).

Similarly, both urinal options (pipe urinals and waterless urinals) were implemented as an augmentation to the baseline equipment set. In both cases, the urinals were replaced with the other options while the toilets remained the baseline equipment set.

For both burn-out latrines and chemical latrines, the baseline latrine equipment was removed entirely and replaced with the potential alternative. The number of replacement units was specified to keep the number of toilet seats consistent (e.g., one ELS was replaced by four chemical latrines or burn-out latrines). To replace the hand washing capability when an ELS was removed, a hand wash station was added to each set of four latrines. At the FY12 ORTB 50 PAX Base Camp, burn-out latrines and hand-wash stations are the baseline equipment set. For this camp, only a simulation replacing the burn-out latrines with chemical toilets was performed.

The replacement of powered latrine systems with unpowered systems allowed for generator reallocation. At the FY12 ORTB 300 PAX Base Camp, the latrines had dedicated generators. In total, three generators could be shut down when using unpowered latrines. At the FY12 ORTB 1000 PAX Base Camp, the latrine generators often supplied other, smaller loads, such as the guard towers or perimeter lights. These loads were allocated to other generators, allowing for a total of nine generators to be shut down.

The LCTL and MIL-TOILAT are similar systems, both under development by NSRDEC, with the MIL-TOILAT designed for 50 Soldiers and the LCTL designed for 150 Soldiers. Both systems are designed with water savings features such as waterless urinals, dual flush low-flow toilets, and sink water recycling for toilet flushing. Additionally, both systems are designed with internal incinerators that burn all the black water they generate. The MIL-TOILAT has additional capabilities that allow it to function as a standalone system, including its own internal generator and a water filtration system to sanitize water for sink and toilet usage. These features were not modeled, since the ORTB Base Camps have available power generation capacity and assume all bulk potable water is imported via convoy to the camp (i.e. a water source to purify is not available). The MIL-TOILAT also includes flexible solar panels to partially power the system. These were included in the model.

To ensure an adequate basis of comparison, the SLB-STO-D integration of the MIL-TOILAT and LCTL into the base camps maintained the toilet-to-personnel ratio of the baseline camp. This was done for two primary reasons. Army regulation specifies a goal ratio of toilet per personnel of 1:20–1:10 [53]. The design size of the MIL-TOILAT equates to a 1:25 ratio and the design size of the LCTL equates to a 1:37.5 ratio. Both systems were confirmed through simulation to incinerate waste at a rate in excess of the processing rate required to handle their design size. Such an implementation would require significant deviation from the Army regulation. The FY12 ORTB Base Camps comply with this regulation. Secondly, the equipment at the FY12 ORTB Base Camps are sized to handle an approximately 30% increase in personnel for a 1 week period. Additional incineration latrine systems would be required to handle this increase in population.

Due to the MIL-TOILAT's smaller design size, it was only modeled at the FY12 ORTB 50 PAX Base Camp. Since the primary driver of resource consumption in the system is the incinerator, the LCTL's more efficient incinerator would be chosen over the MIL-TOILAT at all camps that justify the increased capacity. At the FY12 ORTB 50 PAX Base Camp, the four existing burn-out latrines and hand wash stations were replaced with two MIL-TOILATs, which kept the total number of seats consistent across both scenarios.

The LCTL was implemented at all three ORTB base camps. Systems were implemented to keep the same number of seats as the baseline equipment set. A single LCTL was used at the FY12 ORTB 50 PAX Base Camp, powered by an existing generator with excess capacity. At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, the ELS systems were replaced one-for-one with LCTLs. The FY12 ORTB Base Camps assumed dedicated generators for latrines at both the 300 and 1000 PAX sizes. This assumption was maintained while implementing the LCTL. Since the latrines were isolated in three areas at the FY12 ORTB 300 PAX Base Camp, no generators could be turned off after implementing the LCTL. At the FY12 ORTB 1000 PAX Base Camp, many latrines were in sets of four systems powered by two generators. In these instances, each group of four LCTLs could be powered by a single generator. In total, five generators could be shut down.

The E2RWM Hygiene Complex is currently being evaluated by Force Provider. Consumption factors and a verified shelter model were not available at the time of analysis. For this reason, it was not included in the simulations.

Table 43 shows the results of the simulation of the integration scenarios across the different base camp sizes in the desert environment.

Table 43. Mean Daily Camp Level Summary, Provide Latrine Services, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
50 PAX Camp										
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
TTP, Reduce Toilet Flushes	-	-	-	-	-	-	-	-	-	-
Waterless Urinals	-	-	-	-	-	-	-	-	-	-
Pipe Urinals	-	-	-	-	-	-	-	-	-	-
Burn-Out Latrines	-	-	-	-	-	-	-	-	-	-
Chemical Latrines	195	9.3%	1007	0.0%	81	-8.0%	33	-22.2%	266	0.0%
MIL-TOILAT	226	-5.1%	1097	-8.9%	112	-49.3%	0	100.0%	268	-0.8%
LCTL	221	-2.8%	1057	-5.0%	112	-49.3%	0	100.0%	268	-0.8%
300 PAX Camp										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
TTP, Reduce Toilet Flushes	1040	0.2%	5103	0.1%	7301	16.3%	7107	16.7%	2870	0.0%
Waterless Urinals	1041	0.1%	5106	0.0%	8099	7.2%	7905	7.3%	2870	0.0%
Pipe Urinals	1041	0.1%	5106	0.0%	8099	7.2%	7839	8.1%	2870	0.0%
Burn-Out Latrines	1030	1.2%	5019	1.7%	6489	25.6%	6169	27.7%	2870	0.0%
Chemical Latrines	948	9.0%	5019	1.7%	6512	25.4%	6318	25.9%	2870	0.0%
MIL-TOILAT	-	-	-	-	-	-	-	-	-	-
LCTL	1158	-11.1%	5256	-2.9%	6711	23.1%	6082	28.7%	2877	-0.2%
1000 PAX Camp										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
TTP, Reduce Toilet Flushes	3368	0.2%	17560	0.1%	25791	17.6%	25637	17.7%	10672	0.0%
Waterless Urinals	3374	0.1%	17572	0.1%	29129	7.0%	28977	7.0%	10672	0.0%
Pipe Urinals	3374	0.1%	17572	0.1%	29129	7.0%	28749	7.7%	10672	0.0%
Burn-Out Latrines	3519	-4.2%	17142	2.5%	22775	27.3%	22151	28.9%	10672	0.0%
Chemical Latrines	3090	8.5%	17142	2.5%	22889	26.9%	22737	27.0%	10672	0.0%
MIL-TOILAT	-	-	-	-	-	-	-	-	-	-
LCTL	3690	-9.3%	18090	-2.9%	23622	24.5%	21827	29.9%	10696	-0.2%

A change in TTP proved effective, reducing potable water consumption by 16.3–17.6% and waste water generation by 16.7–17.7% across the FY12 ORTB 300 PAX and 1000 PAX Base Camps. This equates to a 61.3 and 62.3% reduction in the potable water demand by the *Provide Latrine Services* camp level function at the FY12 ORTB 300 PAX and 100 PAX Base Camp, respectively.

A change in TTP would have no impact on the amount of human waste (i.e., feces and urine) collected by the latrines. This waste contributes approximately 5% of the waste water in the *Provide Latrine Services* functional area. The change in TTP achieved a 58.1% and 59.1% reduction in waste water in the *Provide Latrine Services* functional area at the FY12 ORTB 300 PAX and 100 PAX Base Camp, respectively.

While effective, ensuring compliance with a change in TTP to instruct Soldiers to not flush urinals and selectively flush the latrine toilet only after defecation and not after urination may prove difficult. This change would also have an assumed negative impact on QoL(O) and an unknown impact on sanitation in the latrine facilities.

The same impact on water usage by the urinals as the above TTP change can be achieved with the implementation of waterless urinals. Using waterless urinals, however, has no impact on latrine usage by female Soldiers (only present at the FY12 ORTB 1000 PAX Base Camp) and has no impact on Soldiers using the toilets for urination. Implementing waterless urinals saved 7.2% and 7.0% of potable water at the FY12 ORTB 300 PAX and 100 PAX Base Camp, respectively. A reduction in waste water of 7.3% and 7.0% was achieved at the FY12 ORTB 300 PAX and 1000 PAX Base Camp, respectively. Compared to the TTP change, waterless urinals resulted in an approximately 9% reduction in effectiveness at reducing potable water usage and waste water generation.

Pipe urinals, similar to the waterless urinals, impact only the water use of the urinals and therefore only impact male Soldiers. The potable water savings of a pipe urinal are identical to those of a waterless urinal. Pipe urinals also eliminate urine from the waste stream, however, resulting in an additional 0.7–0.8% waste water savings.

Power and fuel savings from a change in TTP or the implementation of other urinal options was negligible. The minor savings achieved was from the reduced usage of the fresh water and waste pumps due to the reduced latrine usage.

Chemical toilets consumed minimal potable water (a small amount of water is mixed with chemical deodorant when each latrine is emptied), effectively reducing the potable water usage in the *Provide Latrine Services* functional area by over 98% at both the FY12 ORTB 300 PAX and 1000 PAX Base Camps. Waste water generated by the *Provide Latrine Services* functional area decreased by over 90%. At the FY12 ORTB 50 PAX Base Camp, where the baseline latrines are burn-out latrines, the opposite is seen, with a net increase in both potable water consumption and waste water generation.

These results demonstrate the potential impact of water reduction technologies on the *Provide Latrine Services* functional area at camps with flushing latrine systems. The implementation of demand side reductions such as waterless urinals and dual flush low-flow toilets can reduce waste water generation in this functional area by over 90% with the potential for no degradation in service.

The implementation of burn-out latrines shows similar reductions at the 300 PAX and 1000 PAX Base Camps. Since there is no chemical deodorant charge, potable water usage in the *Provide Latrine Services* functional area is eliminated. Solid waste backhauled was not increased, since the ash is assumed to be buried in accordance with *ATP 4-25.12* [54].

Both chemical toilets and burn-out latrines have a similar quantity of waste water generated consisting primarily of human waste, over the quantity of which there is little control. The final disposition of this waste, however, varies significantly. The waste water generated by chemical latrines would normally be collected by a contractor, making their use only practical in situations where that is feasible. Burn-out latrines eliminate the need for a contractor to remove the waste water by incinerating the latrine waste, at the expense of fuel consumption.

At the FY12 ORTB 300 PAX Base Camp, the fuel required by burn-out latrines amounts to reinvesting 7.8% of the fuel savings from reducing the number of generators, while still resulting in a net decrease in fuel consumption compared to the baseline. At the FY12 ORTB 1000 PAX Base Camp, the burn-out latrines increase fuel consumption by 12.7% in the desert environment, fully utilizing all the fuel saved from the generators plus additional fuel. The difference in fuel consumption between the FY12 ORTB 300 PAX and 1000 PAX Base Camps is attributable to the different toilet per population ratios between the two camps. At the 300 PAX Base Camp, there is approximately one toilet per 19.5 Soldiers. At the 1000 PAX Base Camp, that ratio decreases to one toilet per 14.5 Soldiers. The fuel consumption of burn-out latrines scales with the number of seats, not the total waste generated. Therefore, this lower ratio increases the proportional fuel consumption at the FY12 ORTB 1000 PAX Base Camp.

Incinerating the latrine waste reduced waste water by less than 2% over the use of chemical toilets at the FY12 ORTB 300 PAX and 1000 PAX Base Camps. At the FY12 ORTB 50 PAX Base Camp, however, the incineration of the latrine waste accounts for a 22.2% reduction in waste water over the use of chemical latrines. In whole gallons, however, the amount of the reduction is small at only 33 gal a day. While at a smaller base camp it may prove practical to eliminate waste water by using burn-out latrines, the method proves much more resource-intensive than full scale waste water treatment systems (see **Section 3.3.3.2**). Given the high fuel cost of eliminating that 2% of waste water at the 300 PAX and 1000 PAX Base Camps, incineration using burn-out latrines is unlikely to be a good trade-off from a resource consumption perspective.

Both burn-out latrines and chemical toilets replaced powered latrine systems with unpowered variations at the FY12 ORTB 300 PAX and 1000 PAX Base Camps. This change resulted in a 1.7% and 2.5% reduction in power consumption in the desert environment at the FY12 ORTB 300 PAX and 1000 PAX Base Camp, respectively. This reduction is more evident in the temperate environment, where power decreased 7.3–10.1%. This is because the largest power reduction is the elimination of the latrine ECUs and space heaters, which draw more power in the temperate environment. While achieving only a small power reduction, by switching to entirely unpowered latrines, many generators could be eliminated. The 8.5–9.3% reduction in fuel in the desert environment by implementing chemical latrines is entirely attributable to this reduction in generators.

The substitution of unpowered latrines is not without cost. **Table 44** shows the QoL(O) scores of the camps in comparison to the baseline score. At both the FY12 ORTB 300 PAX and 1000 PAX Base Camps, implementation of burn-out latrines or chemical latrines results in a net decrease of QoL(O), due both to the type of latrine implemented and the lack of mechanical ventilation in them. At the FY12 ORTB 50 PAX Base Camp, the use of chemical latrines increased the QoL(O) score marginally. Since the SLB-STO-D goal is to maintain the QoL at the base camp, neither option is a likely candidate to achieve the stated resource reduction goals.

Table 44. Comparison of QoL(O) Scores, Provide Latrine Services

	QoL	
Simulation Description	Score	Δ
	50 PAX Camp	
FY12 Baseline	31.3	-
Burn-Out Latrines	-	-
Chemical Latrines	32.0	0.7
	300 PAX Camp	
FY12 Baseline	65.3	-
Burn-Out Latrines	62.0	-3.3
Chemical Latrines	62.6	-2.7
	1000 PAX Camp	
FY12 Baseline	67.0	-
Burn-Out Latrines	63.7	-3.3
Chemical Latrines	64.3	-2.7

Implementation of burn-out latrines and chemical latrines demonstrated both the potential effectiveness of water saving methods of latrine water usage and the ineffectiveness of incinerating latrine waste water in an uncontrolled manner. Both the MIL-TOILAT and the LCTL attempt to balance the benefits and shortcomings of these options, providing systems with decreased water consumption and waste incineration with no impact on the QoL(O) score of the base camp.

The MIL-TOILAT was simulated only at the FY12 ORTB 50 PAX Base Camp, where power increased 8.9–27.7% across the three environments. Since the climate-controlled MIL-TOILAT replaced unpowered burn-out latrines, the increase in power is to be expected. This increase in power, combined with an increase in incineration fuel compared to the burn-out latrine, resulted in a net increase in fuel consumption of 4.7–7.3%. Several factors contribute to the increase in fuel used for incineration. Among them are the fact that the MIL-TOILAT is designed to process waste quickly and meet emissions standards. Additionally, the MIL-TOILAT includes its own hand washing facilities, and therefore incinerates the hand wash water that burn-out latrines do not. Thus, the MIL-TOILAT achieves a 100% reduction in waste water at the 50 PAX camp. In part, this is translated into a very small increase in solid waste from the ash produced by the system. The increase in potable water usage is the price paid for implementing flushing toilets.

The MIL-TOILAT includes an additional feature of flexible solar panels intended to assist with powering the system. These solar panels are included in the results presented in **Table 43**. The solar panels provided a net decrease in power of 1.4–1.9% across the three environments, being most effective in the desert environment. This equated to approximately a 0.5% reduction in fuel consumption across all three environments. Since most of the fuel increase is attributable to direct consumption by the incinerator, the solar panels will have a very small impact on resource consumption. The panels serve another purpose, however, in allowing the system to operate off-grid.

Results for the LCTL implementation at the FY12 ORTB 50 PAX Base Camp were similar. The single system with a single shelter to heat and cool instead of the two MIL-TOILATs resulted in a small power decrease. Additionally, the LCTL's higher incineration efficiency decreased fuel consumption, but not below the baseline level.

At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, the LCTL fared comparatively well in the potable water and waste metrics. The system consumed only 2.5% and 2.8% more water compared to the waterless burn-out latrines at the FY12 ORTB 300 PAX and 1000 PAX Base Camp, respectively. Additionally, since the water used for hand washing is incinerated by the LCTL, the waste water savings are the highest of any latrine option analyzed. Solid waste production increased negligibly due to the system's ash byproduct.

In the fuel and power consumption metrics, the LCTL performed worse than the baseline system. This is to be expected, since the direct fuel consumption by the LCTL's incinerator accounts for most of the fuel increase. Compared to the unpowered options reviewed, such as the burn-out latrine and chemical toilet, the LCTL's fuel consumption fared poorly. This is exacerbated by the fact that the unpowered systems claim fuel savings from shutting down the no longer necessary generators. While the fuel consumed for the incineration of waste water at the 300 PAX Base Camp was greater using the LCTL compared to the burn-out latrine, the fuel consumption at the FY12 ORTB 1000 PAX Base Camp was near identical. This is once again due to the toilet-to-population ratio difference between the two camps and the fact that the burn-out latrine fuel consumption scales with the number of toilets while the LCTL fuel consumption scaled with actual usage.

The LCTL proved to be a QoL(O) neutral system that achieved a great reduction in latrine potable water use. This facility has previously been identified as a necessary functional area to address to meet the SLB-STO-D goal of a 75% reduction in potable water usage. The system has an added benefit of eliminating all waste water from the latrines. This waste water reduction, however, is far more costly than other waste water treatment systems analyzed which achieve a near 90% reduction in waste water at a near negligible fuel cost (see **Section 3.3.3.2**).

An ideal latrine system from a resource consumption aspect was not identified. While the LCTL includes many of the water saving features that prove key in reducing latrine water usage, its incinerator proves costly compared to a separate waste water treatment system (see **Section 3.3.3.2**). Those systems can not only eliminate most of the latrine waste water far more efficiently but can also process other waste water streams as well. The LCTL's entire elimination of the waste stream has merit, however. One potential solution may be a separate sludge incinerator that could eliminate the byproduct of the waste water treatment system.

3.3.2 Provide Subsistence

The *Provide Subsistence* functional area encompasses field feeding and is unique in that it directly impacts every resource type on the base camp, consuming power, fuel, and potable water and producing waste water and solid waste. This functional area can be addressed by augmenting and replacing field feeding equipment as well as changing TTPs. This section focuses on options within *Provide Subsistence* that impact the production of waste water and solid waste.

The *Provide Subsistence* functional area represents a relatively small producer of waste water on the FY12 ORTB Base Camps. Since the 50 PAX base camp does not include kitchens, this functional area produces no waste water. At the 300 PAX and 1000 PAX base camps, waste water production from *Provide Subsistence* accounted for 4.3% and 2.1% of total waste water, respectively.

Most of the solid waste produced at the FY12 ORTB Base Camps is related to field feeding. At the FY12 ORTB 50 PAX Base Camp, all the solid waste generated on the camp is from the dining facilities. At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, field feeding accounts for 54.1% of the solid waste generated. Any capability that enables a reduction in solid waste from field feeding would assist in meeting the SLB-STO-D goal of a 50% reduction in solid waste generation or backhaul.

Current technological efforts focus on two primary areas to address the production of solid and liquid waste: reducing waste at the source by decreasing packaging waste and improving sanitation equipment to recycle water. Additional waste reduction options center around changes to TTPs and the choice of ration mix in the field feeding plan. This section will review the impacts of these technologies and potential changes to TTPs.

3.3.2.1 Meal Plan Changes

The SLB-STO-D's goal is to reduce 25% fuel and 75% water resupply and reduce waste, both waste water and solid waste, by 50% compared to the FY12 ORTB Base Camps. Field feeding, encompassing aspects of refrigeration, meal preparation and cleaning, and food packaging, inherently impacts all resources on the base camp. As shown in **Table 42** above, Field Feeding is the main source of solid waste at the FY12 ORTB Base Camps—accounting for all solid waste at the 50 PAX Base Camp and 54.1% of the solid waste at the 300 PAX and 1000 PAX Base Camps. Reducing the amount of waste generated by field feeding is key to meeting the SLB-STO-D's goal of a 50% reduction in waste generation/backhaul. There are two alternatives to reduce solid waste: reducing the sources of solid waste generation or lessening the need for backhaul by utilizing methods of onsite disposal. This section will analyze the potential impacts of altering the field feeding plan on solid waste generation. See **Section 3.3.4** for a discussion on systems and methods that enable onsite disposal of waste.

Army Techniques Publication (ATP) 4-41 defines food as the fuel for the Soldier. Providing nutritious and high-quality subsistence to Soldiers is paramount to the Army's success and mission accomplishment on the battlefield. Field feeding directly affects the morale, combat effectiveness, and health of the combat Soldier. The objective of the Army Field Feeding System (AFFS) is to provide Soldiers the right meal at the right place and at the right time [35].

Army Regulation (AR) 700-135 states that unit commanders are responsible for overall field feeding [39]. ATP 4-41 states that Soldiers will be provided three quality meals in accordance with Mission, Enemy, Terrain, Troops, Time and Civil considerations (METT-TC). The AFFS standard of three quality meals per day is achieved by using a combination of individual and group operational rations, but the daily ration cycle is constrained to ration availability, phase operations, and the commander's METT-TC [55] [35]. **Table 45** depicts the conditions based theater-wide feeding plan.

Table 45. Theater Feeding Plan Timeline (Condition Based)

Standard	Expeditionary <6 Months					Temporary <24 Months Military LOGCAP	
Deployment Days: D+	1-20 Days	21-30	31-60	61-90	91-180	181 Days to 24 Months	
Method of Distribution	Push supply method = 1 - 90				Pull supply method = 91 and afterwards		
Ration Cycle	M-M-M	U-M-M	U-M-U w/one UGR-A meal every third day	U-M-U	U-M-U	U-M-U	DEPARTMENT OF THE ARMY CONTINGENCY OPERATIONS Menu
Theater Ration Mix	MRE = 100%	UGR-H&S = 34%	UGR-H&S = 56%	UGR-H&S = 34%	UGR-H&S = 10%	UGR-H&S = 05%	Force Provider, LOGCAP or Direct Contract: 90% Support by SPV platform, 10% is combination of MREs and UGRs
		MRE = 66%	MRE = 33%	MRE = 33%	MRE = 20%	MRE = 15%	
			UGR-A = 11%	UGR-A = 33%	UGR-A+ = 70%	UGR-A+ = 80%	
Facilities		MKT, AK, CK, Tents, Refers			MKT, CK, Unit Tents, Force Provider, Refers		Force Provider, LOGCAP, and SPV

Note: Units deploying into developed areas may move directly into the temporary standard depending upon their mission and the theater logistical capabilities at that location.

Ration Cycle, Legend:

M = MRE U = UGR-H&S or UGR-A UGR-A+ = UGR-A with Short Order Supplemental Menus

Abbreviation Legend:

AK = Assault Kitchen
CK = Containerized Kitchen
LOGCAP = Logistics Civil Augmentation Program
MKT = Mobile Kitchen Trailer
MRE = Meals Ready to Eat
Refers (or reefer) = refrigerated containers
SPV = subsistence prime vendor
UGR = unitized group ration
UGR-A = UGR, A-ration
UGR-E = UGR, express
UGR-H&S = UGR, heat and serve

*Source: Reproduced from ATP 4-41, Table 3-1. Theater feeding plan timeline (condition based) [35, p. 3–4]

Dependent on METT-TC, the feeding standard for field kitchens is to move to a normal daily ration mix of group ration/single meal/group ration (UGR/MRE/UGR or U-M-U per **Table 45**). Force structure and equipment is sufficient to distribute, prepare, and serve meals to this standard. The Army family of rations used to support this standard consists of individual and unitized group meals plus the authorized supplements and enhancements [35].

The FY12 ORTB 50 PAX Base Camp uses a ration cycle of two MREs and one UGR-E or a U-M-M. The Unitized Group Ration – Heat & Serve (UGR-H&S) was not included in the ration mix due to the added need for both food service staffing and a field kitchen. This ration cycle is consistent with **Table 45** and the ORTB Operational Order, which specifies that the 50 PAX base will operate with an exchange of personnel every 21 days.

The FY12 ORTB 300 PAX and 1000 PAX Base Camps utilize a ration cycle of one MRE and two UGR-A. This ration mix requires additional field feeding assets such as kitchens, sanitation centers, refrigerators, and freezers. The number of refrigerators and freezers required was calculated based on the ration mix and resupply cycle [6] [7]. While the ration cycle of U-M-U matches the target described in **Table 45**, the FY12 ORTB Base Camps assume an average ration mix of 60% UGR-As and 40% MREs, which is below the target level for a temporary base camp. **Table 46** shows a summary field feeding at the FY12 ORTB Base Camps.

Table 46. Summary of Baseline Field Feeding

Characteristic	50 PAX Base Camp	300 PAX Base Camp	1000 PAX Base Camp
Kitchens	None	2 x ETKS*	2 x CK
Sanitation Centers	None	None	2 x FSC-2
Refrigerators	None	1 x MTRCS	4 x MTRCS
Freezers	None	2 x MTRCS	1 x MTRCS
Ration Mix	UGR-E=30% MRE=70%	UGR-A=60% MRE=40%	UGR-A=60% MRE=40%

* Includes Force Provider Sanitation Center onboard

One change to TTP was investigated for its suitability in contributing to the SLB-STO-D's target solid waste savings of 75% and waste water savings of 50%. These options included the following:

- Change in TTP – A change in TTP to replace hot kitchen meals with MREs.

Three scenarios were simulated which varied the number of MREs served from zero to three MRE meals. Since the FY12 ORTB 50 PAX Base Camp's equipment set does not include kitchens and refrigerators, scenarios involving UGR-As were not simulated at that base camp. Since the simulated scenarios did not represent the Army standard ration cycle of U-M-U, they are considered TTP changes to the base camps.

The first simulation eliminated all UGRs in favor of all MREs, representing an M-M-M ration cycle. This simulates a typical 1 to 20-day scenario as shown in **Table 45**. In accordance with *AR 30-22*, MREs cannot be used as the sole ration for more than 21 days [55]. Since the 50 PAX Base Camp includes a 21-day rotation, this ration cycle meets the doctrinal minimum. An M-M-M ration cycle for the larger camps would be well below doctrinal required values. Implementation of an all MRE ration cycle at the 300 PAX and 1000 PAX Base Camps allowed for the complete elimination of the kitchens, sanitation centers, refrigerators, and freezers. This further allowed for generators that only supported field feeding equipment to be shut down. This resulted in one generator fewer at the 300 PAX Base Camp and five fewer generators at the 1000 PAX Base Camp. This removal of generators was only possible because of the complete elimination of the use of field feeding equipment.

The second simulation included one UGR-A and two MREs, for a U-M-M ration cycle. This simulates a typical 21 to 30-day scenario as shown in **Table 45**. This ration cycle would similarly be below doctrinal minimums for the 300 PAX and 1000 PAX Base Camps. Due to the decrease in the number of UGR-As being served, a freezer was eliminated from the 300 PAX Base Camp and two freezers were eliminated from the 1000 PAX Base Camp.

The third simulation eliminated the MREs in favor of UGR-As for a U-U-U ration cycle. This ration cycle would typically be seen at field hospitals and would be above the required level for all base camps simulated. The *ATP 4-41* states that hospitalized patients will receive three prepared hot meals and other nourishment as medically indicated and individual meals will only be approved on a case-by-case basis as a last resort [35]. At the 300 PAX Base Camp, the existing refrigerator and freezer space was enough to accommodate the third UGR-A. At the 1000 PAX Base Camp, one additional refrigerator and two additional freezers were required. This necessitated the addition of a 60 kW TQG to the camp layout.

Table 47 shows the results of the simulation of the scenarios across the different base camp sizes in the desert environment. Since the FY12 ORTB 50 PAX Base Camp is expeditionary in nature and does not require a field kitchen, results are only shown for the three individual meals scenario (M-M-M).

Table 47. Mean Daily Camp Level Summary, Meal Plan Changes, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
U-M-M (FY12 Baseline)	215	-	1007	-	75	-	27	-	266	-
M-M-M	215	-	1007	-	75	-	27	-	228	14.3%
					300 PAX Camp					
U-M-U (FY12 Baseline)	1042	-	5108	-	8723	-	8529	-	2870	-
M-M-M	964	7.5%	4196	17.9%	8353	4.2%	8159	4.3%	2430	15.3%
U-M-M	1030	1.2%	4892	4.2%	8538	2.1%	8344	2.2%	2650	7.7%
U-U-U	1050	-0.8%	5231	-2.4%	8909	-2.1%	8714	-2.2%	3161	-10.1%
					1000 PAX Camp					
U-M-U (FY12 Baseline)	3376	-	17580	-	31305	-	31153	-	10672	-
M-M-M	3016	8.0%	16155	8.1%	30652	2.1%	30499	2.1%	9036	15.3%
U-M-M	3339	1.1%	17333	1.4%	30978	1.0%	30826	1.0%	9851	7.7%
U-U-U	3466	-2.1%	17898	-1.8%	31632	-1.0%	31480	-1.0%	11751	-10.1%

At the 50 PAX Base Camp, there are no changes to the fuel, power, potable water, and waste water because there is no field kitchen to demand or generate those resources. Therefore, the only changes are to solid waste. The decrease of 14.1% solid waste generated is because the individualized nature of the MRE generates less packaging waste than the UGRs. For example, to feed 64 personnel using individual rations, a unit commander will need 64 MREs; however, to feed 64 personnel using group rations, a unit commander will require four boxes of UGR-Es. Each box of UGR-Es feeds 18 Soldiers, resulting in an excess of food that will generate more waste than just 64 MREs.

These savings were not without cost, however. **Table 48** shows the QoL(O) scores of the camps in comparison to the baseline score. While a small overall reduction, eliminating the UGR-E in favor of the MRE resulted in a net decrease of QoL(O) on the base camp.

Table 48. Comparison of QoL(O) Scores, Meal Plan Changes

Simulation Description	QoL Score	QoL Δ
	50 PAX Camp	
M-M-M	30.7	-0.4
U-M-M (FY12 Baseline)	31.3	-
	300 PAX Camp	
M-M-M	59.9	-5.4
U-M-M	64.0	-1.3
U-M-U (FY12 Baseline)	65.3	-
U-U-U	66.3	1.0
	1000 PAX Camp	
M-M-M	61.6	-5.4
U-M-M	65.7	-1.3
U-M-U (FY12 Baseline)	67.0	-
U-U-U	68.0	1.0

The FY12 baseline of two group rations and one individual meal per day serves as the basis of comparison for the 300 PAX and 1000 PAX base camps. As both base camps share the same ration mix assumptions, solid waste will be proportionally identical across both camp sizes. The two camps include different food preparation and sanitation equipment, as well as different numbers of refrigerators and freezers. Therefore, fuel, power, and potable water consumption and waste water generation will vary between the camp sizes.

The first scenario of three individual rations (M-M-M) shows a reduction from the FY12 baseline in all resource types due to changes in field kitchen use and demands. Eliminating the group rations eliminates the need to operate the field kitchen; thus, the savings on fuel, power, potable water, and waste water are because there is no kitchen usage. The most significant source of fuel savings was not directly from the decrease in power consumption, but from the elimination of the generators powering the field feeding equipment. Additionally, the use of only MREs reduced the amount of generated solid waste by 15.3% due to the difference of packaging and food waste.

The second scenario of one group ration and two individual rations (U-M-M) continues to show a reduction from the FY12 baseline due to changes in field kitchen use and demands. The second simulation included cooking only one meal in comparison to the FY12 baseline of two meals. However, the inclusion of even a single meal necessitated the powering of the kitchens, refrigerators, and freezers. Thus, fuel savings are significantly less than using an all MRE ration mix, since no generators could be eliminated. The solid waste shows a reduction of 7.7%, because the substitution of one UGR for one MRE generates less packaging and food waste.

Both the M-M-M and U-M-M scenario showed resource savings, but portrayed a net decrease in QoL(O) on the base camps. The most significant decrease was seen using an all MRE ration mix. The decrease is partially explained by the change in meal plan, but the elimination of a dedicated dining facility contributed significantly. Dining facilities were eliminated since no hot meals were to be served, and both the 300 and 1000 PAX base camps have dedicated MWR facilities, which could be used by Soldiers looking to socialize while eating. The dining facility was not eliminated at the 50 PAX base camp since that camp had no dedicated MWR facility.

The third scenario of U-U-U shows increases in all resources due to changes in field kitchen use and demands. Eliminating the individual ration increases the use of the field kitchen and increases the refrigeration and freezer requirement. The surge in field kitchen use increases the use of fuel, power, and potable water and increases the generation of waste water and solid waste compared to the FY12 baseline. The fuel increase at the 1000 PAX base camp was more significant than at the 300 PAX base camp due to the requirement to add additional refrigerators and freezers. This addition required an additional TQG, which caused the most significant increase in fuel.

As previously stated, there are two alternatives to reduce solid waste: reducing the sources of solid waste generation or lessening the need for backhaul by utilizing methods of onsite disposal. The altering of the field feeding plan targets the reduction of solid waste generation in a base camp. The results of the analysis show savings in solid waste generation in the three baseline camp scenarios using an M-M-M approach. The analysis also shows a reduction in power, fuel, and water consumption.

The approach of offering three individual rations is the most optimal for reducing the resupply of fuel and water and the generated waste needed to be backhaul; however, this approach is also the change that affects Soldier QoL(O) in the most negative manner. The intention in analyzing the non-materiel (i.e., TTP) approach to meal changes is to assess the savings each of the different scenarios might provide. The intent is not to recommend any option, but to inform Army leaders of the potential savings each of the scenarios might produce and to enable decisions that will satisfy a leader’s METT-TC.

3.3.2.2 Food Preparation and Cleaning

Systems used for food preparation and cleaning include kitchen and sanitation facilities. At the FY12 ORTB 50 PAX Base Camp, there are no kitchen facilities, since the meal plan calls for only MREs and UGR-Es. At the FY12 ORTB 300 PAX Base Camp, the cleaning and sanitation facilities are located inside the kitchen. For a discussion on kitchen facilities, see **Section 3.1.3.1**. Sanitation facilities at the FY12 ORTB 1000 PAX Base Camp include a FSC-2. This section will focus on possible waste and potable water savings that can be achieved in that facility.

At the FY12 ORTB 1000 PAX Base Camp, 654 gal per day of potable water are consumed and waste water are generated by the *Food Preparation and Cleaning* functional area. Of that, nearly 75% of the water is used by the FSC-2. Decreasing the water used by the FSC-2 will assist in meeting the SLB-STO-D goal of a 50% reduction in waste water and a 75% reduction in potable water usage.

One currently-fielded piece of equipment and one technology were investigated for their suitability in contributing to the SLB-STO-D’s target waste water savings of 50% and potable water savings of 75%. For complete descriptions of the equipment, see **Annex C**. These options included the following:

- Water Recycling System (WRS) for Field Food Service Sanitation – A prototype, modular water sanitation system that continuously clarifies and re-circulates sanitation water to prevent the need to empty and refill kitchen sinks.
- Water Reuse Pump Assembly (WRPA) for FSC-2 – A post-FY12 fielded capability that allows water to be safely and sanitarily moved from one FSC-2 sink to another to enable reuse of the rinse and sterilization sink water prior to discard.

Two integration scenarios were investigated through simulation. In the first scenario, the existing FSC-2s were augmented with the use of the WRPA. In the second scenario, the FSC-2s were augmented with the WRS.

Table 49 shows the results of the simulation of the two integration scenarios in the desert environment. In both scenarios, power and fuel increases were negligible, with both systems being a low power draw and only operational during the two 2-h sanitation periods each day.

Table 49. Mean Daily Camp Level Summary, Food Preparation and Cleaning, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
WRS	3377	-0.0%	17598	-0.1%	31036	0.9%	30793	1.2%	10672	0.0%
WRPA	3376	0.0%	17580	0.0%	31145	0.5%	30993	0.5%	10672	0.0%

Following each meal period, the FSC-2 is used to clean and sterilize the field feeding equipment. A typical cleaning routine would entail that each of the three 20-gal sinks be filled to begin the period. Midway through the period, all sinks would be emptied and refilled. The WRPA allows for the water in the rinse sink to be moved to the wash sink and the water in the sterilization sink to be moved to the rinse sink, thereby only requiring one sink to be filled during the refill period. The simulation did not consider any fuel savings from not having to heat the moved water as much as would be required if all fresh potable water was used. The WRPA saved 0.5% of potable water and waste water on a camp-wide scale. However, the WRPA achieved a 33.3% reduction in FSC-2 water usage and a 24.4% reduction in the *Food Preparation and Cleaning* functional area.

The WRS, an NSRDEC-funded project, goes further in that it continuously cleans the water in the FSC-2 sinks, eliminating the need for total sink drains and refills. The WRS processes the sink water with a recycling efficiency of 75% and a rate sufficient to process all the sink water during the 2-hour sanitation period. The water is processed again after each meal to ensure it is ready for the next meal's sanitation period or to allow the water to be disposed of onsite after the final meal of the day. In this way, the WRS allows the FSC-2 sinks to be filled once each morning and emptied once each evening. Fresh bulk potable water is added periodically to replace the water rejected by the WRS.

The WRS reduced waste water by over twice as much as the WRPA with a 1.2% reduction overall. This equated to a 75.0% reduction in waste water generated by the FSC-2 and a 55.0% overall reduction in the *Food Preparation and Cleaning* functional area. Potable water usage was reduced by 0.9% on a camp-wide level, 56.0% by the FSC-2 itself, and 41.2% in the *Food Preparation and Cleaning* functional area.

While the *Food Preparation and Cleaning* functional area accounts for only 2.1% of the FY12 ORTB 1000 PAX Base Camp's total waste water generated and potable water consumed, this area of the camp can relatively easily be augmented to decrease water usage with little negative impact. Both options analyzed produced a sizable water savings with a negligible fuel cost. This cost could potentially be offset by the need to heat water less.

3.3.2.3 Source Reduction

Solid waste can be reduced through two methods: reducing the amount of solid waste that is generated and reducing the need for back-haul by utilizing methods of onsite destruction or disposal. Both options will be analyzed for their contribution to meeting the solid waste reduction metric of 50%. This section will explore the scenario of reducing the source of solid waste before it is even sent to the base camp. These methods collectively are called "source reduction" and mainly relate to solid waste connected with field feeding. **Section 3.3.4** discusses options relating to onsite destruction and disposal.

Field feeding is the biggest driver of solid waste production at the FY12 ORTB Base Camps. At the 50 PAX base camp, 4.16 lb per soldier per day of solid waste is produced—an amount that is derived entirely from field feeding. At the 300 PAX and 1000 PAX base camps, 9.2 lb per soldier per day of solid waste is generated, of which 4.98 lb is derived from field feeding [56]. As field feeding makes up between 54% and 100% of solid waste at the FY12 ORTB Base Camps, any attempt to meet the SLB-STO-D solid waste reduction metric of 50% must include influences on field feeding or onsite disposal.

Three technologies were investigated for their suitability in contributing to the SLB-STO-D target solid waste savings of 50%. For complete descriptions of the technologies, see **Annex C**. These technologies included the following:

- Sustainable Technologies for Ration Packaging Systems (STRaPS) – Straps, pallets, and pallet wraps that are biodegradable, recyclable, and/or reduce the amount of material required.
- Bio-Based Hybrid Materials for Combat Ration Packaging – Plant-based packaging for components such as MRE packages, UGR-E trays, utensils, and trash bags.
- Ration Reconfiguration and Lightweight and Compostable Fiberboard – Modified MRE cases and meal bags to reduce materials needed and switch materials used to be more environmentally friendly.

All the technologies analyzed were developed by NSRDEC. The term "source reduction" refers to the collective impact of all technologies analyzed.

STRaPS developed straps, pallets, and pallet wraps that are biodegradable, recyclable, and/or reduce the amount of material required. The purpose of these modifications was to make solid waste management simpler and less harmful to the environment [57]. The improved straps are included in this analysis; however, the improved pallets were not sufficiently mature at the time of writing to be considered for inclusion.

Bio-Based Hybrid Materials for Combat Ration Packaging seeks to use plant-based packaging for components such as MRE packages, UGR-E trays, utensils, and trash bags. The purpose of these modifications was to reduce "dependence on foreign oil, reduce carbon footprint and increase the bio-based content in ration packaging" [58]. This project was also not sufficiently mature to be considered for inclusion in this report.

Finally, Ration Reconfiguration and Lightweight and Compostable Fiberboard aimed to modify the MRE case and meal bag to be made of more environmentally friendly materials and use less materials overall. This project developed prototypes that reduce the weight of an MRE bag by 30% and of the box used for shipping MREs by 15% [59]. All affected elements are portions of a camp's combustible waste stream and affect only the portion of food waste deriving from MREs. According to analysis by the Environmental Protection Agency, the modified MREs containers do not substantially change the emissions profile when waste is burned, meaning that they could continue to be incinerated in the same way as the current MRE container [60]. Both the MRE bags and cases were considered mature enough for inclusion in this analysis.

Different base camps have different meal schedules. The FY12 ORTB 50 PAX Base Camp provides two MRE meals and one UGR-E meal daily, while the FY12 ORTB 300 PAX and 1000 PAX Base Camps provide two UGR-A meals (with enhancements) and one MRE meal daily. Assuming that Soldiers occasionally miss meals due to off-base work, the actual breakdown of meals is assumed to be 70% MREs and 30% UGR-Es at the 50 PAX base camp and 40% MREs and 60% UGR-As at the 300 PAX and 1000 PAX base camps. The source reduction strategies discussed above impact only MREs, which indicates that they will have the largest impact on base camps that rely more heavily on MREs, such as the 50 PAX base camp.

When source reduction is implemented, daily solid waste production is reduced to 4.05 lb per soldier at the 50 PAX base camp, while daily solid waste production at the 300 PAX and 1000 PAX base camps is reduced to 9.14 lb per soldier [59]. This is a change entirely in combustible materials, a fact which becomes more relevant in base camps that include technologies that combust waste (see **Section 3.3.4**). **Table 50** displays the results of simulations involving source reduction.

Table 50. Mean Daily Camp Level Summary, Source Reduction, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Source Reduction	215	0.0%	1007	0.0%	75	0.0%	27	0.0%	259	2.6%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Source Reduction	1042	0.0%	5108	0.0%	8723	0.0%	8529	0.0%	2852	0.6%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Source Reduction	3376	0.0%	17580	0.0%	31305	0.0%	31153	0.0%	10602	0.7%

Table 50 shows that the impact of source reduction is relatively modest in terms of percentage resource savings and is between 0.6% and 2.6% of solid waste. Source reduction saves a larger percentage of solid waste at the 50 PAX base camp, because Soldiers at this base camp eat two MREs daily, while those at the 300 PAX and 1000 PAX base camp eat only one MRE daily. However, even at the 50 PAX base camp the resource savings are quite small compared to the overall magnitude of desired savings, indicating that additional technologies must be considered to meet the objective reductions.

Nevertheless, source reduction does still provide an impact on the base camp’s solid waste production. The raw values of pounds saved per year are quite substantial: 2,555 lb yearly at the 50 PAX base camp, 6,570 lb yearly at the 300 PAX base camp, and 25,550 lb yearly at the 1000 PAX base camp, all without any assumed impact on QoL(O). Additionally, source reduction has positive impacts aside from contributing to resource savings on the base camp. For example, the reduction in box weight comes about partially through a reduction in its size, an effect which might allow more overall MREs to be shipped on a single truck, reducing the number of convoys required and potentially decreasing fuel needed for vehicle transport. This occurs without any impact on the base camp – no new equipment, training, or maintenance needs to be implemented on the base camp to reap the benefits of source reduction technologies.

Overall, source reduction allows for less material to be sent to base camps, which causes a reduction in the solid waste produced on camp with no additional burden or cost to the base camp itself. Source reductions implemented resulted in solid waste savings of 0.6% to 2.6% across the various base camp sizes. The methods included were the most mature technologies and only impacted MREs; therefore, the solid waste savings are proportional to the number of MREs eaten at the camp. Depending on the field feeding plan of a particular base camp, additional improvements focused on the other packaging sent to base camps may yield a greater impact. Additionally, future source reduction technologies focused on eliminating noncombustible materials from the waste stream may prove more impactful following the implementation of waste destruction systems.

3.3.3 Provide Integrated Waste Water Management

Waste water at a contingency base camp is composed of two primary types: gray water and black water. Gray water is considered less contaminated and includes waste water “discharged from washing machines, laundry sinks, hand-washing sinks, showers and bathtubs that does not contain concentrated animal waste or human sanitary or food wastes.” [29] At the FY12 ORTB Base Camps, gray water is produced by the shower and laundry facilities. Black water is considered waste water “discharged from toilets and urinals containing concentrated human wastes and water from kitchen preparation areas containing concentrated food wastes.” [29] The waste water from hand-washing sinks in the latrines is mixed with other latrine waste water and is considered part of the black water stream.

At the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps, respectively, 27, 8,529 and 31,153 gal per day of waste water are generated. **Figure 18** shows the breakdown of this waste water between black water and gray water. Reducing the logistical burden of removing this liquid waste from the base camp is key to meeting the SLB-STO-D’s goal of a 50% reduction in waste generation/backhaul. Any capability that would allow the reuse of this waste water in place of new, bulk potable water would also assist in meeting the SLB-STO-D's goal of a 75% reduction in potable water usage.

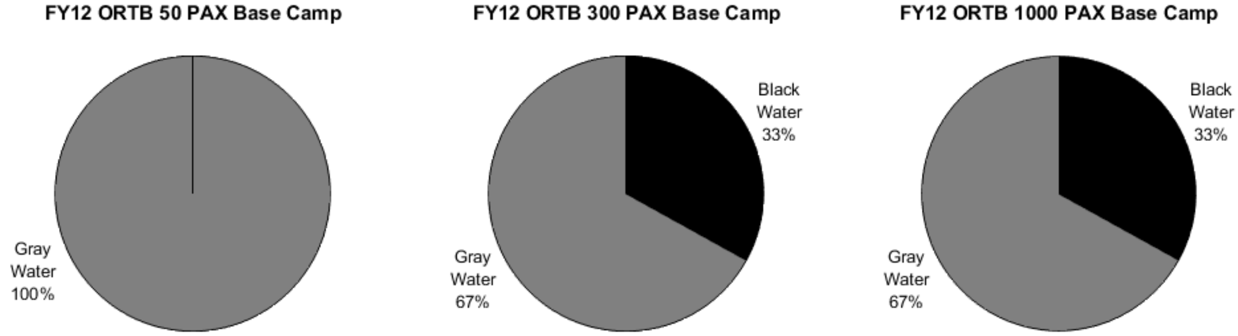

Figure 18. Breakdown of Waste Water at FY12 ORTB Base Camps

Current technological efforts focus on two primary areas to address the waste water concern: the recycling of gray water and the treatment of waste water (black and gray) for onsite disposal. This section will review the impacts of technologies on those areas. Additionally, this section will review the potential impact of broadening current Army regulations to allow the recycling of black water.

3.3.3.1 Gray Water Recycling

Gray water recycling systems use a variety of technologies and processes to convert gray water into a product stream that meets or exceeds the Military Field Water Standards for recycled gray water. Gray water is waste water "discharged from washing machines, laundry sinks, hand-washing sinks, showers and bathtubs that does not contain concentrated animal waste or human sanitary or food wastes." [29] At the FY12 ORTB Base Camps, gray water primarily comes from the shower and latrine facilities. Because the hand-washing sinks in the latrines are mixed with other latrine waste, the water cannot be processed by the gray water systems.

At the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps, respectively, 27, 8,529 and 31,153 gal per day of waste water are generated. Of that, 100% of the waste water at the FY12 ORTB 50 PAX Base Camp and 67% of waste water at the FY12 ORTB 300 PAX and 1000 PAX Base Camps is source separated gray water that can be treated by a gray water recycling system. Reducing the logistical burden of removing this liquid waste from the base camp is key to meeting the SLB-STO-D goal of a 50% reduction in waste generation/backhaul.

Waste water, including gray water, is currently required to be either backhauled by convoy, disposed of by local contractor, or disposed-of onsite using methods such as lagoons. Gray water recycling systems not only reduce the burden of disposing of gray water, but decrease the net amount of bulk potable water that must be transported to the base camp. As the showers and laundry collectively consume between 65.4–67.5% of the potable water at the FY12 ORTB 300 PAX and 1000 PAX Base Camps, reducing the potable water used at these facilities will greatly impact the ability to meet the SLB-STO-D's objective of a 75% reduction in potable water usage. The tradeoff between potable water and waste water reduction, and the fuel that it would be necessary to process to accomplish that reduction is examined below.

Four technologies were investigated for their suitability in contributing to the SLB-STO-D's target waste water savings of 50% and potable water savings of 75%. For complete descriptions of the technologies, see **Annex C**. These technologies included the following:

- Ultra-filtration Gray Water Reuse System (UF-GWRS) – A prototype system that utilizes a three-stage pre-filtration process followed by a two-stage ultrafiltration process.
- Forward Osmosis/Reverse Osmosis (FORO) Graywater Recycling System – A prototype system that utilizes forward osmosis, reverse osmosis, and chlorine injection.
- Gray Water Treatment and Reuse System (G-WTRS) – A prototype system that utilizes a combination of bio filtration, ultrafiltration, and reverse osmosis.
- Shower Water Reuse System (SWRS) – A currently fielded system that is part of the Force Provider Expeditionary (FPE) equipment set designed to integrate directly with two FPE Shower Systems and provide reuse water that meets or exceeds the Military Field Water Standards for long-term use.

A comparison of the resource flows of the various technologies is included in **Table 51**. Technologies were down selected based on their performance against the SLB-STO-D's program goals, their applicability to the SLB-STO-D base camp, and the current plans of the sponsoring organization.

Table 51. Comparison of Resource Flows, Gray Water Recycling

Technology	Average Power (kW)	Peak Power (kW)	Gray Water In (gal/h)	Waste Water Out (gal/h)	Recycled Water Out (gal/h)	Processing Efficiency	Power Efficiency (gal/h/kW)
UF GWRS*	0.5	1.3	97.0	25.0	72.0	74%	135.9
FORO†	1.8	2.7	190.0	23.0	167.0	88%	94.3
G-WTRS‡	9.5	13.6	1304.0	132.0	1171.0	90%	123.3
SWRS§	Unk	23.0	630.0	150.0	480.0	76%	>20.9

[*] Source: Measured demonstration data [10], hourly rates based on an assumed 22 h of operation per day

[†] Source: Measured demonstration data [12], hourly rates based on an assumed 22 h of operation per day

[‡] Source: Martin Page, Project Officer, ERDC-CERL

[§] Source: Specifications [61]

Two of the five technologies reviewed, UF GWRS and FORO, were sponsored by the TARDEC. Both were demonstrated by the SLB-STO-D at the BCIL at Fort Devens, MA. Data collected at the demonstrations showed that the UF GWRS had a higher power efficiency, but processed at a much lower rate and overall processing efficiency than the FORO. While more power intensive than the UF GWRS, the FORO still consumed only 1.8 kW on average while processing. The low power consumption of both systems made the FORO's processing rate and efficiency a more attractive option to meet the SLB-STO-D's objective of a 50% reduction in waste water and a 75% reduction in potable water. Discussions with an SME from TARDEC confirmed their opinion that the FORO was the better candidate system.

The SWRS, a fielded system that is part of the FPE equipment set, consumes significantly more power at a low overall processing efficiency than the FORO. Each pair of Expeditionary Shower

Systems at the FY12 ORTB 300 PAX and 1000 PAX Base Camps, respectively, generate 2,481 and 1,844 gal per day of waste water. Both the FORO and the SWRS are oversized to handle that production. Therefore, although the SWRS is capable of processing at much higher rates, this increase in processing rate is less valuable to meeting the SLB-STO-D's metrics than improving the overall efficiency. For this reason, the FORO was selected as the system to model for the 300 PAX Base Camp.

The G-WTRS system, developed by the U.S. Army Corps of Engineers ERDC-CERL, is a significantly larger system. A single system is more than capable of processing all the gray water from the FY12 ORTB 1000 PAX. Due to the size of the system, however, it would be unlikely to integrate into the existing base camp without significant modification. A single system for the entire base camp would require all gray water producers to be within pumping distance of the treatment plant. Further, the size of the system would make it oversized for the 300 PAX camp. Due to its better power efficiency than the other systems reviewed, the G-WTRS was considered a candidate system for the 1000 PAX Base Camp.

Current Army regulations state that at least 20% of the untreated waste water must be discharged during the gray water recycling process [48]. This discharge limits the potential buildup of any contaminant in the recycled water [62]. Make-up water is then added to replace the discharged water, further diluting the recycled water before it is used. While current regulation limits recycling to only 80% of the gray water stream, both technologies considered (the FORO and G-WTRS) have demonstrated potential recycling efficiencies above the approved rate. Water quality and safety have not been definitively proven at such high recycling rates. For that reason, the SLB-STO-D's simulation assumed a recycling efficiency of the regulation maximum 80%. In further simulations, the impact of the technologies should they prove safe at higher recycling rates was modeled.

Two integration scenarios were investigated through simulation. In the first scenario, the minimum number of FORO systems necessary to recycle all the gray water were used. This scenario was further varied to place a FORO behind each shower and laundry, which would enable an easy integration in the field but at the expense of requiring more systems. In the second scenario, the G-WTRS was utilized to treat all gray water.

To ensure the safety of the recycled water, verification monitoring of water quality would play a vital role (see **Section 3.2.3.1**) [63]. Due to the minimal resource impact of water quality monitoring (a very small increase in power), the water quality monitors were not included in the model.

Since at the FY12 ORTB 50 PAX Base Camp the only gray water source is the hand wash stations (laundry is done by hand and there are no shower facilities), a full-scale gray water recycling system could not be integrated.

At the FY12 ORTB 300 PAX Base Camp, 5,711 gal per day of gray water are generated in the Ready State use-case (7,432 gal per day for the Population Variance scenario). Since the FORO can treat 4,180 gal per day, either scenario requires two gray water recycling systems to treat all the gray water generated on the camp. These systems were placed near the two sets of showers on the camp. Gray water from the laundry is assumed to be pumped to the nearest FORO.

At the FY12 ORTB 1000 PAX Base Camp, 21,156 gal per day of gray water are generated in the Ready State use case (27,193 gal per day for the Population Variance scenario). Since the FORO can treat 4,180 gal per day, 5.1 systems are necessary to handle the Ready State use case, while 6.5 systems are necessary to handle the Population Variance. Six systems were chosen to be used at the 1000 PAX Base Camp. This provides a higher capacity than necessary in the Ready State and would be just under capacity in the Population Variance use case. It is assumed that since the population increase happens for a short period of time (1 week), any excess waste water is stored for processing when the camp population returns to Ready State. This storage requirement would be approximately 2,100 gal per day during the population increase. These systems were placed near sets of four showers and behind the laundry facilities. To achieve this, several sets of showers would likely need to be moved on camp to be in closer proximity to each other.

To enable easier integration, the impact of placing a FORO behind each pair of Expeditionary Shower Systems and behind the laundry facilities was investigated. This required 3 FORO systems at the 300 PAX Base Camp and 11 FORO systems at the 1000 PAX Base Camp.

In the second integration scenario, a single G-WTRS was integrated to provide gray water recycling for the entire 1000 PAX Base Camp. Since the system would be massively oversized for the 300 PAX Base Camp, it was not simulated on the smaller camp. The integration of G-WTRS in a base camp not designed for such an integration highlights issues with system right-sizing and camp layout. In an ideal scenario, gray water would not be transported around the camp using vehicles, which would necessitate dedicated waste water tanks for that purpose. Instead, gray water would be pumped from its source to a treatment area, which limits the distance between the generating facility and treatment system. To integrate the G-WTRS, all shower and laundry facilities would have to be centrally located around the G-WTRS.

Table 52 shows the results of the simulation of the two integration scenarios across the different base camp sizes in the desert environment. Additionally, the results shown include the gray water recycling systems operating at their higher demonstrated processing efficiencies rather than the Army regulated 80%.

Table 52. Mean Daily Camp Level Summary, Gray Water Recycling, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
FORO (80%)	1045	-0.3%	5169	-1.2%	4176	52.1%	3983	53.3%	2870	0.0%
FORO (88%)	1045	-0.3%	5170	-1.2%	3729	57.3%	3534	58.6%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
FORO (80%)	3388	-0.4%	17804	-1.3%	14520	53.6%	14370	53.9%	10672	0.0%
FORO (88%)	3388	-0.4%	17807	-1.3%	12871	58.9%	12714	59.2%	10672	0.0%
G-WTRS (80%)	3386	-0.3%	17760	-1.0%	14526	53.6%	14373	53.9%	10672	0.0%
G-WTRS (90%)	3386	-0.3%	17764	-1.1%	12469	60.2%	12301	60.5%	10672	0.0%

Due to the same equipment and assumptions for the waste water generating facilities at both the 300 and 1000 PAX camps, the ratio of black water to gray water is roughly equal, which results in near identical proportional waste water savings at both camp sizes after integrating a gray water recycling system. This waste water reduction surpasses 53% at the both the 300 PAX and 1000 PAX Base Camps using the Army regulated 80% processing efficiency, meaning implementing either technology would meet the SLB-STO-D's goal of a 50% reduction in waste water.

Potable water savings at the 300 PAX and 1000 PAX Base Camps were 52.1% and 53.6%, respectively, under the Army regulated 80% processing efficiency. This equates to a 79.6% and 79.3% reduction in the potable water used by the showers and laundry facilities at the 300 PAX and 1000 PAX Base Camps, respectively. As expected, this reduction approaches the processing efficiency of the gray water systems. Additionally, gray water recycling demonstrates an advantage over other water saving measures in that there is no cost to QoL(O).

Figure 19 shows the potable water usage by camp level function before and after gray water recycling at the 300 PAX Base Camp. Following the implementation of gray water recycling, the *Provide Latrine Services* camp level function becomes the biggest consumer of potable water on the base camp. A similar trend is seen on the 1000 PAX Base Camp. This functional area should likely be the next focus for water reduction to meet to the SLB-STO-D's goal of a 75% reduction in potable water use on the base camp.

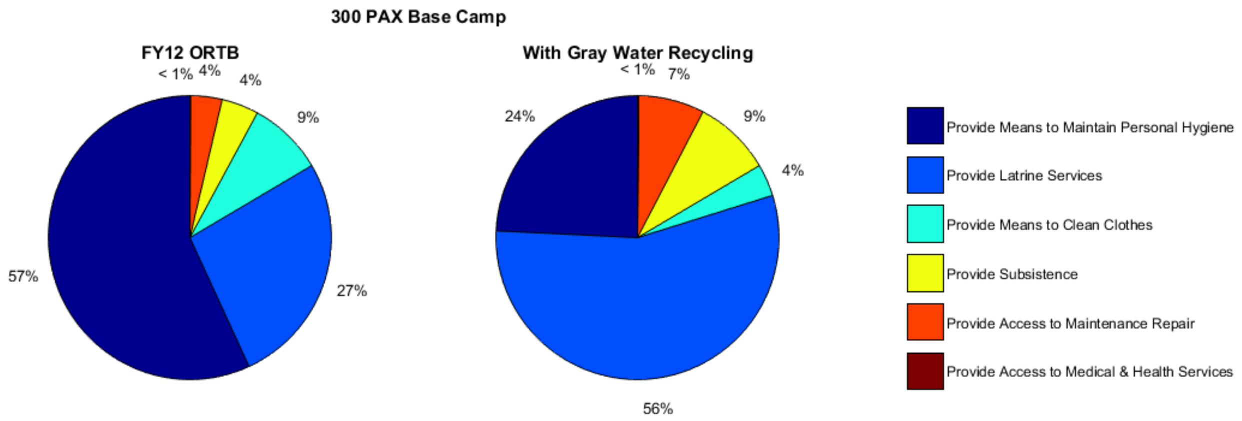

Figure 19. Potable Water Use by Camp Level Function with and without Gray Water Recycling, 300 PAX Base Camp

Additionally, as expected, the potable water savings and waste water reduction at the 1000 PAX Base Camp is near identical with either the FORO or the G-WTRS when the processing efficiency is held constant at 80%. The minor difference between the two runs corresponds to the number of systems and tanks. The gray water recycling systems operate on a batch process. Therefore, a certain amount of water is always left in the various tanks on camp until enough gray water is generated to run the batch. The water left over in the various tanks creates the minor difference in waste water between the two runs.

The power increase to achieve the potable water savings and waste water reduction was minor at both base camps ranging from 1.0–1.2% in the desert environment. This resulted in a small increase in fuel from the increased power production. At the 1000 PAX Base Camp, the G-WTRS proved slightly more efficient in terms of power, however this equated to only a 2 gal per day difference in fuel consumption.

Since the water usage (and therefore waste water generation) assumptions do not vary across environments, the potable and waste water savings are identical across all environments simulated. Like all water systems, however, the FORO and G-WTRS necessitate a cold weather kit to prevent freezing. This is most evident in the temperate environment, where power consumption increased 1.5–3.2% in the FORO scenario and approximately 3.0% in the G-WTRS scenario. This equated to a less than 1% increase in fuel consumption across all camp sizes and scenarios.

While the fuel increase was minor, this demonstrates the importance of choosing the appropriate number of systems. The power used by the gray water recycling systems is in direct proportion with the amount of gray water to be processed. Adding additional systems results in each system being utilized less and therefore only a minor overall increase due to parasitic loads. The cold weather kit scales linearly with the number of systems deployed, regardless of use. Therefore, deploying more systems than necessary has an adverse impact of fuel usage in cold weather climates.

Integration would be easier if the number of systems was increased. To investigate the impact of increasing systems on fuel consumption, a single FORO was implemented behind each pair of showers and behind the laundry facilities. In the temperate environment, the increase in the number of systems equated to a net increase in power consumption of 0.9% at the 300 PAX Base Camp and 1.4% at the 1000 PAX Base Camp over using the minimum number of systems. In either case, however, the additional fuel consumed by the added systems was less than 0.3%. Thus, additional fuel consumption is an unlikely reason to limit the system count. Limiting the system count may still be desirable for other reasons, including system cost, maneuverability, and maintainability.

The simulation results may underestimate the fuel savings of the system in cold weather climates. Eliminating over 53% of the waste water in near real time drastically reduces the number of waste water bladders necessary for storing waste. At the 1000 PAX, it would require eleven 3,000 gal bladders a day to store all the waste water. This number is reduced to less than five per day with gray water recycling. In a cold weather climate where these bladders must be prevented from freezing, a reduction in bladder count would equate to a reduction in power and a fuel savings from reduced cold weather kit.

The results discussed previously all assume a processing efficiency of 80%. This is the maximum recycling efficiency allowed by current Army regulation. Both the FORO and the G-WTRS have demonstrated recycling efficiencies above 80%. Simulations were performed using the higher recycling rates to determine their impact on the camp’s resource consumption.

Power consumption increased negligibly when the processing efficiency was increased. This increase was due to the additional water pumped to and from the gray water recycling systems. This power increase did not translate to a perceptible difference on camp-wide fuel usage.

Potable water savings when using the FORO increased an additional 5.2–5.3% across both base camps. The G-WTRS increased potable water savings an additional 6.6%. Waste water was decreased by similar quantities.

Overall, while recycling at the regulation maximum of 80% drastically decreased the amount of potable water consumed and waste water generated by the showers and laundry, simulations reveal that the potential savings to be gained by increasing the efficiency are still considerable—over 2000 gal per day at the 1000 PAX Base Camp. While these efficiencies have not yet been proven safe, continued focus on this area would likely be warranted. The proposed research could include determining if the recycled water from these systems continues to meet Military Field Water Standards at higher processing efficiencies. It could also include investigating the level of make-up water necessary to dilute the recycled water to acceptable levels and potential lower-class non-potable uses (e.g., toilet flushing) for the recycled water.

Gray water recycling proves to be a key technology in meeting the SLB-STO-D goals of a 75% reduction in potable water usage and a 50% reduction in waste water generation. Even when restricted to Army regulatory efficiencies, gray water recycling single-handedly meets the waste water goal and achieves over two thirds of the potable water savings desired. This comes at a very low fuel cost and no decrease to soldier QoL(O).

3.3.3.2 Waste Water Treatment

Waste water treatment systems utilize an array of technologies and methods to process waste water into a product stream that is suitable for onsite disposal. In contrast to the gray water recycling systems discussed in **Section 3.3.3.1**, waste water treatment systems are capable of processing both gray and black water but only for the purposes of onsite disposal, not for reuse. Black water is "wastewater discharged from toilets and urinals containing concentrated human wastes and water from kitchen preparation areas containing concentrated food wastes." [29] This includes the latrine sink usage due to the combining of liquids in the waste water tank attached to the latrine. Gray water is generated primarily by the showers and laundry facilities.

At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, respectively, 8,529 and 31,153 gal per day of waste water are generated. Reducing the logistical burden of removing this liquid waste from the base camp is key to meeting the SLB-STO-D's goal of a 50% reduction in waste generation/backhaul.

Waste water is currently required to be either backhauled by convoy, disposed of by local contractors, or disposed of onsite using methods such as lagoons. Waste water treatment eliminates the need for costly backhaul or dependence on foreign nationals by enabling onsite discharge and ensures waste water is treated to applicable standards at the cost of increased fuel usage. The tradeoff between waste water reduction and the fuel necessary to process it to accomplish that reduction is examined below.

Five technologies were investigated for their suitability in contributing to the SLB-STO-D's target waste water savings of 50%. For complete descriptions of the technologies, see **Annex C**. These technologies included the following:

- Mobile Bioelectric Filtration System (MBFS) – An activated sludge process combined with a bio-electrochemical system that enables electricity production during waste water treatment.
- TRICON Deployable Baffled Bioreactor (dBBR) – A modified activated sludge process with increased efficiency and performance over conventional systems.
- Wastewater Electrochemical Treatment Technology (WETT) – Based on a series of electrochemical unit operations, the WETT requires no chemical or biological treatment of waste water. It is capable of treating waste water immediately upon system startup.
- Expeditionary Black Waste Treatment Technologies (EBWT) – A prototype black waste reduction system capable of separating, drying, and burning waste, while efficiently using energy recapture.
- Deployable Aerobic Aqueous Bioreactor (DAAB) – A fixed film reactor capable of complete digestion of waste using bio-augmentation to optimize the growth of healthy biofilms. It is capable of treating waste water with 24 h of system startup.

A comparison of the resource flows of the various technologies is included in **Table 53**. Technologies were down selected based on their performance against SLB-STO-D program goals, their applicability to the SLB-STO-D base camp, and the current plans of the sponsoring organization.

Table 53. Comparison of Resource Flows, Waste Water Treatment

Technology	Average Power (kW)	Peak Power (kW)	Waste Water In (gal/h)	Waste Water Out (gal/h)	Product Water Out (gal/h)	Processing Efficiency	Power Efficiency (gal/h/kW)
MBFS[*]	0.3	0.6	19.6	Unk	5.2	27%	19.3
dBBR[†]	0.4	2.1	125.0	12.5	112.5	90%	281.3
WETT[‡]	Unk	30.0	51.6	2.6	49.0	95%	Unk
EBWT[§]	Unk	Unk	Unk	Unk	Unk	100%	50.0
DAAB[¶]	1.3	<10.0	1136.4	11.4	1125.0	99%	839.6

[*] Source: Measured demonstration data

[†] Source: Measured demonstration data (power) [9]; Specifications (all others)

[‡] Source: Specifications [64] [65], hourly rates based on an assumed 22 h of operation per day

[§] Resource flows unknown at time of publication, efficiency based on effort objective

[¶] Source: Publicly available data [66], hourly rates based on an assumed 22 h of operation per day

Three of the five technologies reviewed (MBFS, dBBR, and WETT) were sponsored by the TARDEC. Discussions with an SME from TARDEC concluded that the dBBR system was the most mature activated sludge system. This system also performed significantly better than the MBFS during SLB-STO-D's demonstrations.

TARDEC also noted that during testing the WETT system was near equally efficient at processing waste, albeit at a higher power consumption. The WETT system has the additional benefit of requiring no startup time in comparison to the dBBR system, which can process waste within 24 h only if seeded with over 500 gal of activated sludge. The dBBR startup without sludge depends on temperature and influent concentration, but is estimated to be up to 10 days in the winter. In contrast, the WETT system is not affected by toxic compounds such as grease and oil that may prove problematic to the dBBR biological based system.

The EBWT was sponsored by NSRDEC. The EBWT system was not considered due to lack of information at the time of publication.

The DAAB system, developed by the U.S. Army Corps of Engineers ERDC Environmental Lab is a significantly larger system, with a single system nearly capable of processing all waste water from the FY12 ORTB 1000 PAX. Due to the size of the system, however, it would be unlikely to integrate into the existing base camp without significant modification. A single system for the entire base camp would require all black water producers to be within pumping distance of the treatment plant. Further, the size of the system would make it oversized for the 300 PAX camp. For this reason, the DAAB was not selected as a good fit for the particular use-case of the SLB-STO-D.

While there is a capability tradeoff between the technologies analyzed, the dBBR was chosen for modeling as it best aligned with the SLB-STO-D's program goals and use case. The other likely candidate system, the DAAB, would not scale well for the SLB-STO-D's use case.

Two integration scenarios were investigated through simulation. In the first scenario, the waste water treatment system was sized to treat only black water, primarily from the latrines and kitchens. This represents a typical setup at a camp where another system, such a gray water recycling system, is used to process gray water. The combination of the two systems is investigated further in **Section 4.1.4**.

In the second scenario, the waste water system is sized to treat all waste water (i.e., both black and gray). This would maximize the amount of waste water disposed of onsite and provide the greatest reduction in the waste backhaul requirement.

The integration of waste water systems in a base camp not previously designed for waste water treatment highlights issues with system right-sizing and camp layout. In an ideal scenario, waste water would not be transported around the camp using vehicles, which would necessitate dedicated waste water tanks for that purpose. Instead, waste water would be pumped from its source to a treatment area, which limits the distance between the generating facility and treatment system. For this reason, waste water treatment systems are ideally sized according to the systems that feed them.

For example, the dBBR can treat 2,750 gal per day. At the FY12 ORTB 1000 PAX Base Camp, which includes 20 ELS units configured in pairs, each pair of latrines generates less than 1,200 gal per day of black water under the Population Variance use case. Even with the increased population, the waste water system is significantly oversized for the camp's current layout. To minimize the number of systems required, the facilities that generate waste water must be located in sets within pumping distance of each other and sized to maximize the waste water treatment system's capabilities. In this case, laying out the camp to have sets of four latrines would make integration of the waste water system much easier. Co-locating facilities poses distinct issues with treating kitchen and aid station water because both facilities are generally segregated from latrines. Biological waste water treatment systems such as the TRICON dBBR require a minimum inflow of waste water to sustain their bacterial colony. Since neither facility generates enough waste water to satisfy this minimum processing rate, the kitchens and aid station must be within pumping distance of a larger waste water generator.

Since the 50 PAX camp uses burn-out latrines, provides for laundry done by hand, and does not include shower facilities, a full-scale waste water treatment system could not be integrated. The only source of collected waste water on the camp is from the hand wash stations, which would not provide enough waste water to utilize a dBBR.

At the FY12 ORTB 300 PAX Camp, 2,818 gal per day of black water are generated in the Ready State use case (3,666 gal per day for the Population Variance scenario). Since the dBBR can treat 2,750 gal per day, either scenario requires two waste water treatment systems to treat all the black water generated on the camp. These systems were placed near the two sets of latrines on the camp. Waste water from the kitchen is assumed to be pumped to the nearest dBBR.

If the waste water system is sized to treat all waste water (i.e., both black and gray water), a total of four waste water treatment systems is required. This provides a higher capacity than necessary in the Ready State and would be just under capacity in the Population Variance use case, which would require 4.04 systems. It is assumed that since the population increase happens for a short period of time (1 week), any excess waste water is stored for processing when the camp population returns to Ready State. This storage requirement would be approximately 100 gal per day during the population increase. The four systems were placed near the latrines and showers, the largest producers of waste water.

At the FY12 ORTB 1000 PAX Camp, 9,997 gal per day of black water are generated in the Ready State use case (12,851 gal per day for the Population Variance scenario). Since right-sizing for the Ready State and under sizing for the Population Variance would require an increase of black water storage capacity of approximately 1,850 gal per day of the population increase, five systems were integrated: enough to treat all black water generated during the population increase. Since the camp includes 20 latrines total (in 10 pairs), a single system was integrated for each set of 4 latrines (2 pairs). To achieve this, several sets of latrines would likely need to be moved within the camp to be in closer proximity to each other.

Similarly, the integration plan for treating all waste water on the 1000 PAX camp was designed around the Population Variance use case, which required nearly 15 systems to the Ready State's 12. Since the showers generate more waste water than the latrines, the systems were generally placed nearer the showers or locations with four latrines in close proximity. The isolated latrines not located near showers or other latrines would likely have to be moved to connect to the systems.

Table 54 shows the results of the simulation of the two integration scenarios across the different base camp sizes in the desert environment. As seen in the table, there is a minor increase in power at both the 300 PAX and 1000 PAX camps under both scenarios. This power increase is entirely attributable to powering the waste water treatment system. Similarly, the fuel consumption shown is entirely attributable to the increase in generator fuel consumption to power the system.

Table 54. Mean Daily Camp Level Summary, Waste Water Treatment, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
300 PAX Camp										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
dBBR, Black Water Only	1043	-0.1%	5123	-0.3%	8723	0.0%	6020	29.4%	2870	0.0%
dBBR, All Waste Water	1044	-0.2%	5152	-0.9%	8723	0.0%	912	89.3%	2870	0.0%
1000 PAX Camp										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
dBBR, Black Water Only	3379	-0.1%	17632	-0.3%	31305	0.0%	22238	28.6%	10672	0.0%
dBBR, All Waste Water	3385	-0.3%	17738	-0.9%	31305	0.0%	3357	89.2%	10672	0.0%

Due to the same equipment and assumptions for the shower and latrine facilities being used at both the 300 and 1000 PAX camps, the ratio of black water to gray water is roughly equal, which results in near identical proportional waste water savings at both camp sizes. The waste water reduction in the scenario in which all waste water was treated reached 89%, approaching the dBBR's efficiency of 90%. The waste water treatment system operates on a batch process. Therefore, a certain amount of water is always left in the various waste tanks on camp until enough waste water is generated to run the batch.

Since the water usage and therefore waste water generation assumptions do not vary across environments, the waste water savings are identical across all environments simulated. Like all water systems, however, the dBBR necessitates a cold weather kit to prevent freezing. This is most evident in the temperate environment, where power consumption increased 2-3% in the black water only scenario and approximately 5% in the all waste water scenario. This equated to a less than 1% increase in fuel consumption across all camp sizes and scenarios.

While the fuel increase was minor, this demonstrates the importance of choosing the appropriate number of systems. The power used by the waste water treatment systems scales with the amount of waste water to be processed. Adding additional systems results in each system being utilized less and therefore only a minor overall increase in power due to parasitic loads. The cold weather kit scales linearly with the number of systems deployed, regardless of use. Therefore, deploying more systems than necessary has an adverse impact on fuel usage in cold weather climates.

The simulation results may underestimate the fuel savings of the system in cold weather climates. By eliminating up to 89% of the waste water in near real-time, this drastically reduces the number of waste water bladders necessary for storing waste. At the 1000 PAX, it would require eleven 3,000 gal bladders a day to store all the waste water. This number is reduced to two per day with waste water treatment. In a cold weather climate where these bladders must be prevented from freezing, a reduction in bladder numbers would equate to a reduction in power and a fuel savings from reduced cold weather kits.

While black water treatment systems pose integration challenges on previously deployed camps, those challenges are largely overshadowed by the significant reduction in waste water at a minimal fuel cost.

3.3.3.3 Black Water Recycling

Black water recycling is the next logical step after black water treatment, extending the concept of treatment to reuse rather than disposal. There are many regulatory, doctrinal, and technical challenges to implementing black water recycling on a base camp. This section assumes these challenges have been resolved and analyzes one conceptual implementation of black water recycling using a theoretical application of existing technologies.

While there are currently many municipality-scale black water recycling programs, current Army regulation states that “Black wastewater may not be recycled or reused. It must be treated and/or disposed of in a sanitary manner.” [29] Since black water accounts for 32-33% of all collected waste water at the FY12 ORTB 300 and 1000 PAX Base Camps, recycling this water would have a significant impact on both the camp’s waste water disposal requirement and reducing the amount of potable water transported to the camp.

Previous research by the US Army Corps of Engineers ERDC-CERL reviewed the state of waste water recycling and the policy impacts it has at Continental United States (CONUS) Army installations. This research noted that water reuse for purposes such as irrigation, dust control, and vehicle washing is already being practiced on many CONUS Army installations [67].

Typical municipal wastewater recycling programs implement indirect potable reuse, where the recycled water is returned to recharge groundwater aquifers or augment surface water sources [68]. In contrast to these systems, a black water recycling capability at a forward operating base would necessitate direct reuse, where the recycled product water is immediately reused without an environmental buffer. Direct reuse has been proven feasible at the municipal level with the Winhoek, Namibia water recycling plant [69]. Direct reuse at base camps would provide finer control over the usage of the recycled water, which would allow for the recycled water to be used only for non-potable needs, such as dust suppression or vehicle washing.

In consultation with SMEs from TARDEC, a conceptual implementation to demonstrate a black water recycling capability at a forward operating base was developed as shown in **Figure 20**. Like municipal implementations, the modeled system includes a set of redundant filtration systems. This implementation includes a modified TRICON dBBR (see **Section 3.3.3.2**) to pretreat black water. The TRICON dBBR is assumed to consume 20% more power due to the additional filtering that would be required. The FORO (see **Section 3.3.3.1**) is used to recycle gray water and serves as a secondary filter for the pretreated black water stream. The byproduct from the gray water system is processed by a separate TRICON dBBR, which minimizes the amount of wastewater required for backhaul or contractor disposal.

Water quality monitoring is a critical technological hurdle that needs to be accomplished to ensure the product water meets Military Field Water Standards to enable reuse [44]. Currently-fielded water quality testing equipment such as the WQAS-P and current methods of water sampling require actions by Soldiers with specific MOS. Specialized Soldiers are in limited supply, particularly at smaller base camps, leading to long sampling times and increased risks. These risks are exacerbated with black water recycling systems, since failure to properly treat the black water source could lead to dangerous contamination. Enhancements to water quality monitoring technologies (see **Section 3.2.3.1**) aim to mitigate risk by making water quality monitoring portable, instantaneous, and easier to be performed by Soldiers without a specialized technical background. These technologies would play a vital role in implementing black water recycling at base camps. Due to the minimal resource impact of water quality monitoring (i.e., a very small increase in power), the water quality monitors were not included in the model.

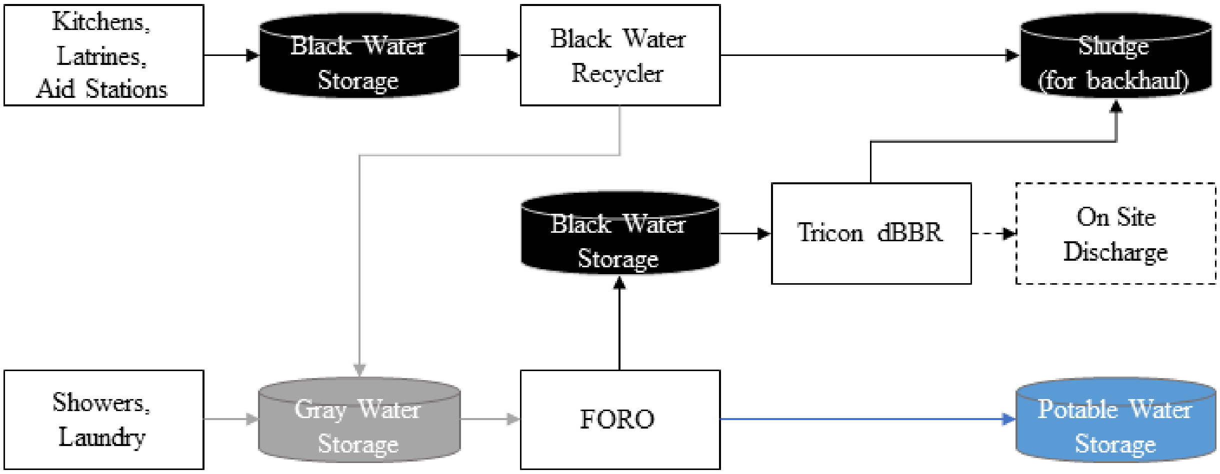

Figure 20. Diagram of Black Water Recycling Conceptual Implementation

Since the 50 PAX base camp uses burn-out latrines, provides for laundry done by hand, and does not include shower facilities, a full-scale wastewater treatment system could not be integrated. The only source of collected wastewater on the camp is from the hand wash stations, which would not warrant the use of a black water recycling system.

Since the focus of this analysis was on potential potable water and wastewater savings, the integration of systems in the FY12 ORTB 300 PAX and 1000 PAX Base Camps was simplified. A black water recycling system was placed with each pair of Expeditionary TRICON Latrines (3 total at the 300 PAX base camp and 10 total at the 1000 PAX base camp). Similarly, a FORO was added behind each pair of Expeditionary Shower Systems (3 at the 300 PAX base camp, 10 at the 1000 PAX base camp). While fewer systems would be required if latrines were moved close to each other, the addition of extra systems does not impact the simulation results on potable water or wastewater. The added systems will show an increase in power consumption in the colder climates due to the additional cold weather gear. To treat the byproduct of the FORO, a single TRICON dBBR was added to the 300 PAX base camp and three TRICON dBBRs were added to the 1000 PAX base camp.

Table 55 shows the results of the simulation of the scenario across the different base camp sizes in comparison to implementing a combination of gray water recycling and wastewater treatment for onsite disposal. As seen in the table, there is a minor increase in power at both the 300 PAX and 1000 PAX base camps under both scenarios. This power increase is entirely attributable to powering the wastewater treatment systems. Similarly, the fuel consumption shown is entirely attributable to the increase in generator fuel consumption to power the systems.

Table 55. Mean Daily Camp Level Summary, Black Water Recycling, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Black Water Recycler	1048	-0.6%	5216	-2.1%	2186	74.9%	523	93.9%	2870	0.0%
dBBR & FORO (80%)	1047	-0.5%	5189	-1.6%	4176	52.1%	467	94.5%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Black Water Recycler	3396	-0.6%	17970	-2.2%	7395	76.4%	1872	94.0%	10672	0.0%
dBBR & G-WTRS (80%)	3389	-0.4%	17833	-1.4%	14526	53.6%	1685	94.6%	10672	0.0%

Table 55 shows a wastewater reduction of 93.9% and 94.0% compared to the FY12 ORTB 300 and 1000 PAX Base Camps, respectively. This reduction is 0.6% smaller than the wastewater reduction achieved by implementing separate gray water recycling and black water treatment for onsite disposal. As shown in **Figure 20**, the black water stream in the recycling implementation goes through both the black water recycler for pretreatment, which rejects 10% of the influent, and the FORO, which rejects another 20% of the remaining stream. The second reject stream is further reduced by the TRICON dBBR. This net effect of the dual processing of black water for recycling is a small increase in total reject water.

The notable savings of using black water recycling come in the reduction of potable water demand. By implementing a black water recycling capability, potable water demand was decreased by 74.9–76.4% across the two base camp sizes. This is a net increase of 22.8% over recycling gray water alone.

Similar to wastewater treatment systems, black water recycling provides additional savings by reducing the number of wastewater bladders necessary for storing waste. At the FY12 ORTB 300 PAX Camp, based on a 3-day resupply, nine 3,000 gal bladders are required to store all the wastewater. This number is reduced to less than one with waste water treatment. At the FY12 ORTB 1000 PAX Camp, there is a similar reduction from 32 3,000 gal bladders to less than 2. In a cold weather climate where these bladders must be prevented from freezing, a reduction in bladder numbers would equate to a reduction in power and a fuel savings from reduced cold weather kits.

In the simulated implementation, the recycled black water and gray water streams were mixed. With minimal reconfiguration and extra equipment, the streams could be processed separately, allowing for finer control over the use of the recycled black water. If separated, the additional water available for reuse with black water recycling would be enough to supply all toilet and urinal flushing needs as well as offset a portion of the water required for vehicle washing.

Following the implementation of a gray water recycling system, the latrines become the single largest consumer of potable water and producer of wastewater. While current Army regulation does not allow for the reuse of black water, the potential savings could amount to an additional 22.8% decrease in potable water, if regulatory restrictions could be overcome.

3.3.4 Provide Integrated Solid Waste Management

Solid waste reduction can be achieved by reducing the amount of solid waste that is generated or by treating the solid waste to reduce the disposal requirement. The ORTB determined that 54% of the solid waste generated on the FY12 ORTB 300 PAX and 1000 PAX Base Camps comes from field feeding. Options to reduce the solid waste generated from field feeding are discussed in **Section 3.3.2**. Treatment of solid waste includes options to reduce the quantity of waste required to be backhauled from the camp after it is generated, namely through various forms of thermal processing (e.g., combustion, gasification, and pyrolysis).

At the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps, respectively, 266, 2,870 and 10,672 lb per day of solid waste are generated. Reducing the logistical burden of removing this solid waste from the base camp is key to meeting the SLB-STO-D’s goal of a 50% reduction in waste generation/backhaul.

Four technologies and one field expedient method were investigated for their suitability in contributing to the SLB-STO-D’s target solid waste savings of 50%. For complete descriptions of the technologies, see **Annex C**. These potential solutions included the following:

- Expeditionary Waste Mitigation Box (Xw-Box) – A prototype solid and liquid waste disposal system that gasifies mixed solid waste and uses the resulting gas to power a black water incinerator.
- Open-Air Burn Pit – An area for the combustion of waste common in Outside CONUS (OCONUS) sites such as Iraq and Afghanistan, which often use ad hoc accelerants common to the base camp such as diesel fuel or JP8.
- Solid Waste Destruction System (SWDS) – Prototype systems for the treatment of solid waste at small contingency bases using technologies that reduce fuel consumption over traditional incinerators.
- Solid Waste Incinerator – Small-scale incinerators designed for contingency base operations that apply engineering controls and multiple burn stages to combust waste and control emissions.
- WEC – A prototype system to treat solid waste using gasification while simultaneously exporting electrical power to reduce the energy requirements of the camp.

Technologies were analyzed based on their performance against SLB-STO-D’s program goals, their applicability to the SLB-STO-D base camp, and the current plans of the sponsoring organization.

Three of the four technologies reviewed (Xw-Box, SWDS, and WEC) are projects sponsored by NSRDEC. Discussions with SMEs from NSRDEC concluded that the SWDS and WEC systems were the most mature options to investigate.

The WEC system currently under review by NSRDEC was demonstrated at Fort Benning, GA in the winter of 2016. The system is designed for battalion-scale contingency base camps and is capable of both treating solid waste and exporting power back to the power grid.

The SWDS project reviewed two candidate systems based on competing technologies, both designed to handle solid waste at small contingency base camps. One system uses a rotary pyrolysis and downdraft gasifier while the other uses a self-powered Ward Furnace combustor. Both prototypes are designed to use minimal fuel and power in the treatment process. According to NSRDEC SMEs, the Ward Furnace combustor was the more mature technology, so it was chosen as the SWDS candidate.

While the Xw-Box system is designed to provide a unique solution to treating both solid and liquid waste, the prototype system did not meet performance objectives and no follow-on work is currently planned. For this reason, the Xw-Box was not considered for this analysis.

Solid waste incineration is currently being considered as a viable option for handling solid waste at forward operating bases. This includes a planned purchase of an Expeditionary Solid Waste Disposal System (ESWDS) by PM FSS. The system chosen for modeling was a BICON-sized version previously evaluated by the National Defense Center for Energy and Environment (NDCEE) [70].

The field expedient open-air burn pit remains an option of last resort at contingency base camps Current army policy on open-air burning notes that "open-air burn pits should be a short-term solution during contingency operations where no other alternative is feasible. For the longer term, incinerators, engineered landfills, or other accepted solid waste management practices shall be used whenever feasible" [71]. The reported health impacts of exposure to burn pit smoke are considerable with research continuing into the long-term impacts of exposure [72].

The options for solid waste management varied considerably in both design and maturity. Since open-air burn pits are an existing option at base camps and solid waste incinerators are a planned addition, both were considered in the analysis. Both the SWDS and WEC were considered as potential future technological enhancements.

The burn pit required no additional considerations for integration. It is assumed that instead of transporting waste from its point of origin (e.g., dining tents, MWR) to a waste management yard, it is instead redirected to the burn pit location. Since the burn pit would scale with the amount of waste generated, only a single burn pit would be needed regardless of camp size.

Integration of the SWDS and incinerators was similar, with all being located on the outer margins of the base camp. This allows waste processing to occur away from habitation and dining facilities. At all camps, the incinerators and SWDS were powered by existing generators that were not fully loaded. The number of SWDS and incinerators was calculated to be oversized for the ORTB Ready State use case, but generally undersized for the Population Variance use case. The overcapacity would allow the waste management systems to catch up within 1 week, when the population returned to steady state.

One key difference between the technologies that accounted for the considerable difference in system counts is the cool down period. The incinerator modeled has a cooldown period of 6 h after each combustion period, which is typical of incinerators of its type. This is why incinerator throughput is largely dependent on the system's chamber size, which is constrained by the container size of the system (the system modeled fits in a BICON container). The SWDS, however, benefits from not cooling down. It expends the most fuel while warming up and keeping this startup time to a minimum keeps fuel consumption low. Therefore, by not significantly oversizing the number of SWDS units and keeping them in use, the fuel consumption is reduced.

Table 56 shows the system counts for the various solid waste management systems analyzed. As shown, up to 19 incinerators would be required to handle the solid waste generated at the three base camps. The U.S. Army Public Health Command has found that while the modeled emissions of a single incinerator unit of this type are able to dispose of a typical waste stream at a deployed location without exceeding exposure guidelines, the use of multiple co-located units requires further investigation. In either case, the incinerator with pollution controls was recommended over the use of an open-air burn pit [73].

Table 56. System Counts, Integrated Solid Waste Management

Base Camp	Open-Air Burn Pit	Incinerator	SWDS	WEC
FY12 ORTB 50 PAX Camp	1	1	1	-
FY12 ORTB 300 PAX Camp	1	6	3	1
FY12 ORTB 1000 PAX Camp	1	19	11	2

Integration of the WEC was complicated by the WEC's power output of approximately 75 kW. This output was modeled based on the projected performance of the prototype system and had not been successfully demonstrated at the time of this analysis. Using all the power generated by the WEC would require an average load of 75 kW at all times. The FY12 ORTB base camps include generators no bigger than 60 kW, with average loads significantly lower than that. For this reason, the WEC was integrated on a camp with six 60 TQG microgrids, which enables higher average loads. Even while using microgrids, most grids did not have an average hourly power consumption of 75 kW at all times. Therefore, the WEC was integrated with an energy storage system[11] that would absorb any overproduction of power and allow it to be used at a later time. While connecting the WEC into a battery enabled integration, it did add losses from the inverters, controllers, and batteries. This was considered an acceptable tradeoff to enable integration. The integration of the battery into the microgrid was basic, allowing only for battery power to be used prior to generator power and not including an algorithm to optimize peak shaving, for example. Even with the inclusion of a large format battery, the WEC was considered much too large and immobile for a 50 PAX base camp.

The WEC's required connection to a grid also limits its geographic placement on the camp. Similarly to the SWDS and incinerators, the WECs were located on the outer edges of camp. The line distance from the WEC to the energy storage system (located with the microgrid) was limited to 300 ft to prevent unacceptable voltage loss. This is based on a similar requirement that the distance from generator to load be no greater than 300 ft [32, pp. 0001-3]. This limited which microgrids could be connected to the WEC. A more robust transmission system allowing the

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[11] The energy storage system modeled was based on a TRICON-sized system previously tested by Sandia National Laboratories and demonstrated at the BCIL at Fort Devens, MA [79].

WECs to be placed further from the energy storage system would have enabled the use of the power in a more effective manner and would have enabled placing the WECs farther from the dining and habitation facilities.

Table 57 shows the results of the simulation of the integration scenarios across the different base camp sizes. The amount of solid waste at the end of the simulation depends on the composition of the waste (i.e., combustible versus noncombustible) and the destruction efficiency of the technology. The FY12 ORTB 300 and 1000 PAX Base Camps have an identical waste makeup due to the identical field feeding plan. The FY12 ORTB 50 PAX Base Camp includes less noncombustible waste in the solid waste makeup. The simulator assumes that all waste is distributed evenly to all waste management technologies and that each technology turns on when a preset amount of waste is present. The small difference in solid waste remaining at the FY12 ORTB 300 and 1000 PAX Base Camps is due to the varying number of systems on each camp, allowing for left over waste to be present in more locations while not triggering the waste management technology to run the next batch. As the camp is assumed to be present for a long period of time at the same location, eventually all waste would be processed and the efficiencies would be identical.

The three technologies analyzed all showed similar destruction efficiencies. While the open-air burn pit showed a higher destruction efficiency, this was due to the assumption that unburned waste, char, and ash in the pit were left on site. All technologies assumed that the remaining solid waste was disposed of in an environmentally conscientious manner via backhaul or other methods. NSRDEC SMEs confirmed that the char and ash residue from the WEC prototype was more than a typical incinerator or SWDS, since the gasification process will inherently leave some char. It was also noted that the SWDS and incinerator would likely have very similar destruction efficiencies in any fieldable version. The incinerator upon which the model was based during the demonstrations was observed to be less efficient at reducing the weight of solid waste than a competing model, explaining the higher amount of solid waste remaining at the end of the simulation [70, p. 272]. Ultimately the amount of solid waste remaining after processing did not vary enough to allow the ability to choose a technology based solely on destruction efficiency. The amount of fuel used to achieve this destruction efficiency is the key metric.

Table 57. Mean Daily Camp Level Summary, Integrated Solid Waste Management, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
50 PAX Camp										
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Open-Air Burn Pit	217	-0.9%	1007	0.0%	75	0.0%	27	0.0%	3	98.8%
Incinerator	232	-7.9%	1009	-0.2%	75	0.0%	27	0.0%	27	89.9%
SWDS	217	-0.9%	1013	-0.6%	75	0.0%	27	0.0%	18	93.2%
Microgrid, Geographically Constrained	-	-	-	-	-	-	-	-	-	-
WEC	-	-	-	-	-	-	-	-	-	-
300 PAX Camp										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Open-Air Burn Pit	1062	-1.9%	5108	0.0%	8723	0.0%	8529	0.0%	352	87.7%
Incinerator	1200	-15.2%	5134	-0.5%	8723	0.0%	8529	0.0%	574	80.0%
SWDS	1059	-1.6%	5169	-1.2%	8723	0.0%	8529	0.0%	499	82.6%
Microgrid, Geographically Constrained	614	41.1%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
WEC	570	45.3%	4416	13.6%	8723	0.0%	8529	0.0%	561	80.5%
1000 PAX Camp										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Open-Air Burn Pit	3448	-2.1%	17580	0.0%	31305	0.0%	31153	0.0%	1292	87.9%
Incinerator	3962	-17.4%	17675	-0.5%	31305	0.0%	31153	0.0%	2120	80.1%
SWDS	3437	-1.8%	17806	-1.3%	31305	0.0%	31153	0.0%	1835	82.8%
Microgrid, Geographically Constrained	1968	41.7%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%
WEC	1797	46.8%	14990	14.7%	31305	0.0%	31153	0.0%	2079	80.5%

Note: FY12 Baseline camps, as simulated, do not include any solid waste destruction equipment or methods

Of the options analyzed, only the open-air burn pit scaled well to all three base camp sizes. Since burning waste efficiently and completely is not the goal of a burn pit, it is to be expected that a minimal amount of fuel would be used as an accelerant to keep the fire going. Further, while large noncombustible materials such as cans from the dining facilities are assumed to be separated from the solid waste stream prior to combustion, unburned residual waste, char, and ash would likely be left in the burn pit and buried, leading to the least amount of solid waste to be disposed of the options analyzed.

The SWDS and incinerator are targeted toward the FY12 ORTB 300 PAX Base Camp, scaling down to the FY12 ORTB 50 PAX Base Camp, but requiring a considerable number of units to keep pace at the FY12 ORTB 1000 PAX Base Camp. The SWDS project was specifically targeted toward smaller base camps. The limiting factor for the incinerator is the system's physical size; the modeled system fits in a BICON container, limiting the size of the combustion chamber and throughput. Incineration technology could be scaled up in size to increase throughput and decrease the number of systems. Both the SWDS and the incinerator saw a small increase in power consumption from the systems, but the overall fuel consumption was dominated by direct consumption by the technologies, with very little attributable to the increase in power generation or the fuel delivery requirement to the added systems. Fuel consumption by the SWDS was significantly less than the incinerator across the three base camp sizes, with the incinerator using 8.8–9.6 times as much fuel as the SWDS.

In the simulation, the WEC is implemented on base camps with a geographically relevant microgrid in place. Therefore, the WEC's performance is best compared to the baseline camp with only the grid and no WEC. The WEC provides 13.6% and 14.7% of the power required in the desert environment at the FY12 ORTB 300 PAX and 1000 PAX Base Camps, respectively. While the WEC is a direct consumer of fuel, the net increase in fuel savings of 4.2% and 5.1% at the FY12 ORTB 300 PAX and 1000 PAX Base Camps in the desert environment, respectively, is from the significant decrease in generator hours due to exported power from the WEC.

Figure 21 shows the change in yearly generator hours (the cumulative hours each generator is running) when a WEC is added to the microgrids. At the 300 PAX Base Camp, the WEC saves 4,318 generator hours over the year. At the 1000 PAX Base Camp, the two WECs save a total of 17,461 generator hours over the year. The large proportional difference in performance is accounted for in the fact that each WEC is sized for approximately 500 personnel, making a single unit significantly oversized for the 300 PAX Base Camp and therefore unused for a considerable amount of time. At the 1000 PAX Base Camp, both WECs are operational near continuously and therefore produce more power. Counterintuitively, generating more waste on the base camp reduces the overall fuel required on the camp.

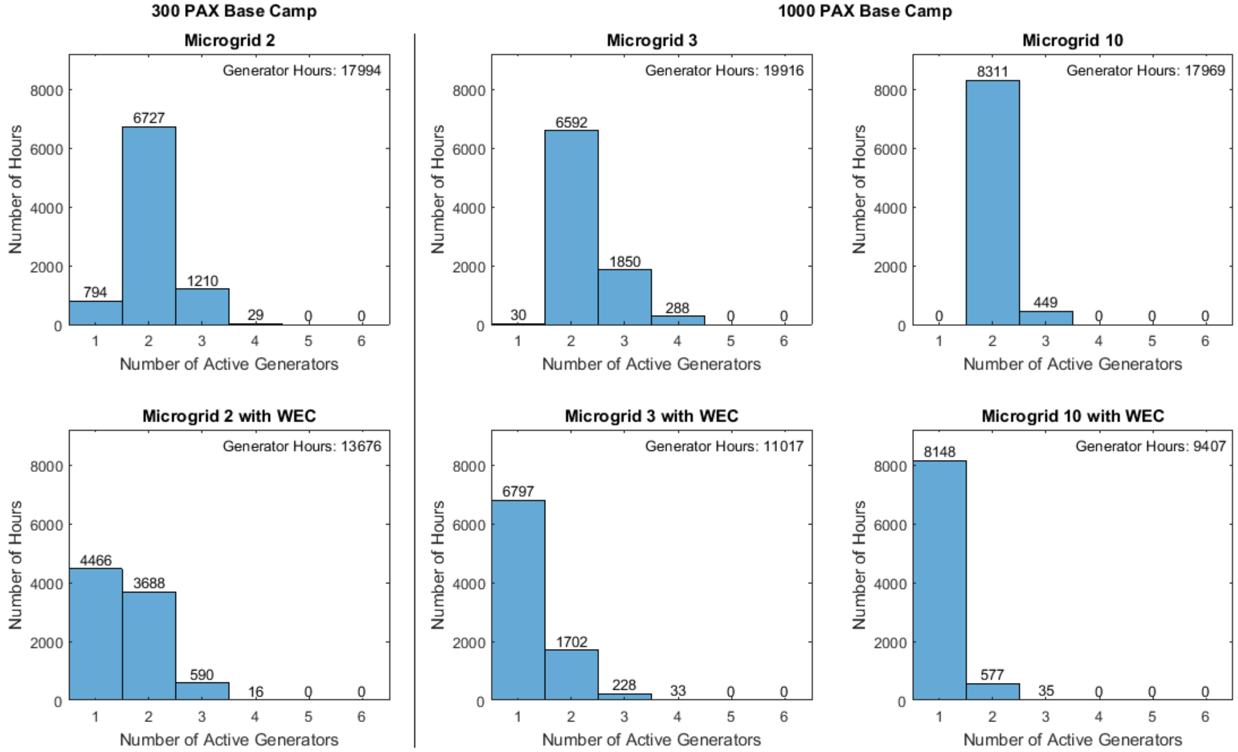

Figure 21. Generator Hours of Microgrids with and without WECs

Overall, the implementation of any of the integrated solid waste management technologies would achieve the SLB-STO-D’s objective of a 50% reduction in waste generation/backhaul. The fuel usage of the possible solutions varies widely, as do the environmental and potential health impacts. The WEC provides a unique capability of exporting power at the expense of added integration complexity. Both the SWDS and incinerator enable easier integration with an added fuel cost. The open-air burn pit is field expedient and requires no additional equipment, but has potential environmental and health concerns.

3.4 Summary of FWW Reduction Options

Numerous options were identified that could contribute to the SLB-STO-D's program objectives to reduce the need for fuel resupply by 25%, reduce the need for water resupply by 75%, and decrease waste generation/backhaul by 50% while maintaining QoL(O) at the base camp. Each option was examined individually to determine its impact on the program objectives and its potential contribution to an integrated solution that meets all the program objectives. Options analyzed included 61 technologies, 8 commercially available items, 4 currently fielded pieces of equipment, 3 field expedient options, and 10 non-materiel changes.

The objective of maintaining QoL(O) proved to be a significant constraint. All but one non-materiel option (reallocating generators according to TM 3-34.46) that successfully contributed to resource reductions also reduced the QoL(O) of the base camp. Similarly, all field expedient options (i.e., burn-out latrines, pipe urinals, and open-air burn pits) and one commercial option (chemical latrines) had a negative impact on QoL(O). Barring a possibility to offset the QoL(O) decrease (see **Section 4.4**), these options cannot be considered as potential solutions to SLB-STO-D's objective resource reductions.

At the FY12 ORTB Base Camps, 82.3–90.1% of all fuel is used to *Provide Electric Power*. Of the options analyzed, the implementation of microgrids proved the most effective, reducing fuel consumption by 39.1–41.7% across the three base camps. Spot generation technologies showed improved performance over the baseline equipment set, though some were hampered by integration challenges due to the layout and power distribution assumptions of the base camps. Additional options such as SCPL and changing the generator allocation strategy showed savings that could be applied to any new power generation technology. As microgrids were the single largest fuel saver across the three base camps and alone met the 25% fuel reduction goal, they are likely to form part of any integrated solution to meeting the SLB-STO-D's objective resource reductions.

Additional fuel reduction can be gained through power demand reductions. The largest reduction in demand was seen by addressing shelter technologies, which reduced power consumption 21.2–70.8% across the three base camps. This resulted in a fuel savings of 8.7–17.9% without including any savings from reallocating generators. Other options addressed areas of the camp that were smaller consumers of power, such as field feeding. While fuel reductions directly related to reduced demand in this area were small, the reduction in peak power draw enabled reallocation of power generation to reduce generator numbers, resulting in appreciable fuel savings.

Reducing the requirement for potable water resupply was similarly investigated on both the supply and demand side. On the supply side, methods to produce water, both using an existing water source such as a lake or well and using moisture in the air, were analyzed. Water purification technologies that enable the use of onsite water sources can provide all of a camp's bulk potable water needs with a small fuel cost. These systems do not align with the FY12 ORTB, which does not specify access to a water source; therefore, this option will not be considered in addressing the SLB-STO-D's resource reduction objectives. However, purifying water at a camp with access to a water source would be the least resource intensive option. The

WFA system, however, can apply to any base camp. The system's fuel consumption requires further demand side reductions to enable a reasonable number of systems to generate all required water.

On the demand side, the *Provide Means to Maintain Personal Hygiene* functional area (i.e., shower facilities and hand wash stations) accounted for 36.0–58.9% of all potable water consumption at the FY12 ORTB Base Camps. Addressing this area with low-flow showerheads saved 16.5–17.1% of potable water at the 300 PAX and 1000 PAX base camps. Altering the length of showers proved more effective at reducing potable water usage, albeit at the expense of QoL(O). Similarly, efforts to reduce water consumption in the *Provide Means to Clean Clothing* functional area by reducing laundry also resulted in decreased QoL(O). Upgrading washer technologies to polymer bead washers at the 1000 PAX base camp saved 2.9% of potable water. Addressing both of these areas with gray water recycling proved even more effective, resulting in a 52.1–53.6% decrease in potable water consumption and similar decrease in waste water production. Gray water recycling was the single biggest contributor to potable water savings identified, making it a key aspect of any integrated solution to meeting the SLB-STO-D's objective resource reductions.

The *Provide Latrine Services* functional area was the second largest consumer of potable water and second largest generator of waste water at the FY12 ORTB 300 PAX and 1000 PAX Base Camps, accounting for 26.6–28.3% of all potable water consumption and 28.7–29.9% of all waste water production. Numerous latrine options were analyzed. Only two, the MIL-TOILAT and LCTL did not lower the QoL(O) on the base camp. While the MIL-TOILAT was detrimental to resource consumption at the 50 PAX base camp since the base camp was equipped with field expedient burn-out latrines as a baseline, the LCTL reduced potable water consumption by 23.1–24.5% and waste water generation by 28.7–29.9% at the 300 PAX and 1000 PAX base camps. While these savings came at a significant fuel cost, potable water must be reduced in the latrines if the objective 75% potable water reduction is to be met. This technology will play an important role

Savings in waste water were further identified in the *Provide Subsistence* functional area. Options analyzed showed a waste water savings of up to 1.2% at the 1000 PAX base camp. While these savings were small, they came at negligible fuel cost.

Treating waste water that could not be eliminated on the supply side was determined to be inexpensive in terms of fuel. The TRICON dBBR consumed only 0.2–0.3% additional fuel while eliminating 89.2–89.3% of all waste water on the base camp. While reducing waste water by not generating it is preferential, since that will also reduce the amount of potable water consumed on the base camp, waste water treatment is a viable option to reduce the disposal requirement.

Solid waste at the FY12 ORTB Base Camps was primarily generated from field feeding. Addressing the solid waste produced through source reduction technologies resulted in a 0.6–2.6% reduction in solid waste. Since the source reduction technologies analyzed impacted only MREs, the impact was muted at the larger camps that primarily serve UGR-As. Larger savings were seen by changing the feeding plan. Savings of up to 15.3% of solid waste were achieved by switching to an all MRE meal plan. Since any reduction in meal plan would be below doctrinal levels at the 300 PAX and 1000 PAX base camp, meal plan changes were not considered a viable option at those camps.

Treating solid waste that could not be eliminated by other means proved inexpensive. All options analyzed would meet the objective reduction of 50% of solid waste but differed in fuel costs to achieve the reduction. At the 50 PAX base camp, the SWDS reduced solid waste by 93.2% and cost only 0.9% of fuel in the desert environment. At the 300 PAX and 1000 PAX base camps, the WEC not only reduced solid waste by 80.5%, but also provided 13.6–14.7% of the base camp power requirement. Both options will prove valuable in meeting the SLB-STO-D objective solid waste reduction.

4 SECOND ORDER EFFECTS

Previously, **Chapter 3** *Fuel, Water, and Waste (FWW) Reduction Options* discussed the performance of the individual technologies and non-materiel solutions, and later **Chapter 5** *Resource Optimized Base Camp Design* will investigate integrated solution sets of multiple technologies and/or non-materiel solutions to meet program objectives. This section will investigate how pairs of technologies or TTP solutions interact and how their interactions affect base camp resource consumption.

It is natural to assume that the savings from a base camp that includes two technologies, A and B, would have savings equal to the sum of savings of a base camp with only technology A and the savings from a base camp with only technology B. However, frequently the resource savings from the integrated camp does not equal the sum of the savings from each change individually due to how the technologies interact. These technologies can interact synergistically (producing greater savings when combined) or antagonistically (producing less savings when combined). Additionally, in certain cases, it makes sense to explore the impact of these changes on QoL(O) in relation to synergistic or antagonistic effects.

For example, consider the case of adding microgrids and LED lights to a base camp. LED lights reduce power consumption, which may enable the microgrid to turn off an additional generator more frequently than it otherwise would, leading to additional fuel savings. These technologies interact synergistically, meaning that their combined savings is more than the combination of their individual savings. These types of combinations are explored in **Section 4.1.** However, synergistic interaction is not always the case for each pair of technologies.

Alternatively, take the case of a base camp where both low-flow showerheads and gray water treatment facilities have been implemented. Individually, each of these technologies reduces potable water consumption of showers. However, the water savings from implementing them simultaneously is not exactly additive because using the low-flow showerheads results in less water being processed and therefore recycled by the gray water recycling facility. In this case, the technologies are *antagonistic* and their combination results in less savings than the sum of their individual savings. These types of combinations are explored in **Section 4.2**.

Beyond purely synergistic or antagonistic effects, it is also possible to explore more broadly the ways technologies on camp can change the impact of TTP methods of reducing resource usage. For example, shortening the length and decreasing the frequency of showers are commonly-used doctrinal methods of reducing potable water use. However, on a base camp with low-flow showerheads, overall potable water usage may be less dependent on the shower length and frequency. In particular, these kinds of changes may or may not impact QoL(O) on the base camp. The scope of the SLB-STO-D's tasking was to find solutions that maintain QoL(O). However, information on solutions that may change QoL(O) will provide a more complete picture of the base camp resource consumption trade space. Interactions of this type will be explored in **Section 4.3**.

Finally, in some cases it is possible to make trade-offs in QoL: one solution that increases QoL in exchange for a solution that reduces QoL. The net QoL scores, along with overall resource savings, will help provide context as to whether these trades are worth pursuing and are explored in **Section 4.4**.

4.1 Synergistic Interactions

The first type of second order effects under investigation are synergistic interactions. Each of these sections shows two or more solutions that, when integrated, produce greater resource savings than the sum of each individually. However, the magnitude of these savings can vary depending on the magnitude of the individual resource savings and the way that the technologies interact.

4.1.1 Convenience Loads and Microgrids

This section investigates combining the TTP solution of eliminating convenience loads with the technology change of implementing microgrids. For context, the *Provide Electric Power* and *Power Generation* functions are the largest consumers of fuel, accounting for 80-90% of the overall fuel, depending on environment. The power generation functional area can be addressed on both the demand and supply side by reducing power consumption or more efficiently producing power.

Convenience loads are present in locations such as billeting, MWR, and dining facilities and represent the power draw associated with soldiers’ personal electronics. As discussed in **Section 3.1.1.5**, removing these convenience loads can produce a reduction in power demand that translates into fuel savings. However, removing convenience loads can also have a negative impact on QoL at the camp, as described below.

The microgrids analyzed as part of this analysis consist of six generators: 60 kW TQGs at the 300 PAX and 1000 PAX base camps and 30 kW TQGs at the 50 PAX base camp. Microgrids produce fuel savings by turning generators on and off to meet the aggregate power demand of its connected power consumers, which is more fuel efficient than running all active generators at all times. For example, 100 kW of power could be provided by five 60 kW generators each supplying 20 kW or two 60 kW generators each supplying 50 kW. The amount of power is exactly the same, but the latter option would use far less fuel because it requires fewer generators. Grids enable the same amount of power to be supplied with fewer generators. In the example discussed in this section, the grids are geographically constrained to a 200-ft radius due to performance limitations of the grids and cables associated with them. The overall power demand and geographic constraints at each camp necessitate 1 microgrid at the 50 PAX base camp, 4 microgrids at the 300 PAX base camp, and 11 microgrids at the 1000 PAX base camp. The 300 PAX and 1000 PAX base camps both include one islanded generator to power areas of the camp too remote and too small to warrant their own microgrid. For more information on microgrids, see **Section 3.1.2.1**.

Shelters without convenience loads have slightly lower peaks, albeit not so low as to allow for generator or microgrid reallocation. **Table 58** describes the total resource savings in the desert environment from all the relevant individual simulation runs as well as the integrated base camp. **Figure 22** illustrates the resource savings for the 300 PAX base camp in the desert environment.

In this figure, the sum of the individual options is not a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp. The resource savings are very similar across environments and across base camp sizes.

Table 58. Mean Daily Camp Level Summary, Convenience Loads and Microgrid, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Convenience Loads Removed	213	1.1%	960	4.7%	75	0.0%	27	0.0%	266	0.0%
Microgrid, 30 kW TQGs	144	33.0%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
Integrated Camp	137	36.3%	960	4.7%	75	0.0%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Convenience Loads Removed	1022	1.9%	4743	7.2%	8723	0.0%	8529	0.0%	2870	0.0%
Microgrid, 60 kW TQGs	614	41.1%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
Integrated Camp	581	44.2%	4743	7.2%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Convenience Loads Removed	3284	2.7%	15876	9.7%	31305	0.0%	31153	0.0%	10672	0.0%
Microgrid, 60 kW TQGs	1968	41.7%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%
Integrated Camp	1820	46.1%	15876	9.7%	31305	0.0%	31153	0.0%	10672	0.0%

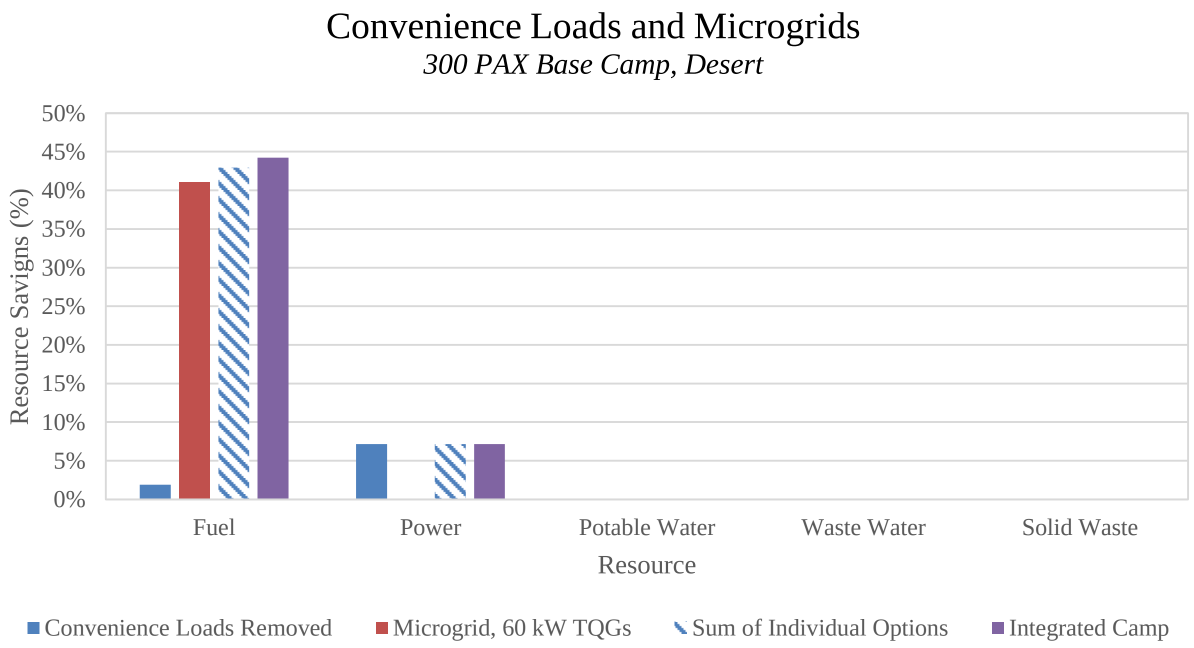

Figure 22. Resource Savings, Convenience Loads, and Microgrids, 300 PAX Base Camp, Desert

In **Table 58**, the only resources affected are power and fuel. The integrated camp has power savings equal to the convenience loads simulation, because the grids by themselves do not save power. However, the fuel savings are synergistic.

This synergistic savings is due to how the reduced power draw stemming from elimination of the convenience loads affects generator function. Removing convenience loads alone is never sufficient to shut off a generator, because the generator is still needed to supply power to the remaining functions of the billet. However, when microgrids are implemented, the savings from eliminating convenience loads across multiple shelters can be added together. This combined amount can at times be great enough to shut off the last generator in the microgrid.

Figure 23 illustrates this impact in terms of a reduction of generator hours. Both plots examine the same microgrid at the 300 PAX base camp in the desert over the course of a year. Each graph shows the number of hours the microgrid spent with a given number of generators "on" over the course of a year and a total number of generator hours. The left-hand figure corresponds to a base camp with microgrids implemented, while the right-hand figure corresponds to the microgrid's behavior after convenience loads were eliminated. Note that removing convenience loads results in more hours where one generator is sufficient and fewer hours where two or three generators were needed. The result is a net reduction of 406 generator hours per year.

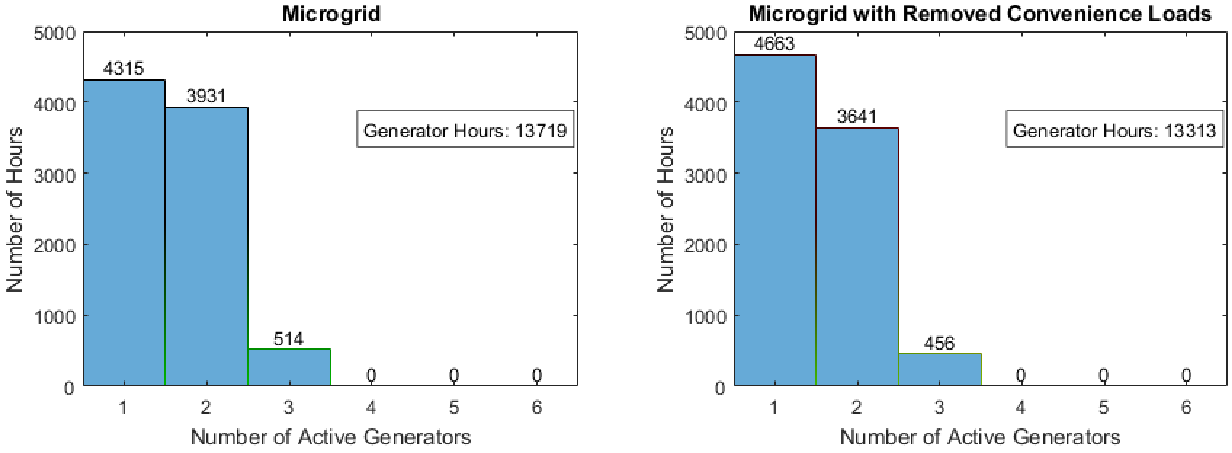

Figure 23. Microgrid Generator Usage with Convenience Loads, 300 PAX Base Camp, Desert

Knowing that the effect is synergistic indicates that the solutions are more effective when integrated on the same base camp. However, the magnitude of the synergistic savings is also important to consider. Here, the effect is moderate, producing fuel savings of about 1.2–2.2%. The majority of the fuel savings comes from the microgrids alone. It is worth noting that removing convenience loads has a negative impact on QoL(O), reducing QoL(O) by 5.7–10.9 points at the FY12 ORTB Base Camps. Interestingly, the convenience loads and microgrid combination is somewhat unusual in being synergistic—most TTP and technology combinations are antagonistic, as the technology obviates the need for a TTP change, as will be discussed in later sections.

4.1.2 LEDs and Microgrids

This section investigates combining LED light technology with microgrid implementation. This combination affects only power and fuel and has an overall synergistic effect. For context, the *Provide Electric Power* and *Power Generation* functions are the largest consumers of fuel, accounting for 80-90% of the overall fuel, depending on environment. The power generation functional area can be addressed on both the demand and supply side by reducing power consumption or more efficiently producing power.

LED lights are implemented as a power-efficient lighting alternative to traditional lighting in base camp shelters, such as the billets and shower changing tents, but not in exterior lighting, such as the flood lights surrounding the perimeter of the camp. Note that it is certainly possible that outdoor lights could be switched to LED lights, but that option was not considered for this model. Usage of LED lights reduces the power demand as well as the fuel usage, as discussed in **Section 3.1.1.6.**

The microgrids analyzed as part of this analysis consist of six generators: 60 kW TQGs at the 300 PAX and 1000 PAX base camps and 30 kW TQGs at the 50 PAX base camp. Microgrids produce fuel savings by turning generators on and off to meet the aggregate power demand of its connected power consumers, which is more fuel efficient than running all active generators at all times. For example, 100 kW of power could be provided by five 60 kW generators each supplying 20 kW or two 60 kW generators each supplying 50 kW. The amount of power is exactly the same, but the latter option would use far less fuel because it requires fewer generators. Grids enable the same amount of power to be supplied with fewer generators. In the example discussed in this section, the grids are geographically constrained to a 200-ft radius (see **Section 3.1.2.1** for a discussion on cable length assumptions). The overall power demand and geographic constraints at each camp necessitate 1 microgrid at the 50 PAX base camp, 4 microgrids at the 300 PAX base camp, and 11 microgrids at the 1000 PAX base camp. The 300 PAX and 1000 PAX base camps both include one islanded generator to power areas of the camp too remote and too small to warrant their own microgrid. For more information on microgrids, see **Section 3.1.2.1**.

When these technologies are integrated on the same base camp, microgrids are implemented as a replacement for the islanded TQGs supplying camp power and LEDs replace fluorescent lights in shelters. Shelters with LED lights have slightly lower peak power draws, but not so low as to allow for generator or microgrid reallocation. **Table 59** describes the total resource savings in the desert environment for all the relevant individual simulations as well as the integrated base camp. **Figure 24** illustrates the resource savings for the 300 PAX base camp in the desert environment. Here, as in previous charts, the sum of the individual options is not a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp. The resource savings are very similar across environments and across base camp sizes.

Table 59. Mean Daily Camp Level Summary, Grid and LED, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
50 PAX Camp										
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Microgrid, 30 kW	144	33.0%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
LED lights	215	0%	991	1.6%	75	0.0%	27	0.0%	266	0.0%
Integrated camp	140	34.9%	991	1.6%	75	0.0%	27	0.0%	266	0.0%
,300 PAX Camp										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Microgrid, 60 kW	614	41.1%	5108	-	8723	0.0%	8529	0.0%	2870	0.0%
LED lights	1039	0.3%	5051	1.1%	8723	0.0%	8529	0.0%	2870	0.0%
Integrated Camp	608	41.7%	5051	1.1%	8723	0.0%	8529	0.0%	2870	0.0%
1000 PAX Camp										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Microgrid, 60 kW	1968	41.7%	17580	-	31305	0.0%	31153	0.0%	10672	0.0%
LED lights	3365	0.3%	17370	1.2%	31305	0.0%	31153	0.0%	10672	0.0%
Integrated Camp	1951	42.2%	17370	1.2%	31305	0.0%	31153	0.0%	10672	0.0%

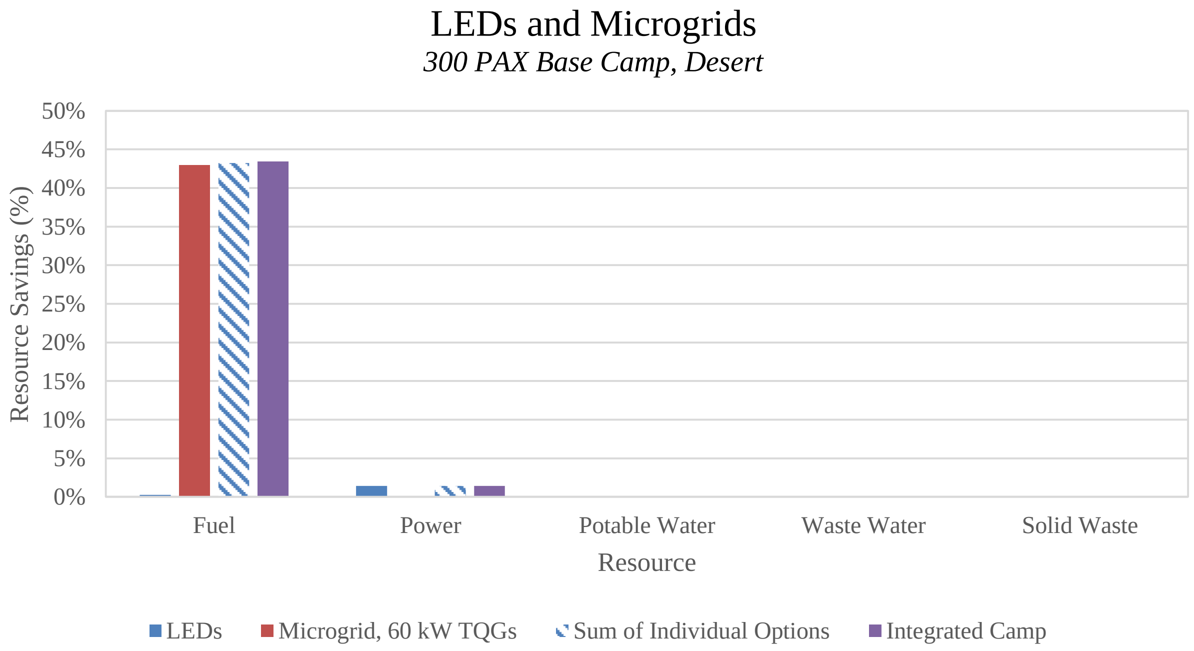

Figure 24. Resource Savings, LEDs and Microgrids, 300 PAX Base Camp, Desert

In **Table 59**, the only resources affected are power and fuel. The integrated camp has power savings equal to those from the LED lights simulation, because the grids by themselves do not save power. However, the fuel savings are synergistic. This synergistic savings is because the reduced power draw coming from implementing LED lights affects generator run time. This behavior is discussed in greater detail in **Section 4.1.1**, but generally is due to the fact that reducing power demand allows grids to operate with low numbers of generators for longer during the year, resulting in greater fuel savings.

Note that, as compared with eliminating convenience loads (see **Section 4.1.1**), the substitution of LED lights has a much smaller power savings—about 1% as compared to what is seen with eliminating convenience loads: 5–10%. In the integrated camp, this translates into a much smaller synergistic effect—less than 1% in fuel savings. While technically the combination of LEDs and microgrids results in a positive synergistic savings, the magnitude is so small as to be almost negligible. The fuel savings unlikely warrants the early replacement of fluorescent lights for LEDs simply because a microgrid was installed. Though there may be additional factors (e.g., maintenance) that make LED lights more beneficial than the fluorescent lights, those factors are independent of the use of microgrids.

Adding in LED lights reduces the power demand, which enables the microgrids to more frequently use fewer generators to supply power. The interaction is synergistic in fuel, allowing for 0.6–1.9% greater fuel reductions. The clear majority of the fuel reduction is due to the implementation of the microgrids, while LED lights bring only very marginal improvements, and the combination brings only small synergistic effects.

4.1.3 Shelters and Microgrids

This section investigates combining improved shelters with microgrid implementation. This combination affects only power and fuel and has an overall synergistic effect. For context, the *Provide Electric Power* and *Power Generation* functions are the largest consumers of fuel, accounting for 80–90% of the overall fuel, depending on environment. The power generation functional area can be addressed on both the demand and supply side by reducing power consumption or more efficiently producing power.

The shelter improvements involve substituting in SIP-Huts and AS TEMPER tents with V1.5 liners, PShades, and 42k ECU units. A brief overview of the implemented technologies follows:

- SIP-Hut – A pre-fabricated structure that is assembled onsite. The SIP-Hut panels are highly insulated and include lighting, outlets, and ECU interfaces
- V1.5 Liner – A prototype liner for AS TEMPER tents that integrates a radiant liner with fabric insulation, a dropped ceiling, insulated ducting, a built-in plenum for soft distribution of conditioned air, and built-in LED lights.
- PShade – A commercially available solar shade with 3.6 kW flexible PV array integrated into the shade materiel that can be erected over an AS TEMPER tent to block a portion of solar radiation from the roof and sides, as well as reduce wind speeds experienced by the tent.
- 42k ECU – A prototype ECU that uses variable speed motors and a variable frequency drive compressor to provide 42 kBTU of air conditioning and 6.6 kW of heat.

The microgrids analyzed as part of this analysis consist of six generators—60 kW TQGs at the 300 PAX and 1000 PAX base camps and 30 kW TQGs at the 50 PAX base camp. Microgrids produce fuel savings by turning generators on and off to meet the aggregate power demand of its connected power consumers, which is more fuel efficient than running all active generators at all times. For example, 100 kW of power could be provided by five 60 kW generators each supplying 20 kW or two 60 kW generators each supplying 50 kW. The amount of power is exactly the same, but the latter option would use far less fuel because it requires fewer generators. Grids enable the same amount of power to be supplied with fewer generators. In the example discussed in this section, the grids are geographically constrained to a 200-ft radius (see

Section 3.1.2.1 for a discussion on cable length assumptions). The overall power demand and geographic constraints at each camp necessitate 1 microgrid at the 50 PAX base camp, 4 microgrids at the 300 PAX base camp, and 11 microgrids at the 1000 PAX base camp. The 300 PAX and 1000 PAX base camps both include one islanded generator to power areas of the camp too remote and too small to warrant their own microgrid. For more information on microgrids, see **Section 3.1.2.1**.

When these technologies are integrated, microgrids are implemented as a replacement for the islanded TQGs supplying camp power and to the improved shelters, AS TEMPER tents and B-Huts. Improved shelters have significantly lower peak power draws, allowing for generator reallocation even before microgrids have been implemented. For example, a baseline billeting tent has a peak of 16.6 kW, while the improved billeting tent has a peak of 12.4 kW, allowing one 60 kW generator to support four improved shelters rather than three baseline shelters when sizing generators and allocating loads based on facility peak power draws. **Table 60** describes the total resource savings in the desert environment from all the relevant individual simulation runs as well as the integrated base camp. **Figure 25** illustrates the resource savings for the 300 PAX base camp in the desert environment. Here, as in previous charts, the sum of the individual options is **not** a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp.

Table 60. Mean Daily Camp Level Summary, Grid and Shelter, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Microgrids, 30 kW	144	33.0%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
Improved Shelters, no generator reallocation	178	17.2%	342	66.0%	75	0.0%	27	0.0%	266	0.0%
Improved Shelters with generator reallocation	157	27.0%	342	66.0%	75	0.0%	27	0.0%	266	0.0%
Integrated camp	82	61.9%	342	66.0%	75	0.0%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Microgrids, 60 kW	614	41.1%	5108	0.0%	8723	0.0%	8529	0.0%	2870	0.0%
Improved Shelters, no generator reallocation possible	905	13.2%	2528	50.5%	8723	0.0%	8529	0.0%	2870	0.0%
Integrated Camp	396	62.0%	2528	50.5%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Microgrids, 60 kW	1968	41.7%	17580	0.0%	31305	0.0%	31153	0.0%	10672	0.0%
Improved Shelters, no generator reallocation	2916	13.6%	8878	49.5%	31305	0.0%	31153	0.0%	10672	0.0%
Improved Shelters with generator reallocation	2770	18.0%	8878	49.5%	31305	0.0%	31153	0.0%	10672	0.0%
Integrated Camp	1218	63.9%	8878	49.5%	31305	0.0%	31153	0.0%	10672	0.0%

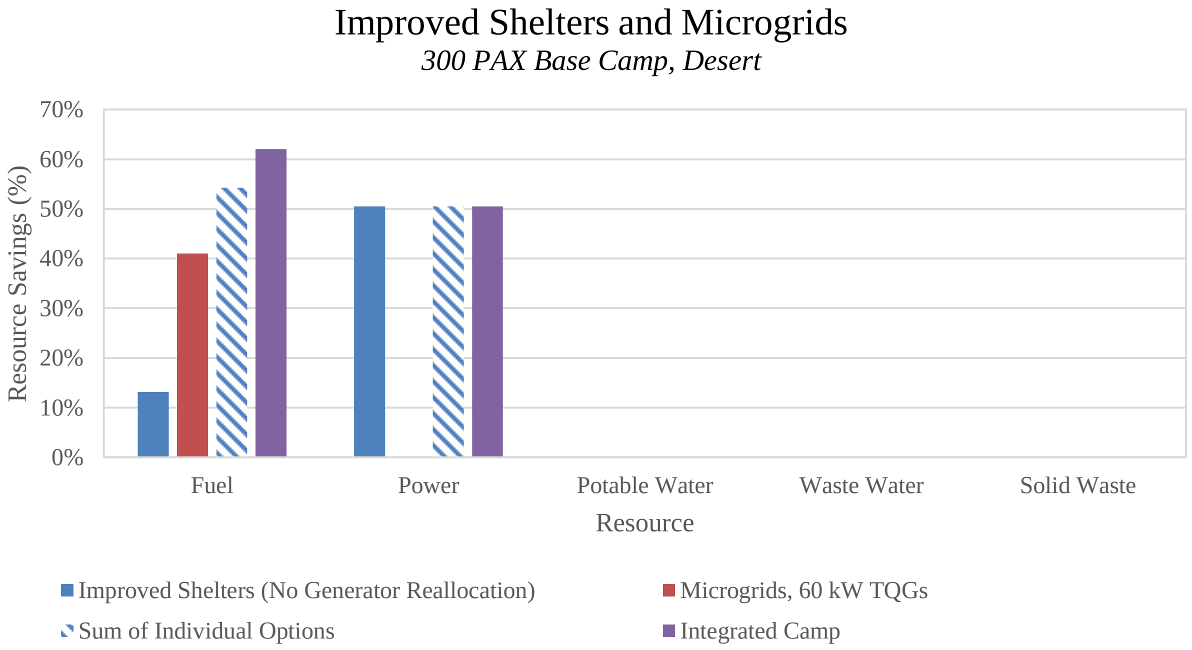

Figure 25. Resource Savings, Improved Shelters and Microgrids, 300 PAX Desert

As shown in **Table 60** and **Figure 25**, the improved shelter system created substantial power and fuel savings by themselves, about 50–66% for power savings and 13–17%% for fuel savings. A fuel savings as high as 27% is possible if camp generators are reallocated along with the integration of the improved shelter systems, depending on the base camp simulated. The synergistic savings for fuel at the 300 PAX base camp is approximately 8%, much larger than the synergistic savings of all the other scenarios analyzed, including the elimination of convenience loads (see **Section 4.1.1**) or implementation of LED light technology (see **Section 4.1.2**).

To investigate how this occurred, it is useful to look at the impact of improved shelters on the microgrid behavior. **Section 4.1.1** examined how removing convenience loads impacted how many generators in the microgrid were needed to meet demand. **Figure 26** illustrates the impact of shelter improvements on the same microgrid as was examined in the convenience loads section.

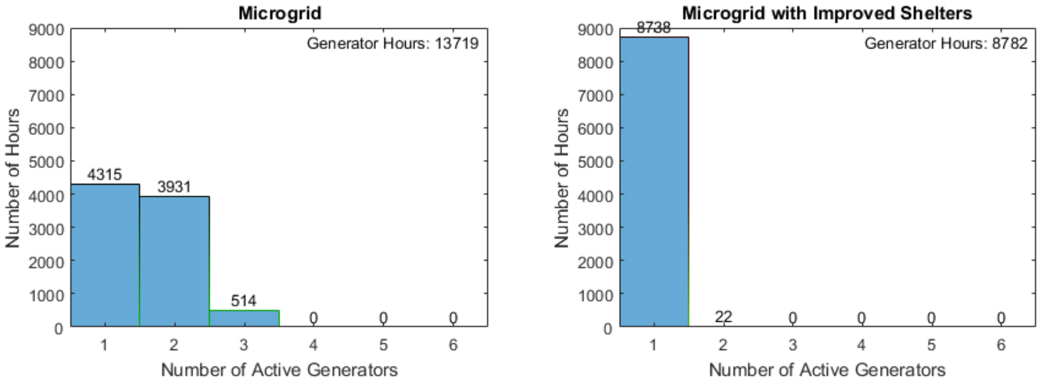

Figure 26. Microgrid Generator Usage with Improved Shelters, 300 PAX Base Camp, Desert

When a microgrid is implemented with the baseline shelters, up to three generators are required to power the loads on the grid. The clear majority of the time is split fairly evenly between requiring only one or two generators to be active. The lack of use of all the generators in the microgrid is impacted by two factors. First, loads are assigned to the microgrid using seasonally-adjusted, connected loads, which is a conservative method (see **Section 3.1.2.1.1**). Second, geographic realities limit the number of loads that can be connected to each microgrid due to voltage drop when excessively long cables are used.

When improved shelters are implemented, for all but 22 h of the year, a single generator is sufficient to supply all power in this microgrid. For context, this microgrid supplies power to two latrines, two showers, two shower changing tents, nine billeting tents, and one MILVAN command structure. The impact upon the microgrid is much larger in **Figure 26** than in **Figure 23** because the improved shelters have a much larger impact on power demand than the removal of convenience loads.

As discussed previously, it is possible at the 50 PAX and 1000 PAX base camps to combine shelter improvements with generator reallocation, providing additional fuel savings without implementing a microgrid. **Figure 27** illustrates the resource savings at the 1000 PAX base camp for shelter improvements both with and without generator reallocation. The fuel savings continue to be synergistic, though the magnitude of the synergistic effect decreases from 8% to 4%. This is because the generator reallocation shuts off some of the same generators that the microgrids shut off, so the sum of the individual options double-counts the fuel savings.

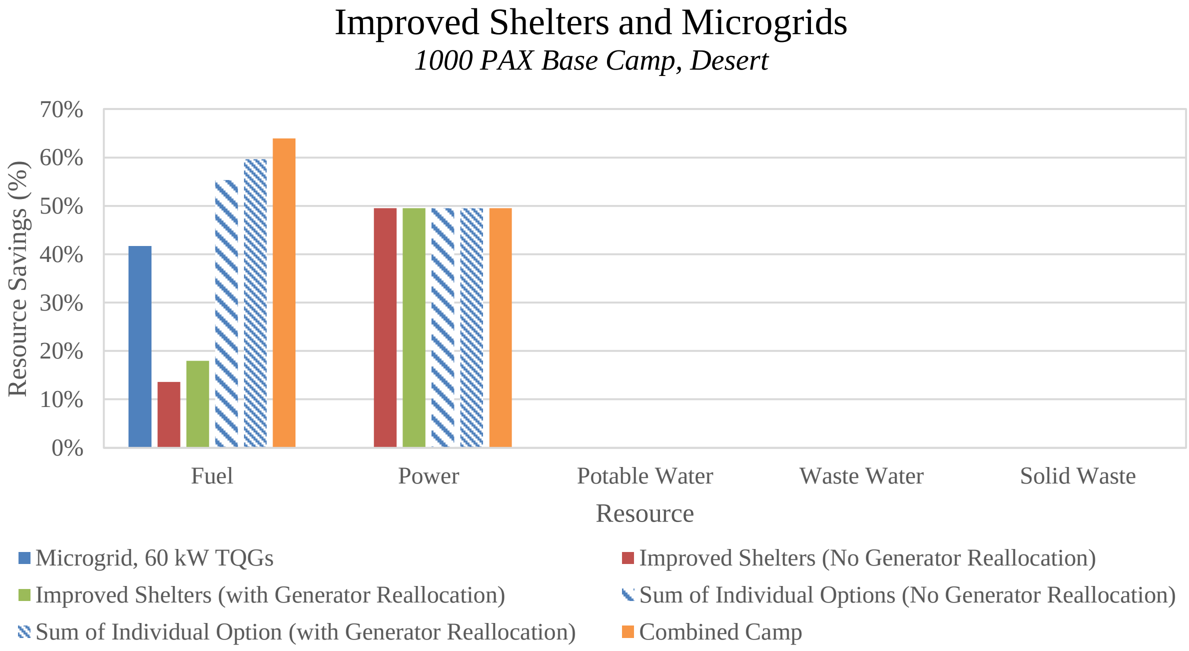

Figure 27. Resource Savings, Improved Shelters and Microgrids, 1000 PAX Base Camp, Desert

Shelters are one of the few technologies that perform substantially differently in different climates. For example, **Table 61**, **Figure 28**, and **Figure 29** show the same shelter improvements as above, but in the temperate environment.

Table 61. Mean Daily Camp Level Summary, Grid and Shelter, Temperate

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
	50 PAX Camp									
FY 12 Baseline	219	-	661	-	75	-	27	-	266	-
Microgrids, 30 kW	131	40.2%	661	-	75	-	27	-	266	-
New shelters, no generator reallocation	193	11.9%	412	37.7%	75	-	27	-	266	-
New shelters with generator reallocation	172	21.5%	412	37.7%	75	-	27	-	266	-
Integrated Camp	92	58.0%	412	37.7%	75	-	27	-	266	-
	300 PAX Camp									
FY 12 Baseline	1096	-	4091	-	8723	-	8529	-	2870	-
Microgrids, 60 kW	625	43.0%	4091	-	8723	-	8529	-	2870	-
New shelters – no generator reallocation possible	1001	8.7%	3173	22.4%	8723	-	8529	-	2870	-
Integrated Camp	501	54.3%	3173	22.4%	8723	-	8529	-	2870	-
	1000 PAX Camp									
FY 12 Baseline	3654	-	14751	-	31305	-	31153	-	10672	-
Microgrids, 60 kW	2144	41.3%	14751	-	31305	-	31153	-	10672	-
New shelters, no generator reallocation	3329	8.9%	11628	21.2%	31305	-	31153	-	10672	-
New shelters with generator reallocation	3179	13.0%	11628	21.2%	31305	-	31153	-	10672	-
Integrated Camp	1709	53.2%	11628	21.2%	31305	-	31153	-	10672	-

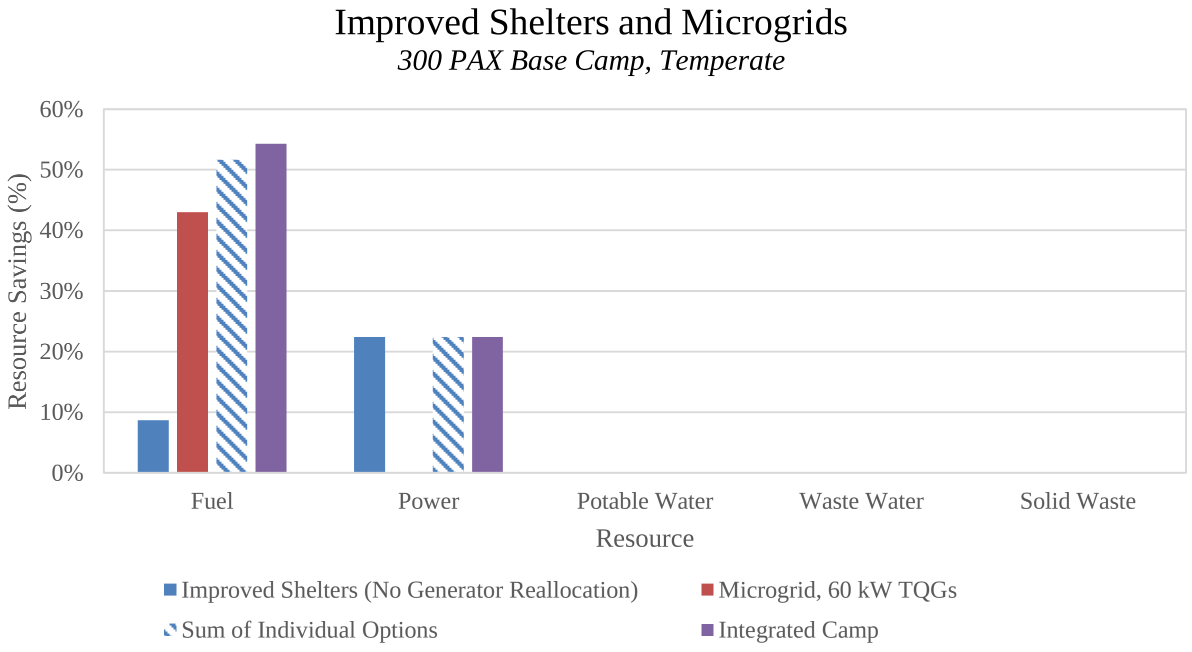

Figure 28. Resource Savings, Improved Shelters and Microgrids, 300 PAX Base Camp, Temperate

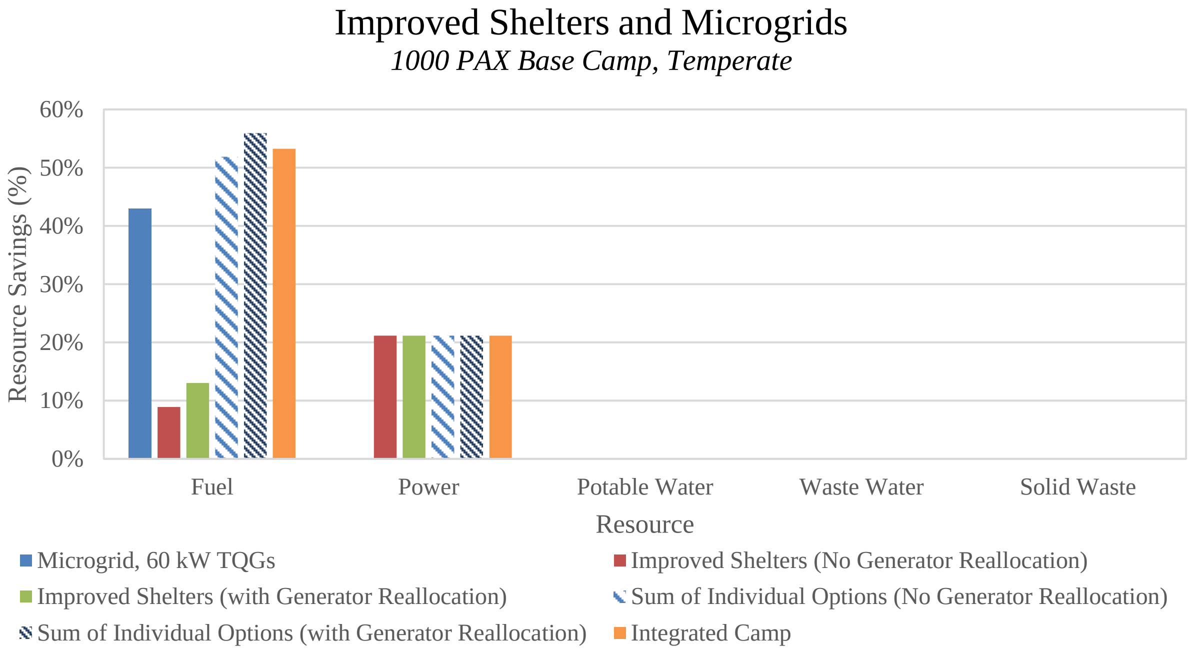

Figure 29. Resource Savings, Improved Shelters and Microgrids, 1000 PAX Base Camp, Temperate

At the 300 PAX base camp, the synergistic effect is present but much smaller: about 3% fuel savings. At the 50 PAX and 1000 PAX base camps, there are two options for the sum of the individual options: with the simulation involving generator reallocation and the simulation without generator reallocation. In both cases, the integrated camp shows synergistic savings when compared to the simulation without generator reallocation, but antagonistic effects as compared to the simulation with generator reallocation.

To investigate why this is the case, it is necessary to consider how the temperate environment differs from the desert one. The shelter improvements include both better insulation and more efficient electric heaters. In temperate environments, fuel-fired heaters are used in the winter, partially offsetting the benefit of electric heaters. However, insulation is always useful in reducing the amount of fuel required for heating and cooling. These fuel-fired heaters additionally require on-camp vehicles to refuel them, so better insulation means less fuel is used by the fuel-fired heaters and fewer refill trips are necessary, reducing vehicle usage. Overall, shelters in the temperate environment depend less upon electric power, reducing the degree of their interaction with the microgrid and thus the synergistic effect. Additionally, certain fuel reductions, such as the reductions in the use of on-camp vehicles to refuel tanks, are present in the integrated camp as well as the shelter improvements individual run. The sum of the fuel savings of the individual options thus double counts the savings, so the integrated camp will have comparatively less fuel savings.

Overall, combining shelter improvements with microgrids produces a moderately-sized synergistic fuel savings (2–8%) in the desert and has smaller or even antagonistic savings in the temperate environment. It is worth noting that the synergistic comparison was conservative in its comparison to a base camp with shelter improvements and generator reallocation already included. While the synergistic savings vary by environment, they can be substantial. This indicates that both microgrids and improved shelters should be given greater consideration for implementation, especially for tandem.

4.1.4 Gray Water Recycling and Waste Water Treatment

This section steps away from microgrids and instead investigates combining waste water treatment with gray water recycling. This combination affects waste water, potable water, power, and fuel, generally having a synergistic effect. As the 50 PAX base camp has very small levels of potable and waste water usage, these systems were not implemented there.

Waste water at a contingency base camp is composed of two primary types: gray water and black water. Gray water is considered less contaminated and includes waste water "discharged from washing machines, laundry sinks, hand-washing sinks, showers and bathtubs that does not contain concentrated animal waste or human sanitary or food wastes" [29]. At the FY12 ORTB Base Camps, gray water is produced by the shower and laundry facilities. Black water is considered waste water "discharged from toilets and urinals containing concentrated human wastes and water from kitchen preparation areas containing concentrated food wastes" [29]. The waste water from hand-washing sinks in the latrines is mixed with other latrine waste water and is considered part of the black water stream.

The relevant SLB-STO-D goals for this section are a 75% reduction in potable water demand and a 50% reduction in waste water production. Reducing the logistical burden of removing this liquid waste from the base camp is key to meeting the SLB-STO-D goal of a 50% reduction in waste generation/backhaul. Any capability that would allow the reuse of this waste water in place of new, bulk potable water would also assist in meeting the SLB-STO-D goal of a 75% reduction in potable water usage.

The two methods of reducing potable water demand are to either reduce the overall amount of potable water used or find ways of reusing water. There is a substantial amount of gray water available on the base camps. At the FY12 ORTB 50 PAX, 300 PAX, and 1000 PAX Base Camps respectively, approximately 27, 6,211, and 23,029 gal respectively of gray water per day are produced. This represents approximately 35.5% (at the 50 PAX base camp) or 71.2–73.6% at the 300 PAX and 1000 PAX base camps of the total potable water used daily on each base camp, so if it were possible to reuse all the gray water, this would result in approximately a 35.5–73.6% reduction in potable water demand. While it is not feasible for 100% of gray water to be recycled into potable water, this is still a useful benchmark for the utility of a gray water recycling system.

Similarly, it is possible to reduce waste water to be backhauled by either reducing the amount of waste water produced or treating the waste water to reduce the amount required to be backhauled. The amount of savings from a waste water treatment system depends on the efficiency of the system, but as discussed in **Section 3.3.3.2** it can approach 28–29% of all waste water.

The gray water recycling system implemented in this section is either a FORO or G-WTRS, depending on camp size. A FORO is a prototype system that utilizes forward osmosis, reverse osmosis, and chlorine injection. A G-WTRS is a prototype system that utilizes a combination of bio filtration, ultrafiltration, and reverse osmosis. In a base camp with only a gray water recycling system, 20% of the output of a gray water recycling unit is considered waste water (black water). An amount of new potable water equal to that discharged as waste is combined with the remaining 80% of treated gray water resulting from the recycling system and re-used as new potable water. At the 300 PAX base camp, the gray water systems used are two FOROs. At the 1000 PAX base camp, one G-WTRS is used instead. For more information, see **Section 3.3.3.1**.

The waste water treatment system is a TRICON dBBR, a modified activated sludge process with increased efficiency and performance. In a base camp with only a waste water treatment unit, 90% of the output of the dBBR can be safely disposed of onsite, with the remaining 10% requiring backhaul. For waste water treatment, 2 dBBRs are used at the 300 PAX base camp and 10 dBBRs at the 1000 PAX base camp. For more information, see **Section 3.3.3.2**.

In the integrated camp, after gray water has been recycled, 80% of the recycled gray water is reused as potable water and the remaining 20% is sent to the waste water system to be treated. The waste water treatment unit behaves exactly as it did before, allowing 90% of its output to be disposed-of onsite with 10% requiring backhaul. In the integrated camp, the systems for both gray water recycling and waste water treatment are present in the same numbers as the individual runs. While the black water treatment unit processes more material in the integrated camp than it did previously, no new facilities are needed because the waste water systems had enough excess capacity to treat the byproduct of the gray water recycling unit. **Table 62** and **Figure 30** illustrate the results of the relevant simulations in the desert environment. Here, as in previous charts, the sum of the individual options is **not** a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp. The resource savings are very similar across environments and across base camp sizes.

Table 62. Mean Daily Camp Level Summary, Gray Water Recycling and Waste Water Treatment, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
dBBR, Black Water Only	1043	-0.1%	5123	-0.3%	8723	0.0%	6020	29.4%	2870	0.0%
FORO (80%)	1045	-0.3%	5169	-1.2%	4176	52.1%	3983	53.3%	2870	0.0%
Integrated Camp	1047	-0.5%	5189	-1.6%	4176	52.1%	467	94.5%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
dBBR, Black Water Only	3379	-0.1%	17632	-0.3%	31305	0.0%	22238	28.6%	10672	0.0%
G-WTRS (80%)	3386	-0.3%	17760	-1.0%	14526	53.6%	14373	53.9%	10672	0.0%
Integrated Camp	3389	-0.4%	17833	-1.4%	14526	53.6%	1685	94.6%	10672	0.0%

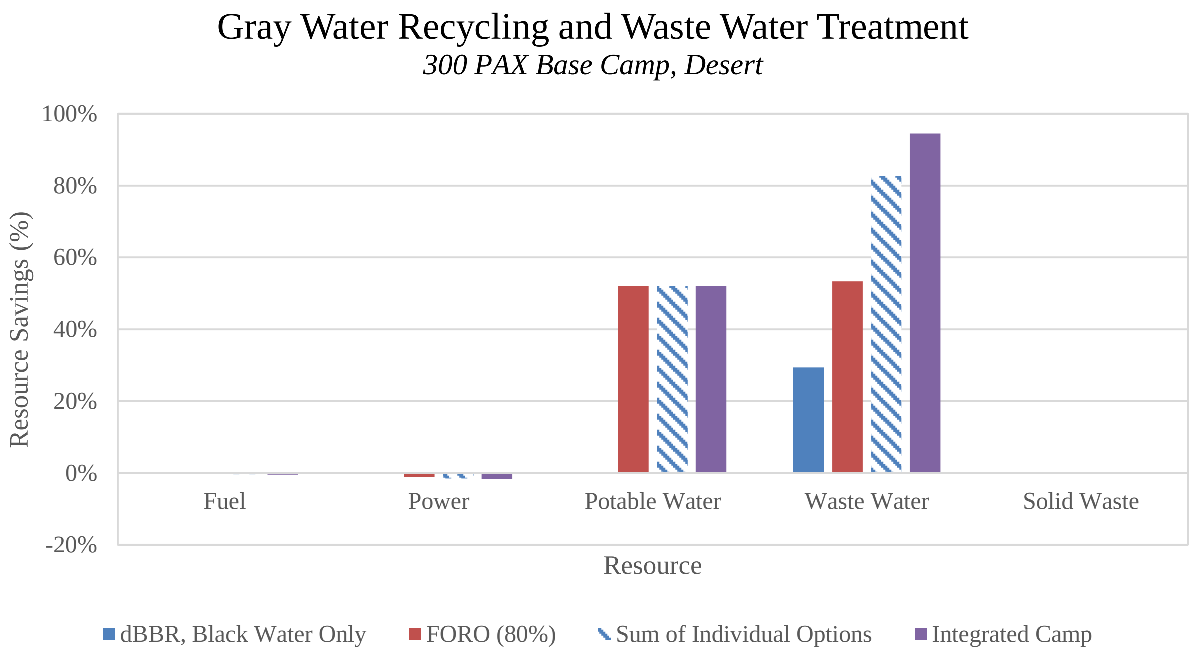

Figure 30. Resource Savings, Gray Water Recycling and Waste Water Treatment, 300 PAX Base Camp, Desert

The waste water savings are substantially synergistic, with savings 12–13% above the sum of the individual options. This comes from the fact that the waste water from the gray water treatment can be treated in the black water system, dramatically reducing the amount that requires backhaul. Potable water savings are equal to the sum of the individual options, because the black water treatment does not impact potable water. Fuel and power savings are negative (i.e., increases in fuel and power usage) and slightly synergistic. This is because 20% of the output from the gray water recycling unit is being sent to the waste water treatment unit, increasing the hours it must run to process the input. However, the magnitude of the power and fuel usage increases are miniscule, especially in comparison with the large waste water savings. In **Section 3.3.3.2**, an option is explored where a waste water treatment unit is sized to treat all waste water, both gray and black water. As compared with a dBBR sized to treat all waste water, the integrated camp discussed in this section has greater waste water savings (about 5.2–5.4%) and much greater potable water savings (52.1–53.6% savings in an integrated camp and none in a dBBR only camp), with very small increases in fuel usage (less than 0.1%).

Waste water treatment reduces the volume of waste water, while gray water recycling both decreases the potable water required and reduces the volume of waste water. When these systems are combined, the waste water byproduct from the gray water recycling unit is sent to the black water system to be treated, resulting in substantial synergistic savings in waste water production and additive levels of savings in water demand. The results of this analysis indicate that waste water treatment and gray water recycling systems, when combined, elicit substantial synergistic savings in waste water production and have additive levels of savings in water demand, suggesting that they would be especially useful to include on the same base camp. Given the very significant magnitude of the synergistic wastewater savings and assumed lack of impact on

QoL, combining gray water recycling and waste water treatment units should be strongly considered.

4.2 Antagonistic Interactions

This section analyzes groups of technologies that, when combined, partially offset each other’s resource savings. For example, if technology A has savings of 20% and technology B has savings of 30%, technology A is antagonistic with technology B if the combined base camp has savings less than 50%. This is because the savings are lower than the sum of the savings (50% resource savings) from each change individually. Note, though, that the combined base camp in this case still has greater resource savings than either technology A or B independently. Thus, if two technologies have an antagonistic relationship, they will do less well combined than might be expected, but frequently will still do better than any technology alone.

4.2.1 Low-flow Showerheads and Gray Water Recycling

This section investigates implementing low-flow showerheads along with gray water recycling, both technologies that impact the shower facilities. Showers are a very important consumer of potable water, representing 51.1–53.0% of potable water usage and 52.3–53.3% of waste water production at the FY12 ORTB 300 PAX and 1000 PAX Base Camps. As the FY12 ORTB 50 PAX Base Camp has no showers, it is not discussed in this section.

The low-flow showerheads are a commercially available item. They can be integrated into the Expeditionary Shower System in place of the baseline showerheads. They reduce the water necessary for showers of any length by about 16.5% over the baseline showerheads. The gray water recycling system is made up of two FOROs at the 300 PAX base camp and one G-WTRS at the 1000 PAX base camp. It takes in gray water from the shower and laundry facilities for treatment, allowing 80% of it to be recycled for reuse in the showers and laundry. For more information on these technologies, please refer to **Section 3.3.3.1**.

When these technologies are combined, low-flow showerheads are swapped in for standard showerheads and the relevant kinds and amounts of gray water recycling units are added to the base camp. While less gray water is produced at this combined base camp, the reduction is not sufficient to use fewer or smaller recycling units. The results of these runs are shown in **Table 63** and **Figure 31** for the desert environment. Here, as in previous charts, the sum of the individual options is **not** a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp. The resource savings are very similar across environments and across base camp sizes.

Table 63. Mean Daily Camp Level Summary, Low-flow Showerheads with Gray Water Recycling, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Low-flow Showerheads	1034	0.8%	5100	0.2%	7288	16.5%	7094	16.8%	2870	0.0%
FORO (80%)	1045	-0.3%	5169	-1.2%	4176	52.1%	3983	53.3%	2870	0.0%
Integrated Camp	1037	0.5%	5146	-0.7%	3890	55.4%	3696	56.7%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Low-flow Showerheads	3354	0.7%	17549	0.2%	25969	17.1%	25817	17.1%	10672	0.0%
G-WTRS (80%)	3386	-0.3%	17760	-1.0%	14526	53.6%	14373	53.9%	10672	0.0%
Integrated Camp	3361	0.4%	17683	-0.6%	13423	57.1%	13270	57.4%	10672	0.0%

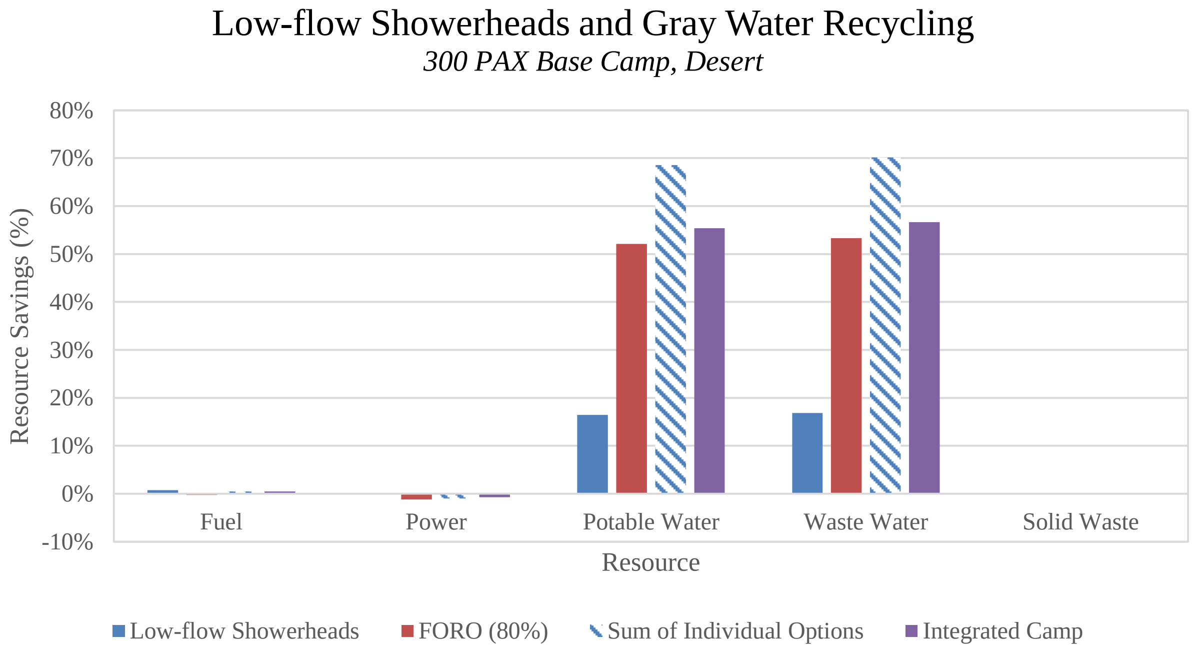

Figure 31. Resource Savings, Low-flow Showerheads and Gray Water Recycling, 300 PAX Base Camp, Desert

Close examination of the potable water and waste water savings indicates that the savings are antagonistic. To understand why, consider how the units interact: the gray water recycling unit recycles a portion of all gray water sent to it. However, the low-flow showerhead reduces the overall amount of gray water, reducing the number of gallons recycled by the gray water recycling unit. When these systems are combined, the overall resource savings are greater than either technology alone, but less than the sum of individual resource savings because the technologies partially offset each other. Aside from water, the combination also has impacts on the fuel and power usage, which is mainly driven by the fact that when the gray water recycling system processes less water, it also uses less power. The choice of which technology or technologies to implement may depend on the logistical difficulty of implementation.

At the FY12 ORTB Base Camps, neither gray water recycling nor low-flow showerheads are present. If it were only possible to implement one of these technologies, gray water recycling would be the best choice due to its resource savings, which are much higher. However, if gray water recycling proves too logistically or financially difficult, implementing low-flow showerheads, which have a very small financial and logistical cost, would still produce reasonable resource savings over the FY12 ORTB Base Camp. At a base camp that already has low-flow showerheads, adding gray water recycling would still be a good idea as the increased resource savings would be quite substantial. In contrast, on a base camp that already has gray water recycling, only marginal gains would be accomplished by adding low-flow showerheads. However, if resource reductions are of the greatest importance, then including both low-flow showerheads and graywater recycling will produce the highest resource savings, albeit at the highest financial and logistical cost.

4.2.2 Low-flow Showerheads and Solar Water Heater

This section investigates combining low-flow showerheads with a solar water heater, both technologies that impact the shower facilities. Showers are a very important consumer of potable water, representing 51.1–53.0% of potable water usage and 52.3–53.3% of waste water production at the FY12 ORTB 300 PAX and 1000 PAX Base Camps. As the FY12 ORTB 50 PAX Base Camp has no showers, it is not discussed in this section.

The low-flow showerheads are a commercially available item. They can be integrated into the Expeditionary Shower System in place of the baseline showerheads. They reduce the water necessary for showers of any length by about 16.5% over the baseline showerheads. The solar water heater operates by focusing light from the sun to preheat water for showers. Depending on sunlight intensity, this is sometimes sufficient to either turn off or turn down the fuel-fired water heater. In this simulation, there are three solar water heaters per pair of showers on the base camp. More information on these technologies can be found in **Sections 3.2.2** and **Section 3.1.4.1**.

In an integrated camp, both low-flow showerheads and solar water heaters are included in the same numbers as they were in each individual simulation. **Table 64** describes the total resource savings in the desert environment from all of the relevant individual simulations as well as the integrated base camp. **Figure 32** illustrates the resource savings for the 300 PAX base camp in the desert environment. Here, as in previous charts, the sum of the individual options is **not** a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp. The resource savings are very similar across environments and across base camp sizes.

Table 64. Mean Daily Camp Level Summary, Low-flow Showerheads with Solar Water Heater, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Low-flow Showerheads	1034	0.8%	5100	0.2%	7288	16.5%	7094	16.8%	2870	0.0%
Solar Water Heaters	1038	0.4%	5105	0.1%	8723	0.0%	8529	0.0%	2870	0.0%
Integrated Camp	1032	1.0%	5098	0.2%	7288	16.5%	7094	16.8%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Low-flow Showerheads	3354	0.7%	17549	0.2%	25969	17.1%	25817	17.1%	10672	0.0%
Solar Water Heaters	3362	0.4%	17567	0.1%	31305	0.0%	31153	0.0%	10672	0.0%
Integrated Camp	3343	1.0%	17539	0.2%	25969	17.1%	25817	17.1%	10672	0.0%

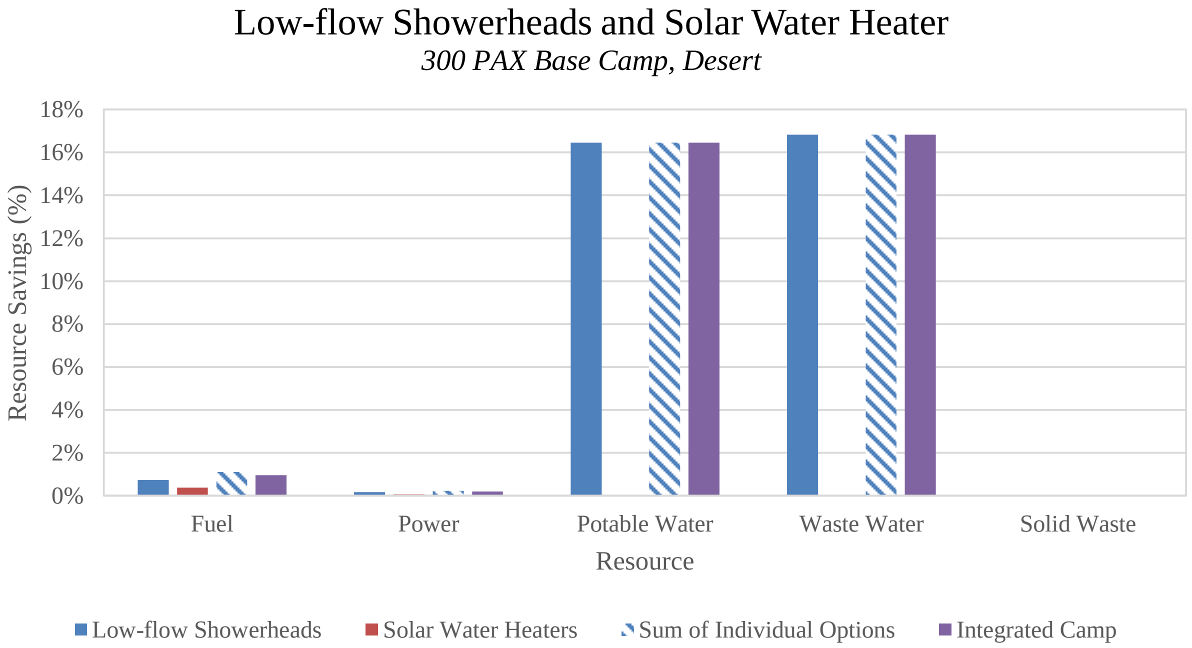

Figure 32. Resource Savings, Low-flow Showerheads and Solar Water Heater, 300 PAX Base Camp, Desert

The savings of potable water and waste water savings are by far the largest of all the resources, but for this analysis, they are also the least interesting. Because they are only impacted by the low-flow showerhead, the resource savings are exactly equal to the sum of the individual options. The antagonistic effect only shows up in power and fuel savings. The way the technologies interact explains why this is the case. Using a low-flow showerhead means that the showers use less water, which means that the solar water heater heats less water. Given that the solar powered water heat saves power and fuel for each gallon of water it heats, this means that the combined base camp has power and fuel savings that are antagonistic while still having slightly more savings than either individual run by itself.

This antagonistic effect is present, but it is worth noting that it is extremely small, affecting on the order of 10 gal a day of fuel at the 300 PAX base camp and 30 gal of fuel a day at the 1000 PAX base camp. Consequently, the interaction of the technologies should not be a major consideration when selecting whether to implement them on a given base camp.

In summary, implementing low-flow showerheads has a slightly antagonistic effect on the fuel savings of the solar powered water heater because there is less water used for showers overall. However, given that the magnitude of this change is so small, the antagonistic effect should not be a major determining factor in selecting which technology to implement.

4.2.3 WEC and Source Reduction

This section investigates combining source reduction technology with a WEC, both of which impact solid waste. Source reduction influences only solid waste produced through field feeding via MREs. Waste related to MREs makes up 48% of all solid waste production at the FY12 ORTB 50 PAX Base Camp and 12.3% of solid waste and the FY12 ORTB 300 PAX and 1000

PAX Base Camps, and is consequently a sizeable driver of overall solid waste production. For more information on source reduction, see **Section 3.3.2.3**.

The WEC impacts fuel through reducing the amount of power the generators need to address. The *Provide Electric Power* and *Power Generation* functions are the largest consumers of fuel, accounting for 80–90% of the overall fuel, depending on environment. The WEC combusts solid waste to produce energy, reducing fuel usage along the way. The final product of a WEC is ash, char, and noncombustible waste that has a drastically smaller weight than the solid waste it consumed. In this way, the “fuel” that a WEC consumes is solid waste. The number of WECs is sized to address all solid waste, which results in one WEC at the 300 PAX base camp and two WECs at the 1000 PAX base camp. Due to the design of the FY12 ORTB Base Camps, a WEC requires a grid and an energy storage system to operate effectively, so all simulations involving WECs also include grids. Note that the WEC is not appropriately sized for a 50 PAX camp, and so this camp is not modeled in this section. For more information on the WEC, see **Section 3.3.4**.

In the integrated base camp, WECs are implemented on base camps that are using source reduction. Source reduction does not impact the number of WEC systems required at each base camp. When source reduction is implemented, there is less solid waste for the WEC to burn, which means the solid waste savings are slightly less than would be expected if the two technologies did not interact. Additionally, reducing the waste reduces the amount of waste the WEC can convert to power, slightly reducing the fuel savings. **Table 65** describes the total resource savings in the desert environment from all the relevant individual simulations as well as the combined base camp. Figure **32** illustrates the resource savings for the 300 PAX base camp in the desert environment. Here, as in previous charts, the sum of the individual options is **not** a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp. The resource savings are very similar across environments and across base camp sizes.

Table 65. Mean Daily Camp Level Summary, Waste to Energy Convertor and Source Reduction, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY 12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
WEC	570	45.3%	4416	13.6%	8723	0.0%	8529	0.0%	561	80.5%
Source Reduction	1042	0.0%	5108	0.0%	8723	0.0%	8529	0.0%	2852	0.6%
Integrated Camp	570	45.3%	4421	13.5%	8723	0.0%	8529	0.0%	560	80.5%
					1000 PAX Camp					
FY 12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
WEC	1797	46.8%	14990	14.7%	31305	0.0%	31153	0.0%	2079	80.5%
Source Reduction	3376	0.0%	17580	0.0%	31305	0.0%	31153	0.0%	10602	0.7%
Integrated Camp	1799	46.7%	15009	14.6%	31305	0.0%	31153	0.0%	2073	80.6%

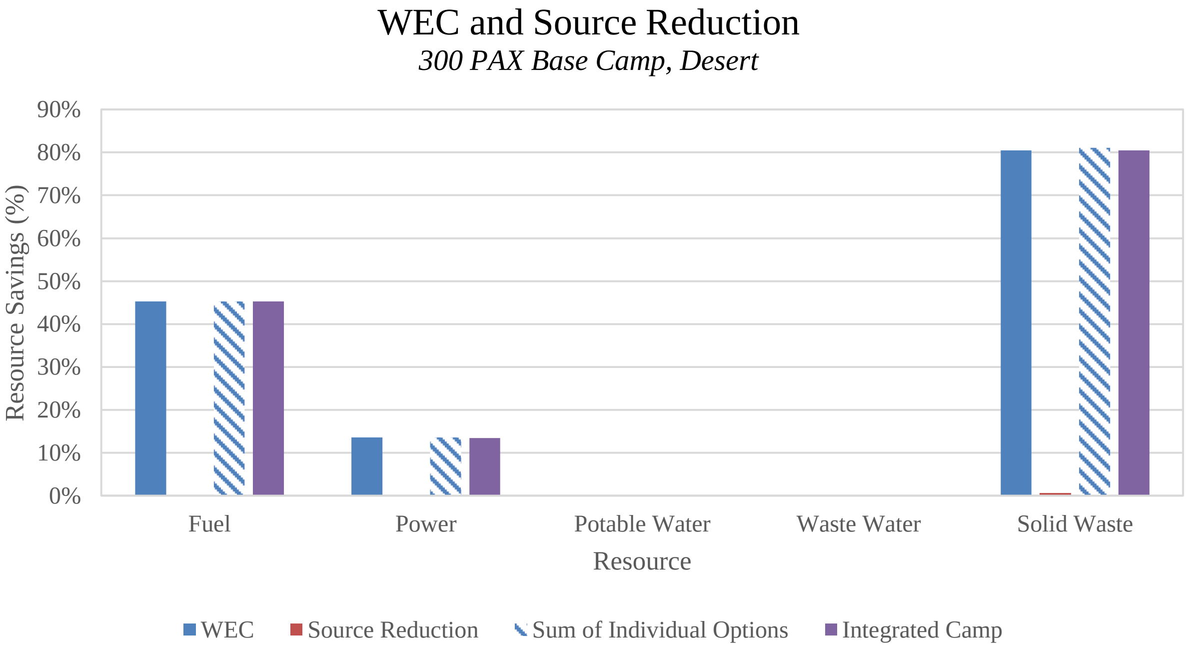

Figure 33. Resource Savings, WEC and Source Reduction, 300 PAX Base Camp, Desert

Overall, the interaction of the two technologies is very slightly antagonistic in solid waste and in fuel. However, the magnitude of solid waste and fuel savings are enormous, approximately 80% and 45% respectively, whereas the antagonistic effects of the WEC's interaction with source reduction costs much less than 1% in solid waste or fuel savings. This is because source reduction has a significantly smaller (i.e., less than 1%) impact on solid waste reduction than the WEC. However, as discussed in **Section 3.3.2.3**, implementing source reduction might have other positive effects besides reducing resource usage, such as allowing convoys to move more MREs in trucks of the same size. Overall, the results indicate that the interaction of the WEC and source reduction in its current form will not be an important factor in deciding whether or not to combine these technologies.

However, the lessons from this analysis can be used to inform future design choices. For example, if the magnitude of solid waste reduction from source reduction was larger, its impact on the WEC would be correspondingly larger, perhaps large enough to seriously impact the ability of the WEC to perform as desired. Additionally, this also illustrates the importance of having as much waste as possible be combustible so it can be processed by the WEC. If source reduction lowered the amount of solid waste and switched a portion of combustible waste to be noncombustible, the effect on the performance of the WEC would be doubly negative because even less material would be converted to energy. In general, on a base camp with a WEC, priority should be given to switching as much waste as possible to be combustible rather than reducing the overall volume of solid waste.

4.2.4 Laundry Reduction and Polymer Bead Washer

This section investigates combining the TTP change of reducing the frequency of laundry service with the materiel change of implementing polymer bead clothes washer. The polymer bead washer is only sized for the 1000 PAX base camp; therefore, this is the only base camp modeled with this technology. At the 1000 PAX base camp, laundry services account for approximately 9% of potable water usage and 9% of waste water production, the third largest consumer of potable water and producer of waste water.

Reducing laundry frequency without increasing the load size lowers the total volume of laundry cleaned and the resources needed, such as water and power. On the other hand, polymer bead laundry technology is a replacement washing machine that uses polymer beads to lower water consumption, slightly increasing power consumption as a side effect. For more information on these options, see **Section 3.2.1**. When these options are implemented together, a polymer bead washer is used and Soldiers are able to wash only half as much laundry.

Table 66 describes the total resource savings in the desert environment from all the relevant individual runs as well as the combined base camp. **Figure 34** illustrates the resource savings for the 1000 PAX base camp in the desert environment. Here, as in previous charts, the sum of the individual options is **not** a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp. The resource savings are very similar across environments.

Table 66. Mean Daily Camp Level Summary, Laundry Reduction and Polymer Bead Washer, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Laundry (50% of Baseline)	3355	0.6%	17220	2.1%	29949	4.3%	29797	4.4%	10672	0.0%
Polymer Bead Washer	3378	-0.1%	17624	-0.3%	30395	2.9%	30243	2.9%	10672	0.0%
Integrated Camp	3356	0.6%	17242	1.9%	29494	5.8%	29342	5.8%	10672	0.0%

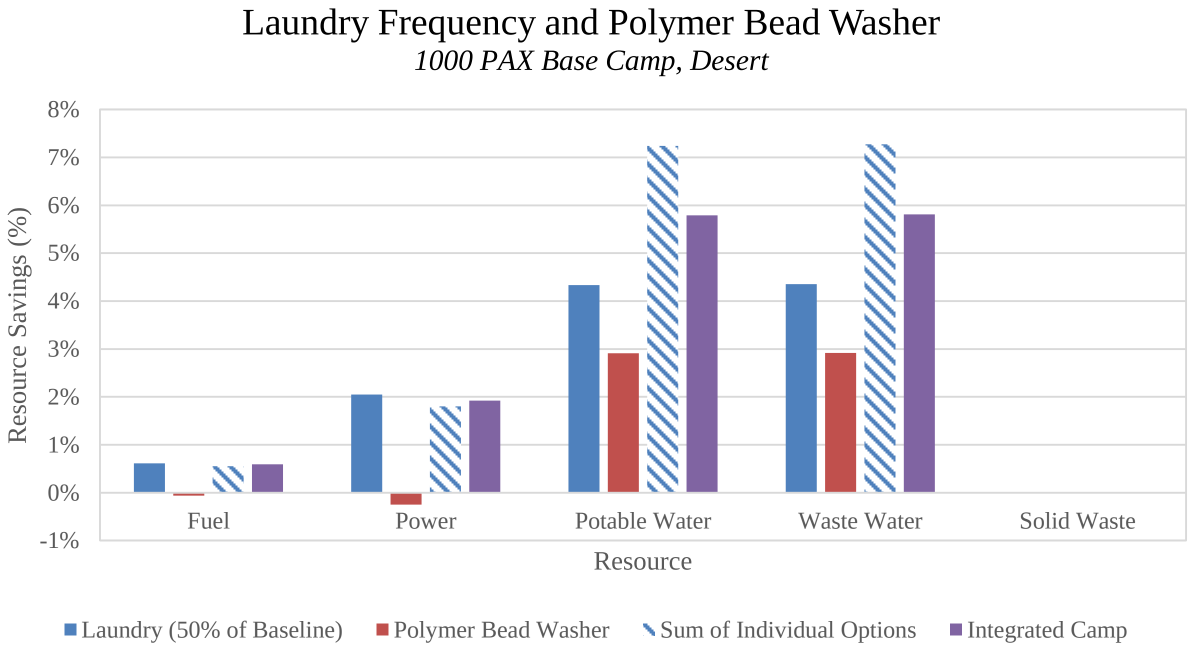

Figure 34. Resource Savings, Laundry Frequency and Polymer Bead Washer, 1000 PAX Base Camp, Desert

These results show that the savings suggested are mainly antagonistic, especially for potable water and waste water. This makes sense, as using a more efficient laundry system produces less savings if there is less laundry to do. For potable water and waste water savings, the antagonistic effect is about 1.5%, which is equal to about half the size of the 2.9% savings coming from implementing the polymer bead washer alone. In other words, implementing a more efficient technology but only using it half as much only results in about half the savings. The fuel savings at the integrated camp are almost exactly equal to the sum of the individual options, though fuel savings overall are quite small for technologies related to laundry. Note that the integrated camp still has resource savings for potable water and waste water greater than either individual camp. Given a base camp that already has a low level of laundry done weekly (equal to half the volume of laundry done on the ORTB base camps), implementing the polymer bead washer only brings added resource savings of about 1.5% for potable water, which may not be sufficient to motivate adding new technologies. However, for a base camp that already has a polymer bead washer, reducing laundry frequency as modeled will bring about an additional 2.9% savings for potable water, which is a stronger increase.

4.3 Operational Quality of Life (QoL(O)) Interactions

The previous sections focus on combining pairs of technologies or non-materiel solutions and investigating whether the overall effect is synergistic or antagonistic resource savings. This section investigates how implementing new technologies can change the cost-benefit analysis associated with non-materiel (i.e., TTP) behavioral modifications. In some cases, these results may be antagonistic, and in some might be synergistic. This section will also consider the impact of non-materiel solutions on QoL(O) and discuss how new technologies can potentially make it possible to improve QoL while decreasing resource usage.

4.3.1 Low-flow Showerheads and Gray Water with Varying Shower Length

This section discusses varying shower lengths while using an Expeditionary Shower System equipped with low-flow showerheads and gray water recycling. A low-flow showerhead reduces potable water demand as well as waste water production by reducing the amount of water used in showers of any length. A gray water recycling unit reduces potable water demand and waste water production by cleaning gray water from showers and laundry facilities so that it can be reused in the laundry and showers. As there are no shower facilities on the FY12 ORTB 50 PAX Base Camp, only the 300 and 1000 PAX base camps are modeled.

Showers are a very important consumer of water, representing 51.1–53.0% of potable water usage and 52.3–53.3% of waste water production at the FY12 ORTB 300 PAX and 1000 PAX Base Camps. Consequently, in order to meet the SLB-STO-D's resource savings of 75% for potable water and 50% for waste water, it is absolutely necessary to address the showers. Additionally, showers are an important driver of QoL(O). Shower frequency and shower duration are responsible for over 2.5 and 1.3 QoL points respectively [20]. Shower frequency is more important than any QoL(O) attribute other than the need to wear body armor and the type of bed available.

This base camp set up is identical to that discussed previously in **Section 4.2.1**. The low-flow showerheads are part of an Expeditionary Shower System and reduce the water used for showers. The gray water recycling system is made up of two FOROs at the 300 PAX base camp and one G-WTRS at the 1000 PAX base camp. For TTP changes, three options for shower length were reviewed. Showers of any length can be extrapolated from the options presented. The first is a doctrinal minimum, which is one 7-min shower [39] and one "field expedient" (approximately 45 s) shower weekly [40]. The second is the baseline 10-min daily showers. Finally, the third option is a daily 15-min shower.

Table 67 shows the impact shower variation has on QoL(O). Note that due to rounding, in certain cases the change in QoL(O) might round to 0.0 even though it has a nonzero impact on the overall level of QoL(O) on the base camp in question. Going to doctrinal minimum shower lengths would bring about a 1.4 to 1.5-point reduction in QoL(O) at the 300 PAX and 1000 PAX base camps. On the other hand, increasing shower lengths to 15-min daily would increase QoL(O) by 0.1 points or less at the 300 PAX and 1000 PAX base camps [20].

Table 67. Comparison of QoL(O) Scores, Shower Length Variation

	QoL	
Simulation Description	Score	Δ
	300 PAX Camp	
Doctrinal minimum	64.0	-1.4
10 min daily showers	65.3	-
15 min daily showers	65.4	0.0
	1000 PAX Camp	
Doctrinal minimum	65.7	-1.5
10 min daily showers	67.0	-
15 min daily showers	67.1	0.1

When these options are combined, showers are varied in length and frequency at a base camp that has both low-flow showerheads and gray water recycling. The overall resource savings are compared to those when shower lengths are varied on the baseline camp.

The first three rows of each base camp size in **Table 68** show the resource flows at base camps with baseline equipment and various shower lengths. Note that for clarity the simulations are placed in order of ascending shower length, meaning that the baseline camp, with 10-min daily showers, is placed second from the top. The last three rows of each base camp size in the table illustrate the same variation in shower lengths, but on a camp with both gray water recycling and low-flow showerheads implemented. Additionally, **Figure 35** illustrates how potable water savings varies based on shower length at the baseline base camp and the modified base camps with low-flow showerheads and gray water recycling.

Table 68. Mean Daily Camp Level Summary, Shower Length Variation, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
Doctrinal minimum, baseline camp	1024	1.7%	5085	0.5%	4755	45.5%	4560	46.5%	2870	0.0%
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
15 min daily showers, baseline camp	1050	-0.8%	5122	-0.3%	10954	-25.6%	10760	-26.2%	2870	0.0%
Doctrinal minimum, low-flow showerheads, and gray water recycling	1024	1.7%	5101	0.1%	3339	61.7%	3145	63.1%	2870	0.0%
10 min daily showers, low-flow showerheads, and gray water recycling	1037	0.5%	5146	-0.7%	3890	55.4%	3696	56.7%	2870	0.0%
15 min daily showers, low-flow showerheads, and gray water recycling	1046	-0.4%	5170	-1.2%	4196	51.9%	4002	53.1%	2870	0.0%
					1000 PAX Camp					
Doctrinal minimum, baseline camp	3315	1.8%	17493	0.5%	16550	47.1%	16398	47.4%	10672	0.0%
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
15 min daily showers, baseline camp	3419	-1.3%	17629	-0.3%	39599	-26.5%	39447	-26.6%	10672	0.0%
Doctrinal minimum, low-flow showerheads, and gray water recycling	3315	1.8%	17538	0.2%	11448	63.4%	11295	63.7%	10672	0.0%
10 min daily showers, low-flow showerheads, and gray water recycling	3361	0.4%	17683	-0.6%	13423	57.1%	13270	57.4%	10672	0.0%
15 min daily showers, low-flow showerheads, and gray water recycling	3387	-0.3%	17765	-1.1%	14567	53.5%	14415	53.7%	10672	0.0%

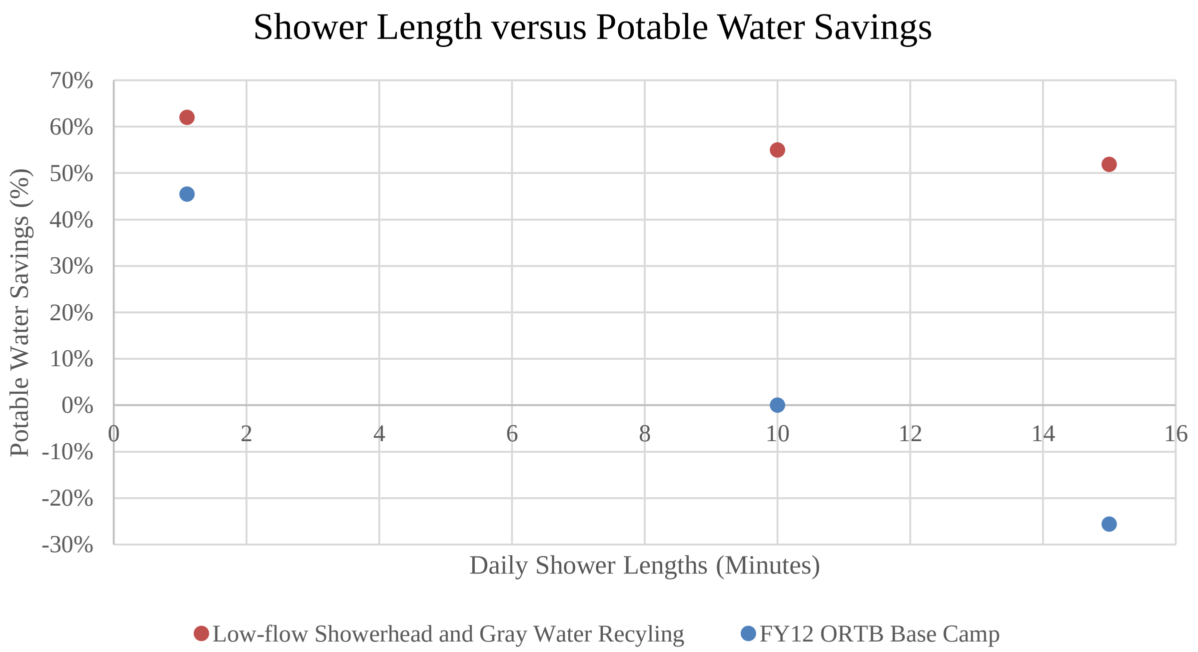

Figure 35. Potable Water Savings from Shower Technologies, 300 PAX Base Camp, Desert

As discussed in **Section 3.2.2**, shower length and resource flows are positively related. The water savings or losses (i.e., depending on if showers are shortened or lengthened) can be quite large. Decreasing shower lengths to doctrinal minimums results in potable water and waste water savings of about 45%. On the other hand, increasing shower lengths to 15-min daily from the baseline incurs negative potable water and waste water savings (i.e., increase in usage over baseline) of about 25%.

However, at the base camp with low-flow showerheads and gray water recycling, no matter what shower length is selected, the magnitude of water and waste water savings is still quite large, approximately 50–60%. This is true even for situations with 15-min showers, which still result in potable water and waste water savings above 50%. This means that with more efficient technologies, it is possible to reinvest resource savings to increase QoL(O). Examination of **Figure 35** makes clear the difference in the magnitude of the impact shower length has—changing shower length has much less impact on resource flows in a camp with new shower technology than the baseline. Specifically, reducing daily showers by 1-min per soldier at the ORTB Base Camp increases water usage by 5.1%. Extending daily showers by 1-min per soldier on a base camp with low-flow showerheads and gray water recycling increases water usage by 0.6–0.8%.

As a side note, though, sometimes it may be necessary to temporarily reduce resource usage to get through an emergency situation. Given these results, it is important to be aware that cutting shower lengths might not be as effective at base camps with water saving technologies already implemented. Even reducing shower length to doctrinal minimums at such a base camp only reduces potable water usage by about 6.3%. However, it is also important to note that increasing shower lengths, and therefore increasing QoL, may be possible without dramatically increasing water usage.

4.3.2 Shelter Consolidation and Improved Shelters

At the FY12 ORTB Base Camps, the average number of Soldiers in a billet is approximately 11 at the 50 PAX base camp, 14 at the 300 PAX base camp, and 17 at the 1000 PAX base camp. Given that the capacity of most billets is 22, it might be appealing to consolidate Soldiers into fewer billets, potentially saving resources. However, given that the population density of a billet is one of the strongest drivers of QoL(O), it might conversely be attractive to increase the number of billeting shelters, increasing resource usage but also increasing QoL(O). This section investigates billeting consolidation both with the baseline shelters and with the improved shelters.

Billeting is a substantial power draw, accounting for anywhere from 31.2% of power (at the 1000 PAX base camp in a temperate environment) to 60.0% (at the 50 PAX base camp in a tropical environment). Because fuel must be used to generate power, reducing the overall power draw can help to meet resource savings benchmarks. It is possible to reduce power draw by the billets by making each billet more efficient. It is also possible to reduce power draw by increasing the number of Soldiers per billet and thereby reducing the number of billeting shelters overall. These options are discussed in **Section 3.1.1**. This section will discuss combining these options by implementing shelter consolidation along with shelter improvements.

The shelter improvements involve substituting in SIP-Huts and AS TEMPER tents with V1.5 liners, PShades, and 42k ECU units. Consolidating to 18 Soldiers per billet involved removing 2 billets out of 6 on the 50 PAX, 5 billets out of 23 on the 300 PAX, and 11 out of 72 billets on the 1000 PAX. Consolidating to 18 Soldiers per billet was chosen because this was the initial assumption in the FY12 ORTB Base Camp configurations, based on an occupancy of up to two 9-person squads per billet. In some cases, billeting consolidation meant that generators could be reallocated, potentially allowing for even greater fuel savings.

This section does not contain estimates of the impact of this modification on QoL(O). This is because the QoL(O) Tool only provides estimates for certain discrete numbers of Soldiers per billet and there are no values in between 9 Soldiers per billet and 18 Soldiers per billet. Given that the number of Soldiers per billet at the FY12 ORTB Base Camps is closest to 18 Soldiers per billet, the current tools for quantifying QoL(O) are not sensitive enough to measure any impact of billeting consolidation.

Table 69 contains the results of simulations for the combined base camp at all three base camp sizes for the desert environment. **Figure 36** illustrates the resource savings as compared with the sum of the individual options for the 300 PAX base camp in the desert environment. Here, as in previous charts, the sum of the individual options is **not** a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp. The resource savings are very similar across environments and across base camp sizes.

Table 69. Mean Daily Camp Level Summary, Billeting Consolidation, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
	50 PAX Camp									
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
18 Soldiers per Billet	183	14.7%	804	20.1%	75	0.0%	27	0.0%	266	0.0%
Improved Shelters with generator reallocation	157	27.0%	342	66.0%	75	0.0%	27	0.0%	266	0.0%
18 Soldiers per Billet, Improved Shelters	134	37.7%	306	69.6%	75	0.0%	27	0.0%	266	0.0%
	300 PAX Camp									
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
18 Soldiers per Billet	986	5.4%	4603	9.9%	8723	0.0%	8529	0.0%	2870	0.0%
Improved Shelters, no generator reallocation	905	13.2%	2528	50.5%	8723	0.0%	8529	0.0%	2870	0.0%
18 Soldiers per Billet, New Shelters	872	16.3%	2438	52.3%	8723	0.0%	8529	0.0%	2870	0.0%
	1000 PAX Camp									
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
18 Soldiers per Billet	3275	3.0%	16789	4.5%	31305	0.0%	31153	0.0%	10672	0.0%
Improved Shelters with generator reallocation	2770	18.0%	8878	49.5%	31305	0.0%	31153	0.0%	10672	0.0%
18 Soldiers per Billet, Improved Shelters	2729	19.2%	8666	50.7%	31305	0.0%	31153	0.0%	10672	0.0%

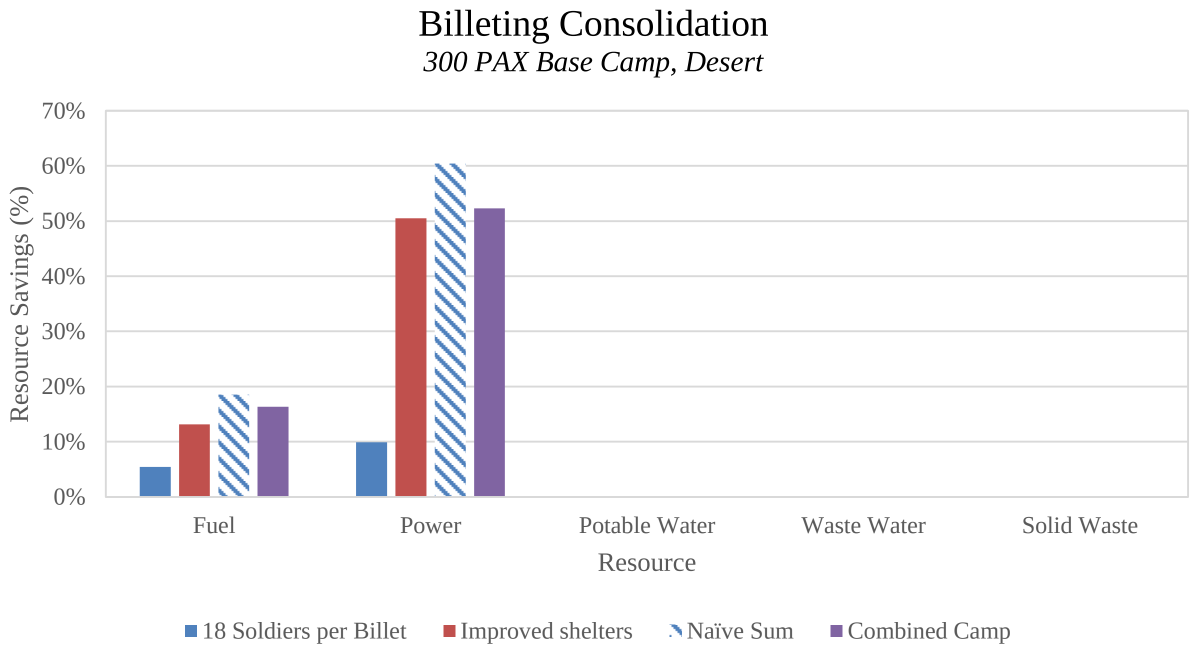

Figure 36. Resource Savings, Billeting Consolidation, 300 PAX Base Camp, Desert

The results show that the savings are antagonistic in power and fuel. This is because consolidating Soldiers and removing excess billets from a camp brings about the most savings when each billet is a large power consumer. When the shelters are made more efficient, the savings that come from removing them becomes smaller. While the savings in the combined base camp is larger than the savings at either individual run base camp, the savings are not much more than those that come from the improved shelters alone. Specifically, if billeting consolidation is implemented on a baseline camp, it results in 3.0–5.4% fuel savings at the 300 PAX and 1000 PAX base camps and 14.7% savings at the 50 PAX base camp. However, when it is implemented on the base camp with improved shelters, billeting consolidation only results in 1.2–3.1% fuel savings at the 300 PAX and 1000 PAX base camps and 10.7% at the 50 PAX base camp. The results indicate that at a base camp with highly efficient shelters, reducing the number of them has a relatively small impact on resource flows.

4.3.3 Billeting Expansion with Improved Shelters and Microgrids

Conversely, another change that could be considered at a base camp is reducing the number of Soldiers per billet. While this would require a larger number of billets in the camp overall, it would also have a substantial increase in the QoL(O) of Soldiers on the camp, raising it by about 0.6 points if the number of Soldiers per billet is decreased to nine. This section investigates how shelter expansion is affected by implementing more efficient shelters on the base camp.

Billeting is a substantial power draw, accounting for anywhere from 31.2% of power (at the 1000 PAX base camp in a temperate environment) to 60.0% (at the 50 PAX base camp in a tropical environment). As a result, increasing the number of shelters is expected to have a large and negative impact on resource savings. However, the number of Soldiers in a billet is also a very important driver of QoL(O). For these reasons, it is useful to investigate the resource tradeoffs associated with this change.

The shelter improvements involve substituting in SIP-Huts and AS TEMPER tents with V1.5 liners, PShades, and 42k ECU units. Additionally, this improved base camp was supplemented with six 60 kW TQG microgrids and LED lights to approximate the Targeted Reduction Base Camp with regards to shelters as closely as possible. Expanding to 9 Soldiers per billet involved adding 2 billets at the 50 PAX base camp, 12 billets at the 300 PAX base camp, and 56 billets at the 1000 PAX base camp, which required adding 1 microgrid at the 300 PAX base camp and 2 microgrids at the 1000 PAX base camp. Note that an expansion of this nature would almost certainly require an expansion in the physical size of the base camp—an additional logistical and security consideration.

Table 70 describes the impact of billeting expansion on QoL(O) and shows that the expansion brings about an increase in QoL(O) of about 0.6 points no matter the base camp size. Note that the number of Soldiers per billet on the baseline camp is between 9 and 18, but much closer to 18. As a result, implementing billeting expansion would likely have a smaller impact on QoL(O) than the table indicates.

Table 70. Comparison of QoL(O) Scores, Billeting Expansion

	QoL	
Simulation Description	Score	Δ
	50 PAX Camp	
18 Soldiers per Billet	31.3	-
9 Soldiers per Billet	32.0	0.6
	300 PAX Camp	
18 Soldiers per Billet	65.3	-
9 Soldiers per Billet	66.0	0.6
	1000 PAX Camp	
18 Soldiers per Billet	67.0	-
9 Soldiers per Billet	67.7	0.6

Table 71 describes the resource savings associated with each simulation, including the integrated base camp for all three camp sizes in the desert environment. **Figure 37** illustrates the resource savings for the 300 PAX camp in the desert environment. Here, as in previous charts, the sum of the individual options is not a simulation, but rather a simple addition of results of the individual simulations to clarify a benchmark against which to measure the integrated camp. The resource savings are very similar across environments and across base camp sizes.

Table 71. Mean Daily Camp Level Summary, Billeting Expansion, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
9 Soldiers per Billet	248	-15.4%	1209	-20.1%	75	0.0%	27	0.0%	266	0.0%
Baseline, Microgrids, Improved Shelters	82	61.9%	342	66.0%	75	0.0%	27	0.0%	266	0.0%
9 Soldiers per Billet, Microgrids, Improved Shelters	83	61.4%	372	63.1%	75	0.0%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
9 Soldiers per Billet	1224	-17.5%	6322	-23.8%	8723	0.0%	8529	0.0%	2870	0.0%
Baseline, Microgrids, Improved Shelters	396	62.0%	2528	50.5%	8723	0.0%	8529	0.0%	2870	0.0%
9 Soldiers per Billet, Microgrids, Improved Shelters	435	58.3%	2729	45.6%	8723	0.0%	8529	0.0%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
9 Soldiers per Billet	4236	-25.5%	23244	-32.2%	31305	0.0%	31153	0.0%	10672	0.0%
Baseline, Microgrids, Improved Shelters	1218	63.9%	8878	49.5%	31305	0.0%	31153	0.0%	10672	0.0%
9 Soldiers per Billet, Microgrids, Improved Shelters	1336	60.4%	9860	43.9%	31305	0.0%	31153	0.0%	10672	0.0%

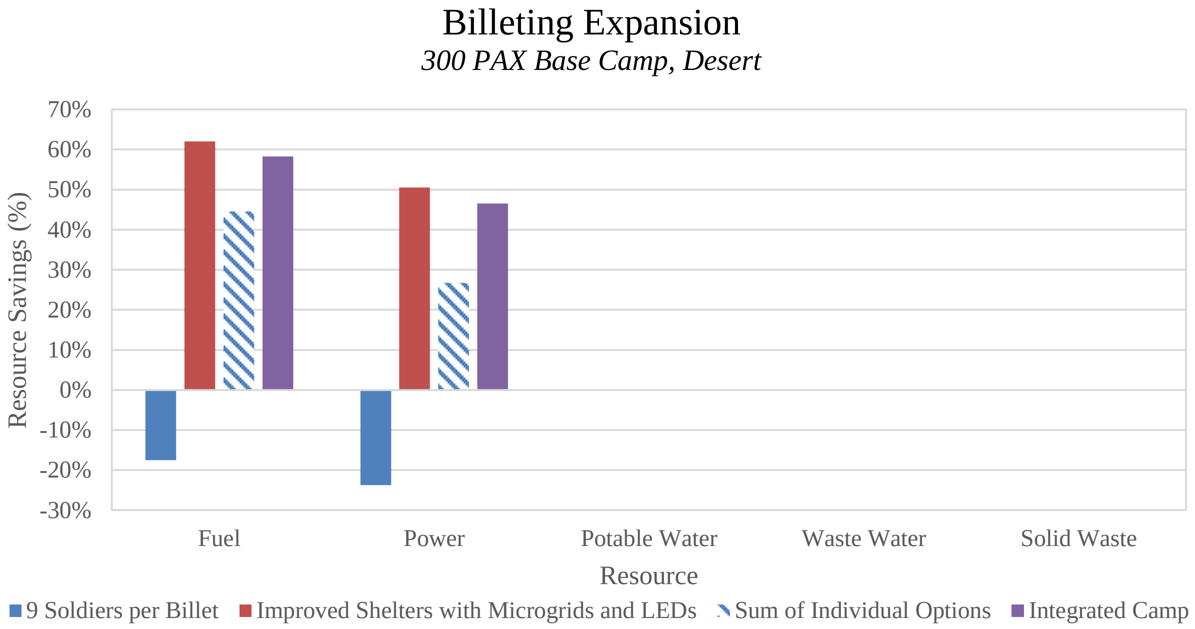

Figure 37. Resource Savings, Billeting Expansion, 300 PAX Base Camp, Desert

The results indicate that, overall, the effect of combining billeting expansion with improved shelters, microgrids, and LEDs is a synergistic savings in power and fuel. In other words, implementing improved technology more than offsets the additional resource cost of billeting expansion. Adding in billeting expansion to a camp with microgrids, LEDs, and improved shelters only reduces fuel savings by about 3%. Doing this same billeting expansion on the FY12 ORTB Base Camps would result in increased fuel costs of 15.4–25.5%, a prohibitively high cost that would probably rule out a billeting expansion of this type. Given that billeting expansion has a positive, though small, impact on QoL(O), a moderately small drop in resource savings might be worth it.

4.3.4 Varying Feeding Plan and Field Feeding Equipment

At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, two kitchen meals are provided each day, for breakfast and dinner, with MREs provided for lunch. Having more kitchen meals in general increases QoL(O), while having fewer increases resource savings. This section explores the resource flow tradeoffs of having fewer or more kitchen meals along with having improved kitchens. The 50 PAX base camp is omitted because it has no kitchens.

Having kitchen meals, as compared with MREs, accounts for 6.9–8.2% of fuel usage, 2.1–4.2% potable water usage, 2.1–4.3% of waste water production, and 14.3–15.3% of solid waste production at the 300 PAX and 1000 PAX base camps. While the numbers involved are relatively modest, aside from solid waste production, the kitchens are still important because they touch every resource flow, so a change in utilization can have impacts in multiple resource areas.

Additionally, the number of hot meals is a strong driver of QoL(O), as **Table 72** describes. Going from two hot meals to one brings about a reduction of 1.3 QoL(O) points at the 300 PAX and 1000 PAX base camps. Moving from two hot meals to three brings about an increase of 1.0 QoL(O) points at the 300 PAX base camp and 0.9 QoL(O) points at the 1000 PAX base camp.

Table 72. Comparison of QoL(O) Scores, Kitchen Meals

	QoL	
Simulation Description	Score	Δ
	300 PAX Camp	
One Kitchen Meal	64.0	-1.3
Two Kitchen Meals	65.3	-
Three Kitchen Meals	66.3	1.0
	1000 PAX Camp	
One Kitchen Meal	65.7	-1.3
Two Kitchen Meals	67.0	-
Three Kitchen Meals	68.0	0.9

At the 300 PAX, new kitchen technologies (see **Section 3.1.3**) include the FF-ETK and HE-MTRCS improved refrigeration and freezer units. At the 1000 PAX base camp, improved technologies include the DESERT as well as the MACK, a version of the CK with improved appliances, and the WRS for Field Food Service Sanitation, which saves water in the cleaning process. When kitchen meals are increased to three a day or decreased to one a day, the appliances are modified so as to be on for one additional or one fewer 4-h meal period. The dining tent stays on continuously regardless of meals. The per-person waste production is modified and takes into account the reduction or increase in waste from MREs to replace the kitchen meals.

Table 54 describes the resource savings associated with the changes listed above. The first three lines of each base camp size list resource flows for the base camp with baseline field feeding equipment. The last three lines list resource flows for base camps with new field feeding improvements as well as variations in number of kitchen meals. **Figure 38** and **Figure 39** describe the resource flows for each base camp size. Figures for both 300 and 1000 PAX base camps are included because the technologies used at each size are substantially different and merit separate analysis.

Table 73. Mean Daily Camp Level Summary, Kitchen Meals Variation Baseline, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
One Kitchen Meal	1030	1.2%	4892	4.2%	8538	2.1%	8244	2.2%	2650	7.7%
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Three Kitchen Meals	1050	-0.8%	5231	-2.4%	8909	-2.1%	8714	-2.2%	3161	-10.1%
One Kitchen Meal, New Kitchens	996	4.4%	4703	7.9%	8576	1.7%	8382	1.7%	2650	7.7%
New Kitchens Baseline	1004	3.7%	4769	6.6%	8799	-0.9%	8605	-0.9%	2870	0.0%
Three Kitchen Meals, New Kitchens	1011	2.9%	4775	6.5%	9022	-3.4%	8828	-3.5%	3161	-10.1%
					1000 PAX Camp					
One Kitchen Meal	3339	1.1%	17333	1.4%	30978	1.0%	30826	1.1%	9851	7.7%
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Three Kitchen Meals	3446	-2.1%	17898	-1.8%	31632	-1.0%	31480	-1.1%	11751	-10.1%
One Kitchen Meal, New Kitchens	3290	2.6%	17037	3.1%	30844	1.5%	30646	1.6%	9851	7.7%
New Kitchens Baseline	3317	1.8%	17186	2.2%	31036	0.9%	30793	1.2%	10672	-
Three Kitchen Meals, New Kitchens	3375	0.0%	17370	1.2%	31228	0.3%	30940	0.7%	11751	-10.1%

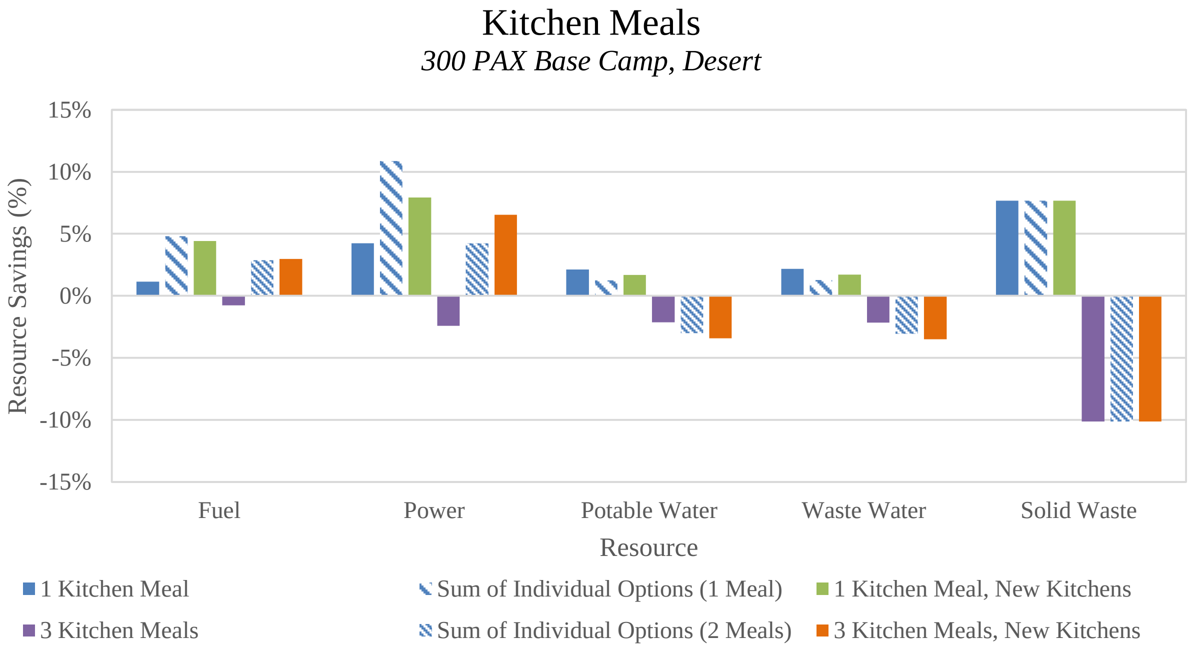

Figure 38. Resource Savings, Kitchen Meals, 300 PAX Base Camp, Desert

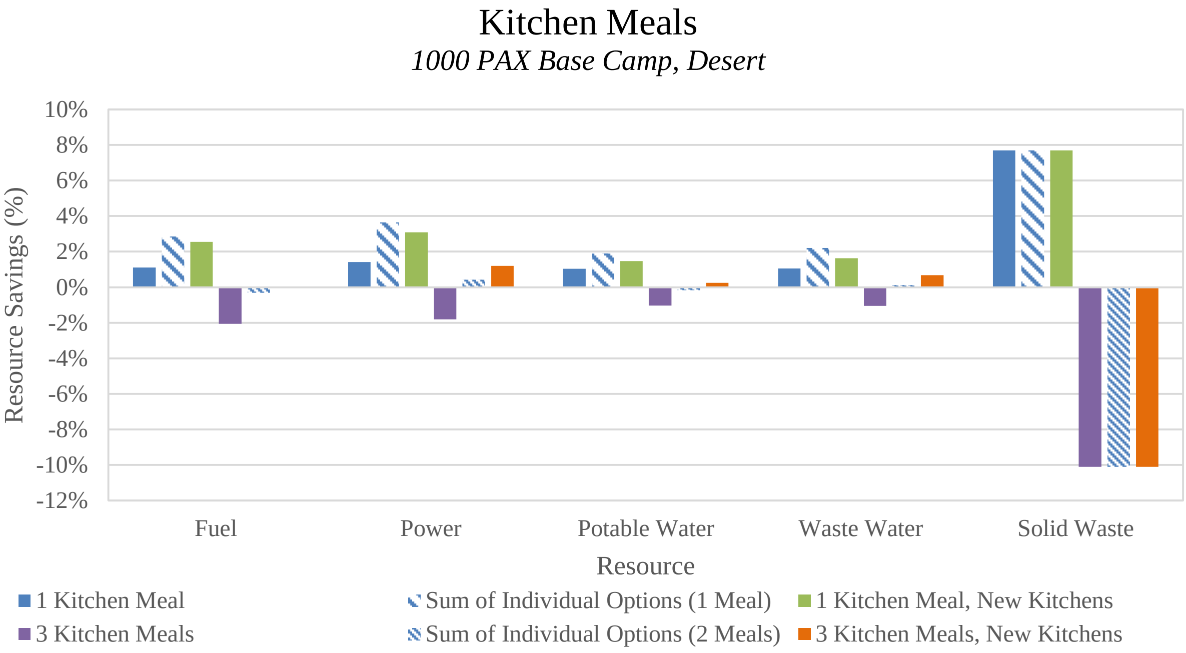

Figure 39. Resource Savings, Kitchen Meals, 1000 PAX Base Camp, Desert

At the 300 PAX base camp, the new kitchen technology used for the baseline two kitchen meals per day results in resource savings in fuel and negative savings (i.e., increase in usage over the baseline) in potable water and waste water production. Solid waste is left unchanged. Having fewer kitchen meals means that the impact of the new kitchen technologies is less, and the resulting resource savings from the integrated camp is closer to that of the baseline camp with only one kitchen meal. In this case, that means that fuel savings are slightly less than the sum of the individual options (i.e., antagonistic) and water savings are slightly more than expected (i.e., synergistic). When there are three kitchen meals a day, the opposite is true—the resource savings from the synergistic camp are closer to the resource savings from camp with improved kitchen technologies. Fuel savings are more than the sum of the individual options (i.e., synergistic) and water savings are less (i.e., antagonistic). Solid waste production is not impacted by the new technologies and so the resource savings at the combined base camp is exactly additive.

At the 1000 PAX base camp, the improved technologies bring about resource savings in fuel, potable water, and waste water production. Having fewer kitchen meals again means that the impact of the new kitchen technologies is less, and the resulting resource savings from the integrated camp is closer to that of the baseline camp with only one kitchen meal. This means that resource savings are antagonistic for every resource except solid waste, where savings are additive because the new technologies do not impact solid waste. Having more kitchen meals means that the impact of the new technologies is greater, and resource savings are synergistic for every resource except for solid waste, which is additive.

4.4 Operational Quality of Life (QoL(O)) Trades

Previously, **Sections 4.1** and **4.2** investigated how combining related technologies and TTP solutions can impact the base camp's resource usage and QoL(O) score. Some of those solutions negatively impact QoL(O). Because maintaining QoL(O) is a part of SLB-STO-D's program objective, it is problematic to recommend implementing these kinds of solutions. One idea to get around this difficulty is to implement QoL(O) "trades" – one solution that decreases QoL(O) being paired with another solution that increases it. The dual aim of these trades is to get the net change in QoL(O) to be closer to zero while maintaining high levels of resource savings. This section will investigate two possible QoL(O) trades, both restricted to impacting the same functional area (e.g., both impacting showers or both impacting meals). The QoL(O) Tool [20] is used to determine how close this tradeoff is to a net zero change in QoL(O), while the DCAM simulation environment is used to determine the resource savings associated with this tradeoff. With these tools it is possible to quantify the benefits and costs of proposed trades in QoL(O) without actually implementing any changes on a real base camp. Investigations of trades following this pattern have the potential to guide decisions of resource savings without reducing or significantly reducing QoL(O).

While this section investigates only two QoL(O) trades, there are a vast number of possible trade scenarios given how many solutions impact QoL(O). Relaxing the requirement that solutions in the trade impact the same functional area would also increase the number of possible trades, though it might also reduce the accuracy of QoL(O) estimation. Additionally, the methodology used to collect and model QoL(O) attributes as part of the QoL(O) Tool [20] could be used to model additional attributes or variations, if desired. Overall, this section considers a select few illustrative examples of the possibilities for QoL(O) trades.

4.4.1 Shower Frequency and Length

Showers can be varied both in length and frequency. These have logical impacts: higher QoL(O) comes from longer and more frequent showers. By increasing one aspect (increasing length) and decreasing the other (decreasing frequency), it is possible to implement a QoL(O) trade. For this trade, the shower length is increased from the baseline 10 min to 15 min, but the shower frequency is decreased from the baseline daily showers to weekly showers. Note that because the FY12 ORTB 50 PAX Base Camp does not have shower facilities, only the 300 and 1000 PAX base camp facilities are discussed in this section.

Showers are an important driver of QoL(O). Shower frequency and shower duration are responsible for over 2.5 and 1.3 QoL(O) points respectively [20]. In particular, shower frequency is more important than any QoL(O) attribute in the QoL(O) Tool other than the need to wear body armor and the type of bed available. **Table 74** describes the impact of the shower frequency-length trade on the QoL(O) at each base camp, which is a reduction in QoL(O) of about 0.9 points [20]. For comparison, decreasing shower frequency without increasing shower length would result in QoL(O) scores about 0.05 points lower [20]. Because increasing shower length only slightly offsets the decrease in QoL(O) associated with reducing shower frequency, the trade is somewhat imbalanced. Future research that included more granularity in shower frequency options, such as showers twice or three times a week, might make it possible to achieve a net impact on QoL(O) closer to zero.

Table 74. Comparison of QoL(O) Scores, Shower Frequency-Length Trade

	QoL	
Simulation Description	Score	Δ
	300 PAX Camp	
15 min weekly showers	64.4	-0.9
10 min daily showers	65.3	-
	1000 PAX Camp	
15 min weekly showers	66.1	-0.9
10 min daily showers	67.0	-

Showers are also a very important consumer of water, representing 51.1–53.0% of potable water usage and 52.3–53.3% of waste water production at the FY12 ORTB 300 PAX and 1000 PAX Base Camps. As discussed in **Section 4.4.1**changes in shower length and frequency can have a dramatic impact on the total amount of water used at the camp, so this trade might be expected to impact potable water and waste water resource savings at the camp.

It is important to note that the QoL(O) trade presented in this section is not on a baseline camp, but is implemented on a base camp that includes materiel changes designed to increase the efficiency of the shower facilities. These include low-flow showerheads in place of the baseline showerheads in the Expeditionary Shower System, as well as a gray water recycling system that is made up of two FOROs at the 300 PAX base camp and one G-WTRS at the 1000 PAX base camp.

Table 75 describes the results of the QoL(O) trade on this improved base camp. The first row illustrates the baseline resource consumption levels. The second row contains resource usage for the standard 10-min daily showers with the low-flow showerheads and gray water recycling included. The third row contains resource usage for a camp with 15-min weekly showers with the same low-flow showerheads and gray water recycling. **Figure 40** illustrates the results for the 300 PAX base camp in the desert. The resource savings are very similar across environments and across base camp sizes.

Table 75. Mean Daily Camp Level Summary, Shower Frequency-Length Trade, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
10 min daily showers with gray water recycling and low-flow showerheads	1037	0.5%	5146	-0.7%	3890	55.4%	3696	56.7%	2870	0.0%
15 min weekly showers with gray water recycling and low-flow showerheads	1025	1.6%	5106	0.0%	3417	60.8%	3223	62.2%	2870	0.0%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
10 min daily showers with gray water recycling and low-flow showerheads	3361	0.4%	17683	-0.6%	13423	57.1%	13270	57.4%	10672	0.0%
15 min weekly showers with gray water recycling and low-flow showerheads	3320	1.7%	17555	0.1%	11692	62.7%	11540	63.0%	10672	0.0%

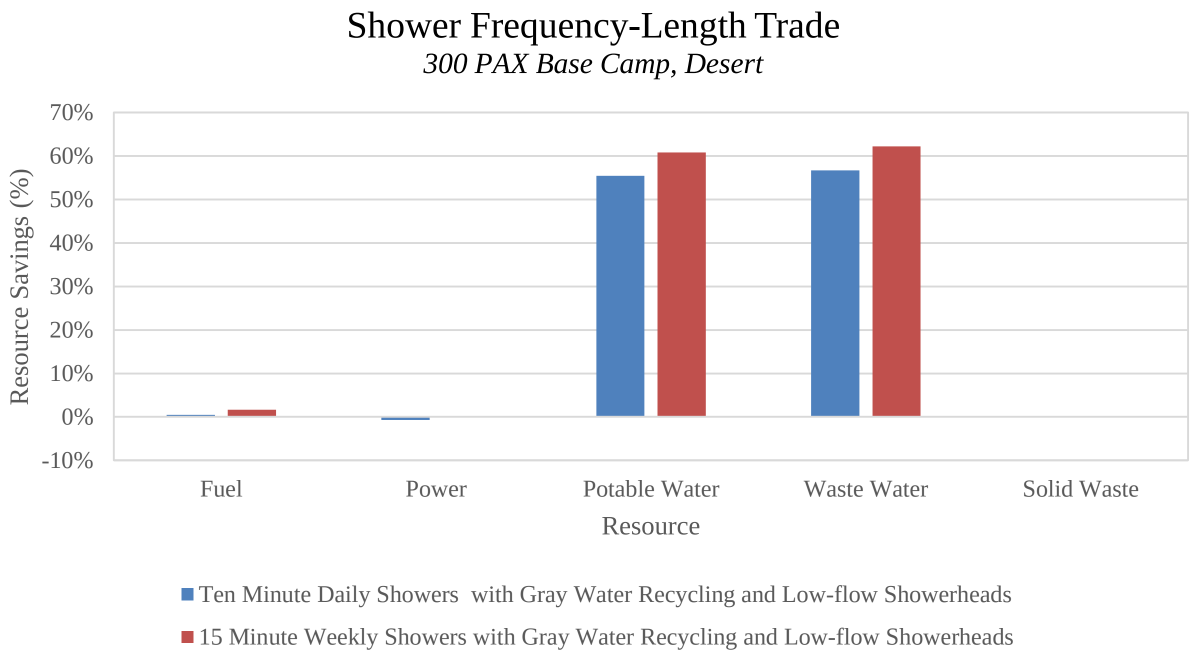

Figure 40. Resource Savings, Shower Frequency-Length Trade, 300 PAX Base Camp, Desert

As mentioned previously, the modified shower schedule has a negative impact on QoL(O). However, it also shows savings in potable water and waste water production, both about a 5% increase as compared to the camp with the materiel shower improvements alone. Additionally, there is a small increase in fuel savings because the gray water recycling unit has less water to process and therefore requires less power. However, the increase in savings from the change in shower scheduling is overshadowed by the potable water savings from simply adding the technological improvements of gray water recycling and low-flow showerheads, which are assumed to have no impact on QoL(O).

The analysis of this trade indicates that the increase in QoL(O) from increasing shower length only partially offsets the drop in QoL(O) due to reduction in shower frequency, leading to a net negative QoL(O) change. This trade does show real savings in resource use, particularly in potable water and waste water. However, the magnitude of these savings is much smaller than the resource savings possible with technological solutions alone. The relatively small improvement in QoL(O) paired with the moderate potable and waste water savings might indicate that this trade-off is useful only when resource savings are more important than QoL(O).

4.4.2 Hot Meals and Dining ECU

The number of hot meals served daily at a base camp is a driver of both resource usage and QoL(O). Similarly, the dining tent ECU consumes power but increases QoL(O). This section investigates whether increasing QoL(O) by increasing the number of hot meals is enough to offset the impact of removing the dining ECU. The impacts under investigation are both in terms of QoL(O), but also in terms of resource savings. Note that because the FY12 ORTB 50 PAX Base Camp does not have kitchen facilities, only the 300 and 1000 PAX base camps will be discussed in this section.

The number of kitchen meals and the presence of dining ECU both have a large impact on QoL(O). **Table 76** describes the impact of the dining ECU-meal trade on the QoL(O) at each base camp. Adding an additional hot meal but removing the dining tent ECU reduces QoL(O) by about 1.8 points at the 300 PAX and 1000 PAX base camps [20]. For comparison, removing the dining tent ECU alone leads to a 2.8 drop in QoL(O) from baseline, and increasing the number of kitchen meals alone leads to a 1.0 increase in QoL(O) as compared with baseline [20]. This indicates that increasing the number of kitchen meals offsets the drop in QoL(O) from removing the dining tent ECU partially but not completely. This trade was selected because the dining ECU and number of daily kitchen meals both impact the functional area related to meals, even though their relative magnitudes are not the same.

Table 76. Comparison of QoL(O) Scores, Dining ECU-Meal Trade

	QoL	
Simulation Description	Score	Δ
	300 PAX Camp	
Three Kitchen Meals, no dining ECU	64.0	-1.8
Two Kitchen Meals	65.3	-
Three Kitchen Meals	66.3	1.0
	1000 PAX Camp	
Three Kitchen Meals, no dining ECU	65.7	-1.8
Two Kitchen Meals	67.0	-
Three Kitchen Meals	68.0	0.9

This QoL(O) trade was made at base camps that included materiel changes designed to increase the efficiency of field feeding. At the 300 PAX base camp, new kitchen technologies (see **Section 3.1.3**) include the FF-ETK and DESERT HE-MTRCS improved refrigeration and freezer units. At the 1000 PAX base camp, improved technologies include the DESERT HE-MTRCS as well as the CKI-I, a version of the CK with improved MACK appliances, and the WRS for Field Food Service Sanitation, which saves water in the cleaning process. When kitchen meals are increased to three a day, the appliances are modified so as to be on for one additional 4-h meal period. The dining tent stays on continuously regardless of meals. The per-person waste production is modified and considers the increase in waste from UGR-As compared to MREs.

Table 77 displays the resource savings results of the simulation. The first row is the baseline. The second row shows a base camp that serves three kitchen meals daily with all new kitchen equipment included. The final row shows a base camp that serves three kitchen meals daily, with all new kitchen equipment included but with the dining ECU shut off. **Figure 41** and **Figure 42** illustrate these results at the 300 PAX and 1000 PAX base camps, respectively.

Table 77. Mean Daily Camp Level Summary, Dining ECU-Meal Trade, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
3 Kitchen Meals, New Kitchens	1011	3.0%	4775	6.5%	9022	-3.4%	8828	-3.5%	3161	-10.1%
3 Kitchen Meals, New Kitchens, Remove ECU	1000	4.0%	4586	10.2%	9022	-3.4%	8828	-3.5%	3161	-10.1%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
3 Kitchen Meals, New Kitchens	3375	0.0%	17370	1.2%	31228	0.3%	30940	0.7%	11751	-10.1%
3 Kitchen Meals, New Kitchens, Remove ECU	3355	0.6%	16991	3.4%	31288	0.3%	30940	0.7%	11751	-10.1%

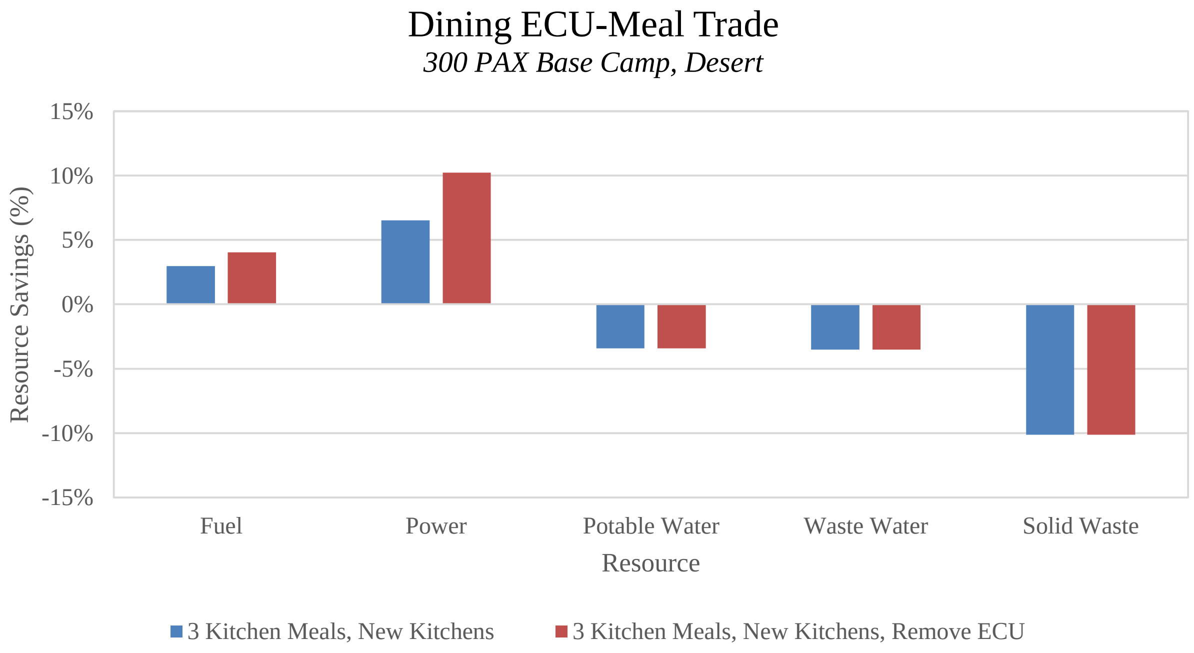

Figure 41. Resource Savings, Dining ECU-Meal Trade, 300 PAX Base Camp, Desert

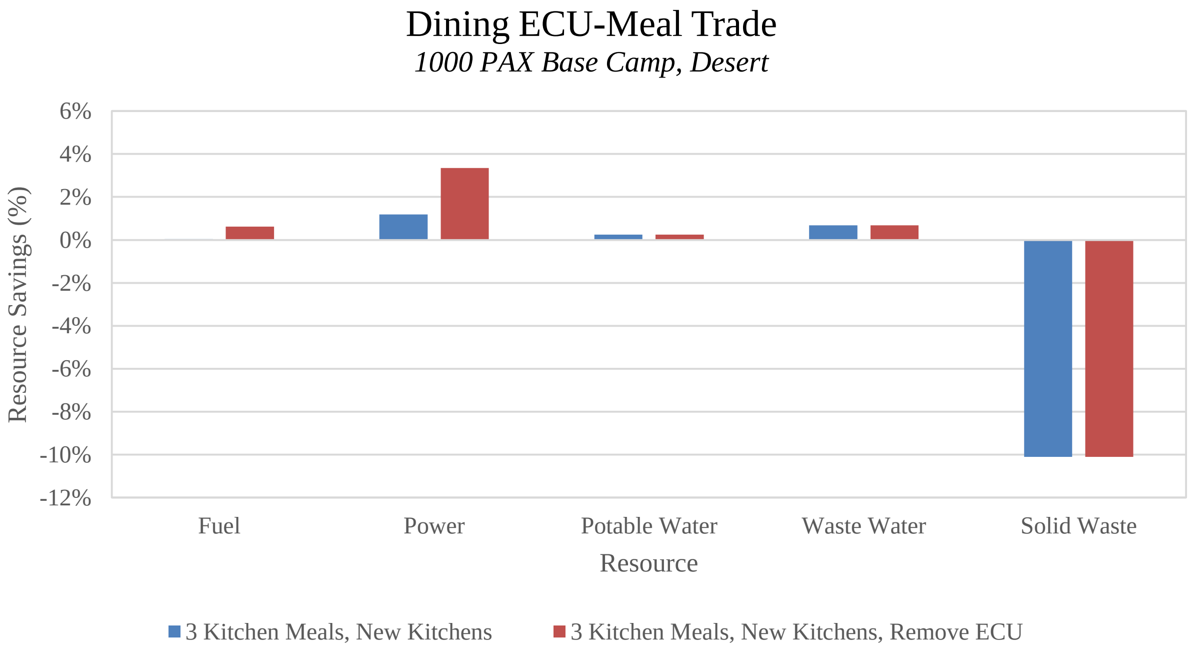

Figure 42. Resource Savings, Dining ECU-Meal Trade, 1000 PAX Base Camp, Desert

Note that the 300 PAX and 1000 PAX base camp kitchen improvements differ substantially in the actual technologies implemented and consequently in the resource flows impacted. However, the ECU in both cases influences power and fuel. At the 300 PAX base camp, removing the ECU increases fuel savings by about 1%. At the 1000 PAX base camp, removing the ECU increases fuel savings by about 0.6%. The fuel savings are positive, albeit quite small in magnitude. Note additionally that increasing the number of kitchen meals provided daily to three meals substantially increases solid waste, which turning off the ECU does nothing to mitigate. Increasing the number of kitchen meals might make more sense on a base camp that already has a waste destruction unit, such as a WEC, in place, because the increase in solid waste would matter much less.

Overall, the trade discussed in this section increased fuel savings at both the 300 PAX and 1000 PAX base camps modeled. However, the reduction in QoL(O) from removing the dining ECU more than offset the increase in QoL(O) from adding in one more kitchen meal daily. Given that the increase in fuel savings is relatively small, this trade might not be worth the net decrease in QoL(O).

5 RESOURCE OPTIMIZED BASE CAMP DESIGN

A main objective of the SLB-STO-D is to demonstrate an integrated approach to moderate sustainment requirements for small contingency base operations via a suite of capabilities that reduce the need to deliver water and fuel to the base and ease the burden of having to collect, manage, and dispose of solid and liquid waste. To that end, the specific target is to reduce the need for fuel resupply by 25%, reduce the need for water resupply by 75%, and decrease waste generation/backhaul by 50% while maintaining QoL(O) at the base camp. These percentage reductions are compared to the *FY12 Operationally Relevant Technical Baseline* [2]. The integrated base camp designs that strive to meet these target reductions are collectively referred to as the Targeted Reduction Base Camps.

To accomplish these reductions, the Targeted Reduction Base Camps must be constrained in the same way the FY12 ORTB Base Camps were constrained. That is, the camps must be structured to meet the SLB-STO-D use cases (both “Ready State” and “Population Variance”), must be capable of being arranged in an operationally relevant manner, and must meet the same level of services provided at the FY12 ORTB Base Camps.

The constraint of maintaining QoL(O) eliminated certain options from consideration. Notably, the simulation results of nearly every TTP change that impacted resource consumption positively impacted QoL(O) negatively. The one exception to this was reallocating generators using TM 3-34.46, which remained a viable option even with the QoL(O) constraint. Additionally, certain materiel changes negatively impacted QoL(O). For example, as discussed in **Section 3.3.1**, the implementation of burn-out latrines at the 300 PAX and 1000 PAX base camps resulted in a decrease in QoL(O). These materiel options were not considered viable candidates for inclusion in the Targeted Reduction Base Camp designs.

Additionally, the constraint of keeping any footprint additions to a reasonable increase impacted the technologies that were available for consideration. The solar water heater, while effective at its stated goal of reducing the fuel consumption of the WH-400, uses a very large area given the reduction provided. Each system requires a minimum of 225 sq ft of space to operate (plus a safety perimeter), with a planned three systems per set. For this reason, the solar water heater was not considered a viable candidate for inclusion in the Targeted Reduction Base Camps.

The DP2 solar array was also eliminated from consideration due to its large size compared to the fuel savings it produced. The solar array provided only a 0.1–0.2% decrease in fuel consumption at the 300 PAX and 1000 PAX base camps and required approximately 1225 sq ft of space, compared to only 160 sq ft for the DESERT HE-MTRCS itself. Given that this real estate would be located near the kitchens, which are generally in the center of camp, this increase was not considered a reasonable trade for the resource savings.

Table 78 shows the equipment list for the three Targeted Reduction Base Camps. This equipment list can be compared to the FY12 ORTB Base Camp equipment list that was shown in **Table 1**.

Table 78. Equipment List, Targeted Reduction Base Camps

	Quantity		
Name	50 PAX	300 PAX	1000 PAX
	Provide Electric Power		
6 x 60 kW TQG Microgrid*	1	3	10
80 kW T-100 (Variable Speed)*	-	1	1
Energy Storage System	-	1	2
Hybrid Power Trailer (HPT)*	-	1	-
	Enable Command and Control		
AS TEMPER 20x32 (v1.5 Liner, PowerShade, 42K ECU, MTH150)	-	1	1
Meteorological Measuring Set, AN-TMQ-52	-	-	1
MILVAN Shelter (COTS ECU)	-	2	9
Network Communications Hub (F100 ECU)	-	-	1
Satellite Transportable Terminal, AN-TSC-185	-	1	-
SIP Hut Shelter (22k Heat Pump)	1	-	2
	Enable Communications		
MILVAN Shelter (COTS ECU)	-	1	-
	Enable Movement & Maneuver		
AS TEMPER 20x32 (v1.5 Liner, PowerShade, 42K ECU, MTH150)	-	-	2
	Execute Protection		
Entry Control Point, Unpowered	1	-	-
Entry Control Point with Electric Gate	-	2	2
Guard Tower	-	-	16
Radar Cluster*	1	1	2
Radar Set, AN-TPQ-36-V-8	-	-	1
	Provide Access to Maintenance/Repair		
Large Area Maintenance Shelter (LAMS) (2 Large Capacity Field Heaters (LCFH))	-	-	1
Lightweight Maintenance Enclosure (LME) (No ECU)	1	1	1
M7 Forward Repair System*	-	1	-
MILVAN Shelter (COTS ECU)	-	1	2
Wash Rack*	-	1	2
	Provide Access to Medical & Health Services		
MILVAN Shelter (COTS ECU)	1	1	2
	Provide Access to MWR Services		
AS TEMPER 20x32 (v1.5 Liner, PowerShade, 42K ECU, MTH150)	-	-	4
Lightweight Maintenance Enclosure (LME) (42K ECU, MTH150)	-	1	-
MILVAN Shelter (COTS ECU)	-	1	2
	Provide Access to Transportation		
Vehicle Support Set*	1	1	1
	Provide Billeting		
AS TEMPER 20x32 (v1.5 Liner, PowerShade, 42K ECU, MTH150)	6	23	72
AS TEMPER 20x32 (Unoccupied, Off)	-	2	4
Containerized Housing Unit	-	-	3
Containerized Housing Unit (Unoccupied, Off)	-	-	2
MILVAN Shelter (COTS ECU)	-	-	4
MILVAN Shelter (Unoccupied, Off)	1	4	4
	Provide Integrated Solid Waste Management		
Solid Waste Destruction System (SWDS)	1	-	-
Waste to Energy Converter (WEC)	-	1	2
	Provide Integrated Waste Water Management		
Forward Osmosis/Reverse Osmosis (FORO) Graywater Recycling System	-	2	6
TRICON Deployable Baffled Bioreactor (dBBR)	-	1	4
	Provide Integrated Water Management		
Handheld Toxin and Pathogen Detector	1	1	1
Microfluidic Sensors for In-line Water Monitoring	1	3	10
Trailerized Water from Air (WFA)	1	-	-
	Provide Latrine Services		
Burn-Out Latrine	4	-	-
Low Cost TRICON Latrine (LCTL) with ECU	-	4	20
	Provide Means to Clean Clothes		
Expeditionary Containerized Batch Laundry (ECBL) with Polymer Bead Washer	-	-	4
Hand Wash Bucket	1	-	-
MILVAN Shelter (COTS ECU) with COTS Washer and Dryer	-	1	-
SIP Hut Shelter (22k Heat Pump)	-	-	1

Table 78. Equipment List, Targeted Reduction Base Camps (continued)

	Quantity		
Name	50 PAX	300 PAX	1000 PAX
	Provide Means to Maintain Personal Hygiene		
AS TEMPER 20x21 (v1.5 Liner, PowerShade, 42K ECU, MTH150)	-	4	20
Expeditionary Shower System (ESS) with Low-flow Showerheads[†]	-	4	20
Hand Wash Station	3	-	-
	Provide On-Base Lighting		
Fuel-Powered Light Set	-	1	1
Perimeter Lights	6	24	70
	Provide Subsistence		
AS TEMPER 20x32 (v1.5 Liner, PowerShade, 42K ECU, MTH150)	1	2	4
Containerized Kitchen System – Improved	-	-	2
DESERT HE-MTRCS	-	3	7
Food Sanitation Center with Water Recyling System (WRS)	-	-	2
Fuel-fired Expeditionary TRICON Kitchen (FF-ETK)	-	2	-
TRICON Refrigerated Container System	-	2	
	Warehouse/Store All Supply Classes		
AS TEMPER 20x32 (v1.5 Liner, PowerShade, 42K ECU, MTH150)	-	-	1
Lightweight Maintenance Enclosure (LME) (No ECU)	-	3	6
MILVAN Shelter (COTS ECU)	-	1	

[*] Augmented with Single Common Powertrain Lubricant

[†] Source tanks were doubled in capacity

The Targeted Reduction Base Camps started with the FY12 ORTB Base Camps, with the team making additions and alterations to the camp layout to accommodate new technologies. In this way, the new designs inherited many of the layout assumptions of the existing base camp and retained the characteristic of being an operationally relevant (not optimized) layout. The Targeted Reduction Base Camps include many improvements over the FY12 ORTB Base Camps.

For *Power Generation*, a functional area that consumed the clear majority of fuel at the base camp, fuel reduction was targeted on both the power supply side and the power demand side. On the supply side, the spot generators were largely replaced with microgrids consisting of six 60 kW TQGs. At the 300 PAX and 1000 PAX base camps, these microgrids utilize the same generators as the FY12 ORTB Base Camps. At the FY12 ORTB 50 PAX Base Camp, 30 kW TQGs are used. The Targeted Reduction Base Camp upgrades these to 60 kW TQGs, since conversations with SMEs from CERDEC suggested that the current focus does not include the development of a microgrid based solely on 30 kW generators.

The size and quantity of the microgrids was dictated more by geography than by facility power demand. At the 300 PAX base camp, while only two microgrids were required based on loads, the geographic layout of the camp includes facilities too distant from each other to connect all on only two microgrids. A third microgrid was required. Similarly, only 7 microgrids were required to handle the entire load of the 1000 PAX base camp, but 10 were required due to geographic constraints. While generator allocation based on TM 3-34.46 was considered a viable option, this method did not change the layout requirements of the 300 PAX base camp when compared to using the baseline method of sizing power generation based on seasonally-adjusted connected loads (see **Section 3.1.2.1.1**). The reduced demand loads calculated using TM 3-34.46 did allow for one microgrid at the 1000 PAX base camp that would have otherwise been overloaded by 35 kW using the baseline method. This microgrid contained the laundry facilities, which have considerable peak loads.

At both the 300 PAX and 1000 PAX base camps, the unique geographic layouts provided opportunities for spot generation to compete with microgrids. At both camps, the maintenance facilities are isolated from most other facilities on the camp. Due to geographic considerations, these facilities would require a dedicated microgrid, which would be vastly underutilized. Powering the maintenance areas at both camps with T-100s eliminated the need for an additional microgrid. The load following capability of the T-100 made it more efficient than TQGs at lower loads, resulting in a 5 gal per day fuel savings over the microgrid. These savings are due to the underutilization of the microgrid, essentially making the comparison between a T-100 and a single 60 kW TQG.

The 300 PAX base camp also contains a unique ECP, located over 400 ft away from the next closest facility. This ECP required dedicated spot generation. Two possibilities were analyzed: using parallel connected MANGENs or using an HPT. The HPT saved approximately 5 gal per day of fuel compared to the MANGENs; therefore, it was chosen for implementation.

SCPL was chosen for implementation in all engines on the base camp, which provided an additional fuel savings. This included both generators and vehicles.

Three different generator types were chosen for this analysis, which provided for better fuel consumption than using a single generator model. Both the HPT and the T-100 could be replaced by TQGs. A scenario that reduces power generation to only 60 kW TQGs, either standalone or in a microgrid, was also analyzed and can be found in Section 5.1.

Power demand was targeted primarily through shelter technologies. *Shelter Heating and Cooling* consumed 47.1–76.9% of power at the FY12 ORTB Base Camps. At the Targeted Reduction Base Camps, all AS TEMPER tents were outfitted with v1.5 Liners and PShades (in the temperate environment, the PShades were removed during the winter due to snow load concerns). The improved energy efficiency of the shelters allowed for all F100 ECUs to be replaced with 42k ECUs. Additionally, all B-Huts were replaced with SIP Huts. The ECUs in those facilities were upgraded to 22k commercial heat pumps. Shelters such as MILVANs were left untouched. Additionally, all interior fluorescent lighting in the AS TEMPER tents was replaced with LED equivalents.

Other power optimizations occurred in the *Provide Subsistence* functional area. All existing MTRCS were replaced one-for-one with DESERT HE-MTRCS. The kitchens at both the 300 PAX and 1000 PAX base camps were also replaced with their upgraded versions, the FF-ETKs and the CK-I.

Approximately half of the fuel consumed by vehicles at the FY12 ORTB Base Camps is due to transporting fuel, water, and solid waste around the camp. Vehicle fuel consumption was addressed both with SCPL as well as by right-sizing water and fuel bladders throughout the camp. Notable changes include doubling the source water tanks for the shower facilities and using 1,000-gal fuel bladders at each microgrid.

At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, both the shower and latrine facilities consumed more than 25% of potable water, necessitating action at both facilities. The Targeted

Reduction Base Camps addressed the reduction on the demand side. The shower facilities were outfitted with low-flow showerheads. Laundry facilities at the 1000 PAX base camp saw the baseline washer replaced with a polymer bead washing machine. Since no potable water demand reduction was possible at the 50 PAX base camp, the resupply reduction requirement was addressed on the supply side. A WFA system was implemented to generate at least 75% of the camp's potable water consumption.

Latrine facilities at the 300 PAX and 1000 PAX base camps were replaced with LCTLs. The choice of LCTLs was based more on their ability to reduce potable water demand by using low-flow fixtures and sink water recycling technology while maintaining QoL(O) than their capability to incinerate waste water. The toilet-to-population ratio was kept consistent with the FY12 ORTB assumptions. The use of LCTLs is a notable deviation from the possibility to achieve maximal savings by sacrificing QoL(O). **Section 5.2** discusses the possible savings achievable when QoL(O) is not constrained. An additional benefit to the use of LCTLs is their standalone nature. Since they incinerate their own waste water, they were not required to be located near a waste water treatment system.

Gray water recycling was also implemented at the Targeted Reduction 300 PAX and 1000 PAX Base Camps. This served to reduce both waste water generation and potable water consumption. Waste water treatment systems were also implemented, though not technically necessary to meet the SLB-STO-D objective waste reduction. Since the latrine facilities chosen incinerate all their black waste, the size of the waste water treatment systems was largely dictated by the byproduct of the gray water recycling system. All water systems were sized for a population variance of 30%. Implementation of the waste water systems factored in the location of existing facilities. Localized swapping of facilities in the FY12 ORTB layouts was performed to group waste water generating facilities where necessary. Additionally, since the gray water recycling systems generate a waste water byproduct that is to be treated by the waste water systems, the gray water producers were arranged so as to minimize the number of waste water treatment systems as well.

At the Targeted Reduction 300 PAX Base Camp, two FORO systems were required after figuring the reduction in gray water generation from the low-flow showerheads. No layout changes were required to use only two FORO systems. One FORO was dedicated to the laundry and a pair of ESSs and the other to a separate pair of ESSs. Only a single TRICON dBBR waste water treatment system was required, however. To use only one system, all black water generators had to be collocated. Most systems were already located at the center of the camp. The second pair of showers had to be moved to this area for it to share the single TRICON dBBR.

At the Targeted Reduction 1000 PAX Base Camp, the G-WTRS proved oversized given the reduction in gray water from the low-flow showerheads and improved laundry facilities. Five FORO systems were required to meet demand; however, since on a camp this size it would be unlikely to collocate all the gray water facilities, geographic realities necessitated a sixth system. Similarly, only two TRICON dBBRs were required to handle all the black water on the camp. Since it would be unlikely to place all showers, laundry, kitchens, and aid stations in only two locations on the camp, an additional two systems were added. Gray and black water generators were roughly separated into four locations on the base camp. Showers were separated into three groupings: east (four ESSs), west (eight ESSs), and central (eight ESSs). Each pair of ESSs had its own FORO and each grouping had a single TRICON dBBR. An additional grouping of the laundry, kitchens, and aid stations, already located in proximity to each other, had a dedicated FORO and TRICON dBBR.

Solid waste was addressed at both generation and destruction. Source reduction was implemented to reduce the amount of solid waste generated on the base camps. Solid waste destruction was handled via a SWDS at the 50 PAX base camp and WECs at the 300 and 1000 PAX base camps. In all cases, an attempt was made to place the solid waste destruction devices at the outer edge of the base camp, away from habitation structures. This proved to limit the microgrid on which to place the WECs.

An attempt was made to place the WECs on the most used microgrids, so the power generated would not have to be stored for long periods of time. This proved impractical at the 1000 PAX base camp, where the densest power consumption occurred at the center of the camp (the location of the MWR fitness facilities). The WECs were placed in less optimal, but more realistic, locations at the edge of the base camp.

The WEC was integrated with an energy storage system that would absorb any overproduction of power and allow it to be used at a later time. The integration of the battery into the microgrid was basic, allowing only for battery power to be used prior to generator power and not including an algorithm to optimize peak shaving, etc.

Table 79 shows the results of the simulation of the Targeted Reduction Base Camp designs across the different base camp sizes in the different environments. A comparison of these results to all other integrated scenarios is shown in **Table 89**.

Table 79. Mean Daily Camp Level Summary, Targeted Reduction Base Camps

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
Desert Environment										
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Targeted Reduction	94	56.2%	340	66.2%	14	81.3%	27	0.0%	19	92.9%
Temperate Environment										
FY12 Baseline	219	-	661	-	75	-	27	-	266	-
Targeted Reduction	109	50.2%	404	38.9%	4	94.7%	27	0.0%	19	92.9%
Tropical Environment										
FY12 Baseline	212	-	951	-	75	-	27	-	266	-
Targeted Reduction	90	57.6%	275	71.1%	2	97.3%	27	0.0%	19	92.9%
					300 PAX Camp					
Desert Environment										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Targeted Reduction	436	58.2%	1925	62.3%	1954	77.6%	180	97.9%	566	80.3%
Temperate Environment										
FY12 Baseline	1096	-	4091	-	8723	-	8529	-	2870	-
Targeted Reduction	553	49.5%	2630	35.7%	1954	77.6%	180	97.9%	566	80.3%
Tropical Environment										
FY12 Baseline	1023	-	4806	-	8723	-	8529	-	2870	-
Targeted Reduction	417	59.2%	1661	65.4%	1954	77.6%	180	97.9%	566	80.3%
					1000 PAX Camp					
Desert Environment										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Targeted Reduction	1467	56.6%	7074	59.8%	5267	83.2%	498	98.4%	2096	80.4%
Temperate Environment										
FY12 Baseline	3654	-	14751	-	31305	-	31153	-	10672	-
Targeted Reduction	1943	46.8%	9878	33.0%	5267	83.2%	498	98.4%	2096	80.4%
Tropical Environment										
FY12 Baseline	3301	-	16463	-	31305	-	31153	-	10672	-
Targeted Reduction	1383	58.1%	6091	63.0%	5267	83.2%	498	98.4%	2096	80.4%

For the 300 PAX and 1000 PAX base camps, the Targeted Reduction Base Camp designs meet all the SLB-STO-D’s objective metrics: a 25% reduction in fuel, a 75% reduction in potable water, and a 50% reduction in waste generation/backhaul. The 50 PAX base camp meets the fuel, potable water, and solid waste measures, but fails to meet the waste water metric.

Overall fuel consumption at the Targeted Reduction 50 PAX Base Camp decreased 50.2–57.6% across the three environments. At the FY12 ORTB 50 PAX Base Camp, the *Provide Electric Power* functional area was by far the largest consumer of fuel, accounting for 71.8–82.4% of the overall fuel depending on the environment. Fuel savings at the Targeted Reduction Base Camp was driven by a reduction of up to 75.6% in this functional area. Even with this reduction, *Provide Electric Power* was still the single largest consumer of fuel, responsible for 38.5–52.5% of overall fuel consumption across the three environments. The second largest decrease in usage across all environments came from *Provide Access to Transportation* functional area, which decreased 87.8–91.2% across all environments. This functional area was the second largest consumer of fuel at the FY12 ORTB Base Camp, consuming 2.2–2.4% of the total fuel. Finally, in the temperate environment only, the fuel usage in the *Shelter Heating and Cooling* functional area decreased 51.2%. This reduction accounted for more gallons of fuel saved in that environment than the reduction in on camp vehicle usage.

The fuel savings in the *Provide Electric Power* functional area was driven by the implementation of microgrids, combined with an overall reduction in power consumed. Only two equipment level functions at the 50 PAX base camp saw a net decrease in power consumption: *Shelter Heating and Cooling* and *Lighting*. The *Shelter Heating and Cooling* functional area saw a decrease of 50.0–82.6% across the three environments, by far the largest kilowatt decrease. This decrease was due to the combined impact of more efficient shelter technologies and more efficient ECUs. *Lighting* decreased 25% across all environments, driven by the implementation of LED lights. Combined with microgrids, this reduced fuel consumption in the *Power Generation* functional area by 68.7–75.6%. Additionally, the generation of power from the solar panels on the PShades provided 6.0–18.2% of the power required on the base camp.

No single area benefited more from the combined savings in *Shelter Heating and Cooling* and *Lighting* than billeting, which accounted for the largest number of shelters of any functional area. In the desert and tropical environments, power demand by *Provide Billeting* plummeted by over 80%, resulting in this functional area falling to second place in terms of power demand, behind *Enable Command and Control*. However, in the temperate environment, changes in billeting had less of an impact because the fuel fired heaters were used in the winter instead of the more efficient ECU system. The fuel fired heaters require a constant power consumption to operate the fan and control electronics. Short of eliminating any heat requirement, the power consumption of fuel fired heaters would remain constant. As a result, the *Provide Billeting* functional area only saw power savings of 51.5% and remained the largest power consumer at the Targeted Reduction Base Camp. Since the power consumption of the *Enable Command and Control* functional area is largely due to many small pieces of equipment in the TOC, it is an unlikely facility to look towards for additional resource savings. Even at the Targeted Reduction Base Camp, *Provide Billeting* is the likely functional area to target for further resource savings. Further resource savings can be achieved in *Shelter Heating and Cooling* with further improvements to shelter technologies. Additionally, improvements to fuel fired heater technology to capitalize on increased shelter efficiency may provide additional benefits.

No true potable water reductions were made at the 50 PAX base camp; potable water savings were the result of onsite generation using WFA. The camp's overall fuel reduction was offset by a net increase in fuel consumption in the *Provide Potable Water* functional area, which consumed between 13 and 14 gal per day, accounting for 12.8–14.9% of the fuel consumption at the Targeted Reduction Base Camp. *Provide Potable Water* became the third most fuel intensive functional area on the base camp, behind *Provide Electric Power* and *Provide Latrine Services*. The same equipment could easily address 100% of water demand, at the expense of additional fuel usage. Increasing the efficiency of the WFA would make this a more tenable solution.

The Targeted Reduction 50 PAX Base Camp showed no improvement in waste water generated. All waste water collected was generated by hand wash stations. Due to the small amount of waste water generated at the camp, it is unlikely that a waste water treatment system would be implemented. It may be possible to dispose of this water in field expedient methods, such as soakage pits to avoid the necessity to backhaul [74] [54]. Alternatively, at the expense of approximately 5 gal per day of direct fuel consumption in the latrines, the burn-out latrines could be replaced with a MIL-TOILAT. While this would have provided a higher QoL(O) for the

Soldiers at the camp and met the SLB-STO-D waste water metric, it seemed unlikely that a standalone latrine system would be implemented to eliminate only 27 gal per day of gray water.

The implementation of the SWDS combined with source reduction technologies saw a decrease in solid waste of 92.9% at the 50 PAX base camp. The high reduction in waste was due to the largely combustible nature of the waste stream. This waste reduction came at a small cost. The *Provide Solid Waste Management* functional area, which includes the SWDS, increased by only 1 gal of fuel per day. Since the reduction in solid waste is impacted by the amount of combustible versus noncombustible waste in the stream and the efficiency of the SWDS, a reduction in noncombustible waste via source reduction or an increase in SWDS efficiency could achieve further gains.

Fuel consumption at the FY12 ORTB 300 PAX and 1000 PAX Base Camps was driven by the same functional areas as the FY12 ORTB 50 PAX Base Camp. The *Provide Electric Power* functional area was by far the largest consumer of fuel, accounting for 79.1–90.3% of the overall fuel depending on the environment. Fuel savings at the Targeted Reduction Base Camps was driven by a reduction of up to 77.6% in this functional area. The second largest decrease in usage across all environments came from the *Provide Access to Transportation* functional area, which decreased 31.7–33.8% across all environments. This functional area was the second largest consumer of fuel at the FY12 ORTB Base Camps, consuming 5.1–5.7% of the total fuel. Finally, in the temperate environment only, the fuel usage in the *Shelter Heating and Cooling* functional area decreased 41.4–49.4%. This reduction accounted for more gallons of fuel saved in that environment than the reduction in on camp vehicle usage.

The fuel savings in the *Provide Electric Power* functional area was attributable to the implementation of microgrids and more efficient spot generation, combined with an overall reduction in power consumed. The *Provide Billeting* functional area had previously been identified as the largest consumer of power, largely due to it accounting for the largest number of shelters of any functional area. This functional area could be broken down into several constituent equipment level functions: *Shelter Heating and Cooling*, *Convenience Loads*, and *Lighting*. These equipment level functions are common across many camp facilities, so addressing these functional areas not only decreased the power consumption in *Provide Billeting*, but also in other functional areas.

The *Shelter Heating and Cooling* functional area, the largest single consumer of power on the base camps, saw a decrease of 38.3–84.8% across the three environments. This decrease was due to the combined impact of more efficient shelter technologies and more efficient ECUs. The impact of the new technologies varied considerably across the environments. At the FY12 ORTB Base Camps, the *Shelter Heating and Cooling* functional area consumed the least amount of power in the temperate environment, followed by tropical, then the desert, with the demand in temperate being 32.4–43.9% less than the demand in the desert environment. Following the implementation of improved shelters and ECUs, the trend changed, with tropical consuming the least power and temperate consuming the most. This is attributable to the continued use of the MTH150 fuel fired heaters in the temperate environment. While the power consumption of these units is low compared to a resistive heating element, this power consumption is relatively unaffected by the increased efficiency of the shelter. If any heat is required, the MTH150 draws the same amount of power (though the fuel consumption of the MTH150 decreased).

Lighting decreased by approximately 15% across all environments, driven by the implementation of LED lights. *Convenience Loads*, the second largest single consumer of power on the FY12 ORTB base camps, was not reduced. A reduction in this functional area would have resulted in a decrease in QoL(O).

In addition to a reduction on the demand side, power consumption was offset by power generated locally at each shelter using PShades. These shades accounted for an average of 115–280 kWh and 356–845 kW per day of power at the Targeted Reduction 300 PAX and 1000 PAX Base Camps, respectively.

Overall, reductions in the *Shelter Heating and Cooling*, *Convenience Loads*, and *Lighting* equipment level functions combined with the localized use of solar power generation reduced power demand in the *Provide Billeting* functional area by 49.5–88.7%.

The power draw of *Provide Billeting* varies substantially depending on the environment of the base camp, largely due to the *Shelter Heating and Cooling* equipment level function. In the desert and tropical environments, *Provide Billeting* saw the largest reduction in power demand. At the Targeted Reduction Base Camps in the desert environment, *Provide Billeting* dropped to the second largest consumer, behind *Enable Command and Control*. In the tropical environment, *Provide Billeting* was third and second place fell to *Provide Subsistence* at the 300 PAX base camp and *Provide Access to MWR Services* at the 1000 PAX base camp. In the temperate environment, *Provide Billeting* retained its place as the largest power consuming functional area. Even at the Targeted Reduction Base Camp, *Provide Billeting* still ranks in the top three largest power consuming functional areas in every environment, implying that there are still gains to be made by improving the energy efficiency of billets and tent shelters in general, as well as potentially implementing more environment-specific ways of reducing power consumption in the *Provide Billeting* functional area.

Provide Latrine Services was also a large consumer of power at the Targeted Reduction Base Camp, accounting for 12.3–15.4% of all power demand at the 300 PAX base camp (13.4–18.0% at 1000 PAX base camp) across the three environments, up from 1.6–7.3% at the FY12 ORTB 300 PAX Base Camp (2.3–10.1% at 1000 PAX base camp). Because the main difference between the LCTL and ETL power consumption is the incinerator, directing waste water to a dedicated treatment facility that uses less power, like the dBBR, would bring about greater power savings. Additionally, since both base camps required a waste water treatment system to process waste water from the gray water recycling systems, aid stations, and kitchens, these systems are present already. The increased power cost to process the additional waste water would be negligible.

Finally, one functional area, *Water Heating*, required a significant amount of power in the temperate environment, roughly 11.5% at the 300 PAX base camp (11.7% in the 1000 PAX base camp). The power demand increased compared to the FY12 ORTB Base Camps, because of the increase in water processing and storage facilities that required cold weather kits. Technology that more efficiently prevents water from freezing could be a help in the temperate environment at reducing power demand.

Power consumption was also offset by the use of a WEC. Not only did the WECs reduce solid waste by over 80% at the 300 PAX and 1000 PAX base camps, they also provided 899 kWh and 3347 kWh per day of power, respectively. This provided up to 35% of the total power consumed by the camps each day at an expense of 2.2–3.2% of the Targeted Reduction Base Camps' fuel, making the WEC far more efficient at power generation than the TQGs. The field feeding plan at both the 300 PAX and 1000 PAX base camps is identical, resulting in near identical waste reduction (the minor difference is attributable to waste left in dumpsters waiting to be incinerated when the simulation ended). Currently, the constraining factors are the proportion of solid waste that is combustible (about 88%) and the efficiency of the waste incineration system (about 92%). As solid waste destruction capabilities are implemented on base camps, it will become increasingly important to eliminate as much noncombustible waste from the solid waste stream as possible. While source reduction was implemented at the improved base camps, the reductions came entirely from combustible material, which in effect reduced the amount of fuel available for the WEC by a small amount.

Many base camps partner with the host nation to contract waste removal by local nationals. This scenario was not considered in meeting the SLB-STO-D's objective metrics and brings unique challenges, since it is possible that the host nation would be less diligent in ensuring environmentally conscientious disposal of waste—potentially leading to health hazards and negative reactions by members of the surrounding community. Additionally, since the WEC produces a positive byproduct in the form of excess power, it may prove beneficial to retain on-base processing of waste. Community integration could be accomplished through the contract of local nationals to operate the WEC.

The Targeted Reduction 300 PAX and 1000 PAX Base Camps saw different technological changes related to field feeding, which had differing impacts on fuel usage. At the 300 PAX base camp, new kitchen technologies include the FF-ETK and DESERT HE-MTRCS refrigeration and freezer units. *Provide Subsistence* increased in fuel demand from 0 gal to 10 gal daily in the desert and tropical environments and from 7 gal to 13 gal daily in the temperate environment, driven by the use of a fuel-fired kitchen instead of an electric kitchen. However, this additional fuel usage was balanced by a sharp decrease in power demand for *Provide Subsistence* of 46.4–58.3% across the three environments, thus leading to a reduction in the fuel needed to address power demand overall. While it is not possible in the integrated base camp to attribute any level of fuel savings from power demand reduction to a particular technology, the impact of field feeding technologies in isolation on the FY12 ORTB Base Camp showed an overall fuel savings of approximately 6.6–7.2% across the three environments (see **Section 4.3.4** for further information).

At the 1000 PAX base camp, new kitchen technologies included the DESERT HE-MTRCS as well as the CK-I (which includes improved MACK appliances) and the WRS, which saves water in the sanitization process. Fuel demand in *Provide Subsistence* increased 20.2–26.2%, while power demand in the same functional area decreased 40.8–54.5% across the three environments. Again, it is not possible to attribute a fuel savings to these technologies directly, but these field feeding technologies implemented in isolation showed a fuel savings of 1.4–1.9% across the three environments (see **Section 4.3.4** for further information).

The combination of more efficient power generation, generation of power with renewables and waste, and a demand side reduction decreased fuel consumption in the *Power Generation* functional area by 65.9–77.6%. Even following this reduction, the *Power Generation* functional area was still the largest consumer of fuel at the base camps.

Reductions in the *Power Generation* functional area would be furthered given the availability of host nation power. While the base camps modeled by SLB-STO-D do not assume connection to a host nation power grid for purposes of meeting the SLB-STO-D objectives, given its availability, host nation power would eliminate all fuel from *Power Generation* (this would not eliminate the need for generators or microgrids for backup power). Connecting the Targeted Reduction Base Camps to host nation power increased fuel savings by over 20% across all base camps and environments, providing for a 72.6–79.7% total fuel savings. Not only did connecting to host nation power eliminate fuel needed at generators and microgrids, it had the secondary effect of decreasing vehicle fuel usage by reducing the need to refill fuel tanks. The remaining fuel was used in equipment that directly consumes fuel, such as the LCTL, which was the largest source of fuel consumption at the 300 PAX and 1000 PAX base camps when host nation power was present. In the presence of host nation power, eliminating direct fuel consumers becomes even more important. Base camp equipment sets may be catered toward power usage of fuel consumption (e.g., resistive instead of fuel-fired heaters, waste water treatment instead of waste water incinerators, electric water heating instead of fuel-powered), yielding a very low overall fuel consumption.

Overall, the Targeted Reduction Base Camp showed potable water savings of 77.6% at the 300 PAX base camp and 83.2% savings at the 1000 PAX base camp. The potable water usage patterns are identical across the three environments and similar between the 300 PAX and 1000 PAX base camps.

The *Provide Latrine Services* functional area was impacted by the switch from Expeditionary TRICON Latrine Systems to LCTLs, producing potable water savings of 86.7% at the 300 PAX base camp and 86.8% at the 1000 PAX base camp. At the 300 PAX base camp, this reduced its ranking from second largest consumer of potable water to fourth largest, behind *Provide Subsistence* and *Provide Access to Maintenance Repair*. At the 1000 PAX base camp, *Provide Latrine Services* remained the second largest potable water consumer, with *Provide Access to Maintenance Repair* in third place. The *Provide Latrine Services* functional area saw its fuel usage go from zero at the FY12 ORTB Base Camp to 19.5–25.9% of overall fuel usage across all three environments at the Targeted Reduction 300 PAX Base Camp (21.0–29.5% at the 1000 PAX base camp). This is equal to approximately half of the fuel used to provide electric power. The sizable increase is due to the fact that the LCTL incinerates all of the waste water it produces. The LCTL was chosen for implementation due to its water saving capabilities. Its waste reduction capabilities came at a much higher fuel cost than other waste treatment systems analyzed. In the case where a waste water treatment facility is available onsite, it would be much more fuel efficient to treat waste from the LCTL at the waste water treatment facility. Additionally, the implementation of low-flow and water recycling technologies included in the

LCTL into a traditional latrine system paired with a waste water treatment system may produce similar potable water gains without the fuel penalty.

Implementation of low-flow showerheads produced identical 28.9% savings at the 300 PAX and 1000 PAX base camps in the *Provide Means to Maintain Personal Hygiene* functional area. The equivalent savings is due to both using ESSs for shower facilities and having the same assumptions behind shower duration and frequency.

The Targeted Reduction 300 PAX and 1000 PAX Base Camps had different technological improvements related to the *Provide Subsistence* functional area. The 300 PAX base camp saw a 20.5% increase in potable water demand due to the switch to the FF-ETK, while the 1000 PAX base camp saw a 55.0% savings due to the addition of the WRS. The 1000 PAX base camp also implemented the polymer bead washing machine, which produced a 33.6% savings in *Provide Means to Clean Clothes*.

Additionally, both base camps included gray water recycling facilities that reduced the amount of potable water required in the shower and laundry facilities. Gray water recycling reduced overall potable water demand by approximately 63.5% at the 300 PAX base camp and 69.2% at the 1000 PAX base camp. Overall potable water savings were strongly driven by the availability of gray water recycling, as it accounted for the vast majority of water savings at both base camps. All other technologies combined provided for an additional 14.1% and 14.0% reduction in water demand at the 300 PAX and 1000 PAX base camps, respectively. Implementing these resource saving options on a base camp without gray water recycling would yield slightly higher savings due to the antagonistic effect of gray water on low-flow showerheads (see **Section 4.2.1).** Gray water recycling provides about 78.4% and 79.4% of the potable water required for showers and laundry facilities at the 300 PAX and 1000 PAX base camps, respectively. Therefore, even though *Provide Means to Maintain Personal Hygiene* consumes 3,526 gal of potable water a day at the 300 PAX base camp, all but 761 of those gallons are supplied by recycled water. This represents a decrease from the FY12 ORTB Base Camp consumption levels for this functional area of 84.7% and 85.4% for the 300 and 1000 PAX camps respectively. Despite this, *Provide Means to Maintain Personal Hygiene* is still the largest consumer of potable water, representing 38.9% and 51.3% of all demand at the 300 PAX and 1000 PAX base camps respectively.

Provide Access to Maintenance Repair represented 16.0% of all potable water demand at the 300 PAX base camp and 11.8% of all demand at the 1000 PAX base camp. Much of this demand comes from use of the pressure washer on camp. No improvement was made to this area of the base camp. Reductions in this functional area could be achieved by using equipment that consumes less water or by using a wash rack that recycles waste water.

Additionally, one option for potable water reduction that remains untapped is the possibility of treating and recycling black water, as discussed in **Section 3.3.3.3**. This would enable black water to be filtered through a multistep filter and reused in place of bulk potable water in select areas of the camp (such as flushing toilets or in the wash rack). While this would require a change in Army doctrine, it has been proven in non-military use and could bring about substantial potable water savings.

Many of the technological changes that produce potable water savings also brought about waste water savings. Low-flow showerheads reduced waste water production in *Provide Means to Maintain Personal Hygiene* by 28.9% at both the 300 PAX and 1000 PAX base camps. The LCTL completely eliminated waste water production from the *Provide Latrine Services* functional area. In the *Provide Subsistence* functional area, the differing equipment sets at the two base camp sizes resulted in differing waste water savings. At the 300 PAX base camp, the implementation of the FF-ETK resulted in a 20.5% increase in waste water production in the *Provide Subsistence* functional area, whereas at the 1000 PAX base camp the WRS reduced waste water production by 55.0% in the same functional area. At the 1000 PAX base camp, the polymer bead washer reduced waste water production in the *Provide Means to Clean Clothes* functional area by 33.6%.

At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, *Provide Means to Maintain Personal Hygiene* was the largest producer of waste water, followed by *Provide Latrine Services, Provide Means to Clean Clothes,* and lastly, *Provide Subsistence*. At the Targeted Reduction Base Camps, *Provide Means to Maintain Personal Hygiene* is still the largest functional area producer of waste water, while *Provide Latrine Services* was eliminated due to the LCTL's incineration function. At the 300 PAX base camp, *Provide Subsistence* jumped to second place in production, while *Provide Means to Clean Clothes* fell to last place; at the 1000 PAX base camp, their positions are reversed.

Gray water recycling units reduced the amount of waste water at showers and laundry facilities, and waste water treatment units reduced the waste water from kitchens, aid stations, and gray water recycling byproduct. As discussed in **Section 4.1.4**, the gray and black water treatment systems interact. Gray water is first treated at the gray water recycling system. Approximately 20% of the output is a black water byproduct, which is then sent to the waste water treatment system. Approximately 90% of the output of the waste water treatment system can be safely disposed of onsite, leaving only 10% requiring backhaul. Overall, only approximately 2% of the original gray water and 10% of the original black water ends up requiring backhaul. The total amount of waste water that remains at the end of the simulation varies. This is due to waste water being held in various tanks on the camp before being emptied into the water processing technologies as well as because the technologies operate as a batch process, waiting for a certain amount of waste water before beginning processing. At a real base camp, eventually all the waste water would be processed.

In considering overall waste water production at the camp, waste water treatment was responsible for a savings of 24.2% at the 300 PAX base camp and 19.0% at the 1000 PAX base camp. Gray water recycling provided a 29.1% and 28.2% savings at the 300 PAX and 1000 PAX base camp, respectively. Overall, these technologies combine to virtually eliminate the need for waste water backhaul; waste water production was reduced by 97.9% at the 300 PAX base camp and 98.4% at the 1000 PAX base camp. This high reduction might indicate a limited ability to further reduce waste water generation; however, opportunities still exist to reduce the amount of waste water these systems must process. Further, the large reduction in volume for disposal may make onsite destruction of the remaining waste water, such as with sludge incinerators, a practical option.

Given that *Provide Means to Maintain Personal Hygiene* remained the largest producer of waste water, it might be tempting to focus on eliminating waste water at the shower facilities. However, the actual values indicate that on the 300 PAX base camp, *Provide Means to Maintain Personal Hygiene* produced about 70.5 gal of waste water daily after savings from gray water recycling and waste water treatment are taken into account, so each of the 312 Soldiers on camp produces about 0.23 gal of waste water from their daily 10-min showers and usage of the shower sinks. It is unlikely that *Provide Means to Maintain Personal Hygiene* should be a focus for waste water reduction given the availability of gray water recycling, though it may still prove valuable to decrease its potable water consumption.

On the other hand, *Provide Subsistence* produced 44.6 gal a day of waste water at the 300 PAX base camp, only a little less than *Provide Means to Personal Hygiene*. Changes in kitchen equipment meant this functional area produced more waste water than the FY12 ORTB Base Camp before gray water recycling and waste water treatment are taken into account. Given that waste water from kitchens cannot be recycled for other purposes, this functional area should remain an area of focus for waste water reduction. At the 1000 PAX base camp, implementation of the WRS provided a sizable reduction in waste water generation in the *Provide Subsistence* functional area. Similar water filtration technologies may prove useful for camps of smaller sizes.

The SLB-STO-D program objectives to reduce fuel and water consumption and waste generation are rooted in a desire to reduce the number of threat exposure hours faced by Soldiers in convoys transporting these resources to and from base camps. According to data from the Center for Army Lessons Learned, resupply casualties in Iraq and Afghanistan have accounted for 10–12% of total Army casualties [75]. Reducing the resource consumption of base camps plays a key role in reducing the human costs to resupply Army units.

Reducing resource consumption at base camps can provide an incredible impact of the threats Soldiers face. Simply meeting the SLB-STO-D target metrics to reduce the need for fuel resupply by 25% and reduce the need for water resupply by 75% (not including any waste reductions) showed a decrease of 39.5% of convoys and 47.8% of transport trucks in convoys. This equated to a 52.8% reduction in threat exposure hours, a reduction of over 489,000 h over a 180-day period. The Targeted Reduction Base Camps exceed the program objectives and would result in an even further reduction in soldier threat hours.

The Targeted Reduction Base Camps demonstrate that sustainment requirements for small contingency base operations can be moderated using a combination of materiel and non-materiel changes. While many variations on this base camp could likely achieve similar resource reductions, the analysis showed that the bulk of the fuel, potable water, and waste reductions were the result of a limited number of technologies: microgrids, gray water recycling, and waste-to-energy. These three capabilities played a vital role in the achievement of the SLB-STO-D program objectives and are the likely targets for further development. With their implementation, the challenge to further reduce FWW requires attacking fuel consumption from the demand side (reducing power consumption through technologies such as improved shelters) and improving what are now considered small consumers, such as field feeding equipment and wash racks.

5.1 Minimizing the Equipment Set

The Targeted Reduction Base Camps include many changes to the equipment set of the FY12 ORTB Base Camps in order to achieve the SLB-STO-D program objectives. While a large number of technologies was shown to meet the letter of the objective, a smaller list of technologies may prove valuable at meeting the intent. Additional scenarios were developed to investigate the impact of implementing fewer technologies on resource consumption and to determine the solution sets' dependence on key technologies.

Four scenarios were investigated on deviations from the Targeted Reduction Base Camp. In the first scenario, a common equipment set was implemented across all three base camp sizes (e.g., a single kitchen system was chosen for use at both the 300 PAX and 1000 PAX base camps). In the second scenario, a single technology was chosen for implementation in each of the three thrust areas (i.e., FWW). In the third scenario, the minimum number of technologies required to meet the program's metrics—four—were implemented. A final scenario varied this implementation to a different set of four technologies.

For the common equipment set scenario, a single system was chosen for each camp function. This reduction in unique pieces of equipment simplifies the catalog of choices and may prove to focus resources on technologies that best scale to the entire solution space.

Several changes to the Targeted Reduction Base Camps were made:

Power generation was handled by TQGs, either gridded or for spot generation. This eliminated the use of the T-100 and HPT at the 300 PAX base camp and the T-100 at the 1000 PAX base camp.

Since the number of AS TEMPER tents and F100s vastly outnumbered other shelter combinations, the improvements to these shelters were chosen. The SIP Huts were eliminated and B-HUTS returned to the base camps.

For the kitchens, the CK-I combined with a FSC with WRS was chosen over the FF-ETK. The DESERT HE-MTRCS was chosen for refrigeration, which was already common to all base camps.

For the laundry, the Expeditionary Containerized Batch Laundry with polymer bead washing machine was chosen over the commercial laundry of the 300 PAX base camp. This change would necessitate a change in TTP at the 300 PAX base camp. Under current assumptions, Soldiers at the 300 PAX base camp do their own laundry in individual loads. Replacing the commercial 20-lb washing machines with 50-lb polymer bead washing machines would require Soldiers to wash their clothes three at a time.

The FORO was chosen for waste water processing due to its impact on both waste water and potable water. The TRICON dBBR was removed from the base camps.

Solid waste destruction was accomplished by the WEC, which was common to the two larger camps. The SWDS was removed from the 50 PAX base camp. Since the WEC is oversized for that camp, it was not replaced.

Options common to all of the base camps remained, including SCPL, water and fuel bladders, source reduction, and LCTLs (at the two larger camps). The WFA system, being unique to the 50 PAX base camp, was removed.

The second scenario went further and selected only the most impactful equipment in each of the three resource types: FWW. For this scenario, only six 60 kW TQG microgrids, FOROs, and WECs were implemented. Since the FORO and WEC were not applicable to the 50 PAX base camp, only the microgrids were implemented.

The third scenario selected the minimum number of different technologies to meet the FWW program metrics. The most impactful equipment set met both the fuel and waste reduction metrics, but fell short of the potable water metric by approximately 25% at the 300 and 1000 PAX base camps. The portfolio of technologies was examined for a set of technologies that would provide an additional 25% potable water reduction while also meeting program targets for fuel and waste backhaul reduction. The LCTL was selected and added to the six 60 kW TQG micro grids, FOROs, and WECs described in the previous scenario. Since the LCTL was not applicable to the 50 PAX base camp, the 50 PAX camp was not simulated.

The fourth scenario varied the four technologies selected to achieve the program metrics. While the WEC was identified as the most impactful waste reduction technology due to its power generation capability, the SWDS proved more efficienct at reducing waste but with a higher fuel cost (see Section 3.3.4). The fourth scenario replaced the single WEC at the 300 PAX base camp with three SWDS and the two WECs at the 1000 PAX base camp with 11 SWDS. The microgrids, FOROs, and LCTLs remained in the same integration as the previous simulation.

Table 80 shows the results of the 2 reduced equipment set scenarios across the different base camp sizes in the different environments. The results of the Targeted Reduction Base Camps are included for comparison. A comparison of these results to all other integrated scenarios is shown in **Table 89**.

Table 80. Mean Daily Camp Level Summary, Minimizing the Equipment Set, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Targeted Reduction	94	56.2%	340	66.2%	14	81.3%	27	0.0%	19	92.9%
Common Equipment Set	84	60.9%	406	59.7%	75	0.0%	27	0.0%	259	2.63%
Most Impactful Equipment Set	131	39.0%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Targeted Reduction	436	58.2%	1925	62.3%	1954	77.6%	180	97.9%	566	80.3%
Common Equipment Set	476	54.3%	1925	62.3%	1712	80.4%	994	88.4%	566	80.3%
Most Impactful Equipment Set	582	44.2%	4477	12.4%	4176	52.1%	3983	53.3%	561	80.5%
Min. Equipment Set	703	32.5%	4624	9.5%	2164	75.2%	1535	82.0%	568	80.2%
Min. Equipment Set (SWDS)	766	26.5%	5377	-5.3%	2164	75.2%	1535	82.0%	505	82.4%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Targeted Reduction	1467	56.6%	7074	59.8%	5267	83.2%	498	98.4%	2096	80.4%
Common Equipment Set	1481	56.1%	7202	59.0%	5267	83.2%	3384	89.1%	2096	80.4%
Most Impactful Equipment Set	1803	46.6%	15214	13.5%	14520	53.6%	14370	53.9%	2079	80.5%
Min. Equipment Set	2248	33.4%	15724	10.6%	6836	78.2%	5044	83.8%	2102	80.3%
Min. Equipment Set (SWDS)	2488	26.3%	18540	-5.5%	6836	78.2%	5044	83.8%	1859	82.6%

Due to the small size of the 50 PAX base camp, the Common Equipment Set Base Camp differed significantly from the Targeted Reduction Base Camp. Solid waste savings were much lower because of the elimination of the SWDS. The remaining waste savings was due entirely to source reduction, which is assumed to take place off base. Identically to the Targeted Reduction Base Camp, there is no waste water savings, but at the Common Equipment set base camp, there was also no potable water savings because of the elimination of the WFA. Power savings were slightly lower due to the elimination of the SIP Hut, but fuel savings were higher due to elimination of the WFA device, which is a heavy fuel consumer. Overall, the only STO-SLB-D objective that this camp meets is for fuel reduction.

The 300 PAX and 1000 PAX Common Equipment Set Base Camps retained the WEC, enabling them to maintain the same level of resource savings for solid waste production. Removal of the dBBR resulted in lower waste water savings. Implementation of the WRS and polymer bead washer at the 300 PAX base camp slightly increased waste water savings, but not enough to offset loss of waste water treatment. However, these changes did combine to slightly increase potable water savings at the 300 PAX base camp. Savings at the 1000 PAX base camp remained constant, because no underlying technologies were changed. In terms of power, the Common Equipment Set 300 PAX Base Camp showed exactly the same savings as the Targeted Reduction Base Camp. However, this obscures underlying changes in power consumption across various functional groups. Switching to the polymer bead washer required slightly more power, as does switching to the CK-I and implementing the WRS. However, eliminating waste water treatment also saved some power, enabling a net zero change in power demand. The 1000 PAX base camp showed a slight decrease in power savings, which was driven mainly by eliminating the SIP Huts, though removing the dBBR slightly offset those savings. Finally, fuel usage was higher in both camp sizes because of higher power demand. This increase was exacerbated at the 300 PAX base camp due to the use of less-efficient equipment in the *Provide Subsistence* functional area.

Overall, the Common Equipment Set 300 PAX and 1000 PAX Base Camps continued to meet each of the SLB-STO-D resource reduction goals. The 50 PAX failed to meet potable water and solid waste goals. Both of these were achievable at the Targeted Reduction Base Camp. This is due to the fact that the 50 PAX base camp, being so much smaller than the other camps, required a customized set of equipment that was largely eliminated when equipment sets were normalized across all camp sizes.

The Most Impactful Equipment Set scenario required an even greater reduction in the number of technologies, so its resource savings differed even more from that of the Targeted Reduction Base Camp.

At the 50 PAX base camp, the only resource savings were in fuel reduction from the implementation of the microgrid. This savings was substantial enough to meet the SLB-STO-D's goal of a 25% fuel consumption reduction.

At the 300 PAX and 1000 PAX base camps, solid waste savings were approximately the same, increasing slightly due to the elimination of LCTLs. Gray water recycling, the only technology for waste water reduction, still had a very impressive waste water savings, totaling over 50% resource reduction at both the 300 PAX and 1000 PAX base camps. Gray water recycling also assisted in reducing potable water demand. However, eliminating the potable water savings achieved by the LCTL meant that it was impossible to meet the SLB-STO-D's potable water reduction goal, as the latrine facilities are responsible for over 25% of potable water consumption. The WEC was able to make a respectable reduction to power demand of about 12.4–13.5%, which combined with implementation of the microgrid reduced fuel consumption by about 44.2–46.6%. Even with implementing only three technologies, every SLB-STO-D resource reduction metric except for potable water consumption was met.

Since the latrine facilities are responsible for over 25% of the potable water consumption at the FY12 ORTB 300 PAX and 1000 PAX Base Camps, addressing latrine water consumption is required to meet the program's objectives. The Minimum Equipment Set added the LCTL to the most impactful equipment set due to its impact on latrine potable water demand. While the LCTL was principally designed to incinerate the waste water it generates, to achieve this economically it includes a number of potable water reduction features: reuse of hand washing water for flushing toilets, dual-flush low-flow toilets, and waterless urinals. The combination of these water saving capabilities resulted in an 86.7% and 86.8% reduction in latrine potable water demand at the 300 PAX and 1000 PAX base camps, respectively. This savings was just enough to meet the potable water reduction metric of 75%. This savings was not without cost, however, as the LCTLs increased fuel consumption by 10.6–13.3% at the two base camps across the three environments. Even with the added fuel consumption, the combination of four technologies—six 60 kW TQG microgrids, FOROs, WECs, and LCTLs—was able to meet all the program's objective resource reductions while maintaining QoL(O).

While the WEC is the most impactful solid waste reduction technology, the SWDS is more efficient at reducing solid waste, but at the expense of increased fuel consumption. Replacing the WEC with SWDS resulted in a net increase in power consumption from the additional equipment on the base camp (in the previous scenario, the WEC's power generation more than offset the power consumption of the FOROs). This added power consumption combined with the direct fuel consumption of the SWDS came at a fuel expense of 5.3–7.3% daily. While significant, this fuel increase still allowed the program's objectives to be met at the 300 PAX and 1000 PAX base camps across all three environments. Additionally, since the SWDS more efficiently reduces solid waste than the WEC, this scenario resulted in an additional 2.2–2.3% solid waste reduction.

The Targeted Reduction Base Camp includes a constellation of new and improved technologies, allowing it to meet or exceed the SLB-STO-D's resource reduction goals. However, including such a variety of equipment can prove logistically difficult, especially when the required equipment varies by base camp size, since base camps may grow over time. Harmonizing the equipment across all three base camps sizes to a common set of equipment eliminated redundancy in equipment. When using a common equipment set, the 300 PAX and 1000 PAX base camps still met every resource reduction goal, while the 50 PAX base camp only met the fuel resource reduction goal. This highlights the unique requirements of smaller, more austere base camps. Going further, using only one piece of equipment for each resource area proved that meeting the SLB-STO-D's goal reductions was largely dependent on a small set of equipment. In this scenario, the 300 PAX and 1000 PAX base camps met every resource reduction metric except for potable water, while the 50 PAX base camp met only the fuel reduction metric. Adding a single additional technology, the LCTL, enabled all the program's objectives to be met at the 300 PAX and 1000 PAX base camps. Only one other combination of four technologies was identified that could meet all the program's objectives: microgrids, FOROs, SWDSs, and LCTLs. This shows that the SLB-STO-D's fuel reduction was not dependent on the power generation capability of the WEC. The solid waste reduction, however, was dependent on an efficient waste treatement technology, though that technology could vary.

While all technologies included in the Targeted Reduction Base Camps positively impact resource consumption or production, a simplified implementation focusing on a few technologies can have a large impact. Meeting most of the SLB-STO-D resource reduction goals can be accomplished using a very limited set of technologies: microgrids, gray water recycling, and waste-to-energy. All goals could be met by adding an additional technology to address latrine water usage. Development and fielding of technologies should focus on these key capabilities to achieve the biggest impact.

5.2 Bounding the Solution Space – Maximizing Resource Savings

The Targeted Reduction Base Camps present a true integrated solution to the SLB-STO-D's problem space, employing constraints on QoL(O), physical geography of the base camp, and operational relevance. The start of **Chapter 4** explored and proved the possibility of meeting the goal resource reductions. This section investigates the potential solutions obtained by relaxing some of those constraints. These solutions will provide bounds on the scope of the solution space to provide context for realistic savings. For example, relaxing the requirement that QoL(O) be maintained would produce greater resource savings than the Targeted Reduction Base Camp, but the savings would not be unlimited. This section provides an upper limit on the possible resource savings given the technologies and TTP changes discussed in **Chapter 3**.

There are two primary courses of action to reduce resource consumption at a base camp: supplement or enhance the equipment at the base camp or change the TTPs by which the camp operates. Both options have merits in their own right.

Equipment augmentation or replacement with improved systems can often result in resource savings. However, in real world application, consideration must be given to the number of systems required, their placement on the base camp, and a host of other issues including maintenance requirements and cost. In the interest of maximizing resource savings, those constraints are not applied in this section. Any technology option that positively impacts the goal metrics of FWW reduction were considered for implementation.

Changes to TTPs generally have little to no monetary cost and, barring doctrinal approval delays, can be implemented near immediately. Often, however, these changes impact the QoL(O) of the Soldiers on the base camp. While the SLB-STO-D objective is to maintain QoL(O), in the interest of maximizing fuel savings, that constraint is not considered in this section. TTP changes have a unique advantage in that they can be implemented for any duration desired. The SLB-STO-D use case designates the camp as an ongoing concern, and all considered solutions must be fully implementable at all times going forward. For that reason, courses of action below the doctrinal minimum were not considered for long-term resource savings. Other TTP changes may prove useful in short-term situations, such as a missed resupply, and are discussed more in their respective sections in **Chapter 3.**

Three distinct base camps were modeled: one implementing only TTP changes, one using augmented and new equipment, and one combining both. None of these base camp designs are considered realistic solutions to resource savings nor are they being recommended for implementation. They serve to provide bounds to the solution space. They will also help to determine the impact that further constraining the base camp has on resources.

The first base camp included the identical equipment set to the FY12 ORTB Base Camps (see **Table 1**). Select TTP changes were overlaid on the camp. These changes were the following:

- The field feeding plan at the 50 PAX Base Camp was changed to three MREs per day in accordance with Army Regulation 30-22 [55]. Since the field feeding plan at the FY12 ORTB 300 PAX and 1000 PAX Base Camps was below the theatre-wide average required by DA PAM 30-22, no changes to the feeding plan were implemented [76].
- Laundry at the 300 PAX and 1000 PAX base camps was reduced to 7.2 lb per soldier per week in accordance with the Surgeon General’s recommendation noted in the *CASCOM Water Planning Guide* [40]. Since laundry at the 50 PAX base camp is done by hand, no changes were made.
- Showers at the 300 PAX and 1000 PAX base camps were reduced to the Army’s goal of one 7 min shower and one field expedient shower per soldier per week [40] [39]. While times will vary, a field expedient shower was estimated to be 45 s. Since there are no showers at the 50 PAX base camp, no changes were made.
- Latrine usage was not limited; however, flushing only occurred after defecation and not urination. Urinals were never flushed.

- Billeting tents were consolidated at 22:1 to maximize capacity of the tents. This is below the Army standard square footage per occupant.
- Convenience loads were eliminated.
- Heating is required in all facilities where personnel live, work, or recreate [26]. ECUs were shut down in all ancillary structures (changing tents and latrines).
- Vehicle usage was limited to only refiling water and fuel tanks on the base camp. All other movement of goods and personnel is assumed to be done without trucks or fuel-powered equipment.
- Generators were reallocated according to TM 3-34.46. Since this base camp is not constrained by geography, the generator allocation used the planning factors derived according to the method described and loads were assigned to generators to minimize the total number of generators required.

The second base camp scenario included all potential resource reduction options that would require new equipment, including both new technologies and materiel solutions. **Table 81** summarizes the deviations from the FY12 ORTB Base Camps.

Table 81. Equipment Set Changes, Maximizing Resource Savings

New Equipment	Replaced Equipment	Applicability 50 PAX	 300 PAX	 1000 PAX
Six 60 kW TQG Microgrid	Island TQGs	Yes	Yes	Yes
SIP-Huts	B-Huts	Yes	No	Yes
AS TEMPER Tents (v1.5 liner, PowerShade)	AS TEMPER Tents (single ply liner, no shade)	Yes	Yes	Yes
42k ECU	F100 ECU	Yes	Yes	Yes
LED shelter lights	Fluorescent shelter lights	Yes	Yes	Yes
Burn-out latrines	Expeditionary Latrines Systems	No	Yes	Yes
FF-ETK	Expeditionary TRICON Kitchen System	No	Yes	No
CK-I	CK	No	No	Yes
WRS	Augments FSC-2	No	No	Yes
DESERT HE-MTRCS with DP2 Solar Shade	MTRCS	No	Yes	Yes
Low-flow showerheads	Baseline showerheads in ESS	No	Yes	Yes
Solar water heater	Augments WH-400	No	Yes	Yes
Polymer bead washing machine	Baseline washing machine in ECBL	No	No	Yes
FORO	N/A	No	Yes	No
G-WTRS	N/A	No	No	Yes
TRICON dBBR	N/A	No	Yes	Yes
WEC with Energy Storage System	N/A	No	Yes	Yes
SWDS	N/A	Yes	No	No
WFA*	N/A	Yes	No	No
Source Reduction	N/A	Yes	Yes	Yes
Fuel and Water Bladders	Various tanks	Yes	Yes	Yes

* Applicable to any base camp, used here to address potable water reduction not achieved by other options

The third base camp scenario included a combination of the first two base camps.

The camps discussed in this section differ from the Targeted Reduction Base Camps in a few key points. Nearly every change in TTP reviewed impacted QoL(O) negatively, with the exception of reallocating generators according to a different method (using TM 3-34.46), which remained a viable option even with the QoL(O) constraint. Also, certain materiel changes negatively impacted QoL(O). For example, as discussed in **Section 3.3.1**, the implementation of burn-out latrines at the 300 PAX and 1000 PAX base camps saw a decrease in QoL(O). Relaxing the requirement that QoL(O) be maintained means that these options could be implemented.

Additionally, these simulations relax the requirement of the Targeted Reduction Base Camp of keeping any footprint additions to a reasonable increase. The solar water heater, while effective at its stated goal of reducing the fuel consumption of the WH-400, uses a very large area given the reduction provided. Each system requires a minimum of 225 sq ft of space to operate (plus a safety perimeter), with a planned three systems per set. For this reason, the solar water heater was not considered a viable candidate at the Targeted Reduction Base Camp, but can be included in these scenarios.

The DP2 solar array was also eliminated from consideration at the Targeted Reduction Base Camp for its large size compared to the fuel savings it produced. The solar array provided only a 0.1–0.2% decrease in fuel consumption at the 300 PAX and 1000 PAX base camps and required approximately 1225 sq ft of space, compared to only 160 sq ft for the DESERT HE-MTRCS itself. Given that this real estate would be located near the kitchens, which are generally in the center of camp, this increase was not considered a reasonable trade for the resource savings. However, in these bounding runs, geographic considerations are eliminated, so the DP2 can be implemented.

In bounding the solution space, geographic constraints are omitted. Besides allowing the implementation of the solar water heater and DESERT DP2, this also allows different ways of loading generators and microgrids. In many cases, generators and microgrids can address additional power demand, but are constrained by the physical limits of what facilities can be placed in close enough proximity to the power source to be connected. The relaxation of physical constraints means that in certain cases TQGs, T-100s, HPTs, and sometimes even entire microgrids can be eliminated in the bounding scenarios, increasing efficiency and reducing the amount of fuel needed to address power demand.

Table 82 shows the results of the simulation of the three scenarios across the different base camp sizes in the desert environment. The Targeted Reduction Base Camp is included for comparison. A comparison of these results to all other integrated scenarios is shown in **Table 89**.

Table 82. Mean Daily Camp Level Summary, Maximize Resource Savings, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Targeted Reduction	94	56.2%	340	66.2%	14	81.3%	27	0.0%	19	92.9%
TTP/Non-Materiel Only	134	37.7%	656	34.9%	75	0.0%	27	0.0%	228	14.3%
Materiel Only	94	56.2%	340	66.2%	14	81.3%	27	0.0%	19	92.9%
Combined Materiel and TTP	89	58.6%	260	74.2%	14	81.3%	27	0.0%	17	93.6%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Targeted Reduction	436	58.2%	1925	62.3%	1954	77.6%	180	97.9%	566	80.3%
TTP/Non-Materiel Only	500	52.0%	3455	32.4%	3023	65.3%	2822	66.9%	2870	0.0%
Materiel Only	335	67.9%	1431	72.0%	1670	80.9%	186	97.8%	560	80.5%
Combined Materiel and TTP	258	75.2%	950	81.4%	1076	87.7%	132	98.5%	560	80.5%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Targeted Reduction	1467	56.6%	7074	59.8%	5267	83.2%	498	98.4%	2096	80.4%
TTP/Non-Materiel Only	1618	52.0%	11708	33.4%	9486	69.7%	9305	70.1%	10672	0.0%
Materiel Only	1243	63.2%	5443	69.0%	4296	86.3%	629	98.0%	2073	80.6%
Combined Materiel and TTP	894	73.5%	3056	82.6%	1988	93.7%	294	99.0%	2072	80.6%

5.2.1 TTP/Non-Materiel Changes Only

The implementation of TTP changes at the FY12 ORTB 50 PAX Base Camp showed no improvement in potable water consumed or waste water generated. This is due to the low level of services provided at the base camp. With no flushing toilets, running showers, or laundry, there is very little that can be done long-term to further reduce water consumption. Potable water consumption is attributable to hand wash stations and doing laundry by hand, neither of which can be reduced or eliminated long-term.

All waste water collected at the 50 PAX base camp is generated by hand wash stations. It may be possible to dispose of this water in field expedient methods, such as soakage pits to avoid the necessity to backhaul [54] [74]. However, since soakage pits may not be used in all locations due to temperature or water table concerns, they were not assumed to be a viable option for resource reduction.

The power and fuel savings at the 50 PAX base camp were substantial, driven largely by the consolidation of billets and elimination of convenience loads. Billeting consolidation shut down one additional tent (and associated ECU). This consolidation, combined with a different method of generator allocation, reduced the number of generators necessary on the base camp from six to three. This reduction in generator count was the primary driver of fuel savings. While the generator layout was not technically constrained to geography, given the small size of the FY12 ORTB 50 PAX Base Camp, it is likely the layout chosen could be used after the constraint is applied.

Solid waste decreased by a small amount as a result of switching from a UGR-E to an MRE for one meal a day. Since there are no kitchens at the FY12 ORTB 50 PAX Base Camp, this field feeding change had no impact on the other camps' resources.

Due to the level of services provided at the FY12 ORTB 300 PAX and 1000 PAX Base Camps, the impact of the TTP changes was significantly different than at the FY12 ORTB 50 PAX Base Camp. The drastic reduction in shower times (from a 10 min per day baseline to a single 7 min shower and one field expedient shower per week) and cutting the laundry by more than 50% produced potable water savings of over 65% at both base camps and waste water reduction of over 66%.

Power savings at the larger base camps were similar at over 32% in the desert environment. Like the 50 PAX base camp, these savings were driven by the elimination of convenience loads and consolidation of billets. At the 300 PAX base camp, three billets were eliminated during consolidation. At the 1000 PAX base camp, 11 billets were eliminated.

Fuel savings at both the 300 PAX and 1000 PAX base camps were significant, at approximately 52% at both camps in the desert environment. Combined with the reduction in tent count from consolidating billeting and the lower facility peak loads from eliminating convenience loads, 14 of 23 generators were shut down at the 300 PAX base camp and 45 of 73 generators were shut down at the 1000 PAX base camp.

The changes to TTPs were not without collateral cost, however. As shown in **Table 83**, QoL(O) decreased at all base camps. The most significant driver of the decrease was the elimination of convenience loads, which resulted in the decrease in the *MWR* functional area. The large decrease was due to the sheer number of attributes impacted by the elimination of convenience loads. The decrease in the *Hygiene* functional area was largely driven by the decrease in shower frequency, which is the largest contributor to QoL(O) in that functional area, with an additional penalty for removing the latrine ECU. While each change by itself does not decrease QoL(O) an unacceptable amount, the overall impact of all the TTP changes is significant. The implementation of materiel solutions obviates the need to implement certain TTP changes that reduce QoL(O).

Table 83. Comparison of QoL(O) Scores, Maximizing Resource Savings

Base Camp	Field Feeding	Hygiene	Billets	MWR	Spiritual/ Psych. Support	Personal Security	Work Area	Total
50 PAX Camp								
FY12 Baseline	7.1	0.5	9.5	7.8	0.0	0.0	6.4	31.3
TTP/Non-Materiel Only	7.0	0.5	8.1	4.5	0.0	0.0	6.4	26.5
Materiel Only	7.1	0.5	9.5	7.8	0.0	0.0	6.4	31.3
Combined Materiel and TTP	7.0	0.5	8.1	4.5	0.0	0.0	6.4	26.5
300 PAX Camp								
FY12 Baseline	11.9	14.1	9.5	20.7	0.3	2.4	6.4	65.3
TTP/Non-Materiel Only	11.9	11.5	8.1	12.6	0.3	2.4	6.4	53.1
Materiel Only	12.0	10.8	9.5	20.6	0.3	2.4	6.4	62.0
Combined Materiel and TTP	11.9	9.9	8.1	12.6	0.3	2.4	6.4	51.6
1000 PAX Camp								
FY12 Baseline	13.0	13.8	9.5	21.3	0.7	2.4	6.4	67.0
TTP/Non-Materiel Only	13.0	11.1	8.1	12.8	0.7	2.4	6.4	54.4
Materiel Only	13.0	10.5	9.5	21.2	0.7	2.4	6.4	63.7
Combined Materiel and TTP	13.0	9.6	8.1	12.8	0.7	2.4	6.4	52.9

The QoL decrease at the FY12 ORTB 50 PAX Base Camp was less than the two larger camps, with an overall reduction of 4.8. This is due to fewer TTP changes having an impact on the relatively austere 50 PAX base camp. Changes to the hygiene facilities had no impact on the smaller camp, and the changes to the convenience loads were limited due to there being no dedicated MWR facilities at the camp. Notably, however, the overall resource savings were also lower at the 50 PAX base camp.

The results of the TTP-only simulation show that while it is possible to achieve significant resource reductions using TTP changes alone, it is not possible to meet the SLB-STO-D’s objective resource reduction of 75% potable water and 50% waste. A 25% reduction in fuel is likely possible with only TTP solutions, even when constrained to geography. This reduction is almost achieved using only the generator loading strategy described in TM 3-34.46 (see **Section 3.1.2.1** for the results of reallocating generators at the FY12 ORTB Base Camps). Materiel changes are a necessity to achieving all the SLB-STO-D resource reduction goals, explaining why the Targeted Reduction Base Camps employed the mix of solutions it did.

Further, the reduction that is achievable is largely dependent on the level of services available at the base camp at the time of implementation. Little or no impact to water and waste resources can be made at a relatively austere camp, such as the FY12 ORTB 50 PAX Base camp. Significant water and waste water savings can be achieved at the FY12 ORTB 300 PAX and 1000 PAX Base Camps, both of which have a high level of services, with long shower times and ample laundry; however, these savings come at a cost of QoL(O).

5.2.2 Materiel Changes Only

The implementation of materiel solutions on the base camps yielded significant fuel reduction across all base camps and environments. Fuel savings at all camps were driven by the implementation of microgrids, combined with an overall reduction in power consumed. The power reduction was driven by the *Shelter Heating & Cooling* functional area. At the 300 PAX base camp, this functional area saw a decrease of 76.8% in the desert environment. Combined with microgrids, this reduced fuel consumption in the *Power Generation* functional area by 83.7% at the 300 PAX base camp in the desert environment. Compared to the Targeted Reduction Base Camps, the large fuel savings was mostly attributable to removing the geographic constraints on microgrid design, which enables fewer grids to power the base camps.

At the 50 PAX base camp, the fuel reduction ranged from 50.2–57.6%, with the smallest reduction in the temperate environment and the largest in the tropical environment. This pattern is observed across all base camp sizes, with smaller savings in the temperate environment being driven by the use of fuel fired heaters. This reduction at the 50 PAX base camp accounts for reinvesting some fuel savings into generating water onsite using the WFA. This is only required at the smallest of the base camps. At the larger camps, potable water savings can be achieved other ways. At the 300 PAX and 1000 PAX base camps, the fuel savings achieved were 60.5–68.9% and 54.7–64.9%, respectively. These savings were reduced by the increase in fuel consumed by the burn-out latrines.

Potable water savings at the 50 PAX base camp were the result of onsite generation using WFA. This accounts for between 13 and 14 gal per day of fuel consumption, making *Provide Potable Water* the third most fuel intensive functional area on the base camp, behind *Provide Electrical Power* and *Provide Latrines Services*.

At the larger camps, the potable water reduction was achieved largely in the *Provide Latrine Services* and *Provide Means to Maintain Personal Hygiene* functional areas. The change from flushing toilets to burn-out latrines eliminated all potable water at the latrine facilities with a small amount transferred to the *Provide Means to Maintain Personal Hygiene* functional area from the hand wash stations. This change also eliminated 100% of the waste water generated by those facilities. Combining low-flow showerheads and gray water recycling reduced consumption in *Hygiene and Showers* by over 33% at both base camps. A similar reduction was achieved in the *Laundry* functional area.

The implementation of materiel changes at the FY12 ORTB 50 PAX Base Camp showed no improvement in waste water generated. Due to the small amount of waste water generated at the camp, it is unlikely that a waste water treatment system would ever be implemented. As previously discussed, a field expedient method (e.g., a soakage pit) would be a more likely option.

At the larger camps, waste water was reduced by nearly 98%. This was a due to a combination of reducing potable water usage, recycling gray water, using burn-out latrines, and implementing a waste water treatment system.

Implementation of solid waste destruction devices across the three base camps showed a marked improvement in the amount of waste that must be backhauled, reducing the backhauled waste by over 80% in all cases. The quantity of waste was reduced slightly using source reduction technologies, but the reduction is overwhelmingly driven by the destruction systems utilized: the WEC and SWDS. The amount of solid waste remaining depended on the proportion of noncombustible waste in the waste stream and the destruction efficiency of the incineration device.

Following the implementation of the materiel changes, QoL(O) decreased slightly at the 300 PAX and 1000 PAX base camps, while no change was measurable at the 50 PAX base camp. This drop in QoL(O) was entirely attributable to the replacement of the ELS with the burn-out latrines. Since the baseline equipment at the 50 PAX base camp is burn-out latrines, no QoL(O) change occurred. This particular equipment set change contributed to a reduction in potable water consumption and waste water generation, at the expense of fuel consumption. As discussed in **Section 3.3.1**, incineration of waste water is not efficient in large quantities. Additionally, since there are other black water generators on the base camp (e.g., kitchens and the byproduct from the gray water recycling systems), another form of waste water treatment was already required to handle those streams. Thus, the appeal of the burn-out latrine in terms of the SLB-STO-D's objective metrics is not the waste reduction, but rather the potable water reduction. To maintain QoL(O) while meeting the objective metrics, latrine facilities other than burn-out latrines are necessary.

While the number of equipment set changes were numerous and the base camp design was not constrained to geography or QoL(O), the materiel changes implemented provided more than enough savings to meet the SLB-STO-D's objective metrics in all cases but waste water at the 50 PAX camp. While the savings were more significant, these were the same objectives met by the Targeted Reduction Base Camp with additional constraints in place.

5.2.3 Combined TTP and Materiel Changes

While the application of TTP changes to the base camps with resource savings technologies implemented showed an increase in savings, this increase was small compared to the savings achieved by making the same TTP changes at the FY12 ORTB Base Camps. Fuel savings increased only 2.4% at the 50 PAX base camp in the desert environment, compared to a 37.7% savings by implementing the same changes at the FY12 ORTB Base Camp. At the larger camps, the application of TTP changes to the technology driven base camps showed less than 20% of the fuel savings achieved at the FY12 ORTB Base Camps.

A similar decrease in impact is seen in other resources as well. Making the TTP changes at the improved base camp netted a 6.8% and 7.4% increase in potable savings at the 300 PAX and 1000 PAX base camps, respectively. Waste water decreased by only 1% over the materiel-improvements-only camp. These results reflect the pattern whereby combining TTP and materiel solutions produces resource savings that partially offset each other. A broader discussion of this phenomenon can be found in **Section 4.2**.

5.2.4 Comparison to Targeted Reduction Base Camp

At the 50 PAX size camp, the camp with the materiel-changes-only scenario eliminated constraints applied in the Targeted Reduction Base Camp, but did not have any greater resource savings due to the small size and limited technology set present. The unbounded TTP simulation had smaller levels of resource savings than the Targeted Reduction Base Camp, which is in line with the limited efficacy of TTP solutions overall. Combining materiel and TTP changes achieved slightly higher resource savings than the Targeted Reduction Base Camp. Additional savings came from TTP changes such as increasing the proportion of meals that are MREs, billeting consolidation, and eliminating convenience loads. Note that the combined materiel and TTP resource savings are only slightly more than the materiel changes alone, because the TTP solutions mainly interacted antagonistically with the existing technology solutions. The similarity of the combined results to the Targeted Reduction Base Camp results indicates that geographical and QoL(O) restrictions are less important at the 50 PAX base camp.

At the 300 PAX and 1000 PAX base camps, combining materiel and TTP changes had universally higher resource savings than the Targeted Reduction Base Camps due to the relaxed restrictions on maintaining QoL(O) and abiding by geographic constraints. Removing the LCTL and switching to burn-out latrines in the combined scenario increased solid waste savings as well as reduced potable water demand. The TTP solutions related to laundry and shower usage produced small savings in waste water production and larger savings in potable water demand. The Targeted Reduction Base Camps had a larger waste water production, but increased waste water recycling and treatment capabilities, which partially offset the larger amounts of waste water. This antagonistic interaction is similar to that shown in **Section 4.2**, where reducing shower length when gray water recycling and waste water treatment units are present has resource savings that partially offset each other.

For power and fuel savings, the combined materiel and TTP-changes base camps show significantly greater savings than the Targeted Reduction Base Camps. Some of these savings were due to TTP or technological solutions that reduced QoL(O) or expanded the physical size of the camp too much to be operationally relevant. Since generating electrical power was the main consumer of fuel, reducing power demand reduced fuel usage. Additionally, eliminating geographic constraints meant that microgrids and generators could be more heavily loaded, increasing the efficiency with which power was generated and further increasing fuel savings. The base camps with combined materiel and TTP changes put bounds on resource savings overall. The Targeted Reduction Base Camps are fairly close to the solid waste and waste water bounds, but further below the fuel and potable water upper bound, indicating that QoL(O), geographical, and operational relevance constraints have the largest impact on achieving resource savings in these categories.

The combination of TTP changes and materiel changes had a lower QoL(O) score than the individual base camps. The majority of the QoL(O) decrease compared to the baseline resulted from the TTP changes. The resource savings from these changes, while significant when made at the FY12 ORTB Base Camps, proved less significant at a base camp with resource saving technologies already in place. Similarly, the application of resource saving technologies at a base camp with lower services (and therefore lower QoL(O)) will see a reduction in their effectiveness. As compared with the Targeted Reduction Base Camps, relaxing constraints related to QoL(O), geography, and operational relevance in the combined base camp produced only small increases in resource savings for solid waste and waste water at the 300 PAX and 1000 PAX base camps. Larger resource savings were obtained for fuel and potable water at the 300 PAX and 1000 PAX base camps.

5.3 Minimizing Threat Hours in Convoys – Volumetric Resupply

The SLB-STO-D’s objectives to reduce the fuel and potable water consumption and waste generation at base camps directly impact the number of trucks required in resupply convoys. According to data from the Center for Army Lessons Learned, resupply casualties in Iraq and Afghanistan have accounted for 10–12% of total Army casualties [75]. Reducing the resource consumption of base camps plays a key role in reducing the human costs to resupply Army units.

If the human costs of resupply convoys are prioritized over the monetary cost of resources, the unconventional trading of resources to reduce the number of trucks in resupply convoys would be favored. For example, trading 1 gal of fuel for 2 gal of water would be a good trade in terms of reducing convoy size, while perhaps not being considered a good trade in terms of monetary cost.

The basis for these simulations are the base camp designs described in **Section 5.2**. Like the results of that section, these results help to bound the solution space and show the best-case impact of the options reviewed. The Targeted Reduction Base Camps described at the start of **Section 4.4** will also be discussed for comparison. A change in implementation of technologies at the Targeted Reduction Base Camps would produce results somewhere between the minimum number and the baseline value.

The SLB-STO-D’s use case assumes the following about the equipment used in resupply convoys:

- Bulk potable water is transported by an M1120 HEMTT LHS with M1076 Palletized Load System trailer, both carrying HIPPOs for a total capacity of 4,000 gal.
- Fuel is transported by a M978 HEMTT Fuel Servicing Truck with Modular Fuel System trailer or a M1088 Tractor Truck with M969A1 Semi-Trailer Refueler, with a total capacity of 5,000 gal.
- Cargo such as bulk bottled water is transported by a M1120 HEMTT LHS with M1076 Palletized Load System trailer with a 22-ton total capacity.

While solid and liquid waste is assumed to be disposed of by a local national contractor, this disposal comes at both a financial cost and a dependence on outside assistance. In some cases, this arrangement may not be possible or practical. In that regard, reduction in truck count to remove waste from the base camp still plays an important role. The SLB-STO-D assumption for waste removal vehicles is the following:

- Waste water is removed by vacuum trucks with a capacity of 4,000 gal, the same capacity as the potable water trucks that deliver to the camp.
- Solid waste is removed in 20-ft ISO containerized loads by a M1120 HEMTT LHS with M1076 Palletized Load System trailer with a 22-ton total capacity. Approximately 25% of this capacity is consumed by the weight of the empty containers.

Deviations from the base camp designs described in **Section 5.2** were minimal. At the 300 PAX base camp, the FF-ETK was removed and the baseline electric ETK was added back. This change was made because, while the system saves approximately 2 gal per day of fuel, it uses an extra 76 gal per day of potable water. It would cost more than 2 gal per day to generate that amount of water with a WFA system.

The major change at all camps was the implementation of WFA systems (see **Section 3.2.3.2** for a discussion of the WFA). The WFA's dependence on the environment resulted in different system counts and usage schedules across the three environments. **Table 84** shows the system counts across the three base camp sizes and environments. The usage schedules were chosen to coincide with the most ideal operating hours based on average water production in each environment. The system counts and schedules were optimized to produce as near to 100% of the camps' potable water needs as was possible.

Table 84. System Counts, WFA

Base Camp	Desert	Temperate	Tropical
50 PAX Base Camp	1	1	1
300 PAX Base Camp	4	8	4
1000 PAX Base Camp	8	8*	8

* Seasonal variation in production makes this unsustainable

The system counts were increased, where practical, to provide enough additional capacity to survive low production months. At the 300 PAX base camp, this amounted to adding another four units in the temperate environment. Even with this addition, monthly water production would be approximately 15,000 gal short in the month of January (production for all other months would match demand). To prepare for this shortfall, excess water production would have to begin in November. This storage cost would be not only in footprint, but also in power to prevent the bladders from freezing. This additional cost is not factored into the simulation. The number of systems at the 1000 PAX base camp to have production match consumption year-round would have to roughly double. Eight units will, on average, cover demand. Since the simulator is limited to daily usage schedule, in all cases, the number of systems bears little impact on the total fuel consumption, as system schedules were calculated to meet daily average consumption.

Table 85 shows the results of the simulations across the different base camp sizes and across the different environments. Since the WFA systems are sized to produce at least 100% of the potable water required on the base camp, the overall result is a slight negative potable water consumption (i.e., net production). This overproduction was minimized by varying the usage schedules of the WFA systems. Due to only a single WFA system being required on the 50 PAX base camp and the simulator having an hourly time step, the overproduction was more significant than at the larger camps.

Table 85. Mean Daily Camp Level Summary, Minimizing Threat Hours in Convoys

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
	50 PAX Camp									
Desert Environment										
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Volumetric Resupply	94	56.3%	260	74.2%	-6	108.0%	27	0.0%	17	93.6%
Temperate Environment										
FY12 Baseline	219	-	661	-	75	-	27	-	266	-
Volumetric Resupply	101	53.9%	281	57.5%	-14	118.7%	27	0.0%	17	93.6%
Tropical Environment										
FY12 Baseline	212	-	951	-	75	-	27	-	266	-
Volumetric Resupply	91	57.1%	220	76.9%	-23	130.7%	27	0.0%	17	93.6%
	300 PAX Camp									
Desert Environment										
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Volumetric Resupply	624	40.1%	1134	77.8%	-2	100.0%	177	97.9%	560	80.5%
Temperate Environment										
FY12 Baseline	1096	-	4091	-	8723	-	8529	-	2870	-
Volumetric Resupply	630	42.5%	1542	62.3%	-2	100.0%	177	97.9%	560	80.5%
Tropical Environment										
FY12 Baseline	1023	-	4806	-	8723	-	8529	-	2870	-
Volumetric Resupply	549	46.3%	1013	78.9%	-13	100.1%	177	97.9%	560	80.5%
	1000 PAX Camp									
Desert Environment										
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Volumetric Resupply	1361	59.7%	3056	82.6%	-18	100.0%	294	99.0%	2072	80.6%
Temperate Environment										
FY12 Baseline	3654	-	14751	-	31305	-	31153	-	10672	-
Volumetric Resupply	1552	57.5%	4217	71.4%	-8	100.0%	294	99.1%	2072	80.6%
Tropical Environment										
FY12 Baseline	3301	-	16463	-	31305	-	31153	-	10672	-
Volumetric Resupply	1199	63.7%	2523	84.7%	-10	100.0%	294	99.1%	2072	80.6%

Waste water and solid waste production do not vary across environment. While potable water, which in most simulations does not vary with environment now does, for all intents and purposes, 100% of water is being produced, which would mean no bulk water is being transported in convoys[12]. Fuel varies considerably with the environment. This is driven primarily by the *Shelter Heating and Cooling* functional area as well as the varying performance of the WFA systems.

Table 86 shows the total number of trucks required to transport the resources to and from the volumetrically optimized base camps as well as the Targeted Reduction Base Camp (see **Section 4.4**). Note that vehicles in convoys perform more functions than included here. Examples include force protection, wreckers, cargo carriers, etc. However, the subset of vehicles that carry fuel water and waste are the targets for reductions.

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[12] The SLB-STO-D objectives do not include potable water required for hydration (i.e., drinking water). This water would still have to be brought to the base camp (either in bulk or bottled) via convoy.

Table 86. Yearly Truck Resupply Requirement, Minimizing Threat Hours in Convoys

	Fuel		Potable Water		Waste Water		Solid Waste		Total	
Simulation Description	Trucks	Δ	Trucks	Δ	Trucks	Δ	Trucks	Δ	Trucks	Δ
					50 PAX Camp					
Desert Environment										
FY12 Baseline	16	-	7	-	3	-	3	-	29	-
Targeted Reduction	7	56.3%	2	71.4%	3	0.0%	1	66.7%	13	55.2%
Volumetric Resupply	7	56.3%	0	100.0%	3	0.0%	1	66.7%	11	62.1%
Temperate Environment										
FY12 Baseline	16	-	7	-	3	-	3	-	29	-
Targeted Reduction	8	50.0%	1	85.7%	3	0.0%	1	66.7%	13	55.2%
Volumetric Resupply	8	50.0%	0	100.0%	3	0.0%	1	66.7%	12	58.6%
Tropical Environment										
FY12 Baseline	16	-	7	-	3	-	3	-	29	-
Targeted Reduction	7	56.3%	1	85.7%	3	0.0%	1	66.7%	12	58.6%
Volumetric Resupply	7	56.3%	0	100.0%	3	0.0%	1	66.7%	11	62.1%
					300 PAX Camp					
Desert Environment										
FY12 Baseline	77	-	796	-	779	-	32	-	1684	-
Targeted Reduction	32	58.4%	179	77.5%	17	97.8%	7	78.1%	235	86.0%
Volumetric Resupply	46	40.3%	0	100.0%	17	97.8%	7	78.1%	70	95.8%
Temperate Environment										
FY12 Baseline	80	-	796	-	779	-	32	-	1687	-
Targeted Reduction	41	48.8%	179	77.5%	17	97.8%	7	78.1%	244	85.5%
Volumetric Resupply	46	42.5%	0	100.0%	17	97.8%	7	78.1%	70	95.9%
Tropical Environment										
FY12 Baseline	75	-	796	-	779	-	32	-	1682	-
Targeted Reduction	31	58.7%	179	77.5%	17	97.8%	7	78.1%	234	86.1%
Volumetric Resupply	41	45.3%	0	100.0%	17	97.8%	7	78.1%	65	96.1%
					1000 PAX Camp					
Desert Environment										
FY12 Baseline	247	-	2857	-	2843	-	118	-	6065	-
Targeted Reduction	108	56.3%	481	83.2%	46	98.4%	24	79.7%	659	89.1%
Volumetric Resupply	100	59.5%	0	100.0%	27	99.1%	23	80.5%	150	97.5%
Temperate Environment										
FY12 Baseline	267	-	2857	-	2843	-	118 -		6085	-
Targeted Reduction	142	46.8%	481	83.2%	46	98.4%	24	79.7%	693	88.6%
Volumetric Resupply	114	57.3%	0	100.0%	27	99.1%	23	80.5%	154	97.5%
Tropical Environment										
FY12 Baseline	241	-	2857	-	2843	-	118	-	6059	-
Targeted Reduction	101	58.1%	481	83.2%	46	98.4%	24	79.7%	652	89.2%
Volumetric Resupply	88	63.5%	0	100.0%	27	99.1%	23	80.5%	138	97.7%

Note: All truck quantities rounded up to the nearest whole truck

While total fuel consumption varies with environment, this variance has little impact on the total required trucks to deliver fuel. Even at the 1000 PAX base camp, the Targeted Reduction Base Camp showed a variance of only 41 trucks over the course of a full year. As resource consumption is driven down further and optimized for volumetric resupply, this difference is reduced to only 16 trucks.

At the 50 PAX base camp, the number of trucks required to resupply the camp differed minimally between the Targeted Reduction Base Camp and the volumetric resupply scenario. This is due to the use of the WFA systems to produce at least 75% of the potable water at the Targeted Reduction Base Camp. In essence, optimizing this camp for volumetric resupply involved generating less than 25% of the camp's potable water consumption using WFA. The additional fuel consumption of the additional WFA runtime did not amount to another fuel truck needing to be delivered over the course of a year. However, the complete elimination of delivery of potable water eliminated the need for a water truck.

At the larger camps, the cost of constraining the camp in an operationally relevant manner and maintaining QoL(O) had a greater impact. These constraints caused an increase in yearly truck counts of 8.4–10.4% of the baseline amount across the two camps.

At both camps, the driving factor behind the truck count was potable water usage, which in turn dictated the need to dispose waste water. This potable water need was driven by the level of services on the base camps (e.g., flushing toilets, running showers, and onsite laundry facilities). Implementation of technologies saved 77.5% and 83.2% of the required potable water trucks in the resupply convoy at the 300 PAX and 1000 PAX base camps, respectively. Even with this reduction, potable water trucks still made up the bulk of the resource carrying trucks.

On the volumetrically optimized base camp, where services were cut to further reduce potable water demand, without WFA systems in place, the 300 PAX and 1000 PAX base camps would have required 99 and 182 yearly potable water trucks for resupply, respectively. At the 300 PAX base camp, under the worst-case weather conditions for the WFA system, those 99 water trucks were traded for only 27 fuel trucks, a reduction of 72.7%. Similarly, only 34 fuel trucks were added and 182 water trucks were removed at the 1000 PAX base camp, a reduction of 81.3%.

The Targeted Reduction Base Camps exceed the SLB-STO-D’s goal resource reduction targets while maintaining QoL(O) and reduce the required resource carrying trucks in convoys by over 55% at the 50 PAX base camp, over 85% at the 300 PAX base camp, and over 88% at the 1000 PAX base camp. While significant, the constraint of maintaining QoL(O) was not without cost. At the 1000 PAX base camp, maintaining the QoL(O) level took over twice as many trucks as a camp with doctrinal minimum level of services, even before factoring in optimizing for volume.

By optimizing for truck count, up to 97.7% of resupply trucks in convoys required for FWW hauling can be eliminated. Achieving this reduction may not be practical and requires significant trades from Army decision makers. On one hand, the monetary cost of fuel is substantially higher than bulk water. Equating those resources to optimize for trucks is necessary. On the other hand, given the current state of regulation and technology, the level of service and resulting QoL(O) has a direct correlation to the number of trucks required for resupply. A reduction in base camp services would also be required to reach the lower bound of trucks. However, even before these trades, a reduction of up to 89.2% is possible.

5.4 Alternative Use Case – Availability of Water

The SLB-STO-D FY12 ORTB assumed an isolated base camp without any natural resources available and this assumption is maintained in the Targeted Reduction Base Camps. However, one of the major benefits of using the DCAM modeling tool is its flexibility in modeling. It is possible to simulate variations to the use case, such as the case where it is possible to produce bulk potable water onsite using water filtration technologies. This section will use the Targeted Reduction Base Camps as the starting point, add and remove technologies to best fit the availability of natural water, and examine the impact of these changes on total resource savings.

Water purification technologies are discussed in **Section 3.2.3.3**. It was found that the TWPS or SUWP (for base camps of smaller size) can produce all required potable water with minimal increases in fuel usage or impact on the footprint of the base camp. The Targeted Reduction 300 PAX and 1000 PAX Base Camps incorporate additional water saving technologies, reducing the total amount of water required to be provided by the TWPS. Because the Targeted Reduction 50 PAX Base Camp does not incorporate any water saving technologies, it still requires the same equipment usage schedule as the FY12 ORTB Base Camp. **Table 87** summarizes the system counts and usage schedules required at the FY12 ORTB Base Camps compared to the Targeted Reduction Base Camps. As discussed in **Section 3.2.3.1,** for any of these base camps, inline water quality monitoring would be necessary to provide continuous assurance that water produced by these technologies is safe for use.

Table 87. System Counts and Usage Schedules, Water Purification Equipment

Base Camp	FY12 ORTB	Targeted Reduction
50 PAX Camp	One SUWP (4 h daily)	One SUWP (4 h daily)
300 PAX Camp	One TWPS (8 h daily)	One TWPS (3 h daily)
1000 PAX Camp	Two TWPS (13 h daily)	One TWPS (9 h daily)

With the availability of natural water, certain technological improvements would no longer be required. At the 50 PAX base camp, the WFA system would be eliminated because it requires more fuel per gallon of potable water produced than the SUWP. At the 300 PAX and 1000 PAX base camps, the LCTLs in the Targeted Reduction Base Camp are removed and replaced with the baseline ELS. While the ELS uses more water than the LCTL, it also uses less fuel. At a base camp with a natural water source, increasing water use to reduce fuel use is generally a good trade.

Table 88 shows the results of the simulation of the scenario where natural water is available across the different base camp sizes in the desert environment. The Targeted Reduction Base Camp is included for reference. A comparison of these results to all other integrated scenarios is shown in **Table 89**.

Table 88. Mean Daily Camp Level Summary, Availability of Water, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
	50 PAX Camp									
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Targeted Reduction	94	56.2%	340	66.2%	14	81.3%	27	0.0%	19	92.9%
Water Source	80	62.8%	342	66.0%	-5	106.7%	27	0.0%	19	92.9%
	300 PAX Camp									
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Targeted Reduction	436	58.2%	1925	62.3%	1954	77.6%	180	97.9%	566	80.3%
Water Source	330	68.3%	1893	62.9%	-360	104.1%	371	95.7%	560	80.5%
	1000 PAX Camp									
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Targeted Reduction	1467	56.6%	7074	59.8%	5267	83.2%	498	98.4%	2096	80.4%
Water Source	1059	68.6%	6957	60.4%	-700	102.2%	1292	95.9%	2072	80.5%

The major point of comparison will be between the Water Source run and the Targeted Reduction Base Camp. As discussed above, these camps differ only slightly in technologies implemented on base camp, as well as in the assumption of the presence of a natural water source nearby.

At the FY12 ORTB 50 PAX base camp, the ability to purify water onsite showed no change in waste water or solid waste produced. This is because there is no change in equipment set from the Targeted Reduction Base Camp that impacts these resources at the 50 PAX base camp.

The ability to purify water onsite eliminated the need for potable water shipment into the camp as the SUWP produced enough water to meet all demand. Switching from the WFA, which consumed a large amount of fuel, to the SUWP, which consumed a small amount of power, produced a very small increase in power demand (about 0.2%) and a sizeable reduction in fuel usage (about 6.6%). Note, however, that the difference in potable water reduction compared to the Targeted Reduction Base Camp is only 25.4%. Having a water source nearby does have an impact on the amount of potable water required for resupply, but the Targeted Reduction Base Camp, through the WFA, is already able to address a sizable amount of potable water supply. In fact, the WFA at the Targeted Reduction 50 PAX Base Camp is capable of addressing 100% of potable water demand, but is limited to addressing only 81.3% of demand because supplying all potable water would require a reduction of 8.8% in fuel savings, as discussed in **Section 3.2.3.2**.

At the FY12 ORTB 300 PAX and 1000 PAX Base Camps, the impact of natural water availability differs slightly from that at the FY12 ORTB 50 PAX Base Camp. This is partially due to the impact of removing the LCTL in favor of the ELS. The LCTL produces small amounts of solid waste, while the ELS produces larger amounts of waste water. As a result, switching to the ELS brings about a small (0.2–0.1%) reduction in solid waste and a larger (2.2–2.5%) increase in waste water production. Implementing the TWPS allows potable water demand to be completely supplied onsite, bringing about potable water demand reductions of about 19.0–26.5% as compared with the Targeted Reduction Base Camp. Introducing the TWPS brings about a small increase in power demand (0.6%), but eliminating the LCTL brings about a much larger savings in fuel, about 10.1–12.0%.

Note again that while purifying water onsite eliminates potable water resupply, the Targeted Reduction Base Camp already reduced the lion's share of potable water demand. Because potable water demand has already been reduced so sizeable with other technologies, the impact of water purification is much smaller than at the FY12 ORTB Base Camps (see **Section 3.2.3.3**), which had a much higher potable water demand. Interestingly, while switching to the ELS brings about sizable fuel savings, it also has a very large water cost. About half of the time the TWPS is active, it is producing potable water exclusively for the ELS.

The 300 PAX and 1000 PAX base camps continued to have a gray water recycling system. While a reduction in potable water demand becomes less important with the ability to purify water onsite, as discussed in **Section 4.1.4**, a waste water treatment system and gray water system in conjunction operate synergistically. Working together, they produce more waste water savings than the sum of each technology independently. Given that waste water continues to require backhaul, the savings in this resource area remain important.

It is also possible to size the waste water treatment system to treat all waste water (not just black water), as shown in **Section 3.3.3.2**. When this is implemented on the FY12 ORTB Base Camp, the waste water savings are about 5% lower than in a FY12 ORTB Base Camp with gray water recycling and waste water treatment. A reduction in savings of this size might be worth it if it means entirely eliminating the requirement for gray water recycling equipment. However, it is important to note that the impact of removing or adding technologies depends heavily on the other technologies or TTP changes present on the particular base camp. Removing gray water recycling and increasing the capacity of waste water treatment might have a different impact on a camp that can purify water than it had on the FY12 ORTB Base Camp.

The ability to purify water onsite proved inexpensive in terms of fuel and can eliminate the need to bring in bulk potable water via convoy. Water reduction technologies become less important as water becomes less expensive, leading to the prioritization of fuel reduction over water reduction. At the Targeted Reduction Base Camp where water reduction technologies are present, the presence or absence of a natural water source is less impactful. While still helpful to have natural water, it is less vital than it was at the FY12 ORTB Base Camp.

5.5 Summary of Resource Optimized Base Camp Design

Resource optimized base camps vary by the constraints placed on the camp's design. As constraints are added or removed from the camp design, the set of potential solutions expands and contracts accordingly. The changes in resource consumption between these base camps highlight both the costs of constraining the design and the potential bounds of the solution space. **Table 89** shows a comparison of the results to all resource optimized base camps.

Table 89. Mean Daily Camp Level Summary, Integrated Materiel and TTP Options, Desert

	Fuel		Power		Potable Water		Waste Water		Solid Waste	
Simulation Description	gal	Δ	kWh	Δ	gal	Δ	gal	Δ	lb	Δ
					50 PAX Camp					
FY12 Baseline	215	-	1007	-	75	-	27	-	266	-
Targeted Reduction	94	56.2%	340	66.2%	14	81.3%	27	0.0%	19	92.9%
Common Equipment Set	84	60.9%	406	59.7%	75	0.0%	27	0.0%	259	2.63%
Most Impactful Equipment Set	131	39.0%	1007	0.0%	75	0.0%	27	0.0%	266	0.0%
TTP/Non-Materiel Only	134	37.7%	656	34.9%	75	0.0%	27	0.0%	228	14.3%
Materiel Only	94	56.2%	340	66.2%	14	81.3%	27	0.0%	19	92.9%
Combined Materiel and TTP	89	58.6%	260	74.2%	14	81.3%	27	0.0%	17	93.6%
Volumetric Resupply	94	56.3%	260	74.2%	-6	108.0%	27	0.0%	17	93.6%
Water Source	80	62.8%	342	66.0%	-5	106.7%	27	0.0%	19	92.9%
					300 PAX Camp					
FY12 Baseline	1042	-	5108	-	8723	-	8529	-	2870	-
Targeted Reduction	436	58.2%	1925	62.3%	1954	77.6%	180	97.9%	566	80.3%
Common Equipment Set	476	54.3%	1925	62.3%	1712	80.4%	994	88.4%	566	80.3%
Most Impactful Equipment Set	582	44.2%	4477	12.4%	4176	52.1%	3983	53.3%	561	80.5%
TTP/Non-Materiel Only	500	52.0%	3455	32.4%	3023	65.3%	2822	66.9%	2870	0.0%
Materiel Only	335	67.9%	1431	72.0%	1670	80.9%	186	97.8%	560	80.5%
Combined Materiel and TTP	258	75.2%	950	81.4%	1076	87.7%	132	98.5%	560	80.5%
Volumetric Resupply	624	40.1%	1134	77.8%	-2	100.0%	177	97.9%	560	80.5%
Water Source	330	68.3%	1893	62.9%	-360	104.1%	371	95.7%	560	80.5%
					1000 PAX Camp					
FY12 Baseline	3376	-	17580	-	31305	-	31153	-	10672	-
Targeted Reduction	1467	56.6%	7074	59.8%	5267	83.2%	498	98.4%	2096	80.4%
Common Equipment Set	1481	56.1%	7202	59.0%	5267	83.2%	3384	89.1%	2096	80.4%
Most Impactful Equipment Set	1803	46.6%	15214	13.5%	14520	53.6%	14370	53.9%	2079	80.5%
TTP/Non-Materiel Only	1618	52.0%	11708	33.4%	9486	69.7%	9305	70.1%	10672	0.0%
Materiel Only	1243	63.2%	5443	69.0%	4296	86.3%	629	98.0%	2073	80.6%
Combined Materiel and TTP	894	73.5%	3056	82.6%	1988	93.7%	294	99.0%	2072	80.6%
Volumetric Resupply	1361	59.7%	3056	82.6%	-18	100.0%	294	99.0%	2072	80.6%
Water Source	1059	68.6%	6957	60.4%	-700	102.2%	1292	95.9%	2072	80.5%

The Targeted Reduction Base Camp incorporated a set of materiel and non-materiel changes to the FY12 ORTB Base Camps engineered to meet the SLB-STO-D’s resource reduction goals, maintain QoL(O), and remain operationally relevant. For the 300 PAX and 1000 PAX base camps, the Targeted Reduction Base Camp designs met all the SLB-STO-D’s objective metrics: a 25% reduction in fuel, a 75% reduction in potable water, and a 50% reduction in waste generation/backhaul. The 50 PAX base camp met the fuel, potable water, and solid waste measures, but failed to meet the waste water metric.

Variations of the Targeted Reduction Base Camp were investigated to determine the impacts of scalable technologies and reducing the unique technological additions to the base camp. Using a common equipment set across all three base camp sizes proved detrimental at the 50 PAX base camp, but less so at the 300 PAX and 1000 PAX base camps. The overlap in service offerings at the two larger camps produced a significant overlap in equipment sets. Even after normalizing the equipment sets, both of these camps met the SLB-STO-D’s objective resource reductions. Technologies did not scale well to the 50 PAX base camp, as a common equipment set eliminated most improvement at this camp. The 50 PAX base camp met only the fuel reduction goals using a common equipment set. Camps of this size have unique needs due to their austere nature and using equipment designed for larger camps does not make practical sense.

While all technologies included in the Targeted Reduction Base Camps positively impact resource consumption or production, a simplified implementation focusing on a single technology in each of the FWW thrust areas had a large impact. Meeting most of the SLB-STO-D resource reduction goals was accomplished using a very limited set of technologies: microgrids, gray water recycling, and waste-to-energy. All goals could be met by adding an additional technology to address latrine water usage.

The Targeted Reduction Base Camps were required to be operationally relevant and maintain QoL(O). Both proved to be significant restrictions on the efficiency of the base camps. By removing these constraints, an upper bound of resource savings was identified. The analysis was divided into three steps focusing on only TTP changes, only materiel changes, and a combination of both. TTP changes alone, constrained only by doctrinal minimum values, could not achieve the SLB-STO-D's objective resource reductions and materiel solutions were required. Additionally, overlaying TTP changes on a technologically advanced camp provided minimal resource savings at a significant cost to QoL(O). Constraining QoL(O) and geography cost little at the 50 PAX base camp due to its small size and low baseline level of QoL(O). At the 300 PAX and 1000 PAX base camps, these constraints mostly impacted fuel and potable water consumption. With constraints removed, fuel consumption decreased an additional 14.0% and 16.9% in the desert environment at the 300 PAX and 1000 PAX base camp, respectively.

As one of the key drivers to reducing resource consumption on contingency base camps is the subsequent reduction in threat hours faced by Soldiers in convoys, the logical extension of SLB-STO-D's goal is to minimize these threat hours. Simply meeting the SLB-STO-D's target metrics to reduce the need for fuel resupply by 25% and reduce the need for water resupply by 75% (not including any waste reductions) showed a decrease of 39.5% of convoys and 47.8% of transport trucks in convoys. This equated to a 52.8% reduction in threat exposure hours, a reduction of over 489,000 h over a 180-day period. Optimizing for threat hours requires a volumetric analysis with a goal of reducing the total number of trucks regardless of the resource they carry. By optimizing for truck count, up to 97.7% of resupply trucks in convoys required for FWW hauling can be eliminated.

Finally, while the SLB-STO-D's use case is defined in the FY12 ORTB, variations on this use-case can be simulated. One such variation includes the ability to produce bulk potable water onsite using water filtration technologies. The ability to purify water onsite proved inexpensive in terms of fuel and eliminated the need to bring in bulk potable water via convoy. Water reduction technologies became less important as water became less expensive, leading to the prioritization of fuel reduction over water reduction. At the Targeted Reduction Base Camp where water reduction technologies are present, the presence or absence of a natural water source is less impactful than at base camps that consume more water, such as the FY12 ORTB Base Camp.

6 CONCLUSIONS AND INSIGHTS

The main objective of the SLB-STO-D program was to demonstrate through modeling and simulation how the Army can achieve the interim objectives of a reduction in fuel consumption by 50%, potable water consumption by 75%, and waste generation for backhaul by 50%, while maintaining QoL(O) at contingency base camps. This report documents the contributions of individual options to that objective and also describes an integration of those options that achieves the objective savings.

The results of this analysis show that it is possible to exceed the SLB-STO-D program objective fuel, potable water, and waste reductions using an integration of materiel and non-materiel solutions. The materiel options included a combination of commercially available equipment and technologies within the Army's Science and Technology portfolio. **Table 90** shows a summary of the resource savings over the FY12 ORTB Base Camps. The objective reductions were achieved across all camp sizes and environments with the exception of the waste water at the 50 PAX Base Camp. Since the waste water collected from that camp is only from hand wash stations, it is likely to be eliminated in a field expedient method such as a soakage pit rather than requiring added equipment.

Table 90. FWW Savings, Targeted Reduction Base Camp

Environment	Fuel (gal)	Power (kWh)	Potable Water (gal)	Waste Water (gal)	Solid Waste (lb)
			50 PAX Camp		
Desert	56.2%	66.2%	81.3%	0.0%	92.9%
Temperate	50.2%	38.9%	94.7%	0.0%	92.9%
Tropical	57.6%	71.1%	97.3%	0.0%	92.9%
			300 PAX Camp		
Desert	58.2%	62.3%	77.6%	97.9%	80.3%
Temperate	49.5%	35.7%	77.6%	97.9%	80.3%
Tropical	59.2%	65.4%	77.6%	97.9%	80.3%
			1000 PAX Camp		
Desert	56.6%	59.8%	83.2%	98.4%	80.4%
Temperate	46.8%	33.0%	83.2%	98.4%	80.4%
Tropical	58.1%	63.0%	83.2%	98.4%	80.4%

Some of the key insights presented are summarized below:

- Resource reduction at base camps can have a meaningful impact on the safety of Soldiers. An initial operational effectiveness analysis was conducted and showed that meeting (not exceeding) the SLB-STO-D's target metrics to reduce fuel and water resupply showed a decrease of 39.5% of convoys and 47.8% of transport trucks in convoys. This equated to a 52.8% reduction in threat exposure hours, a reduction of over 489,000 h over a 180-day period. Including the reductions in solid and liquid waste would provide even greater savings.
- Water is the largest resource transported to a base camp in terms of volume. Solutions that reduce the need for potable water to be transported to and gray and black water transported from the base camp play a significant part in meeting the SLB-STO-D's overall logistic reduction metrics.

- Materiel solutions play a key role in all integrated solutions that meet the objective measures. Although non-materiel solutions alone can meet the 25% reduction in fuel and 50% reduction in waste water, most have a major negative impact on QoL(O). Non-materiel solutions alone cannot meet the objective metrics related to potable water and solid waste.
- The bulk of the fuel, potable water, and waste reductions were the result of a limited number of technologies: microgrids, gray water recycling, and waste-to-energy converters. These three capabilities played a vital role in the achievement of the SLB-STO-D program objectives and are some opportunities for further development. Note: waste-to-energy converters produce a large continuous power output which must be coupled to a microgrid or very large energy consumer.
- Non-materiel courses of action may not have as great an impact following the implementation of certain technologies. For example, on a base camp with gray water recycling and low-flow showerheads, reducing shower times has a much smaller impact on water savings. Conversely, the resource cost for increased shower times is lessened.
- Power generation is the main driver of fuel consumption, even after optimizing the base camp for resource consumption and production. Options that enable reallocation of power generation to eliminate entire generators have a much larger impact on fuel consumption than those that just reduce overall power demand. In this way, materiel options with lower peak power demands can provide significant fuel savings even if their average power consumption is equal and the implementation of microgrids can enhance the fuel savings of small power savers. Non-materiel options offer a significant increase in benefit if they enable a reduction in generator count.
- After water saving options are implemented, latrine water usage is reduced considerably, but shower facilities still consume the most potable water of any facility on the base camp. Water consumption by the kitchen and maintenance facilities both increase as a proportion of total water used, making them future areas to target.
- Both waste water and solid waste can be greatly reduced using a single materiel solution each with only a minor impact on the fuel consumption.
- Geographic realities present a significant burden on implementing the minimal number of systems. Microgrids are limited by low power density and geographic sprawl. Water systems are limited by the need to collocate water consumers, waste water producers, and waste water systems. To provide fully integrated water and waste water management at a base camp, careful consideration must be given to system size and the layout of the camp. Oversized systems require the centralization of facilities or the transporting of resources around the camp. Smaller systems enable easier implementation into existing camp designs, but require more equipment.

The SLB-STO-D's objectives are a great start towards achieving the Army's vision of a Net Zero base camp. This analysis showed that to attain self-sustainability, several areas remain to be addressed:

- Army regulations may prove to limit self-sustainability. Doctrine limits gray water recycling systems to recycling 80% of the source water and prohibits the recycling of black water. Water must not be eliminated unnecessarily from the base camp ecosystem. Loosening these regulations and expanding water recycling programs provide an avenue for centralized reduction in potable water consumption and waste production without the need to address the many small consumers and producers on the base camp. As water must be replenished, water collection systems or WFA will play a key role in regenerating the water supply.

- Noncombustible waste must be addressed at the source. A greater holistic approach could be benefited from by ensuring a sustainable total life cycle management of the source material prior to the material entering the base camp. While waste-to-energy conversion transfers solid waste into a positive resource, its efficiency is highly dependent on the amount of noncombustible waste in the stream. Eliminating this noncombustible waste prior to reaching the base camp will be required.
- Renewable energy can have a meaningful impact on power consumption, but the space required for large scale implementation with current efficiencies reduces its possibility. Technologies that increase efficiencies and the incorporation of renewable energy without requiring additional space, such as through solar shades, can help to achieve self-sufficiency. Because distributed small scale renewable energy systems do not allow for the elimination of generators, their impact on fuel is diminished. Integration of these distributed systems may prove to enable larger fuel savings.
- Energy storage systems will be required to enable renewable energy and further the efficiency of microgrids. Renewable energy is limited to certain times of day—solar panels only produce power when the sun is out, turbines only produce power when there is wind, etc. For these sources to be fully utilized, energy storage systems sized for base camps must be implemented. The future investments in energy storage systems can continue to address the logistical challenges that come along with those systems such as weight and safe transportation. Further, the intelligent interaction of energy storage systems and microgrids will enable efficiency features such as peak shaving, load leveling, and the reduction of spinning reserve capacity.
- Black water cannot be eliminated from the base camp ecosystem. Black water is currently an untapped resource on the base camp, with current regulations making it a liability with no potential benefit. Research and development into safe recycling systems for black water combined with identifying safe uses for recycled black water will reduce the demand for water resupply.
- Recycling gray water for potable water may eliminate the need to bring fresh potable water to base camps via convoy or the costly generating of fresh potable water onsite. Current implementations of gray water recycling systems produce non-potable water that is limited to use in facilities such as showers and laundry. Facilities such as dining facilities and aid stations cannot use this recycled water. By developing systems that produce potable water, the product water can be used for all purposes on the base camp.
- Power distribution technology for tactical generators must be improved to fully realize the potential of microgrids. Grid stability and reliability is critical to ensuring mission success when deployed and realizing the full benefits that a microgrid provides. Microgrids are limited by low power density and geographic sprawl, since current power distribution systems (i.e., PDISEs) have limited cable lengths over which voltages can be maintained. This is particularly evident when connecting a waste-to-energy converter to a microgrid, because they are typically located away from other camp facilities. To fully utilize a microgrid and minimize the number of microgrids needed, power must be able to be distributed beyond the current capability. Furthermore, intelligent power management

and distribution systems could provide a significant impact that would increase security, agility and adaptability of the power systems to enable the Solder to efficiently transmit/transfer power from source capabilities to load requirements.

While this analysis demonstrates the possibility of drastically reducing the fuel and potable water consumption and waste production of base camps using an integration of materiel and non-materiel options, the purview of this report is limited to the resource reducing capability of each option. An analysis on characteristics such as readiness and maturity, human systems integration, survivability, reliability, availability, maintainability, sustainability, supportability, and force projection can be found in the SLB-STO-D's *Selected Technology Assessment* report [1].

For materiel changes, including the implementation of technologies still under development, certain assumptions as to the fit and maturity of the technologies had to be made. The SLB-STO-D's analysis focused on the capability the technology provided as it related to resource consumption and production. The technologies analyzed are at various places in the maturity path and development cycle with most needing additional development to reach a level of maturity required for fielding. The current operational acceptability of many technologies analyzed is also included in the SLB-STO-D's *Selected Technology Assessment* [1].

7 RECOMMENDATIONS

This analysis report includes the results of the simulation of various options to save FWW at base camps. The best data available at the time of writing were used in this analysis.

For materiel changes including the implementation of technologies still under development, certain assumptions as to the fit and maturity of the technologies had to be made. The SLB-STO-D held integrated demonstrations to demonstrate many technologies. A key assumption of this analysis is that these technologies would perform similarly in an even more operational environment for an extended period of time.

The technologies analyzed are at various stages of maturity level, technology development cycle, and potential transition path, with most needing additional development to reach the level of maturity required for becoming Programs of Record (POR). It is recommended that the Army continue to focus research and development efforts related to base camp technologies that demonstrated and showed through modeling, simulation, and analysis a large potential impact to reduce FWW to ensure these technologies develop into fielded capabilities.

The following technologies and capabilities showed great promise in achieving resource reduction at base camps. Mitigating identified issues through further development will help the Army achieve a Net Zero base camp. The following technologies are in no particular order.

- Microgrids – Microgrids are hindered by implementation issues at geographically dispersed base camps. Improved power distribution equipment may help to reduce the number of microgrids needed, increasing fuel economy and decreasing the amount of equipment to maintain them. Additionally, the microgrid demonstrated by the SLB-STO-D requires more evaluation to include a various mix of loads, generators, alternate power sources, and power storage solutions.
- SCPL – SCPL proved a simple one-for-one replacement with a great potential for fuel savings in vehicles and generators. While some generator-based testing has occurred, further evaluation is necessary to determine SCPL’s impact on generators.
- V1.5 Liner – The V1.5 Liner greatly increased the efficiencies of shelters, but its survivability is currently unknown. Demonstrations show some susceptibility to damage, but further research is required to determine how damage degrades performance.
- 42k ECU – Right-sizing ECUs proved vital in reducing peak power consumption of shelters and enabling generator reallocation. While performing well during demonstration, only a few test articles exist and additional testing under various conditions is required.
- Water Quality Monitoring – Water quality monitoring technologies show promise as mitigation technologies and enablers of water recycling and waste water treatment. Certain systems have proven fragile, while others are difficult to use. Further development is required prior to fielding.
- Gray Water Recycling – Both gray water systems analyzed showed great promise as capabilities but are still immature. Additionally, Army regulations may limit the amount of recycled water they can produce below their technical capabilities. Further

development is needed and investigation is required to determine the safe peak recycling rate of these technologies.

- Black Water Treatment – Black water treatment showed great promise as a method to safely dispose of a large percentage of black water without the need for dangerous and costly backhaul. Further development is required to make these systems ready for fielding. Beyond just treatment, the next step could be black water recycling.
- Black Water Recycling – Black water is currently an untapped resource on the base camp, with current regulations making it a liability with no potential benefit. Research and development into safe recycling systems for black water combined with identifying safe uses for recycled black water may prove the next big water reduction technology.
- Source Reduction – Source reduction technologies are various. While some have proven mature, such as changes to MRE packaging, others require further development. The reduction of noncombustible waste components brought to base camps will play a key role in reducing the waste backhaul requirement after waste destruction systems are implemented.
- WEC – Integration issues concerning the WEC were identified due to its power output potential. Further issues relate to geographic placement on the base camp. Power distribution may prove the limiting factor in WEC placement and must be investigated further. Technology implementations are also immature and require further research and development prior to fielding.

Additionally, while the SLB-STO-D program objective required maintaining QoL(O) on the base camps, it is currently unknown how this quantification of QoL(O) interacts with other behavioral and environmental conditions to drive mission readiness. Further research is recommended to determine the impact of QoL(O) on Soldier readiness.

Finally, a key aspect of the SLB-STO-D's success was the exhibition of various technologies in integrated demonstrations. These demonstrations proved invaluable in gathering performance data and determining how technologies operate in concert with each other and with other sustainment equipment. They provided information to project officers not readily garnered through other channels, enhancing technology development and inserting soldier feedback into the development process early. The SLB-STO-D recommends that the Army maintains an enduring capability of integrated demonstrations of sustainment technologies in the Army's Science and Technology portfolio.

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LIST OF ACRONYMS

AARID	Adaptive Armament Reactive Interface Domains
AEESS	Advanced Energy Efficient Shelter Systems
AFFS	Army Field Feeding System
AK	Assault Kitchen
AMMPS	Advanced Medium-Sized Mobile Power Source
AMSAA	Army Materiel System Analysis Agency/Activity
AR	Army Regulation
ARDEC	Armament Research, Development and Engineering Center
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
AS TEMPER	Air Supported Tent, Extendable, Modular, Personnel
ASTMIS	Army Science and Technology Management Information System
ATP	Army Techniques Publication
BCIL	Base Camp Integration Laboratory
B-Huts	Barracks Huts
BK	Battlefield Kitchen
BSB	Brigade Support Battalion
CASCOM	Combined Arms Support Command
CBITEC	Contingency Basing Integration and Technology Evaluation Center
CERDEC	Communications-Electronics Research, Development and Engineering Center
CERL	Construction Engineering Research Laboratory
CHU	Containerized Housing Units
CK	Containerized Kitchen
CK-I	Containerized Kitchen - Improved
CIMS	Containerized Ice Making System
CIMT	Containerized Ice Making Technology
CONUS	Continental United States
COTS	Commercial Off-the-Shelf
CP	Command Post
CSSB	Combat Sustainment Support Battalion
DAAB	Deployable Aerobic Aqueous Bioreactor
DAG	Data Authentication Group
dBBR	TRICON Deployable Baffled Bioreactor
DCAM	Detailed Component Analysis Model
DESERT	Desert Environment Sustainable Efficient Refrigeration Technology
DIF	Diffuse Horizontal Irradiance
DMMS	Deployable Metering and Monitoring System
DNI	Direct Normal Irradiance
DoD	Department of Defense
DP2	DESERT Power 2
DRR	Demonstration Readiness Review

E2RWM	Energy Efficient Rigid Wall Module
E2RWM E3	EERWM with Energy Storage
EBWT	Expeditionary Black Waste Treatment Technologies
ECBLS	Expeditionary Containerized Batch Laundry System
ECP	Entry Control Points
ECU	Environmental Control Unit
EEECU	Energy Efficient Environmental Control Unit
EIO	Energy Informed Operations
ELS	Expeditionary Latrine System
ERDC	Engineer Research and Development Center
ESS	Energy Storage Systems
ESWDS	Expeditionary Solid Waste Disposal System
ETK	Expeditionary TRICON Kitchen
ExFOB	Experimental Forward Operating Base
FBCT	Fully Burdened Cost Tool
FF-ETK	Fuel Fired-Expeditionary TRICON Kitchen
FORO	Forward Osmosis/Reverse Osmosis
FPE	Force Provider-Expeditionary
FSC	Forward Support Company
FSC-2	Food Sanitation Center-2
FWW	Fuel, Water, and Waste
G-WTRS	Gray Water Treatment and Reuse System
HE-MTRCS	High Efficiency-Multi Temperature Refrigeration Container System
HEMTT	Heavy Expanded Mobility Tactical Truck
HIPPO	Water Tank Rack
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HPT	Hybrid Power Trailer
ICE	Innovative Cooling Equipment
IECU	Improved Environmental Control Unit
JLTV	Joint Light Tactical Vehicle
JOEI	Joint Operational Energy Initiative
JP-8	Jet Propulsion fuel, type 8
LCTL	Low Cost TRICON Latrine
LED	Light Emitting Diode
LIA	Logistics Innovation Agency
LINER	Non-woven Composite Insulation Liner
LHS	Load Handling System
LOGCAP	Logistics Civil Augmentation Program
MACK	Modular Appliances for Configurable Kitchens
MANGEN	1kWe JP-8 fueled, Man-Portable Generator Set
MBFS	Mobile Bioelectric Filtration System
MBSE	Model-Based Systems Engineering
MBU	Modern Burner Unit
MIL-TOILAT	Minimized Logistic TRICON Integrated Latrine

MEP	Mobile Electric Power
METT-TC	Mission, Enemy, Terrain, Troops-Time and Civil
MKT	Mobile Kitchen Trailer
MOS	Military Occupational Skill
MRE	Meals, Ready to Eat
MSCoE	Maneuver Support Center of Excellence
MTH	Military Tactical Heater
MTRCS	Multi Temperature Refrigerated Container System
MWPS	Mobile Water Purification System
MWR	Morale, Welfare, and Recreation
NDCEE	National Defense Center for Energy and Environment
NILM	Nonintrusive Load Monitoring
NSRDEC	Natick Soldier Research, Development and Engineering Center
OCONUS	Outside CONUS
OPLOG	Operational Logistics
ORTB	Operationally Relevant Technical Baseline
OV-1	Operational View - 1
PAX	Personnel
PEO CS&CSS	Program Executive Office Combat Support & Combat Service Support
PdD CBI	Product Director Contingency Basing Infrastructure
PDISE	Power Distribution Illumination Systems, Electrical
PM FSS	Program Manager Force Sustainment Systems
POR	Programs of Record
PSHADE	PowerShade
PV	Photovoltaic
QMEG	Quiet, Multi-Fuel Migrating Combustion Chamber Engine & Generator
QoL	Quality of Life
QoL(O)	Operational Quality of Life
RDECOM	Research, Development and Engineering Command
RDS	Rapidly Deployable Shelter
REDUCE	Renewable Energy for Distributed Under-supplied Command Environments
RIF	Rapid Innovation Fund
SCPL	Single Common Powertrain Lubricant
SAGE	Smart and Green Energy
SEEDS	Smart Energy Efficient Deployable Shelters
SIP-Hut	Structural Insulated Panel - Hut
SLB-STO-D	Sustainability Logistics-Basing Science and Technology Objective - Demonstration
SLIM	Self-Sustaining Living Module
SME	Subject Matter Expert
SPSS	Solar Powered Shelter System
SPSWH	Self-Powered Solar Water Heater
SPV	Subsistence Prime Vendor

SRHS	Shelter Radiant Heating System
STEM	Shelter Thermal Energy Model
STRaPS	Sustainable Technologies for Ration Packaging Systems
STO-D	Science and Technology Objective-Demonstration
SUSS	Small Unit Sustainment System
SUWP	Small Unit Water Purifier
SWDS	Solid Waste Destruction System
SWRS	Shower Water Reuse System
TAC	Tactical Action Center
TARDEC	Tank and Automotive Research, Development and Engineering Center
TECD	Technology-Enabled Capability Demonstration
TEMPER	Tent, Extendable, Modular, Personnel
TM	Technical Manual
TOC	Tactical Operations Center
TQG	Tactical Quiet Generator
TRADOC	Training and Doctrine Command
TRICON	Tri-wall Container
TRL	Technology Readiness Level
TSD	Thermal Storage Device
TTPs	Tactics, Techniques, and Procedures
TWPS	Tactical Water Purification System
UGR-A	Unitized Group Ration – A option
UGR-E	Unitized Group Ration - Express
UGR-H&S	Unitized Group Ration – Heat & Serve
UF-GWRS	Ultra-Filtration-Gray Water Reuse System
ULCANS	Ultra-Lightweight Camouflage Net System
V&V	Verification and Validation
V2G/V2V	Vehicle-to-Grid/Vehicle-to-Vehicle
VFOB	Virtual Forward Operating Base
WAM	Wind Acceleration Module
WEC	Waste to Energy Converter
WETT	Wastewater Electrochemical Treatment Technology
WFA	Water from Air
WH	Water Heater
WQAS-P	Water Quality Analysis Set-Purification
WRPA	Water Reuse Pump Assembly
WRS	Water Recycling System
Xw-Box	Expeditionary Waste Mitigation Box

ANNEX A – DETAILED RESULTS, TARGETED REDUCTION BASE CAMPS

A.1 50 PAX BASE CAMP

Table A-1. Mean Daily Camp Level Summary, Targeted Reduction 50 PAX Base Camp

Resource Type	Desert	Temperate	Tropical
Power Demand (Mean kWh/day)	340	404	275
Fuel Demand (Mean gal/day)	94	109	90
Potable Water Demand (Mean gal/day)	14	4	2
Waste Water Production (Mean gal/day)	27	27	27
Solid Waste Production (Mean lbs/day)	19	19	19

Table A-2. Mean Daily Fuel Demand (gal/day) by Camp Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Electric Power	46	49	42
Provide Latrine Services	20	20	20
Execute Protection	13	13	13
Provide Access to Transportation	0	1	0
Enable Command and Control	0	0	0
Provide Billeting	0	9	0
Provide Potable Water	14	14	13
Provide Solid Waste Management	1	1	1
Provide Subsistence	0	2	0
TOTAL	94	109	90

Note: Values may not sum to total due to rounding

Table A-3. Mean Daily Fuel Demand (gal/day) by Equipment Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Power Generation	46	49	42
Latrine	20	20	20
Protection	13	13	13
On-Camp Vehicles	0	1	0
Produce Water from Other Sources	14	14	13
Shelter Heating and Cooling	0	11	0
Solid Waste Destruction	1	1	1
TOTAL	94	109	90

Note: Values may not sum to total due to rounding

Table A-4. Mean Daily Power Demand (kWh/day) by Camp Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Billeting	115	179	65
Enable Command and Control	157	130	162
Provide Subsistence	30	48	14
Provide Access to Medical & Health Services	20	30	17
Execute Protection	8	8	8
Provide Access to Maintenance Repair	3	3	3
Provide Solid Waste Management	6	6	6
TOTAL	340	404	275

Note: Values may not sum to total due to rounding

Table A-5. Mean Daily Power Demand (kWh/day) by Equipment Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Shelter Heating and Cooling	193	221	127
Communications and Computers	92	92	92
Lighting	48	48	48
Convenience Loads	47	47	47
Protection	17	17	17
Refrigeration	0	0	0
Solar Power Generation	-62	-26	-61
Solid Waste Destruction	6	6	6
TOTAL	340	404	275

Note: Values may not sum to total due to rounding

Table A-6. Mean Daily Potable Water Demand (gal/day) by Camp Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Means to Clean Clothes	46	46	46
Provide Means to Maintain Personal Hygiene	27	27	27
Provide Access to Medical & Health Services	2	2	2
Provide Potable Water	-61	-71	-73
TOTAL	14	4	2

Table A-7. Mean Daily Potable Water Demand (gal/day) by Equipment Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Laundry	46	46	46
Hygiene and Showers	29	29	29
Produce Water from Other Sources	-61	-71	-73
TOTAL	14	4	2

Table A-8. Mean Daily Waste Water Production (gal/day) by Camp Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Means to Maintain Personal Hygiene	27	27	27
TOTAL	27	27	27

Table A-9. Mean Daily Waste Water Production (gal/day) by Equipment Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Hygiene and Showers	27	27	27
TOTAL	27	27	27

Table A-10. Mean Daily Solid Waste Production (lbs./day) by Camp Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Solid Waste Management	19	19	19
TOTAL	19	19	19

Table A-11. Mean Daily Solid Waste Production (lbs./day) by Equipment Level Function, Targeted Reduction 50 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Solid Waste Production	259	259	259
Solid Waste Destruction	-240	-240	-240
TOTAL	19	19	19

A.2 300 PAX BASE CAMP

Table A-12. Mean Daily Camp Level Summary, Targeted Reduction 300 PAX Base Camp

Resource Type	Desert	Temperate	Tropical
Power Demand (Mean kWh/day)	1925	2630	1661
Fuel Demand (Mean gal/day)	436	553	417
Potable Water Demand (Mean gal/day)	1954	1954	1954
Waste Water Production (Mean gal/day)	180	180	180
Solid Waste Production (Mean lbs/day)	566	566	566

Table A-13. Mean Daily Fuel Demand (gal/day) by Equipment Level Function, Targeted Reduction 300 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Power Generation	224	284	206
On-Camp Vehicles	40	41	40
Maintenance	18	18	18
Protection	13	13	13
Water Heating	8	16	7
Lighting	3	3	3
Food Prep and Cleaning	10	10	10
Process Black Water	108	108	108
Shelter Heating and Cooling	0	49	0
Solid Waste Destruction	12	12	12
Totals	436	553	417

Note: Values may not sum to total due to rounding

Table A-14. Mean Daily Power Demand (kWh/day) by Camp Level Function, Targeted Reduction 300 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Billeting	442	693	249
Provide Subsistence	392	396	373
Enable Command and Control	458	473	465
Provide Means to Maintain Personal Hygiene	146	282	84
Provide Access to MWR Services	208	235	195
Provide Means to Clean Clothes	206	227	206
Provide On-Base Lighting	144	144	144
Provide Latrine Services	237	404	224
Provide Access to Maintenance/Repair	20	26	18
Provide Access to Medical & Health Services	20	30	17
Execute Protection	14	14	14
Warehouse/Store All Supply Classes	12	17	11
Process Black Water	7	42	6
Provide Electric Power	19	19	19
Provide Solid Waste Management	-445	-486	-409
Recycle Gray Water	45	116	45
TOTAL	1925	2630	1661

Note: Values may not sum to total due to rounding

Table A-15. Mean Daily Power Demand (kWh/day) by Equipment Level Function, Targeted Reduction 300 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Shelter Heating and Cooling	740	1142	416
Lighting	342	342	342
Refrigeration	271	193	280
Convenience Loads	366	366	366
Communications and Computers	344	344	344
Food Prep and Cleaning	49	49	49
Laundry	203	203	203
Water Heating	44	302	41
Water Pumping	22	22	22
Protection	14	14	14
Maintenance	3	3	3
Hybrid Power Generation	19	19	19
Process Black Water	195	195	195
Provide Energy Storage	454	412	490
Recycle Gray Water	40	40	40
Solar Power Generation	-280	-115	-264
Solid Waste Destruction	-899	-899	-899
TOTAL	1925	2630	1661

Note: Values may not sum to total due to rounding

Table A-16. Mean Daily Potable Water Demand (gal/day) by Camp Level Function, Targeted Reduction 300 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Means to Maintain Personal Hygiene	3526	3526	3526
Provide Latrine Services	309	309	309
Provide Means to Clean Clothes	751	751	751
Provide Subsistence	446	446	446
Provide Means to Maintenance/Repair	312	312	312
Provide Access to Medical & Health Services	8	8	8
Recycle Gray Water	-3398	-3398	-3398
TOTAL	1954	1954	1954

Table A-17. Mean Daily Potable Water Demand (gal/day) by Equipment Level Function, Targeted Reduction 300 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Hygiene and Showers	3534	3534	3534
Latrine	309	309	309
Laundry	751	751	751
Food Prep and Cleaning	446	446	446
Maintenance	312	312	312
Recycle Gray Water	-3398	-3398	-3398
Water Pumping	0	0	0
TOTAL	1954	1954	1954

Table A-18. Mean Daily Waste Water Production (gal/day) by Camp Level Function, Targeted Reduction 300 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Means to Maintain Personal Hygiene	3526	3526	3526
Provide Latrine Services	0	0	0
Provide Means to Clean Clothes	751	751	751
Provide Subsistence	446	446	446
Process Black Water	-1145	-1145	-1145
Recycle Gray Water	-3398	-3398	-3398
TOTAL	180	180	180

Table A-19. Mean Daily Waste Water Production (gal/day) by Equipment Level Function, Targeted Reduction 300 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Hygiene and Showers	3526	3526	3526
Latrine	435	435	435
Laundry	751	751	751
Food Prep and Cleaning	446	446	446
Process Black Water	-1580	-1580	-1580
Recycle Gray Water	-3398	-3398	-3398
TOTAL	180	180	180

Table A-20. Mean Daily Solid Waste Production (lbs./day) by Camp Level Function, Targeted Reduction 300 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Solid Waste Management	560	560	560
Provide Latrine Services	6	6	6
TOTAL	566	566	566

Table A-21. Mean Daily Solid Waste Production (lbs./day) by Equipment Level Function, Targeted Reduction 300 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Solid Waste Production	2852	2852	2852
Process Black Water	6	6	6
Solid Waste Destruction	-2292	-2292	-2292
TOTAL	566	566	566

A.3 1000 PAX BASE CAMP

Table A-22. Mean Daily Camp Level Summary, Targeted Reduction 1000 PAX Base Camp

Resource Typ	Desert	Temperate	Tropical
Power Demand (Mean kWh/day)	7074	9878	6091
Fuel Demand (Mean gal/day)	1467	1943	1383
Potable Water Demand (Mean gal/day)	5267	5267	5267
Waste Water Production (Mean gal/day)	498	498	498
Solid Waste Production (Mean lbs/day)	2096	2096	2096

Table A-23. Mean Daily Fuel Demand (gal/day) by Camp Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Electric Power	763	986	690
Provide Access to Transportation	122	123	121
Provide Subsistence	36	44	36
Provide Means to Maintain Personal Hygiene	32	92	27
Provide On-Base Lighting	28	28	28
Execute Protection	26	26	26
Provide Access to Maintenance/Repair	9	64	3
Enable Command and Control	0	0	0
Enable Movement & Maneuver	0	4	0
Provide Access to MWR Services	0	8	0
Provide Billeting	0	114	0
Provide Latrine Services	408	408	408
Provide Means to Clean Clothes	0	0	0
Provide Solid Waste Management	45	45	45
Warehouse/Store All Supply Classes	0	2	0
TOTAL	1467	1943	1383

Note: Values may not sum to total due to rounding

Table A-24. Mean Daily Fuel Demand (gal/day) by Equipment Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Power Generation	763	986	690
On-Camp Vehicles	122	123	121
Food Prep and Cleaning	36	36	36
Water Heating	32	60	27
Lighting	28	28	28
Protection	26	26	26
Maintenance	3	3	3
Process Black Water	408	408	408
Shelter Heating and Cooling	5	229	0
Solid Waste Destruction	45	45	45
TOTAL	1467	1943	1383

Note: Values may not sum to total due to rounding

Table A-25. Mean Daily Power Demand (kWh/day) by Camp Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Billeting	1416	2327	896
Enable Command and Control	2075	2132	2069
Provide Means to Maintain Personal Hygiene	704	1376	393
Provide Access to MWR Services	1320	1432	1269
Provide Subsistence	664	559	636
Provide Means to Clean Clothes	805	935	795
Provide On-Base Lighting	420	420	420
Provide Latrine Services	948	1784	884
Execute Protection	263	263	263
Enable Movement and Maneuver	45	68	11
Warehouse/Store All Supply Classes	28	47	13
Provide Access to Maintenance/Repair	84	96	80
Provide Access to Medical & Health Services	41	61	34
Enable Communications	3	5	3
Process Black Water	17	158	16
Provide Solid Waste Management	-2019	-2156	-1848
Recycle Gray Water	158	370	157
TOTAL	7074	9878	6091

Note: Values may not sum to total due to rounding

Table A-26. Mean Daily Power Demand (kWh/day) by Equipment Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Shelter Heating and Cooling	2751	4444	1534
Convenience Loads	1704	1704	1704
Communications and Computers	1448	1448	1448
Lighting	1189	1189	1189
Laundry	764	764	764
Refrigeration	376	187	400
Protection	427	427	427
Food Prep and Cleaning	119	119	119
Water Heating	206	1154	197
Water Pumping	77	77	77
Maintenance	9	9	9
Process Black Water	731	731	731
Provide Energy Storage	1328	1192	1500
Recycle Gray Water	138	138	138
Solar Power Generation	-845	-356	-798
Solid Waste Destruction	-3347	-3347	-3347
TOTAL	7074	9878	6091

Note: Values may not sum to total due to rounding

Table A-27. Mean Daily Potable Water Demand (gal/day) by Camp Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Means to Maintain Personal Hygiene	13108	13108	13108
Provide Latrine Services	1171	1171	1171
Provide Means to Clean Clothes	1802	1802	1802
Provide Subsistence	384	384	384
Provide Means to Maintenance Repair	624	624	624
Provide Access to Medical & Health Services	17	17	17
Recycle Gray Water	-11839	-11839	-11839
TOTAL	5267	5267	5267

Table A-28. Mean Daily Potable Water Demand (gal/day) by Equipment Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Hygiene and Showers	13125	13125	13125
Latrine	1171	1171	1171
Laundry	1802	1802	1802
Food Prep and Cleaning	384	384	384
Maintenance	624	624	624
Recycle Gray Water	-11839	-11839	-11839
Water Pumping	0	0	0
TOTAL	5267	5267	5267

Table A-29. Mean Daily Waste Water Production (gal/day) by Camp Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Means to Maintain Personal Hygiene	13108	13108	13108
Provide Latrine Services	1	1	1
Provide Means to Clean Clothes	1802	1802	1802
Provide Subsistence	294	294	294
Provide Access to Medical & Health Services	17	17	17
Process Black Water	-2885	-2885	-2885
Recycle Gray Water	-11838	-11838	-11838
TOTAL	498	498	498

Note: Values may not sum to total due to rounding

Table A-30. Mean Daily Waste Water Production (gal/day) by Equipment Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Hygiene and Showers	13125	13125	13125
Latrine	1640	1640	1640
Laundry	1802	1802	1802
Food Prep and Cleaning	294	294	294
Process Black Water	-4525	-4525	-4525
Recycle Gray Water	-11838	-11838	-11838
TOTAL	498	498	498

Table A-31. Mean Daily Solid Waste Production (lbs./day) by Camp Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Provide Solid Waste Management	2072	2072	2072
Provide Latrine Services	24	24	24
TOTAL	2096	2096	2096

Table A-32. Mean Daily Solid Waste Production (lbs./day) by Equipment Level Function, Targeted Reduction 1000 PAX Base Camp

Functional Area	Desert	Temperate	Tropical
Solid Waste Production	10602	10602	10602
Process Black Water	24	24	24
Solid Waste Destruction	-8530	-8530	-8530
TOTAL	2096	2096	2096

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ANNEX B – REQUESTING DATA, DOCUMENTATION, AND TOOLS

Fill in the following application.

US Army Natick Soldier Research, Development, and Engineering Center (NSRDEC)
Expeditionary Basing and Collective Protection Directorate (EBCP)
Natick, MA

Sustainability Logistics-Basing, Science and Technology Objective Demonstration (Formerly TECD-4a)

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COTS/GOTS: **None**

ESTIMATED COMPLETION DATE: **N/A**

PURPOSE: (Clearly identify the intended purpose/use of the material plus impact of not receiving material).

The above listed data items are being provided for the purpose of ____________________________________

Processing or analysis of the data items will be distributed ONLY to _________________________________

REQUESTING ORGANIZATION NAME: ____

REQUESTING ORGANIZATION AUTHORIZED POINT OF CONTACT (POC):

NAME (Print): ______________________________ DATE: ____

TELEPHONE: ______________________________ E-MAIL:____

ORGANIZATION: ____

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Date: __________

Name (Please Print): ___Ben Campbell____

Position: __________Lead Systems Engineer____

Telephone: _____(508) 233-5451____________ E-mail: ____benjamin.j.campbell26.civ.civ@mail.mil________

Authorized Signature: ___________________________________

U.S. GOVERNMENT SPONSOR APPROVAL: The above request is approved for the purpose stated by the requester.

____

(NSRDEC – SLB-STO-D) (Date)

NAME: ___Gregg Gildea________________________

ANNEX C – TECHNOLOGY DESCRIPTIONS

C.1 1 KW MAN-PORTABLE GENERATOR (MANGEN)

Figure C-1. MANGEN Sets

The MANGEN (**Figure C-1**) is a man-portable generator set capable of delivering up to 1 kW of power. It uses a commercial-off-the-shelf spark ignition engine modified with a catalyst-based conversion kit to enable it to burn JP-8.

The MANGEN aims to provide electrical power in a compact, lightweight unit that reduces fuel and maintenance costs, while reducing procurement costs

MANGEN offers the following capabilities and benefits:

- High power density (< 34 lb for 750 W)
- Multi-fuel
- Efficient across load profiles
- Rapid start-up in cold conditions
- Load following (i.e., no wet stacking)
- Potential to apply the same technology to larger generators:
    - 2 kW multi-fuel generator at less than 50 lb
    - 3 kW multi-fuel electric start generator at less than 200 lb

The MANGEN was demonstrated by the Sustainability Logistics Basing-Science and Technology – Demonstration (SLB-STO-D) at the Base Camp Integration Laboratory (BCIL) in September–October 2014 and again in July 2015. The system is currently at Technology Readiness Level (TRL) 7 and is anticipated to transition to Project Manager-Expeditionary Energy & Sustainment Systems (PM E2S2) as part of a Technology Transition Agreement (TTA).

Technical Point of Contact (POC): Ed Nawrocki, Communications Electronics Research, Development and Engineering Center (CERDEC), edmund.a.nawrocki2.civ@mail.civ, 443-395-4799.

C.2 18K ENERGY EFFICIENT ENVIRONMENTAL CONTROL UNIT (EEECU)

The 18k EEECU (**Figure C-2**) is a commercially available environmental control unit (ECU) that provides heating and cooling capabilities with an energy efficiency ratio of 20% higher than the current ECUs available in the market. The system is equipped with on-board diagnostics, inrush current limiting (i.e., soft-start), fresh-air input through an air fan system, and a two-speed evaporator blower that creates a more comfortable heated environment by reducing the effect of evaporative cooling.

Figure C-2. 18k EEECU

Photo Credit: HDT Global [80]

18k EEECU offers the following capabilities and benefits:

- 18,000 BTU/h cooling capacity
- 13,660 BTU/h heating capacity
- Energy efficiency ratio 20% higher than the current ECUs on the market
- Light weight, low noise, and low power consumption

The 18k EEECU is a commercially available, International Traffic in Arms Regulations (ITAR) restricted item.

C.3 22K HEAT PUMP

Figure C-3. 22k Heat Pump

Adapted from *Ductless Split Systems* [81]

The 22k heat pump (**Figure C-3**) is a commercial-off-the-shelf ductless heat pump system. The system consists of a wall-mounted indoor unit and a compressor unit located outside the shelter.

The 22k heat pump offers the following capabilities and benefits:

- 21,400 BTU/h cooling capacity
- 23,200 BTU/h heating capacity
- Up to 15.5 Seasonal Energy Efficiency Ratio cooling efficiency
- Up to 9 Heating Seasonal Performance Factor heating efficiency
- Variable-speed digital inverter compressor
- Turbo mode setting for fast temperature adjustment
- Noise level as low as 26 decibels
- Dehumidify mode
- Available in various heating and cooling capacities

The 22k heat pump is commercially available.

C.4 42K ENVIRONMENTAL CONTROL UNIT (42K ECU)

Figure C-4. 42k ECU

The 42k ECU (**Figure C-4**) is a commercially available ECU that provides heating, cooling and dehumidification for expeditionary shelters, rigid wall shelters, vans, ISO containers, etc. The 42k ECU uses variable speed compressor technology to reduce the amount of power consumed.

The 42k ECU offers the following capabilities and benefits:

- 42,000 BTU/h cooling capacity
- Increased energy efficiency by using variable speed motors that adjust to environmental conditions and comfort setting.
- Lower maintenance and replacement costs
- Built-in compartments to house insulated flexible ducts, electrical power cable, and remote control
- Transport or storage covers for all openings for supply and return air
- Lifting and tie-down provisions
- Skid mounted with fork-lift pockets for ease of movement and set-up
- Bolted frame for ease of repair (all frame members are available as spare parts)
- Built-in electrical phase monitor
- Duct connection for Nuclear Biological Chemical filtration equipment

The 42k ECU was included as part of the Natick Soldier Research, Development and Engineering Center's (NSRDEC's) Energy Efficiency Optimization of Combat Output/Patrol Base Shelters to Reduce Fuel Consumption project. The system was demonstrated by the SLB-STO-D at the BCIL in July 2015 and is currently at TRL 5.

Technical POC: Robin Szczuka, NSRDEC, robin.szczuka.civ@mail.mil, 508-233-4519.

C.5 60K INNOVATIVE COOLING EQUIPMENT (ICE) ENVIRONMENTAL CONTROL UNIT (ECU)

The ICE (**Figure C-5**) ECU is a prototype ECU that provides heating, cooling, and dehumidification for expeditionary shelters, rigid wall shelters, vans, ISO containers, etc. The system aims to increase energy efficiency through state-of-the-art advancements in HVAC technology.

Figure C-5. 60k ICE ECU

The ICE ECU offers the following capabilities and benefits:

- 60,000 BTU/h cooling capacity
- 34,140 BTU/h (10 kW) heating capacity

The ICE ECU was demonstrated by the SLB-STO-D at the BCIL in July 2015.

Technical POC: Bill Campbell, CERDEC, william.e.campbell@us.army.mil, 703-704-3941.

C.6 60K IMPROVED ENVIRONMENTAL CONTROL UNIT (IECU)

The 60k IECU (**Figure C-6**) is a fielded ECU that provides environment control for soft-wall and rigid-wall shelters. The system utilizes a scroll compressor technology and microchannel coils that provides better weight reduction compared to previously developed ECUs. Additionally, a reduction in inrush current reduces the required generator size.

Figure C-6. 60k IECU

Photo Credit: Claire Heininger (PEO C3T) [82]

The 60k IECU offers the following capabilities and benefits:

- 62,000 BTU/h cooling capacity
- 30,000 BTU/h heating capacity
- Requires only a 14 kW generator
- Environmentally friendly refrigerant
- Provides environmental control against extreme weather

The 60k IECU is a currently-fielded system (NSN 4120-01-543-0741).

C.7 ACCELERATED VAPOR RECOMPRESSION WATER PURIFIER

The Accelerated Vapor Recompression Water Purifier (**Figure C-7**) is a prototype adaptation of a commercially-available mobile water desalination system. The system uses advanced distillation technologies to provide potable/drinking water from any water source over the full range of military temperature extremes.

The aim of the Accelerated Vapor Recompression Water Purifier is to provide an alternative to traditional reverse osmosis systems that supply water to base camps. Additionally, the system aims to be simple enough to be operated by unskilled MOSs.

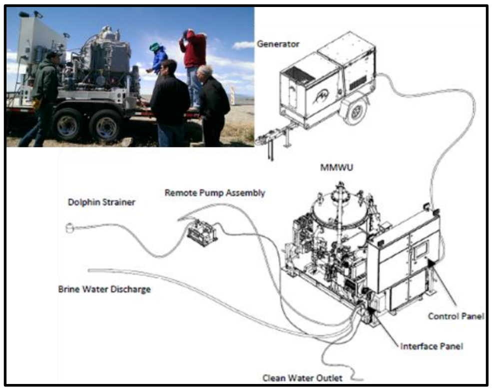

Figure C-7. Accelerated Vapor Recompression Water Purifier

The Accelerated Vapor Recompression Water Purifier offers the following capabilities and benefits:

- Designed for mobility/transportation
- Excess heat may be advantageous in cold weather
- Lower consumables operating costs
- Less sensitive to biological fouling because it uses no filters
- Requires less maintenance
- May be more effective at contaminant removal
- May require less verification testing by operator

Technical POC: Lisa Neuendorff, Tank and Automative Research, Development and Engineering Center (TARDEC), lisa.neuendorff@us.army.mil, 586-282-4161.

C.8 ADVANCED ENERGY EFFICIENT SHELTER SYSTEMS (AEESS)

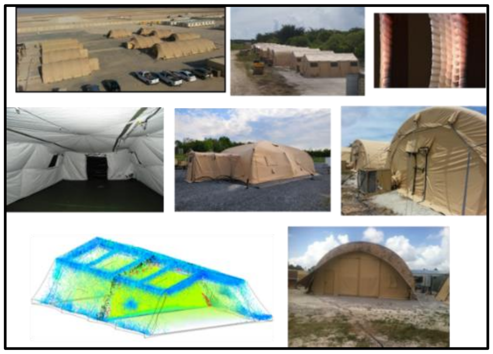

Figure C-8. Advanced Energy Efficient Shelter Systems

The AEESS (**Figure C-8**) program is a Joint Service, multi-organizational effort focused on optimized fuel consumption of shelters and a reduction in manpower requirements.

The AEESS aims to evaluate complete, state-of-the-art shelter systems in operational environments. Through the implementation of mature Department of Defense (DoD) and industry-developed technologies, AEESS hopes to advance the state-of-the-art to reduce logistics and cost impact and further reduce fuel consumption on the battlefield.

AEESS offers the following benefits:

- Optimized shelter systems that are validated in an operationally relevant environment
- Energy efficient shelter systems that reduce fuel consumption on the battlefield and manpower requirements for the Warfighter
- Significant reductions in shelter system power consumption

The AEESS program encompasses several technologies with varying TRLs and potential transition paths to Programs of Record (PORs).

Technical POC: Clinton McAdams, NSRDEC, clinton.b.mcadams.civ@mail.mil, 508-233-6933.

C.9 ADVANCED NANOGRID POWER MANAGEMENT


Figure C-9. Advanced Nanogrid Power Management (shown with a light set)

Advanced Nanogrid Power Management (**Figure C-9**) is an electrical power distribution and management system that automatically balances the loads between phases at the load end instead of the power generation end. The system eliminates the need for power wasting load banks to balance the phases. It is intended to be used in hard-wall shelters or similar structures or any application requiring electrical phase balancing capabilities.

Advanced Nanogrid Power Management offers the following capabilities and benefits:

- Reduces the need for load banks
- Eliminates the maintenance required to manage a large equipment database
- Eliminates the need to prioritize electrical loads and/or modify electrical equipment
- Makes allowances for the use of commercial items

Advanced Nanogrid Power Management was demonstrated by SLB-STO-D at the BCIL in July 2015 and is currently at TRL 6.

Technical POC: Melvin Jee, NSRDEC, melvin.w.jee.civ@mail.mil, 508-233-5245.

C.10 BIO-BASED HYBRID MATERIALS FOR COMBAT RATION PACKAGING

Bio-Based Hybrid Materials for Combat Ration Packaging (**Figure C-10**) is a project to develop bio-based ration packaging items for the Warfighter that reduces dependence on foreign oil, reduces carbon footprint, and increases the bio-based content in ration packaging. The project aims to develop bio-based products that include the Unitized Group Ration – Express (UGR-E) trays, utensils, trash bags, Meals, Ready to Eat (MRE) accessory packets, beverage bags, and meal bags.

Figure C-10. Bio-Based Hybrid Materials for Combat Ration Packaging

Bio-Based Hybrid Materials for Combat Ration Packaging offers the following capabilities and benefits:

- Soy flour-based film
- Domestic-grown soybeans for use in hybrid packaging
- More cost effective than conventional polymer based items

Technical POC: Jo Ann Ratto Ross, joann.r.ross.civ@mail.mil, NSRDEC, 508-233-5315.

C.11 BURN-OUT LATRINE

The burn-out latrine (**Figure C-11**) is a field expedient construct to provide toilet facilities to military personnel living in austere conditions. It is typically made of plywood and wood and is compartmented into privacy stalls. A 55-gal drum is cut in half and handles are welded to the sides of the modified drum for ease of mobility. A wooden seat with a stable, retractable lid is integrated on top of the drum.

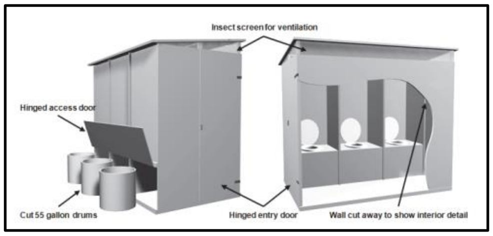

Figure C-11. Burn-Out Latrine

Reprinted from ATP 4-25.12, *Unit Field Sanitation Teams* [54]

The burn-out latrine is particularly well suited for use in jungle areas with less-than-ideal soil conditions, such as those with high water tables, but can also be used when the ground is hard or rocky and digging is difficult or impossible. The use of JP-8 fuel is effective for incinerating the waste in barrels, but needs to be used with caution. The latrine must be burned out every 18 to 24 h or when the latrine is half full. This procedure is repeated until only residue of ash remains.

Burn-out latrines are an existing, field-expedient method for disposal of latrine waste. Reference ATP 4-25.12, *Unit Field Sanitation Teams* for additional information [54].

C.12 CHEMICAL LATRINE

Figure C-12. Chemical Latrines

Reprinted from ATP 4-25.12, *Unit Field Sanitation Teams* [54]

Chemical latrines (**Figure C-12**) are portable, standalone latrine systems that allow mobility throughout the camp and do not require any pre-existing services to be provided on-site. A chemical latrine generally collects liquid and solid waste in a holding tank that uses chemical elements to minimize the waste odor output. They are generally the preferred method of human waste disposal during field training exercises or during contingency operations.

Logistics personnel can generally coordinate the acquisition of chemical latrines. It is essential to provide maintenance for the chemical latrines and ensure daily accumulated waste are pumped out for disposal in an Army-approved wastewater system. During contingency operations, engineer personnel may generate a sewage lagoon for disposal of chemical latrine waste.

Chemical latrines are a currently-used method for disposal of latrine waste. Reference ATP 4-25.12, *Unit Field Sanitation Teams* for additional information [54].

C.13 CONTAINERIZED ICE MAKING SYSTEM (CIMS)

The CIMS (**Figure C-13**) is an ice making plant housed in a TRICON designed for field feeding and medical military applications, as well as humanitarian aid and disaster relief efforts. The CIMS aims to increase the ice production rate compared to existing systems and provide increased mobility and transportability.

Figure C-13. CIMS

Photo Credit: HDT Global [83]

By enabling the production of ice onsite, the CIMS reduces or eliminates the need for contracted ice and reduces the risks to delivery vehicles in convoys in hostile environments.

CIMS offers the following capabilities and benefits:

- Generates 1,800 lb of ice per day at 130 °F ambient temperature
- Fully automated system makes ice, bags the ice, seals the bags, stores the bags internally, and stops when full
- Stores 30–60 10 lb bags of ice
- Transportable by 5-ton and larger trucks, ship, rail, and aircraft (both fixed and rotary wing)
- Moveable with standard material handling equipment
- Supports Army Force Provider, Air Force Basic Expeditionary Airfield Resources (BEAR), field feeding, and medical elements for all services, humanitarian aid, and disaster relief efforts

Program Manager Force Sustainment Systems (PM FSS) has conducted market research on the potential of producing potable ice at the point of consumption [77].

The CIMS is commercially available.

C.14 CONTAINERIZED ICE MAKING TECHNOLOGIES (CIMT)

The CIMT (**Figure C-14**) project aims to develop an advanced technology for a containerized ice machine that will have greater capability and use less fuel than the currently deployed systems and near-term solutions.

By enabling the production of ice onsite, the CIMT system reduces or eliminates the need for contracted ice and reduces the risks to delivery vehicles in convoys in hostile environments.

CIMT offers the following capabilities and benefits:

- Less fuel consumption than legacy systems and field expedient solutions
- Suitability to hot/dusty/outdoor environments
- Greater ice production rate
- Mobility/transportability
- Modularity
- Compatibility with alternative sources of energy and smart grids

Figure C-14. CIMT

The CIMT prototype was demonstrated by the SLB-STO-D at the BCIL in May–June 2016 and is currently at TRL 5.

Technical POC: Alexander Schmidt, NSRDEC, alexander.j.schmidt4.civ@mail.mil, 508-233-4244.

C.15 DEPLOYABLE AEROBIC AQUEOUS BIOREACTOR (DAAB)

Figure C-15. DAAB

Photo Credit: ERDC [84]

The DAAB (**Figure C-15**) is a deployable, expandable, low energy, and low maintenance waste water treatment platform. The basic DAAB consists of two units: a Biological Treatment Unit and a Control and Power Unit (CPU).

The system aims to reduce the complexity and logistics for treating wastewater in the field and to produce water for direct non-potable reuse or to be fed into a reverse osmosis unit for potable reuse.

The DAAB offers the following capabilities and benefits:

- Capable of treating 25,000 or more gal per day of raw municipal wastewater (expandable to >80,000 gal per day with three added Biological Treatment Units)
- High quality effluent within 48 h of delivery
- Ships and operates within two 20-ft ISO containers
- Semi-autonomous, potential for remote monitoring, dependable robust treatment of wastewater
- Can use grid power or onboard 30 kW generator
- Simplified setup and operations and maintenance for waste water treatment

The DAAB is currently at TRL 6.

Technical POC: Scott Waisner, Engineer Research and Development Center (ERDC), scott.a.waisner@usace.army.mil, 601-634-2286.

C.16 DEPLOYABLE METERING AND MONITORING SYSTEM (DMMS)

The DMMS is a multi-component electronic system for monitoring, data acquisition, analysis, and information dissemination of base camp sustainment/logistics elements (e.g., energy, fuel, water, waste).

DMMS provides a DoD Information Assurance Certification and Accreditation Process (DIACAP) approved wireless metering solution (**Figure C-16**) that consists of a suite of electrical meters and sensors to monitor base camp functional elements. These include inline advanced electrical meters and sensors for monitoring supply and demand side power and sensors to monitor fuel and temperature status.

Figure C-16. DMMS interfacing with a generator set (top) and DMMS wireless metering solution (bottom)

DMMS offers the following capabilities and benefits:

- Meters and sensors are enclosed in portable transit cases to facilitate rapid deployment and set-up (i.e., “Plug and Play”).
- Connects to open architecture dashboard.
- Interfaces with Contingency Base-Energy Management System (CB-EMS) — a computerized dashboard for data acquisition and analysis of base camps sustainment/logistics elements. CB-EMS provides a dashboard to facilitate informed decision making and enables data analysis that provides a means for data collection and visualization
- CB-EMS interfaces with Army’s Wide Area Visualization Environment (WAVE) toolset — a computerized visualization tool that integrates data from multiple systems for monitoring, management, and planning of operational energy use

DMMS was demonstrated by SLB-STO-D at the Contingency Basing Integration Technology Evaluation Center (CBITEC) in April 2015 and is currently at TRL 5.

Technical POC: Tom Decker, ERDC, charles.t.decker.civ@mail.mil, 217-373-3361.

C.17 DESERT ENVIRONMENT SUSTAINABLE EFFICIENT REFRIGERATION TECHNOLOGY (DESERT) HIGH EFFICIENCY MULTI-TEMPERATURE REFRIGERATED CONTAINER SYSTEM (HE-MTRCS)

The DESERT HE-MTRCS (**Figure C-17**) is an augmentation to the currently-fielded MTRCS with a High-Efficiency Refrigeration Unit (HERU). The HERU is intended as a plug-and-play replacement to the cooling systems in existing Army 20-ft cold-storage containers; the MTRCS is only one demonstration platform.

Figure C-17. DESERT HE-MTRCS

Compared to legacy systems, the system aims to be twice as efficient, twice as effective, and operational in extremely hot environments. Fuel savings are achieved due to the higher efficiency, while additional savings are possible via the ability to interface with renewable energy sources such as solar photovoltaics. It includes an on-board generator set for backup power or for operation while mobile.

The DESERT HE-MTRCS offers the following capabilities and benefits:

- Reduced energy requirement as compared to legacy system
- Max power draw of 8 kW under demanding conditions
- No power surges, so it will require a smaller generator than existing systems
- Greater reliability — doubled mean-time between failures from 500 to 1000 h
- High temperature capability to 135 °F ambient
- Lower procurement, production, and replacement costs
- Meets or exceeds all existing operational requirements
- Computerized diagnostics to ease maintenance requirements

The DESERT HE-MTRCS was demonstrated by SLB-STO-D at CBITEC in April 2015 and is approaching TRL 6. The system has a TTA with PM FSS and is currently undergoing exit criteria testing for a potential transition.

Technical POC: Alexander Schmidt, NSRDEC alexander.j.schmidt4.civ@mail.mil, 508-233-4244.

C.18 DESERT POWER 2 (DP2) SOLAR ARRAY

Figure C-18. DP2 Solar Array

The DP2 Solar Array (**Figure C-18**) is a standard Solar Shade System Type I shade shelter modified by the inclusion of 2 kW of flexible solar panels. The solar shade is designed to provide general purpose solar protection and is constructed from lightweight, open weave material designed to reduce solar effects by a minimum of 60%. The addition of flexible solar panels provides a power generation capability at no additional footprint.

The DP2 Solar Array offers the following capabilities and benefits:

- Reduced solar effects by a minimum of 60%
- Provide 2 kW power generation capability with no additional footprint requirement

The DP2 Solar Array was demonstrated by SLB-STO-D at CBITEC in April 2015.

Technical POC: Alexander Schmidt, NSRDEC alexander.j.schmidt4.civ@mail.mil, 508-233-4244.

C.19 ENERGY EFFICIENCY (E2) OPTIMIZATION OF COMBAT OUTPOST/PATROL BASE (COP/PB) SHELTERS TO REDUCE FUEL CONSUMPTION

E2 Optimization of COP/PB Shelters to Reduce Fuel Consumption intends to reduce fuel consumption in COP/PB shelters through demand control management, battery storage, improved electrical component design, and energy efficient shelter improvements. The program aims to reduce fuel and energy consumption, minimize generator run-time and logistical burden, and improve quality of life.

The E2 program offers the following capabilities and benefits:

- Improved AS TEMPER V1.5 shelter (**Figure C-19**) with energy efficient components including thermal insulation, radiant barrier, solar shade, redesigned vestibule, passive ventilation, and LED lighting.
- Energy-efficient 42k BTU, 3.5-ton variable speed ECUs with heating, cooling and dehumidification (**Figure C-20**).
- Microgrid Storage and Distribution Unit (MSDU) battery storage and distribution system and 60 kW “Smart Generator” with 2 kW solar panels (5 kW maximum capability) and auto start/stop capability (**Figure C-21**)
- Power monitoring software capability

The E2 systems were developed under the Rapid Innovation Fund Broad Agency Announcement. They were demonstrated by the SLB-STO-D at the BCIL in July 2015. The E2 Optimization of COP/PB Shelters to Reduce Fuel Consumption program encompasses several technologies with varying TRLs.

Technical POC: Robin Szczuka, NSRDEC, robin.szczuka.civ@mail.mil, 508-233-4519.

Figure C-19. Prototype Shelter System with V1.5 Liner

Figure C-20. 42K ECU

Figure C-21. Generator, MSDU, and Solar Array (left to right)

C.20 ENERGY EFFICIENT RIGID WALL MODULE (E2RWM) BILLETING SHELTER

The E2RWM Billeting Shelter (**Figure C-22**) is an ISO compatible 8 ft by 8 ft by 20 ft expandable shelter which expands to provide 340 sq ft of billeting space for up to 10 soldiers. The shelter is constructed of a steel ISO frame with structurally insulated composite fold out panels that make up the expandable walls and roof. The shelter weighs 8,500 lb fully packed out and has integrated forklift pockets capable of being off loaded. The expandable containerized shelter is capable of being set up by four personnel in 30 min or less once positioned on the ground.

Figure C-22. E2RWM Billeting Shelter

Photo Credit: David Kamm, NSRDEC [85]

The E2RWM Billeting Shelter offers the following capabilities and benefits:

- Mobility/transportability
- Low maintenance
- Easy to set up in a short period of time
- Standard military 60-amp power cable connection
- Onboard HVAC system can maintain between 60 °F and 85 °F interior temperature in ambient temperatures of -25 °F–125 °F
- Integrated smoke and carbon monoxide detector

The E2RWM shelters were demonstrated by PM FSS at the BCIL.

The E2RWM Billeting Shelter is a commercially available item.

C.21 ENERGY EFFICIENT RIGID WALL MODULE (E2RWM) HYGIENE COMPLEX

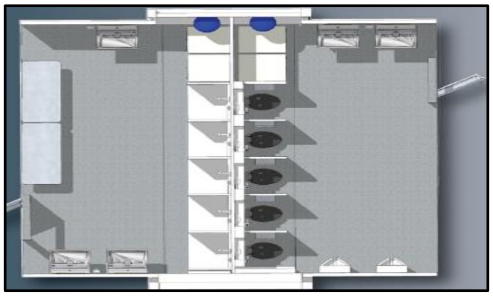

Figure C-23. E2RWM Hygiene Complex

Photo Credit: Berg Premier Camp Solutions [86]

The E2RWM Hygiene Complex (**Figure C-23**) is an ISO compatible 8 ft by 8 ft by 20 ft expandable shelter which expands to provide 340 sq ft of hygiene space. The shelter is constructed of a steel ISO frame with structurally insulated composite fold out panels that make up the expandable walls and roof. The shelter weighs 8,500 lb fully packed out and has integrated forklift pockets capable of being off loaded. The expandable containerized shelter is capable of being set up by four personnel in 30 min or less once positioned on the ground.

The E2RWM Hygiene Complex offers the following capabilities and benefits:

- Mobility/transportability
- Low maintenance
- Easy to set up in a short period of time
- Integrated smoke and carbon monoxide detector
- Contains the following:
    - Four washer/dryer units
    - Five toilets
    - Five shower stalls
    - Two urinals
    - Four sinks
    - Wall mount exhaust fans

The E2RWM shelters were demonstrated by PM FSS at the BCIL.

The E2RWM Hygiene complex is a commercially available item.

C.22 ENERGY EFFICIENT RIGID WALL MODULE WITH ENERGY STORAGE (E2RWM - E3)

The E2RWM – E3 (**Figure C-24**) is an ISO compatible 8 ft by 8 ft by 20 ft expandable shelter which expands to provide 340 sq ft of space. The shelter is constructed of a steel ISO frame with structurally insulated composite fold out panels that make up the expandable walls and roof. The shelter has integrated forklift pockets capable of being off loaded.

Figure C-24. E2RWM - E3

Photo Credit: U.S. Army Acquisition Support Center [87]

The E2RWM – E3 combines a rigid wall shelter with an integrated solar array and energy storage. The solar array is mounted to the roof of the shelter.

The E2RWM – E3 offers the following capabilities and benefits:

- Mobility/transportability
- Low maintenance
- Easy to set up in a short period of time
- Integrated smoke and carbon monoxide detector
- Integrated solar power generator and energy storage with no additional footprint requirement

The E2RWM shelters were demonstrated by PM FSS at the BCIL.

C.23 ENERGY INFORMED OPERATIONS (EIO) MICROGRID

EIO aims to develop, implement, and support an intelligent power system interface standard and associated applications which allow optimization of power and energy resources based on mission requirements. EIO can integrate laptop computers (**Figure C-25**), Tactical Quiet Generators (TQGs) (**Figure C-26**), batteries, Intelligent Power Distribution (IPD) systems (**Figure C-27**), and Power Distribution and Illumination Systems, Electrical (PDISEs) to optimize base camp power resources to ultimately save fuel and reduce maintenance costs.

Figure C-25. Laptop to monitor power and status of the microgrid

EIO offers the following capabilities and benefits:

- Open standards for centrally controlled intelligent power system interfaces
- Applications for awareness and control of power resources
- Improved efficiency in operational energy to reduce cost and logistics burden of fuel resupply
- Ability to prioritize and utilize power resources according to mission needs, thus enabling commanders with information and flexibility to complete the mission in a resource constrained environment
- More reliable and resilient energy network to ensure the availability of power across the battlespace

Figure C-26. TQGs

EIO was demonstrated by SLB-STO-D at CBITEC in April 2015 and at the BCIL in June–July 2015 and May–June 2016. EIO is currently at TRL 6.

Figure C-27. IPD

Technical POC: Michael Gonzalez, CERDEC, michael.l.gonzalez.civ@mail.mil, 443-395-4381.

C.24 ENERGY STORAGE SYSTEM

Figure C-28. Energy Storage System

An energy storage system (**Figure C-28**) is a ready-built system that incorporates batteries, inverters, and control hardware into a fully contained package that can sink, store, and supply electrical energy. Several systems are commercially available in various configurations. Many are packaged in ISO containers for ease of transport.

When paired with a microgrid, the energy storage system enables peak shaving and load leveling, which reduce the fuel consumed by the generators. Additionally, the system can be used to store power from renewable energy sources and can also sink power from large energy producers.

An energy storage system offers the following capabilities and benefits:

- Diesel, solar, and wind capability ready
- Seamless bidirectional storage
- Easy installation on any site
- Integration with microgrids to enable peak shaving and load leveling
- Integration into hybrid energy systems to reduce generator run time
- 246 Amp-hour capacity (as demonstrated by SLB-STO-D, system configurations vary)

An energy storage system was demonstrated as part the EIO microgrid by SLB-STO-D at the BCIL in May–June 2016.

Technical POC: Michael Gonzalez, CERDEC, michael.l.gonzalez.civ@mail.mil, 443-395-4381.

C.25 EXPEDITIONARY BLACK WASTE TREATMENT TECHNOLOGIES (EBWT)

EBWT (**Figure C-29**) provides a low maintenance, power, and water demand black waste treatment system for expeditionary combat outposts that improves hygiene and habitability and lowers logistical burden through reductions in water, fuel, and backhaul of waste.

The system aims to reduce maintenance and transportation of waste as well as achieve fuel and water savings. Additionally, the EBWT will improve habitability, hygiene, and soldier health.

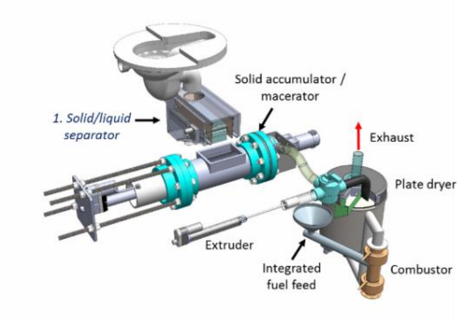

Figure C-29. EBWT

EBWT offers the following capabilities and benefits:

- Solid waste incineration
- Can be integrated into current latrine equipment
- Black waste reduction system capable of separating, drying, and burning waste, while efficiently using energy recapture.

Technical POC: Chris Aall, NSRDEC, christian.d.aall.civ@mail.mil, 508-233-5188.

C.26 EXPEDITIONARY WASTE MITIGATION BOX (XW-BOX)

Figure C-30. Xw-Box

The Xw-Box (**Figure C-30**) is a system for onsite disposal of the solid waste and latrine waste generated by a small contingency base (150 PAX). The system gasifies mixed solid waste and uses the resulting combustible gas to power a black water incinerator.

The Xw-Box aims to reduce the logistics related to backhauling solid and latrine waste with a reduction in fuel compared to incinerators and burn pits.

The Xw-Box offers the following capabilities and benefits:

- Gasification technology based on Tactical Garbage to Energy Refinery (TGER) 2.0 system demonstrated at Aberdeen Proving Ground in 2013
- Packaged in three TRICONs that include:
  - Solid waste preparation (sizing, drying)
  - Gas generation (gasification, cleanup)
  - Incineration latrine with hand washing station
- Reduces combustible solid waste by 90%
- Latrine provides 50% of capacity needed for a 150 PAX basecamp

The Xw-Box was developed under the 2013 Rapid Innovation Fund Broad Agency Announcement. The system is currently at TRL 5 and has a TTA with PM FSS for a potential transition.

Technical POC: Leigh Knowlton, NSRDEC, leigh.a.knowlton.civ@mail.mil, 508-233-5138.

C.27 FORWARD OSMOSIS/REVERSE OSMOSIS (FORO) GRAYWATER RECYCLING SYSTEM

The FORO (**Figure C-31**) is a gray water recycling system that can be integrated with water purification systems, shower and laundry facilities, and field feeding and medical systems. The system provides an improved capability that can adapt to widely varying load conditions to treat more influent streams with less fouling and increased recovery of treated water.

The FORO allows contingency bases to reduce non-potable water resupply needs and reduces transportation assets required to haul waste water and provide potable water currently used for non-potable uses as well as reduce the water logisitcal footprint.

The FORO offers the following capabilities and benefits:

- TRICON-based system
- Minimal manpower requirements with automatic control and operation
- Reduction in transportation assets required to haul wastewater and provide potable water currently used for non-potable uses
- Reduction in the water logistical footprint
- Reduction in health risks from waste water-associated vectors

Figure C-31. FORO: front (top) and back (bottom)

The FORO was demonstrated by the SLB-STO-D at the BCIL in May–June 2016. The system is currently at TRL 6 and has a TTA with PM Petroleum and Water Systems (PAWS) for a potential transition.

Technical POC: Lateefah Brooks, TARDEC, lateefah.c.brooks.civ@mail.mil, 586-282-6587.

C.28 FUEL AND WATER BLADDERS

Fuel and water bladders are generic terms that refer to collapsible fabric tanks that allow for bulk storage of fuel and water. The bladders come in a various sizes and configurations, including onion tanks for water storage and pillow tanks for water or fuel storage.

A fuel bladder (**Figure C-32**) provides storage for a variety of petroleum liquids and generally is equipped with a spill containment system to ensure personnel safety and prevent environmental damage. The tanks are constructed of tough elastomeric-coated nylon fabric.

Figure C-32. Fuel Bladder

Photo Credit: Dave Carrier, AMSAA [87]

Water bladders (**Figure C-33**) provide potable water storage containers when quick storage facilities are needed where permanent potable water storage facilities are not available or when the storage of potable water is needed only on a temporary basis.

Figure C-33. Water Bladder

The bladders offer the following capabilities and benefits:

- Highly mobile
- Easily transportable
- Quick setup/tear down
- Available in various sizes and configurations

Fuel and water bladders are fielded items that come in a variety of configurations. Common configurations include the 1,000-gal collapsible, fabric fuel tank (NSN 5430-01-621-3870) and the 3,000-gal collapsible, self-supporting, sealed top water storage tank (NSN 5430-01-469-8744).

C.29 FUEL FIRED EXPEDITIONARY TRICON KITCHEN (FF-ETK)

Figure C-34. FF-ETK

The FF-ETK (**Figure C-34**) is an augmented ETK with new energy efficient fuel-fired kitchen appliances. The system aims to save fuel by using fuel-fired appliances compared to electric appliances.

The FF-ETK offers the following capabilities and benefits:

- Reduces energy consumption used for cooking
- Electrical power required for each cooking appliance will typically be 60 W or less; therefore, the total electrical input for cooking will be reduced to less than 1.0 kW—a reduction of over 95% as compared to electrical appliances.
- Leverages the Army’s modular appliance initiative for maneuver field kitchens

The FF-ETK was demonstrated by the SLB-STO-D at the BCIL in July 2015. The system is currently at TRL 6 and has a TTA with PM FSS for a potential transition.

Technical POC: Joseph Quigley, NSRDEC, joseph.j.quigley6.civ@mail.mil, 508-233-5860.

C.30 GRAY WATER TREATMENT AND REUSE SYSTEM (G-WTRS)

G-WTRS (**Figure C-35**) is an integrated, robust, and operationally-efficient water reuse system that can reduce water demand at contingency operating bases. The system uses robust biofiltration pre-treatment systems that can tolerate intermittent flows and produce water for low-tier reuse applications (e.g., toilet flushing and equipment washing) or further treatment for high-tier reuse (e.g., showers and laundry).

Figure C-35. G-WTRS

Photo Credit: National Defense Center for Energy and Environment [88]

The G-WTRS allows contingency bases to reduce non-potable water resupply needs and reduces transportation assets required to haul waste water and provide potable water currently used for non-potable uses as well as reduce the water logisitcal footprint.

G-WTRS offers the following capabilities and benefits:

- Scalable, high-flux reverse-osmosis (RO) membrane systems that operate at low pressure to efficiently purify gray water for high-tier reuse applications.
- Designed for 600–1000 personnel base camps and can be easily extended to other Army water treatment applications
- Detection and quantitation of lead and perchlorates

The G-WTRS was demonstrated by ERDC at CBITEC in June 2016 and is currently at TRL 5.

Technical POC: Martin Page, ERDC, martin.a.page@usace.army.mil, 217-373-4541.

C.31 HANDHELD TOXIN AND PATHOGEN DETECTOR

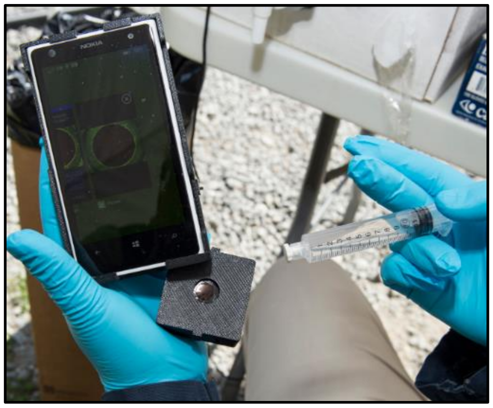

Figure C-36. Handheld Toxin and Pathogen Detector

The Handheld Toxin and Pathogen Detector (**Figure C-36**) is a system that provides water quality monitoring. The system consists of a cellphone, detection devices, and sampling titrators.

The handheld system addresses challenges regarding contaminate detection and process verification for mobile water treatment and supply systems. This enables the safe use of water treatment, recycling, and purification systems, thus reducing resupply and backhaul needs of a base camp.

The Handheld Toxin and Pathogen Detector offers the following capabilities and benefits:

- Sampling and rapid handheld detection for high risk contaminants
- Improved water quality monitoring
- Ease of use for non-MOS soldiers
- Protects soldier health through improved process monitoring
- Solves a capability gap for long-term tactical water purification, which currently requires skilled manpower due to equipment complexity

The Handheld Toxin and Pathogen Detector was demonstrated by the SLB-STO-D at the BCIL in May–June 2016 and is currently at TRL 5.

Technical POC: Lisa Neuendorff, TARDEC, lisa.k.neuendorff.civ@mail.mil, 586-282-4161.

C.32 HYBRID POWER TRAILER (HPT)

Figure C-37. HPT

The HPT (**Figure C-37**) is an electrical power generation system that couples a standard Army 15 kW TQG with an 80-kWh lithium ion battery mounted on a trailer. The system decreases generator run time, reduces fuel consumption, enables silent operation, and provides power redundancy for military applications.

Th**e HPT** uses an onboard battery energy storage system as the main power source to the load, and the onboard generator is run to recharge the battery as required. The system more efficiently adjusts to load fluctuations than traditional generators and reduces generator size and runtime. This reduces fuel consumption and fueling operations and extends system maintenance intervals. The HPT can also connect to renewable energy inputs and make excess energy available on demand.

The HPT offers the following capabilities and benefits:

- Reduces fuel consumption compared to island generators
- Provides 28 h of silent operation at low loads (< 2 kW)
- Enables silent operation by powering loads only with battery
- Trailer mounted
- Integrates with renewable energy sources

The HPT was demonstrated by ERDC at the ERDC Forward Operating Base Laboratory (EFOB-L) from June–November 2014 and by the SLB-STO-D at CBITEC in April 2015. The system is currently at TRL 6.

Technical POC: Tom Decker, ERDC, charles.t.decker.civ@mail.mil, 217-373-3361.

C.33 IMPROVED F100 (IF100)

Figure C-38. IF100

The IF100 ECU (**Figure C-38**) is an augmentation of the currently-fielded F100 ECU with power saving technology. Like the F100, the IF100 provides heating, cooling, and ventilation for rigid wall shelters or tents and is powered by 208VAC 3-phase power.

In heating mode, the conversion of electrical power to heat for the IF100 is identical to the legacy F100. In cooling mode, the IF100 reduces the recirculating fan and compressor speeds when demand is below 50% capacity, lowering power demand. Maximum cooling capacity and minimum compressor power are both dependent on ambient temperature and identical to the standard F100.

The IF100 offers the following capabilities and benefits:

- 60,000 BTU/h cooling capacity
- 34,140 BTU/h (10 kW) heating capacity
- One-to-one replacement for existing F100
- Variable speed fan and compressor reduce power consumption in cooling mode
- Operates in severe environments
- Operates in temperature ranging from -50 ºF to 135 ºF
- Onboard storage of two 6 ft long flexible air ducts, 15 ft long condensate drain hose and a 25 ft long power cord simplifies the F100 setup/teardown
- Onboard operator control: Off/Cool/Heat/Vent
- Low-noise level (i.e., <76dBA at 1 m)
- Lightweight (540 lb)

The IF100 is an augmentation of the currently-fielded F100 ECU (NSN 4120-01-617-1273).

C.34 JOINT INTER-SERVICE FIELD FEEDING (JIFF) BURNER

Figure C-39. JIFF burner prototype

The JIFF (**Figure C-39**) is a government owned JP-8 burner for field kitchen appliances developed through a Joint Service project. When paired with close-coupled heat exchangers such as those found in modular appliances, it will reduce fuel consumption by significantly improving heat transfer efficiency as compared to legacy burners and cooking systems. The JIFF burner will also be a low power, low cost, reliable, and universal burner that eliminates challenges associated with sole source procurements and lack of configuration control.

The JIFF burner offers the following capabilities and benefits:

- Low cost (~$1000)
- Low power (<60 W)
- Low noise (quiet operation)
- High reliability (proven pressure atomized design)
- Scalable (50–150 kBTU/h operating range for various applications)
- Government owned (cost control and full configuration control)
- Light weight and compact (~20 lb)

The JIFF burner was demonstrated in conjunction with the FF-ETK by the SLB-STO-D at the BCIL in July 2015. The system is currently at TRL 6 and is anticipated to transition to PM FSS as part of a TTA.

Technical POC: Tony Patti, NSRDEC, anthony.patti.civ@mail.mil, 508-233-6980.

C.35 LOW COST TRICON LATRINE (LCTL)

Figure C-40. LCTL

The LCTL (**Figure C-40**) is a TRICON-based latrine system with an integrated waste water incinerator. The system's incineration capability is designed to handle 150 PAX, enabling it to replace two Expeditionary TRICON Latrine Systems in a Force Provider Expeditionary module.

The system includes water saving functions such as low-flow toilets, waterless urinals, and sink-water recycling for toilet flushing. It aims to provide 100% waste remediation through black water incineration.

The LCTL offers the following capabilities and benefits:

- Mobility/transportability
- Reduced waste management/backhaul requirements
- Waste incineration capability
- Low maintenance
- Contains the following:
    - Four low-flow toilet commodes
    - Two waterless urinals
    - Five fold-out sinks

The LCTL is currently at TRL 5.

Technical POC: Chris Aall, NSRDEC, christian.d.aall.civ@mail.mil, 508-233-5188.

C.36 LOW-FLOW SHOWERHEAD

Low-flow shower heads (**Figure C-41**) are commercially-available items that typically use either aeration or laminar flow methods to reduce the amount of water dispensed by a showerhead. Typical flow rates are less than 2.5 gal/min with more efficient versions consuming even less water.

Low-flow shower heads offer the following capabilities and benefits:

- One-to-one replacement with fielded showerheads
- Overall reduction in base camp water demand
- Significant reduction in the cost and logistical burden associated with base camp resupply

Figure C-41. Baseline showerheads (top) and low-flow showerheads (bottom)

The applicability of low-flow showerheads to Army base camps was investigated as part of NSRDEC’s Exploration of Water Demand Reduction Technologies for Forward Operating Base Organizational Equipment project and demonstrated by the SLB-STO-D at the BCIL in May–June 2016.

Low-flow showerheads are a commercially available item.

Technical POC: Chris Aall, NSRDEC, christian.d.aall.civ@mail.mil, 508-233-5188.

C.37 MICROFLUIDIC SENSORS FOR IN-LINE WATER MONITORING

The Microfluidic Sensors for In-Line Water Monitoring (**Figure C-42**) system consists of a suite of sensors for in-line water monitoring applications. The system is capable of providing quality assurance information for over 30 days use of field water produced using new processing techniques. The system is also capable of enabling the performance optimization of water treatment equipment.

Microfluidic Sensors for In-Line Water Monitoring offer the following capabilities and benefits:

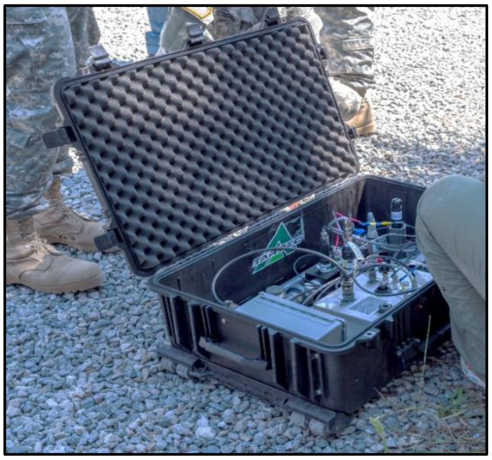

Figure C-42. Microfluidic Sensors for In-Line Water Monitoring

- Autonomous, battery powered
- Wireless and network-capable sensors compatible with most computing devices, smart phones, and media players.
- Interoperable with most water treatment and handling systems using supplied connections
- Testing raw and product water with <5% inaccuracy for each water quality parameter and <5 min total analysis time
- Non-specific MOS operator can be trained within 2 h
- Potential to save water by optimizing the performance of water treatment equipment

The Microfluidic Sensors for In-Line Water Monitoring were demonstrated by the SLB-STO-D at the BCIL in July 2015 and are currently at TRL 6.

Technical POC: Lisa Neuendorff, TARDEC, lisa.neuendorff@us.army.mil, 586-282-4161.

C.38 MINIMIZED LOGISTIC TRICON INTEGRATED LATRINE (MIL-TOILAT)

The MIL-TOILAT (**Figure C-43**) is a self-sufficient TRICON-based latrine system sized to process the human waste generated by a 50 PAX base camp. It includes a water filtration and reverse osmosis purification system that allows the use of any local water as a supply feed. The system has the capability to recycle gray water for toilet flushing and provide 100% waste remediation through black water incineration. It contains a deployable 2 kW solar cell used for charging batteries that provide power for water pumping and lighting. It also has a backup 5 kW generator that can be integrated with shore power.

Figure C-43. MIL-TOILAT

The MIL-TOILAT offers the following capabilities and benefits:

- Stand-alone operation
- Mobility/transportability
- Reduce waste management/backhaul requirements
- Waste incineration capability
- Reverse osmosis purification
- 2 kW photovoltaic array charges internal batteries
- Built-in 5 kW backup generator
- Contains the following:
    - Two low-flow toilet commodes
    - Two waterless urinals
    - Two fold-out sinks

The MIL-TOILAT is currently at TRL 6.

Technical POC: Elizabeth Swisher, NSRDEC, elizabeth.d.swisher.civ@mail.mil, 508-233-5457.

C.39 MINIMIZED LOGISTICS HABITAT UNIT (MILHUT)

Figure C-44. MILHUT

The MILHUT (**Figure C-44**) provides a military habitation system that is easily transported, rapidly set up, primarily self-sufficient in operation, and provides enhanced mission capability to deployed Warfighters. Through implementation of renewable energy technologies, the MILHUT system reduces the reliance on resupply operations, and therefore lengthens the time Warfighters can be deployed in remote locations without resupply. Furthermore, the system increases the comfort and mission readiness by providing essential capabilities in the areas of hygiene, habitation, and food preparation, which are not normally available during deployments of this nature.

The MILHUT offers the following capabilities and benefits:

- A fully integrated three TRICON MILHUT system for remote deployments, integrated with a 32-ft AS TEMPER shelter system
- Significant reduction in the cost and logistical burden associated with base camp resource resupply
- Fewer personnel and vehicles required to perform hazardous resupply of base camps, which means a greater number of soldiers available for mission essential operations

The MILHUT was demonstrated by the SLB-STO-D at CBITEC in February–March 2016 and is currently at TRL 6.

Technical POC: Chris Aall, NSRDEC, christian.d.aall.civ@mail.mil, 508-233-5188.

C.40 MOBILE BIOELECTRIC FILTRATION SYSTEM (MBFS)

The MBFS (**Figure C-45**) provides waste water treatment at contingency bases to reduce non-potable water resupply needs and waste water backhauling. It also provides an improved capability that can adapt to widely varying load conditions with rapid startup and waste-to-energy conversion for net-zero system operation.

The MBFS offers the following capabilities and benefits:

- Reduction in transportation assets required to haul wastewater and provide potable water currently used for non-potable uses
- Onsite treatment to dischargeable standards for 90% of input stream providing order of magnitude reduction in waste water
- Improved safety/force protection at base camps
- Reduction in health risks from waste water associated vectors

The MBFS was demonstrated by the SLB-STO-D at the BCIL in May–June 2016 and is currently at TRL 5.

Technical POC: Lateefah Brooks, TARDEC, lateefah.c.brooks.civ@mail.mil, 586-282-6587.

Figure C-45. MBFS

C.41 MOBILE WATER PURIFICATION SYSTEM (MWPS) WITH ADAPTIVE ARMAMENT REACTIVE INTERFACE DOMAIN (AARID) FILTER

Figure C-46. MWPS with AARID filter

The MWPS with AARID filter (**Figure C-46**) is a commercially available water filtration system outfitted with a prototype filter created from a government proprietary, visible light activated, photovoltaic material that can deactivate contaminants without the use of chemicals and is infinitely renewable without cost or human intervention.

The system aims to reduce contingency basing water logistics burden by decreasing water demand via recycling and purification with secondary contributions to reduction of fuel and power. The use of the AARID material aims to increase the life of tactical water purification system pre-filters, reduce consumables usage, and reduce costs.

AARID offers the following capabilities and benefits:

- Naturally renewable and self-cleaning using light sources such as sunlight or LEDs
- Insoluble in water and lack of toxicity, eliminating the effect of contaminating drinking water
- Provides filter robustness and enhances UV decontamination, reducing cycling time and power draw, and eliminating some pre-filter components of the system, which optimizes pre-filter life
- Reduces logistics burden, maintenance costs, and environmental impact to sustain high tempo operations with locally generated water
- Provides water generation on demand at the point of need, shortened mean time to repair, increased operational availability, and reduced need for intermediate staging bases.

AARID is currently at TRL 6.

Technical POC: Kimberly Griswold, Armament Research, Development, and Engineering Center (ARDEC), kimberly.griswold.civ@mail.mil, 973-724-4680.

C.42 MODULAR APPLIANCES FOR CONFIGURABLE KITCHENS (MACK)

The MACK is a suite of modular fuel-fired kitchen appliances (**Figure C-47**) that can be configured for use across all Army field feeding platforms. The modular appliances are designed to replace current fuel-fired appliances which are inefficient, loud, expensive, and exhaust heat and combustion products into the kitchen workspace.

Figure C-47. MACK

MACK offers the following capabilities and benefits:

- Far quieter and easier to use than current appliances and do not vent heat and exhaust into cooking area
- Standardized design concept that minimizes the number of inventoried parts and reduces the total number of national stock numbers
- Standard suite across all mobile kitchen platforms simplifies training; all kitchens use common components that can scale to outfit kitchens with different capacities
- Modular nature of components enables easy disassembly into man-portable pieces for integration into different platforms or buildings
- Reduction in fuel consumption of 50% on average across all appliance types compared to current JP-8 appliances
- Reduction in typical power requirements per appliance from approximately 90 W (modern burner unit) to 50 W (JIFF burner)

The MACK appliances were demonstrated by SLB-STO-D at CBITEC in April 2015. The MACK is currently at TRL 6 and is anticipated to transition to PM FSS as part of the Battlefield Kitchen POR.

Technical POC: Joseph Quigley, NSRDEC joseph.j.quigley6.civ@mail.mil, 508-233-5860.

C.43 NANOPARTICLE-POLYMER COMPOSITE PHOTOVOLTAIC FILMS

The Nanoparticle-Polymer Composite Photovoltaics Films (**Figure C-48**) are prototype films using nano-enhanced power/energy-harvesting technology that will provide more power/energy than traditional photovoltaic films

The films aim to improve power generation in low-light conditions, allowing for the charging of batteries at dusk, dawn, and during overcast skies. Additionally, they are intended to be lightweight, resulting in a net weight reduction by assuring confidence that fewer batteries can be carried by Soldiers on operational missions.

Figure C-48. Nanoparticle-Polymer Composite Photovoltaics Films

Nanoparticle-Polymer Composite Photovoltaics Films offer the following capabilities and benefits:

- Improved efficiency of radiative energy harvesting from the environment
- More time for power harvesting under overcast skies, dusk/dawn, etc., to charge batteries faster (i.e., more harvested energy)
- Concealment by the potential use of a matte finish

The Nanoparticle-Polymer Composite Photovoltaics Films were demonstrated by the SLB-STO-D at the BCIL in May–June 2016 are currently at TRL 4.

Technical POCs: Richard Osgood, NSRDEC, richard.m.osgood.civ@mail.mil, 508-233-5494 and Nicholas LeGrand, NSRDEC, nicholas.j.legrand.civ@mail.mil, 508-233-5246.

C.44 NONINTRUSIVE LOAD MONITORING (NILM)

NILM is a process to disaggregate appliance-level power information from a centralized sensor package located at the generator or panel. This allows for accountability of devices consuming power, condition-based management, and inference of human activity from electrical activity.

NILM offers the following capabilities and benefits:

- Centralized sensor package
- Reduced sensor count compared to load-based sensors
- Holistic view of all electrical loads
- Possible detection of signs of wear or failure from changes in electrical signals

Nonintrusive load monitoring was demonstrated at the BCIL in September 2013.

C.45 NON-WOVEN COMPOSITE INSULATION LINER

The Non-Woven Composite Liner (**Figure C-49**) was an Army Manufacturing Technology (MANTECH) project to develop an improved manufacturing process for a non-woven composite insulation liner to be used for energy conservation in expedient soft wall shelters. The non-woven composite tent liner provides improved thermal performance for soft wall shelters resulting in less fuel consumption to climate control the shelter.

The Non-Woven Composite Liner offers the following capabilities and benefits:

- Reduced fuel consumption to environmentally control soft wall shelters
- Reduction of shelters' infrared signature.
- Better maintainability of habitable temperature conditions within Army deployed shelter systems.
- Soldiers will experience a higher quality of life due to better climate control and enhanced ease of insulated shelter set-up.

Figure C-49. Top to bottom: Non-Woven Composite Liner installed in an AS TEMPER shelter, non-woven composite fibrous batting, and manufacturing quilt lines

The Non-Woven Composite Liner was demonstrated by SLB-STO-D at the BCIL in September–October 2014 and again at the BCIL in July 2015. The system is currently at TRL 9 and has been transitioned to PM FSS.

Technical POC: Elizabeth Swisher, NSRDEC, elizabeth.d.swisher.civ@mail.mil, 508.233.5457.

C.46 ONSITE AUTOMATIC CHILLER FOR INDIVIDUAL SUSTAINMENT (OACIS)

The OACIS (**Figure C-50**) is a bottled water distribution system that efficiently transports, chills, stores, and dispenses bottled water to Soldiers. It uses advanced, high-efficiency vapor compression refrigeration to cool up to 1500 bottles per day to 60 °F in 135 °F ambient temperature.

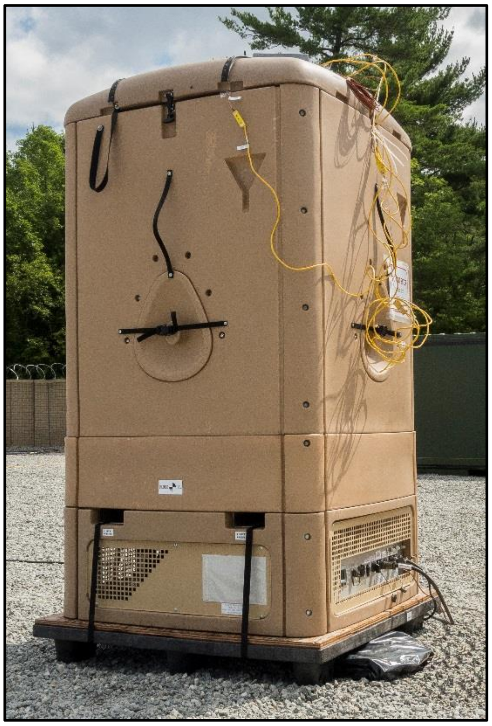

Figure C-50. OACIS

The OACIS aims to prevent heat illnesses by encouraging hydration with cool water, which is known to be more palatable and assist in cooling down core body temperature during rigorous physical exertion. Heat illnesses and dehydration can significantly degrade the physical performance of Soldiers with a concomitant deleterious effect on mission readiness.

OACIS offers the following capabilities and benefits:

- Uses significantly less energy to cool and store water, especially if solar power is available
- Warfighter hydration status, health, and morale — and therefore readiness — increases with increased availability of chilled bottled water throughout base camps
- Dispenses individual bottles of variable sizes
- Holds 500 L

The OACIS was demonstrated by SLB-STO-D at the BCIL in July 2015 and is currently at TRL 6.

Technical POC: Alexander Schmidt, NSRDEC, alexander.j.schmidt4.civ@mail.mil, 508-233-4244.

C.47 OPEN-AIR BURN PIT

An open-air burn pit is an area for the combustion of waste common in OCONUS sites such as Iraq and Afghanistan, which often use ad hoc accelerants common to the base camp such as diesel fuel or JP8. Open-air burn pits vary in size with larger instances generally burning constantly.

Current army policy on open-air burning notes that “open-air burn pits should be a short-term solution during contingency operations where no other alternative is feasible. For the longer term, incinerators, engineered landfills, or other accepted solid waste management practices shall be used whenever feasible” [71]. The reported health impacts of exposure to burn pit smoke are considerable with research continuing into the long-term impacts of exposure [72].

Open-air burn pits are an existing, field-expedient method for disposal of solid waste. Reference DoD Instruction 4715.19, *Use of Open-Air Burn Pits in Contingency Operations* for additional information [71].

Figure C-51. Open-air burn pit at Bagram Airfield

Photo Credit: Mark Rankin, U.S. Army Corp of Engineers [89]

C.48 PIPE URINAL

The Pipe Urinal (**Figure C-52**) is one of many urine disposal facilities available for Soldiers to utilize during convoys or other continuous operations that restrict the place and time permitted for urination. Pipe urinals are usually 1 inch in diameter and 36 inches long and placed at each corner of a soakage pit. A funnel of tar paper, sheet metal, or similar material is placed in the top of each pipe and covered with a screen. The upper rim of the funnel extends about 30 inches above the ground surface.

Pipe urinals are an existing, field-expedient method for disposal of latrine waste. Reference ATP 4-25.12, *Unit Field Sanitation Teams* for additional information [54].

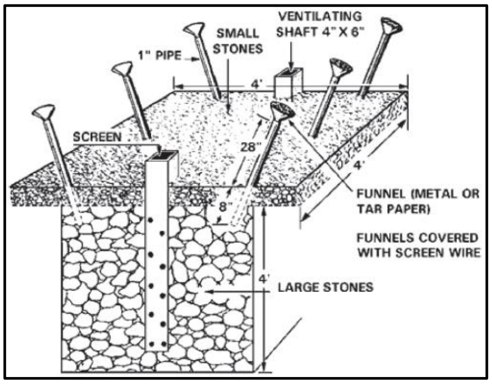

Figure C-52. Pipe Urinals

Reprinted from ATP 4-25.12, *Unit Field Sanitation Teams* [54]

C.49 POLYMER BEAD WASHING MACHINE

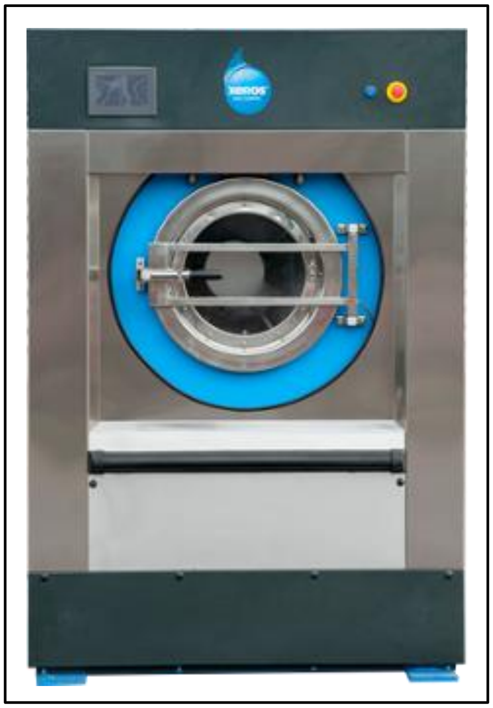

Figure C-53. Polymer Bead Washing Machine

Photo Credit: Xeros Inc. [90]

The polymer bead washing machine (**Figure C-53**) is a commercially available washing machine that uses polymer laundry beads (i.e., tiny, spheroidal plastic chips) that can absorb stains, dye, and soil, removing them away from fabrics. By replacing water with reusable polymer laundry beads, the system allows for cleaning using less water and chemicals than traditional commercial laundry systems. The beads allow lower wash temperatures and are color stain absorbent to minimize the risk of colors mixed in with the wash load.

Polymer bead washing machines offer the following capabilities and benefits:

- Improved performance by utilizing low temperature and conserving energy
- Environmentally friendly to operational environment
- Bead process minimizes the amount of water consumed in each wash cycle
- Reduces the amount of water and detergent utilized per wash.

The applicability of polymer bead washing machines to Army base camps was considered as part of NSRDEC’s Exploration of Water Demand Reduction Technologies for Forward Operating Base Organizational Equipment project.

The polymer bead washing machine is commercially available.

Technical POC: Chris Aall, NSRDEC, christian.d.aall.civ@mail.mil, 508-233-5188.

C.50 POWERSHADE (PSHADE)

The PShade (**Figure C-54**) is a fabric structure with a built-in photovoltaic array that is designed to shade and provide power to tents, rigid-wall shelters, vehicles, etc.

Figure C-54. PShade over rigid-wall shelter

Photo Credit: David Kamm, NSRDEC [85]

The congressionally funded PShade program intends to reduce cost and improve photovoltaic component parts by focusing on extending durability of the base textile materials, reducing manufacturing cost of components via optimized design and manufacturing processes, and increasing the efficiency of the balance of systems by implementation of grid tie capability/high efficiency power electronics. These combined efforts hold promise to provide a higher electrical generating capability at a lower weight and cost, offering a more attractive alternative/supplement to traditional fuel fired electrical generators.

PShade offers the following capabilities and benefits:

- Reduced initial procurement cost by 20–30% over existing system
- Increased power density by 10–20% over existing system
- Increased lifespan from a 3-year specification to 10 years
- Reduced deployment effort required for erection by reduction of weight of structural components

The PShade was demonstrated by SLB-STO-D at CBITEC in April 2015 and is currently at TRL 7.

Technical POC: Steven Tucker, NSRDEC, steven.r.tucker10.civ@mail.mil, 508-233-6962.

C.51 QUIET, MULTI-FUEL MCC ENGINE & GENERATOR (QMEG)

The QMEG (**Figure C-55**) is a multi-fuel migrating combustion chambered engine and generator combination that provides electrical power in a small soldier portable package.

Figure C-55. QMEG Prototype

The QMEG offers the following capabilities and benefits:

- Small soldier portable engine
- Multi-fuel capability (JP-8 and DF-2)
- Revolutionary migrating combustion chambered engine with high efficiency and low vibration and noise
- Capability of direct (120 VAC) power and low voltage (28 VDC) for battery charging

The QMEG is currently at TRL 4.

Technical POC: Thomas Podlesak, CERDEC, thomas.f.podlesak.civ@mail.mil, 443-395-4786.

C.52 RAPIDLY DEPLOYABLE LIGHTWEIGHT SHELTERS (RDS) FOR AUSTERE ENVIRONMENTS

The RDS for Austere Environments provides a shelter (**Figure C-56**) that is lightweight and rapidly deployable for expeditionary forces.

RDS offers the following capabilities and benefits:

- Less logistical burden associated with transporting habitation systems for soldiers deployed in austere environments
- Less fuel consumption due to greater thermal efficiency provided by insulated composite panels
- Weather hardened panels are not subject to wind-buffeting and cold cracking, allowing an extended life-span for the structure in its deployed state

Figure C-56. RDS for Austere Environments

The RDS was demonstrated by the SLB-STO-D at CBITEC in April 2015 and is currently at TRL 6.

Technical POC: Chris Aall, NSRDEC, christian.d.aall.civ@mail.mil, 508-233-5188.

C.53 RATION RECONFIGURATION AND LIGHTWEIGHT AND COMPOSTABLE FIBERBOARD

The Ration Reconfiguration and Lightweight and Compostable Fiberboard project provides a packaging for the MRE case (**Figure C-57**) and individual ration that will reduce the logistics footprint, use less material during production, and produce less waste after consumption.

Figure C-57. MRE Fiberboard Containers (top: current solid fiberboard, bottom: coated corrugated container)

Ration Reconfiguration and Lightweight and Compostable Fiberboard offers the following capabilities and benefits:

- Redesigned coated corrugated fiberboard case structure to include materials that are capable of being recycled and do not include harmful additives.
- Case design will also be considerably lighter, reducing the waste of the system
- Redesigned individual MRE meal bag packaging to include a thermoformed bag that occupies less space in the box. This will use less material for each MRE, which will reduce material used, reduce waste, and allow for the same number of rations to be packed into a smaller box.
- Improved shipping logistics from reduced fuel costs and space saved
- Reduction in solid waste generated from the MRE system

The Ration Reconfiguration and Lightweight and Compostable Fiberboard project was demonstrated by the SLB-STO-D at the BCIL in June 2016 and is currently at TRL 6.

Technical POC: Corey Hauver, NSRDEC, corey.d.hauver.civ@mail.mil, 508-233-5315.

C.54 RENEWABLE ENERGY FOR DISTRIBUTED UNDER-SUPPLIED COMMAND ENVIRONMENTS (REDUCE)

Figure C-58. REDUCE

The REDUCE (**Figure C-58**) is a renewable energy based hybrid power system mounted on a Light Tactical Flatdeck Trailer (LTT-F). The system can provide up to 4 kW of 120/240 VAC power using a combination of energy sources: solar panels, wind turbines, JP-8/diesel genset, and shore power. The REDUCE includes 2 kW of non-glass encapsulated silicon solar panels and 6–12 kWh of energy storage.

The REDUCE aims to implement smart technology and integrate renewable energy into the power grid to reduce power requirements from generators. The system will reduce fuel logistics to contingency base camps as compared to similarly sized standalone power generation systems.

The REDUCE offers the following capabilities and benefits:

- Lightweight renewable power sources
- High Mobility Multipurpose Wheeled Vehicle (HMMWV) towable
- Improved energy storage with 6–12 kWh Lead acid battery storage
- Next generation fueled power sources
- Intelligent power management and controls

The REDUCE was demonstrated by SLB-STO-D at the BCIL in September–November 2014 and is currently at TRL 5.

Technical POC: David Teicher, CERDEC, david.teicher.civ@mail.mil, 443-395-4376.

C.55 RUGGEDIZED LED LIGHTS

Ruggedized LED lights (**Figure C-59**) are a commercially available one-to-one replacement for legacy fluorescent shelter light. The lights are electromagnetic interference hardened with a light output and dispersion comparable to fluorescent lights with significantly less energy consumption.

Figure C-59. Ruggedized LED Lights

Photo Credit: Jameson, LLC [91]

LED lights offer the following capabilities and benefits:

- Light weight, requires on one man set up
- Longer life than fluorescent
- Lower power consumption
- Capable of push button dimming and black out modes
- Operational in extreme hot and cold weather
- Electromagnetic interference hardened
- Capable of connecting over 30 lights together without tripping breaker (military specification requires only 12)
- Interoperable with legacy fluorescent shelter lights

Ruggedized LED lights are a currently a fielded system (NSN 6230-01-596-4722).

C.56 SAFEPORT

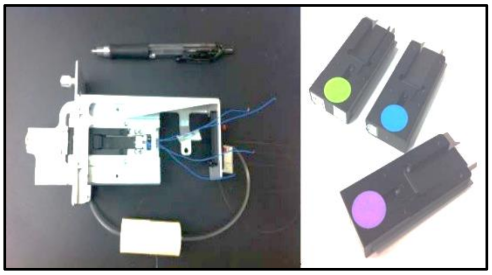

Figure C-60. SafePort

Photo Credit: ERDC [49]

SafePort (**Figure C-60**) is a microfluidics-based water analysis system that performs real-time detection of hazardous and toxic compounds in water. The system is field deployable, which allows rapid environmental assessment in a compact package and is designed to be operable by soldiers with minimal technical background.

The system has the potential to save water by optimizing the performance of water treatment equipment.

SafePort offers the following capabilities and benefits:

- Real time water analysis avoids training impacts, construction delays, and health effects
- Rapid results improve decision tools and lowers costs
- Hardware tested in high fidelity lab environment with real field samples
- Detection and quantitation of lead and perchlorates
- Reduced cost per sample
- Analysis chips can be customized for any application
- Smartphone interface allows real time logging of time, location, and acquired data

SafePort is currently at TRL 6.

Technical POC: Travis King, ERDC, travis.l.king@usace.mil, 217-373-4428.

C.57 SCORPION ENERGY HUNTER RENEWABLE ENERGY SYSTEM

The Scorpion Energy Hunter Renewable Energy System (**Figure C-61**) is a combined power management, energy storage, and energy harvesting system contained in a containerized and deployable arrangement. The system offers flexibility to fit into different power and energy desires, such as reducing generator run time, fuel consumption, generator maintenance cost, noise levels, and collecting renewable energy.

The Scorpion Energy Hunter Renewable Energy System offers the following capabilities and benefits:

- Adjustable 5 kW solar array maximizes energy harvesting
- Integrated 30 kW Intelligent Power Center provides on demand back-up generator power
- 105 kWh value-regulated lead acid battery energy storage system
- 18 kW, 120/208 VAC, 3-phase power (deployable systems available from 15–200 kW)
- Sets up in 90 min or less with two people

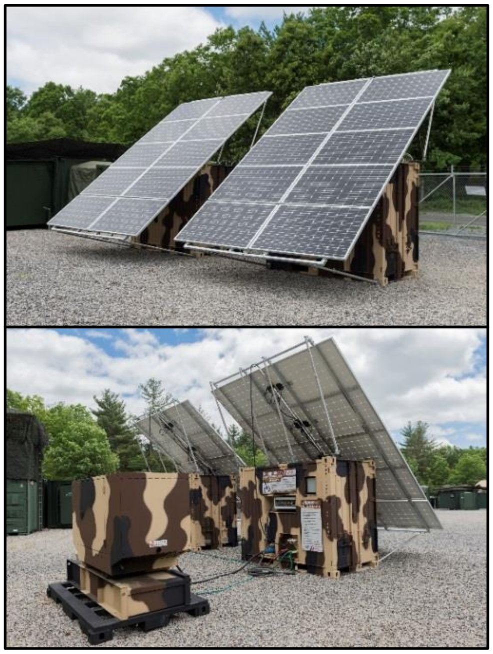

Figure C-61. Scorpion Energy Hunter Renewable Energy System

The Scorpion Energy Hunter Renewable Energy System is commercially available and was demonstrated by PM FSS at the BCIL.

Technical POC: Thomas Merrill, PM FSS, thomas.a.merrill8.civ@mail.mil, 508-233-4143.

C.58 SELF-POWERED SOLAR WATER HEATER (SPSWH)

Figure C-62. SPSWH

The SPSWH is a water heating system that uses parabolic mirrors to focus solar energy to provide instant hot water. The system is self-powered with solar panels and energy storage and contains a thermal storage device that stores excess heat energy for use later.

The SPSWH aims to supplement legacy fuel-fired water heaters such as the WH-400 and M80 by preheating the water to reduce or eliminate the fuel required. The system is modular and adaptable, capable of providing hot water to support field kitchen and sanitation center operations as well as showers and latrines.

The SPSWH offers the following capabilities and benefits:

- Provides an instant hot water source for up to 240 gal per day
- Automatic tracking of the sun to maximize energy capture
- Metallic phase-change thermal storage device stores excess heat energy for use later
- Coupling additional units provides additional hot water capacity
- Four modular, man-portable components with thermal/electricity collectors
- Solar panels and energy storage system power tracking hardware and internal pumps (i.e., no power connection to a generator or shore power)
- Transports and stores in TRICON shipping container
- Low maintenance and high reliability (mostly solid state)
- Supplements or offsets legacy fuel-fired water heater assets

Sets up in less than 4 h by four personnel

The SPSWH was demonstrated by SLB-STO-D at the BCIL in May–June 2016 and is currently at TRL 4.

Technical POC: Peter Lavigne, NSRDEC, peter.g.lavigne.civ@mail.mil, 508-233-4939.

C.59 SELF-SUSTAINING LIVING MODULE (SLIM)

Figure C-63. SLiM

The SLiM (**Figure C-63**) is a modular, scalable shelter that provides habitation optimized for efficiencies, self-sustainment, reduced logistics burden, and Warfighter performance. The SLiM provides life support functions for approximately 20 personnel within a global architecture with scalable infrastructure capabilities.

The shelter system includes power generation, power storage, and a billeting structure. The power generation and storage is provided by a 10 kW generator, batteries, and ground based solar array. The SLiM structure includes built-in insulation, lighting, outlets, ECU interfaces, and ECU.

The SLiM offers the following capabilities and benefits:

- Shelter/billeting and missions planning space for around 20 personnel
- Maintains habitable internal temperatures and living conditions
- Expeditionary in nature (regardless of environmental conditions/water exposure)—compactable for shipment/transport, air-droppable, or vehicle-carried/towed
- Minimizes manpower required for set-up, no material handling equipment required
- Interoperates with standard base camp utility structures
- Increased efficiencies in power and water consumption and waste management
- Decreases operations and maintenance costs
- Increases Warfighter focus on mission operations vs. base camp establishment

The SLiM was demonstrated by the SLB-STO-D at the BCIL in May–June 2016 and is currently at TRL 5.

Technical POC: Elizabeth Swisher, NSRDEC, elizabeth.d.swisher.civ@mail.mil, 508-233-5457.

C.60 SHELTER RADIANT HEATING SYSTEM (SRHS)

Figure C-64. SRHS

The SRHS (**Figure C-64**) is a radiant floor heating system designed to efficiently heat an AS TEMPER shelter in cold weather climates. The system uses energy efficient positive temperature coefficient (PTC) technology that allows electrical resistance radiant heating to be used instead of traditional bulky hydronic systems (as is commonly used in commercial and residential applications). The SRHS either replaces or augments current ECUs.

The SRHS aims to reduce the energy required to heat expeditionary military shelters, thereby mitigating the logistical burden of fuel resupply. This will reduce fuel transport requirements due to energy reduction. The system will also significantly reduce the logistical burden associated with ECUs and ducting.

The SHRS offers the following capabilities and benefits:

- A design and manufacturing process that is financially feasible and proficient
- Lightweight, rapidly deployable, portable, and durable
- Integrated safety measures to mitigate concerns regarding potential shock hazards
- Zone temperature control to increase inhabitant personal space comfort
- Silent environmental control of shelter interior
- Increased soldier comfort levels by eliminating hot spots created by forced hot air heating systems
- Quicker deployment of basecamps in cold climates

The SRHS was demonstrated by the SLB-STO-D at CBITEC in February–March 2016 and is currently at TRL 6.

Technical POC: Chris Aall, NSRDEC, christian.d.aall.civ@mail.mil, 508-233-5188.

C.61 SHOWER WATER REUSE SYSTEM (SWRS)

The SWRS (**Figure C-65**), part of the Force Provider Expeditionary 150-man camp, is a fully self-contained water purification system designed to recover and recycle up to 10,000 gal per day from a shower waste water flow of 12,000 gal per day. The system integrates directly into the existing water supply and gray water system supporting two Force Provider Expeditionary Shower Systems and provides reuse water that meets or exceeds the Military Field Water Standards for long term use. Capability improvements will enable the system to treat laundry water in addition to shower water.

Figure C-65. SWRS

The SWRS allows contingency bases to reduce non-potable water resupply needs and reduces transportation assets required to haul waste water and provide potable water currently used for non-potable uses as well as reduce the water logistical footprint.

The SWRS offers the following capabilities and benefits:

- Provides graywater reuse that can be integrated into current support equipment, including shower and laundry systems
- Minimal manpower requirements with automatic control and operation
- Reduction in transportation assets required to haul waste water and provide potable water currently used for non-potable uses
- Reduction in the water logistical footprint
- Reduction in health risks from waste water-associated vectors

The SWRS is a currently-fielded system (NSN 5419-01-546-968).

C.62 SINGLE COMMON POWERTRAIN LUBRICANT (SCPL)

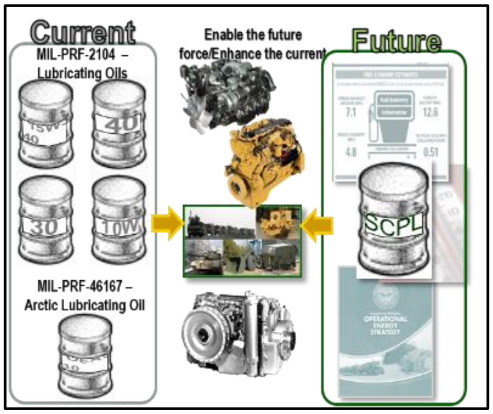

Figure C-66. SCPL

SCPL (**Figure C-66**) is multipurpose, heavy-duty diesel engine oil that provides multifunctional performance (e.g., engine, transmission, hydraulic systems). SCPL is a superior powertrain lubricant that will reduce fuel consumption, logistical burden, and maintenance requirements.

SCPL offers the following capabilities and benefits:

- Reduces fuel logistics burden and concomitant number of resupply fuel convoys
- Less fuel translates to significant cost savings
- Reduces lubricant resupply and waste disposal by increasing oil life by over two times
- Reduces misapplications and equipment downtime (i.e., multifunctional)
- Enhanced lubricant capabilities improve vehicle performance for more power and torque
- Increases equipment readiness by increasing reliability and durability

The SCPL is currently at TRL 9.

Technical POC: Allen Comfort, TARDEC, allen.s.comfort.civ@mail.mil, 586-282-4225.

C.63 SMALL UNIT SUSTAINMENT SYSTEM (SUSS)

Figure C-67. SUSS

Photo Credit: Ariana Costa, NSRDEC [92]

The SUSS (**Figure C-67**) is an expeditionary, rapidly deployable base camp that is transportable by trailers and breaks down into man-portable parts to support Army small units. The system is designed as a small tactical operations center and includes a generator, LED lighting, ECUs, solar panels, and a portable latrine and shower.

The SUSS aims to enable small units to conduct mission operations without the need for resupply or finding fractional habitation solutions. The speed, ease of set up, and efficiencies of the systems will result in more Warfighters being available for mission operations.

The SUSS offers the following capabilities and benefits:

- Optimizes habitation systems that support the unique expeditionary needs of small units and their lack of material handling equipment
- Rugged, rapidly deployable habitation and life support to enhance Warfighter quality of life specific to squad and small unit operations and needs
- Optimizes manpower requirements
- Improves situational awareness
- Increases survivability
- Optimizes habitation
- Reduces logistics footprint
- Enhances supportability and reduces cost
- Easily set up and relocatable, highly transportable, and self-sustaining
- Sets up by eight personnel in less than an hour

The SUSS is currently at TRL 6.

Technical POC: Ariana Costa, NSRDEC, ariana.n.costa.civ@mail.mil, 508-233-4566.

C.64 SMALL UNIT WATER PURIFIER (SUWP)

The SUWP is a developmental project that integrates advanced components and state of the art reverse osmosis techniques to produce a lightweight water purification system capable of producing up to 30 gal per hour. The system uses advanced, simple, robust pretreatment that produces membrane quality feed water and a lightweight, energy efficient high-pressure pump incorporating energy recovery.

The SUWP aims to reduce the distribution footprint and waste associated with bottled water while reducing soldier risk by reducing the requirement for water convoys.

The SUWP offers the following capabilities and benefits:

- Lightweight and energy efficient
- Reduces the distribution footprint and waste associated with bottled water
- Reduces soldier risk by reducing water convoys
- Fills the Petroleum and Water CBA Gap # 22: develop a man-portable water system

The SUWP is currently at TRL 4.

Technical POC: Lateefah Brooks, TARDEC, lateefah.c.brooks.civ@mail.mil, 586-282-6587.

C.65 SMART ENERGY EFFICIENT DEPLOYABLE SHELTERS (SEEDS)

SEEDS (**Figure C-68**) is a prototype Utilis TM60 shelter that minimizes shelter energy losses using advanced insulation and improvements to the shelter skin, shelter fly, and high performance computational modeling for optimized design technology.

The SEEDS project aims to reduce fuel for shelter heating and cooling, which reduces the number of vehicles in resupply missions, thus reducing the threat hours for soldiers.

SEEDS offers the following capabilities and benefits:

- Less energy consumption than a conventional shelter
- High performance computational test bed to evaluate advanced materials and designs to mitigate energy losses in shelters
- Optimized design of shelters with improved fly, skin, and liner materials
- Reduced infiltration with no windows, optimized air gaps, and vestibule
- Prediction of long term performance and durability of shelter materials, including advanced insulation materials

Figure C-68. SEEDS shelter: exterior (top) and interior (bottom)

Photo Credit: ERDC-CERL [28]

The SEEDS was demonstrated by ERDC-CERL at the EFOB-L from October 2015 to October 2016. The system is currently at TRL 6.

Technical POC: William Brown, ERDC, william.t.brown@usace.army.mil, 217-373-7292.

C.66 SOLAR PANEL

Figure C-69. Solar panels arranged into solar array

Solar panels (Figure C-69) are a collection of solar cells designed to absorb the energy in sunlight and convert it into electrical power. Solar panels are commercially available in many configurations (e.g., sizes, efficiencies, shapes, and materials).

The arrangement of solar panels in relation to the sun dictates how much and what types of radiation it absorbs. Panels are generally either laid flat on the ground, titled towards the sun, or equipped with solar tracking systems to always point towards the sun.

Solar panels can be either rigid or flexible. Rigid panels are generally more efficient (i.e., require less surface area for the same power generation) than flexible panels.

Solar panels offer the following capabilities and benefits:

- Captures energy from a renewable energy source
- Least negative impact on the environment compared to other energy sources
- No noise
- Can be deployed anywhere
- Commercially available in many configurations

Solar panels are commercially available.

C.67 SOLAR POWER SHELTER SYSTEM (SPSS)

The SPSS (**Figure C-70**) is a commercially available hybrid power system with an integrated solar array, battery, and control system designed to mount to the top of standard ISO containers.

The system aims to provide a renewable energy (solar power) capability to augment basecamp electrical power thereby reducing diesel fuel required by the generators. By using less fuel, the SPSS decreases warfighter risks of transporting fuel in high risk areas by reducing fuel convoys on the battlefield.

The SPSS offers the following capabilities and benefits:

Figure C-70. SPSS

- Provides plug and play solar power unit that mounts on top of ISO containers and shelters
- Provides usable/storable power to support military base camps and containerized system applications
- Requires zero footprint by combining solar powered generation with battery storage to minimize logistics footprint on battlefield
- Provides backup/alternative power source with battery storage capacity
- Transportable and stackable system using standard materiel handling equipment
- Environmental friendly (no carbon dioxide emissions, noiseless operation)

Simple installation and limited maintenance required

The SPSS is part of a PM FSS-managed Foreign Comparative Test project that seeks to test and evaluate the system against Army requirements to determine the technical feasibility of integrating solar power renewable energy system capabilities into the Force Provider Expeditionary base camp environment.

The SPSS was demonstrated by the SLB-STO-D at the BCIL in July 2015 and is currently at TRL 6.

Technical POC: Thomas Merrill, PM FSS, thomas.a.merrill8.civ@mail.mil, 508-233-4143.

C.68 SOLID WASTE DESTRUCTION SYSTEM (SWDS)

Figure C-71. SWDS

The SWDS (**Figure C-71**) is a solid waste treatment system that uses a self-powered Ward Furnace combustor to reduce solid waste by 90%. The system is designed for the efficient onsite disposal of the solid waste generated by small contingency bases (150–300 PAX). The SWDS is mechanically simple, accepts bagged waste, and requires minimal electricity and fuel to operate.

The system aims to reduce the logistics in terms of backhauled waste and reduce fuel consumption as compared to competing options—incinerators and burn pits.

The SWDS offers the following capabilities and benefits:

Self-powered combustor requires minimal electricity and fuel

- Mechanically simple
- Throughput of up to a half ton per day
- Accepts bagged waste
- Benign residuals and emissions
- Minimal manpower for operation and waste sorting
- Reduces combustible solid waste by 90%

The SWDS is currently at TRL 5.

Technical POC: Leigh Knowlton, NRSDEC, leigh.a.knowlton.civ@mail.mil, 508-233-5138.

C.69 SOLID WASTE INCINERATOR

Solid waste incinerators (**Figure C-72**) are a mobile waste treatment solution that involves the combustion of organic substances contained in waste products that transform the waste into ash, fumes, and heat. Commercially-available systems come in numerous footprints, including TRICON, BICON, and skid-mounted systems.

The current field-expedient method of eliminating solid waste at contingency bases by burning in open burn pits generates uncontrolled emissions that have the potential to cause adverse impacts to human health and the environment. Incinerators attempt to address this technology gap by utilizing a controlled method to burn waste.

Figure C-72. Solid Waste Incinerator

Solid waste incinerators offer the following capabilities and benefits:

- Ability to provide small scale solid waste treatment at contingency base camps
- Reduced environmental and health impacts associated with emissions
- Reduction in volume of solid waste required for disposal

PM FSS has conducted market research on the potential of mobile, small scale incinerators for field deployment. [78]

Technical POC: Jeff Wallace, NSRDEC, jeffrey.d.wallace18.civ@mail.mil, 508-233-6098.

C.70 STRUCTURAL INSULATED PANEL HUT (SIP-HUT)

Figure C-73. SIP-Hut (left) and B-Hut (right)

The SIP-Hut (**Figure C-73**) is an alternative to semi-permanent barracks (commonly known as Barrack Huts or B-Huts). SIP-Huts are constructed of pre-manufactured structural insulated panels that have a high insulating value (both thermal and acoustic) and provide for quick assembly/disassembly. The SIP-Hut takes one-third the time to construct and is twice as energy efficient as the current B-Huts.

SIP-Huts offer the following capabilities and benefits:

- Potential 80% reduction in energy consumption compared to non-insulated B-Hut
- 50-60% reduction in squad-hours construction time compared to B-Hut (not including roof) with non-skilled labor

SIP-Huts were demonstrated by the SLB-STO-D at CBITEC in April 2016 and are currently at TRL 6.

Technical POC: Tom Decker, ERDC, charles.t.decker.civ@mail.mil, 217-373-3361.

C.71 SUSTAINABLE TECHNOLOGIES FOR RATION PACKAGING SYSTEMS (STRAPS)

STRaPS (**Figure C-74)** is a sustainable materials alternatives program for secondary and unit load-level ration packaging systems to reduce weight, waste, environmental footprint, logistics costs, and use of petroleum-based plastics.

STRaPS offers the following capabilities and benefits:

- Straps, pallet wraps, and pallets with bio-based, biodegradable, recyclable, compostable, and/or decreased material usage
- Development of an efficient ration packaging system that reduces logistical burden on the warfighters and minimizes negative impact on the environment.

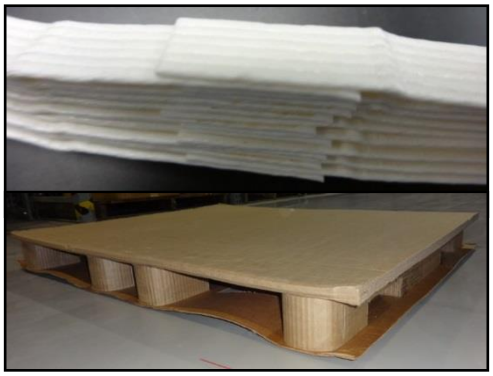

Figure C-74. STRaPS: paper based strapping (top) and fiberboard pallet (bottom)

Photo Credit: USAMC LOGSA Packaging, Storage, and Containerization Center [93] [94]

The STRaPS program contains multiple technologies. The paper-based straps are currently at TRL 6. The fiberboard pallets and the biodegradable stretch wrap were considered “no-go.”

Technical POC: Jo Ann Ratto Ross, NSRDEC, joann.r.ross.civ@mail.mil, 508-233-5315.

C.72 T-100 HMMWV TOWABLE GENERATOR (T-100)

The T-100 (**Figure C-75**) is a HMMWV or Joint Light Tactical Vehicle (JLTV) towable generator capable of producing 80 kW of electrical power. The T-100 integrates a commercial off-the-shelf engine and ultracapacitor energy storage technology, resulting in a highly power dense, fuel efficient 80 kW system that reduces the logistics and transportation burdens of the battlefield.

Figure C-75. T-100

The T-100 offers the following capabilities and benefits:

- Improved fuel efficiency which reduces Operations and Sustainment cost and logistics burden of fuel resupply
- Continuous power output of 80 kW (at 0.8 power factor (PF))
- 120/208 VAC (4 wire), 3-phase, 60 Hz output
- Use of load-following system to reduce fuel consumption, component wear, and noise signature at low loads
- Reduced weight compared to TQGs—only 2,500 lb, enabling it to be trailer-mounted (4000 lb with trailer) and towed behind a HMMWV or JLTV
- Reduced noise signature to enhance soldier survivability and reduce soldier fatigue
- Enhanced reliability by 15% as compared to similar legacy systems
- Integrated fuel tank sized to allow 8 h of continuous operation at 100% load

The T-100 was demonstrated by SLB-STO-D at the BCIL in May–June 2016 and is currently at TRL 6.

Technical POC: Ed Nawrocki, CERDEC, edmund.a.nawrocki2.civ@mail.mil, 443-395-4799.

C.73 TACTICAL WATER PURIFICATION SYSTEM (TWPS)

The TWPS (**Figure C-76**) is a fully contained mobile water purification system capable of purifying, storing, and dispensing water Military Field Water Standards for long term use. It generates up to 1500 gal/h of potable water from a water source. The TWPS can produce potable water from a broad range of water sources (e.g., fresh water, brackish water, and sea water).

Figure C-76. TPWS

Photo Credit: Staff Sgt. Mark A. Moore II, 2nd Brigade Combat Team PAO [95]

TWPS offers the following capabilities and benefits:

- Processes fresh or salt water
- Removes nuclear, biological, and chemical agents
- Compatible with the Palletized Load System (PLS) truck (M1074, M1075), Heavy Expanded Mobility Tactical Truck (HEMTT) Load Handling System (LHS) truck (M1120) and PLS trailer (M1076) for transport.
- Available in Army (flat rack) and Marine Corps (skid-mounted) variants

The TWPS is a currently a fielded system (NSN 4610-01-488-9656).

C.74 TRICON DEPLOYABLE BAFFLED BIOREACTOR (DBBR)

Figure C-77. Tricon dBBR

The dBBR (**Figure C-77**) is a stand-alone, biological-based system designed to provide waste water treatment capabilities at contingency bases to reduce waste water back hauling. Treatment of waste water to meet EPA secondary treatment standards allows for safe onsite discharge.

The dBBR offers the following capabilities and benefits:

- TRICON-based system
- Minimal manpower requirements with automatic control and operation
- Adapts to widely varying load conditions and rapid start-up
- Reduces the logistic burden and health risk to the Warfighter

The dBBR was demonstrated by the SLB-STO-D at the BCIL in July 2015. The system is currently at TRL 6 and is part of a TTA with PM FSS and PM PAWS for a potential transition.

C.75 ULTRAFILTRATION GRAY WATER REUSE SYSTEM (UF GWRS)

The UF GWRS (**Figure C-78**) is a stand-alone gray water recycling system that can be integrated with water purification systems, shower and laundry facilities, and field feeding and medical systems. The system provides an improved capability that can adapt to widely varying load conditions to treat more influent streams with less fouling and increased recovery of treated water.

The UF GWRS allows contingency bases to reduce non-potable water resupply needs and reduces transportation assets required to haul waste water and provide potable water currently used for non-potable uses as well as reduce the water logisitcal footprint.

The UF GWRS offers the following capabilities and benefits:

Figure C-78. UF GWRS – Interior View

- TRICON-based system
- Minimal manpower requirements with automatic control and operation
- Reduction in transportation assets required to haul wastewater and provide potable water currently used for non-potable uses
- Reduction in the water logistical footprint
- Reduction in health risks from waste water-associated vectors

The UF GWRS was demonstrated by the SLB-STO-D at the BCIL in July 2015. The system is currently at TRL 6 and is part of a TTA with PM FSS and PM PAWS for a potential transition.

Technical POC: Lateefah Brooks, TARDEC, lateefah.c.brooks.civ@mail.mil, 586-282-6587.

C.76 ULTRA-LIGHTWEIGHT CAMOUFLAGE-NET SYSTEM (ULCANS) SHADE

Figure C-79. ULCANS Shade over TEMPER shelter

The ULCANS Shade (**Figure C-79**) is a multispectral, lightweight camouflage fly shade that both conceals shelters and provides passive heat mitigation. The shades are produced from two-ply ULCANS materials that provide multispectral protection against visual, near infrared, and thermal infrared sensors.

The ULCANS Shade has been shown to reduce fuel and power usage associated with a shelter's ECU by reducing the temperature of the shelter compared to unshaded tents. The shades reduce solar radiation, which damage shelters and equipment.

The ULCANS Shade offers the following capabilities and benefits:

- Enhances survivability by providing protection against visual, as well as near-infrared, thermal infrared, and broad-band radar threats
- Passive heat mitigation
- Reduces solar radiation up to 85%

The ULCANS Shade is a currently-fielded system that comes in a variety of configurations. Common configurations include the Shade Fly for the AS TEMPER Type XXXI (NSN 8340-01-649-2252) and the Shade Fly for the AS TEMPER Type XXXVIII (NSN 8340-01-649-2215).

C.77 V1.5 LINER

Figure C-80. V1.5 LINER

The V1.5 Liner (**Figure C-80**) is a tent liner that combines traditional shelter insulation with radiant barrier materials. The liner features a multi-layer insulation, built-in plenum, and built-in LED lights.

By providing improved thermal performance in highly-agile soft wall shelters, soldiers will experience a higher quality of life due to better climate control, and enhanced ease of insulated shelter set-up.

The V1.5 Liner offers the following capabilities and benefits:

- Higher quality of life due to better climate control
- Reduction of shelters' infrared signature.
- Better maintainability of habitable temperature conditions within Army deployed shelter systems.

The V1.5 Liner was included as part of NSRDEC's Energy Efficiency Optimization of Combat Output/Patrol Base Shelters to Reduce Fuel Consumption project. The system was demonstrated by the SLB-STO-D at the BCIL in July 2015 and at CBITEC in April 2016. The system is currently at TRL 6.

Technical POC: Elizabeth Swisher, NSRDEC, elizabeth.d.swisher.civ@mail.mil, 508.233.5457.

C.78 VEHICLE-TO-GRID/VEHICLE-TO-VEHICLE (V2G/V2V) POWER SYSTEM

The V2G/V2V Power System (**Figure C-81**) is a roll-up/roll-away vehicle-based AC power system with cyber-secure bidirectional power and communications management and grid services. The system includes On-Board Vehicle Power (OBVP)-capable tactical host vehicles and supporting ancillary equipment for microgrid connectivity. Grid services include peak shaving, power regulation, and current source mode.

Figure C-81. Tactical V2G/V2V

The system aims to better utilize vehicle systems that are capable of electrical power production (i.e., currently vehicles utilized approximately 5% of time on the base camp). By combining with an energy storage system and microgrid capability, the system will save fuel and reduce threat hours for soldiers (i.e., save lives).

The V2G/V2V Power System offers the following capabilities and benefits:

- Very fast-forming, integrated, robust, ad-hoc, reconfigurable, vehicle-based power supply for austere contingency bases
- Sets up in less than 20 min
- Utilizes two MaxxPro MRAPs to produce 120 kW each and two M1152 HMMWVs to produce 30 kW each of DC power that is sent to Tactical Vehicle-to-Grid Modules (TVGMs)
- TVGMs produce 240 kW of 208V/120VAC 3-phase AC power
- Variable-speed operation and energy storage (~90 kWh) enabling anti-idle, grid services, and optimized generator operation (fewer but at/closer to rated power)
- Communications standards between vehicles and TVGMs for grid management, vehicle-faults, and maintaining vehicle mission readiness
- Validated tactical vehicle V2G and V2V power and communications sharing

The V2G/V2V Power System was demonstrated by SLB-STO-D at the BCIL in May–June 2016. Elements of the V2G/V2V system are at TRL 7, with some components at TRL 6.

Technical POC: Steve Kolhoff, TARDEC, steven.w.kolhoff.civ@mail.mil, 586-282-3588.

C.79 WASTE TO ENERGY CONVERTER (WEC)

Figure C-82. WEC

The WEC (**Figure C-82**) is a system that converts solid waste into a fuel gas that is used by an integrated generator to produce electricity. The WEC technology is suitable for the generation of electricity in large Combat Outposts and/or small Forward Operating Bases.

The aim of the WEC is to reduce the logistical burden of contingency basing in terms of backhauled waste while simultaneously reducing the amount of fuel used to power a base camp, which translates to fewer trucks on the road and reduced threat hours for Soldiers.

The WEC offers the following capabilities and benefits:

- Processes 2 tons per day of mixed non-hazardous solid waste
- Packaged in 20 ft ISO containers for deployability
- Includes power generation for net energy export
- Automatic control and operations with minimal manpower
- Benign residuals and emissions
- Reduces carbonaceous solid waste by 95%
- Exports electric power (projected at 75 kWh/h)

The WEC was demonstrated at Fort Benning, GA in winter 2016. The system is currently at TRL 5.

Technical POC: Leigh Knowlton, NSRDEC, leigh.a.knowlton.civ@mail.mil, 508-233-5138.

C.80 WASTEWATER ELECTROCHEMICAL TREATMENT TECHNOLOGY (WETT)

The WETT (**Figure C-83**) is a stand-alone, electrochemical-based system designed to provide waste water treatment capabilities at contingency bases to reduce waste water back hauling. Treatment of waste water to meet EPA secondary treatment standards allows for safe onsite discharge. The system does not use biological treatment processes and can treat waste water immediately upon startup.

Figure C-83. WETT

Photo Credit: Terragon Environmental Technologies [96]

The WETT offers the following capabilities and benefits:

- Onsite treatment to dischargeable standards for 90% of input stream providing order of magnitude reduction in wastewater
- TRICON-based system
- Disinfects water with no chemical additives
- Capable of treatment immediately upon startup
- Capable of processing a blend of waste streams emanating from latrines, field feeding, and gray water recycling systems
- Not affected by toxic compounds, grease, oil, or other aspects that pose problems for biological systems
- Minimal manpower requirements with automatic control and operation
- Reduction in transportation assets required to haul wastewater
- Improved safety/force protection at base camps
- Reduction in the water logistical footprint
- Reduction in health risks from waste water-associated vectors

The WETT technology project is currently at TRL 6 and has a TTA with PM PAWS for a potential transition.

Technical POC: Lateefah Brooks, TARDEC, lateefah.c.brooks.civ@mail.mil, 586-282-6587.

C.81 WATER FROM AIR (WFA)

Figure C-84. WFA

The WFA (**Figure C-84**) is a system that generates water from atmospheric humidity using absorption/desorption desiccant technology, energy recovery, and condensation. The system provides next generation water production and distribution capabilities through mobile water-from-air generation/storage. The system is mounted on a 7.5-ton trailer and produces up to 500 gal of water per day.

The WFA offers the following capabilities and benefits:

- Fills WFA capability gap identified in Petroleum & Water Functional Solutions Analysis
- Reduces the logistical footprint associated with bulk liquid storage and distribution
- Economic analysis using the Sustain the Mission Project methodology demonstrates payback in less than 1 year
- Reduces or eliminates basecamp water resupply

The WFA was demonstrated by the SLB-STO-D at the BCIL in July 2015. The system is currently at TRL 6 with potential to transition to PM PAWS.

Technical POC: Lateefah Brooks, TARDEC, lateefah.c.brooks.civ@mail.mil, 586-282-6587.

C.82 WATER RECYCLING SYSTEM (WRS) FOR FIELD FOODSERVICE SANITATION

The WRS (**Figure C-85**) is a low powered portable water recycling unit that clarifies and re-circulates sanitation water to significantly reduce water requirement.

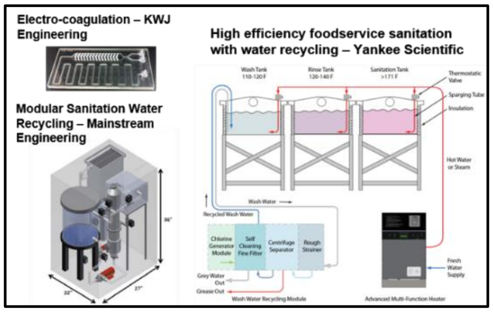

Figure C-85. WRS

The WRS aims to maintain a reliable, safe, efficient, field foodservice sanitation capability that significantly reduces water and fuel requirements. It conserves water by eliminating the need for complete sink refills that occur during the sanitization period. Water in the sinks is constantly circulated and filtered, so the sinks only need to be topped off as water is lost during the filtration process.

The WRS offers the following capabilities and benefits:

- Modular, man-portable components
- Supports a full range of Military field kitchens (e.g., Assault Kitchen, Assault Kitchen – Enhanced, Mobile Kitchen Trailer – Enhanced, Modernized Basic Expeditionary Airfield Resources 550 Kitchen, Electric Single Pallet Expeditionary Kitchen, Expeditionary Field Kitchen, Force Provider Kitchen, as well as future field kitchen platforms)
- Eliminates the need to completely empty and refill sanitation sinks

The WRS is currently at TRL 3.

Technical POC: Peter Lavigne, NSRDEC, peter.g.lavigne.civ@mail.mil, 508-233-4939.

C.83 WATER REUSE PUMP ASSEMBLY (WRPA) FOR FOOD SANITATION CENTER (FSC)

The WRPA (**Figure C-86**) consists of a stainless-steel basket and a hose with a water pump that is designed to easily transfer water between the FSC's wash, rinse, and sanitizing sinks. The system is manually controlled using a momentary switch.

The WRPA conserves water by decreasing the number of complete sink refills that occur during the sanitization period. Water in the sanitizing sink can be transferred to the rinse sink and water from the rinse sink can be transferred to the wash sink, allowing only a single sink to be refilled with fresh water.

The WRPA is currently-fielded as part of the FSC-2 (NSN 7360-01-496-2112) system.

Figure C-86. WRPA

Reprinted from TM 10-7360-211-13&P, Operator's, Unit, and Direct Support Maintenance Manual Including Repair Parts and Special Tools List for Food Sanitation Center (FSC) [97]

C.84 WATERLESS URINALS

Waterless urinals (**Figure C-87**) resemble conventional urinals but do not flush—they drain by gravity and the outflow connects to a regular toilet plumbing system. In waterless urinals, urine passes through a sealing liquid (e.g., a specially designed oil based fluid or vegetable oil) that floats atop the urine. This prevents odors and eliminates the need for water to move the urine into the plumbing system. There are two varieties of waterless urinal: cartridge based and non-cartridge based units. Cartridge based systems enclose the sealing liquid in a replaceable cartridge where non-cartridge systems have the sealing liquid added directly to the drain.

Waterless urinals offer the following capabilities and benefits:

- One-to-one replacement of existing urinals
- Connects to existing plumbing system
- Save water by eliminating flushing

Waterless urinals are commercially available.

Figure C-87. Waterless Urinal

Photo Credit: Environmental Protection Agency [98]

C.85 WIND ACCELERATION MODULE (WAM)

The WAM (**Figure C-88)** passively accelerates wind, increasing extractable power. By accelerating the ambient wind speed, WAM arrays can generate power even under low wind speeds. Unlike other forms of renewable energy (e.g., solar), wind is present 24 h per day, enabling the WAM to generate power at all times.

Figure C-88. WAM concept over expandable TRICON

Photo Credit: V^2 Wind Inc. [99]

The WAM offers the following capabilities and benefits:

- Ability to produce usable electric power with higher consistency at low wind speeds, conducive to use in austere situations
- Higher rated power production, more annual production out of a small package and deployment
- Rugged, highly efficient, rapid deployment

The WAM is currently at TRL 4.

Technical POC: Laura Biszko, NSRDEC, laura.c.biszko.civ@mail.mil, 508-233-4499.

ANNEX D – CAMP AND EQUIPMENT LEVEL FUNCTIONS

Table D-1. Camp Level Function Descriptions

Function	Description
Enable Command and Control	Facilities that enable command and control of the base camp. These facilities include Tactical Operations Centers, Command Posts, and Tactical Command Posts.
Enable Communications	Facilities that enable communications both on the base camp and outside of the base camp. These facilities include the Key Leader Engagement Area on the 1000 PAX camp.
Enable Movement & Maneuver	Facilities that enable movement and maneuver both within the base camp and outside of the base camp. These facilities include the Quick Reaction Force Staging Area on the 1000 PAX camp.
Execute Protection	Facilities that provide and execute the protection of the base camp. These facilities include the radar clusters, guard towers, and entry control points.
Provide Access to MWR Services	Facilities that provide Morale, Welfare, and Recreation (MWR) activities and services to the troops on the base camp. These facilities include all MWR facilities as well as the Army and Air Force Exchange Service and Chapel.
Provide Access to Maintenance/Repair	Facilities that provide maintenance and repair services on the base camps. These facilities include wash racks, the M7 Forward Repair System, and other maintenance facilities.
Provide Access to Medical & Health Services	Facilities that provide medical services. These facilities include aid stations.
Provide Access to Refueling	Facilities that enable vehicles to refuel. These facilities include the fuel storage tanks.
Provide Access to Transportation	Facilities that provide non-tactical transportation capabilities for support functions on the base camp. These facilities include support vehicles.
Provide Billeting	Facilities that provide billeting of the personnel on the base camp. These facilities include billeting shelters, both hard and soft wall.
Provide Electric Power	Facilities that provide power to the base camp. These facilities include generators.
Provide Integrated Solid Waste Management	Facilities that manage solid waste on the base camp. These facilities include the solid waste distributed collection facilities as well as solid waste treatment systems such as incinerators.
Provide Integrated Waste Water Management	Facilities that manage waste water within the base camp. These facilities include waste water tanks and bladders.
Provide Integrated Water Management	Facilities that manage water across the base camp. These facilities include water tanks and bladders.
Provide Latrine Services	Facilities that provide latrine services across the base camp. These facilities include latrines, burn-out latrines, etc.
Provide Means to Clean Clothes	Facilities that enable the base camp personnel to have clean clothes. These facilities include laundry facilities.
Provide Means to Maintain Personal Hygiene	Facilities that provide personal hygiene capabilities to the base camp personnel. These facilities include shower facilities and hand washing stations.

Function	Description
Provide On-Base Lighting	Facilities that provide lighting on the base camp level. These facilities include all perimeter light sets.
Provide Potable Water	Facilities that produce or filter water for potable uses. These facilities include water generation systems and water filtration systems.
Provide Subsistence	Facilities that provide for the storage, preparation and serving of food on the base camp. These facilities include the kitchen, food refrigeration and the dining facilities.
Warehouse/Store All Supply Classes	Facilities that provide a storage capability on the base camp. These facilities include supply offices and tents.

Table D-2. Equipment Level Function Descriptions

Function	Description
Communications and Computers	All components related to communications and computers. These components include laptops, printers, phones, radios, satellites, etc.
Convenience Loads	All components that are considered convenience for personnel on the base camp. This includes personal laptops, cell phones, televisions, etc.
Food Prep and Cleaning	All components involved in food preparation and cleaning. This includes cooking components within the kitchen and cleaning components within the Food Sanitation Center.
Hygiene and Showers	All components utilized for personal hygiene. This include showers, sinks, etc.
Latrine	All components utilized for latrine usage. This includes toilets and urinals.
Laundry	All components utilized for washing and drying personal clothing. This includes washers and dryers.
Lighting	All components utilized for lighting the base camp. This includes light bulbs within shelters as well as guard tower spotlights.
Maintenance	All components utilized for maintenance activities. This includes air compressors, the wash rack and the M7 Forward Repair System.
On-camp Vehicles	All vehicle components. This includes trucks, fork lifts, tractors, etc.
Power Distribution	All components that distribute power throughout the base camp. This includes all power distribution elements.
Power Generation	All components that generate power for the base camp’s needs. This includes all generators.
Process Black Water	All components that process black water to enable onsite disposal. This includes all waste water treatment systems.
Produce Water from Other Sources	All components that produce bulk potable water by means other than filtration. This includes the Water from Air (WFA) technology.
Protection	All components that execute protection. This includes guard tower cameras, radars, and vehicle gates.
Purify Bulk Water	All components that provide water filtration. This includes water filter systems such as the Tactical Water Purification System (TWPS).
Recycle Gray Water	All components that process and recycle gray water. This includes technologies such as the Gray Water Treatment and Reuse System (G-WTRS) and Forward Osmosis/Reverse Osmosis Graywater Recycling System (FORO).
Refrigeration	All components that provide refrigeration. This includes the Multi Temperature Refrigerated Container System and other refrigerators.
Shelter	All components that provide shelter (soft and hard wall). This includes TEMPER tents, Triple Containers (TRICONs), Military Van (MILVAN) Containers, B-Huts, etc.
Shelter Heating and Cooling	All components that provide shelter heating and cooling. This includes all environmental control units as well as fuel fired heaters.
Solar Power Generation	All components that produce electrical power from the sun. This includes all solar panels.

Function	Description
Solid Waste Destruction	All components that destroy or otherwise reduce the quantity of solid waste. This includes burn pits, incinerators, and similar technologies.
Solid Waste Generation	All components that produce solid waste. This includes the solid waste generation component.
Store Fuel	All components that store fuel. This includes various fuel tanks and bladders.
Store Noncombustible Waste	All components that store noncombustible waste. This includes dumpsters.
Store Potable Water	All components that store potable water. This includes various potable water tanks and bladders.
Store Solid Waste	All components that store solid waste. This includes dumpsters.
Store Waste Water	All components that store waste water. This includes various waste water (gray and black) tanks and bladders.
Water Heating	All components that heat water. This includes the water heater burner as well as the heat traces.
Water Pumping	All components that pump water throughout the camp. This includes all pumps.
Communications and Computers	All components related to communications and computers. These components include laptops, printers, phones, radios, satellites, etc.
Convenience Loads	All components that are considered convenience for personnel on the base camp. This includes personal laptops, cell phones, televisions, etc.