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COST BENEFIT ANALYSIS: CLOSED-CELL POLYURETHANE FOAM USE IN DOD FORWARD-DEPLOYED STRUCTURES AND AS AN ALTERNATIVE BUILDING MATERIAL TO REDUCE OPERATIONAL FUEL DEMAND AND ASSOCIATED COSTS

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The purpose of this project is to identify the costs and benefits associated with the application of closed-cell spray foam insulation to forward-deployed, semipermanent/nonpermanent structures, and to provide recommendations regarding future integration, use, and employment. According to the Department of Defense (DOD), forward-deployed generators, used to provide power to base support activities, are the largest single consumer of fuel throughout the battlefield. Eighty percent of the energy provided by generators is assessed to power environmental control units that run incessantly due to the poor insulating properties of the structures, according to a 2010 study conducted by the Department of the Air Force Civil Engineer Support Agency. Recent DOD policy has focused more on energy use and consumption but fails to address, and provide solutions for, major consumers of fuel throughout the battlefield. The incorporation of closed-cell, spray foam insulation into legacy DOD forward-deployed construction practices yields a significant return on investment, short-payback/break-even period, and reduces mission and personnel risk to deployed military forces.

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

ACE	Army Corps of Engineers (U.S. Army)
ACC	American Chemistry Council
AEPI	U.S. Army Environmental Policy Institute
AFCESA	Department of the Air Force Civil Engineer Support Agency
AMSAA	United States Army Material Analysis Activity
ASD	Assistant Secretary of Defense
ASD (OEP&P)	Assistant Secretary of Defense for Operational Energy Plans and Programs
AT&L	acquisition, technology and logistics
BEP	break-even period
B-Hut	Barracks Hut
BY	budget-year dollars
CBA	cost benefit analysis
CCSF	closed-cell spray foam
CALL	Center for Army Lessons Learned
CENTCOM	United States Central Command
CJCS	Office of the Chairmen, Joint Chiefs of Staff
CLU	containerized living unit
COB	Contingency Operating Base
COCOM	combatant commander
CRS	Congressional Research Service
DESC	Defense Energy Support Center
DLA	Defense Logistics Agency
DLA-E	Defense Logistics Agency-Energy
DLIS	Defense Logistics Information Service
DoA	Department of the Army
DOD	Department of Defense
DOT	Department of Transportation
DSB	Defense Science Board
ECU	Environmental Control Unit
EITS	external insulation of temporary structures
EPA	Environmental Protection Agency
ESG	Energy and Security Group
F	Fahrenheit
FBCE	fully burdened cost of energy
FBCF	fully burdened cost of fuel
FBC tool	fully burdened cost tool

FOB	Forward Operating Base
FY	fiscal year
Gal/gal	gallon
GAO	Government Accountability Office
GFC	ground force commander
GP-M	general purpose-medium tent
GP-L	general purpose-large tent
HEMTT	Heavy Expanded Mobility Tactical Truck
IDA	Institute for Defense Analyses
IPT	integrated project team
JCIDS	Joint Capabilities Integration and Development System
JCTD	Joint Capability Technology Demonstration
JFOB	Joint Forward Operations Base
JIC	joint inflation calculator
JP-8	Jet Propulsion Fuel, Type 8
JUONS	Joint Urgent Operational Needs Statement
KPP	Key Performance Parameter
kW	kilowatt
LIA	U.S. Army G-4 Logistics Innovation Agency
MDMP	Military Decision Making Process
MNF-W	Multinational Forces-West
MOP	measure of performance
mpg	miles per gallon
MTOE	Mission Table of Organization and Equipment
MTVR	Medium Tactical Vehicle Replacement
NCCA	Naval Center for Cost Analysis
NPV	net present value
NSN	national stock number
NTC	National Training Center
OCO	Overseas Contingency Operations
OCSF	Open Cell Spray Foam
OMB	Office of Management and Budget
OPTEMPO	Operational Tempo
OEP&P	Operational Energy Plans and Programs
OSD	Office of the Secretary of Defense

OSD (PA&E)	Office of the Secretary of Defense for Program Analysis and Evaluation
PPBS	Planning, Programming, and Budgeting System
PPE	Personal Protective Equipment
PSTF	Power Surety Task Force
psi	pounds per square inch
R&D	research and development
REF	Rapid Equipping Force
ROI	return on investment
ROC	Required Operating Capabilities
SMP	Sustain the Mission Project
SOUM	Safety of Use Message
SPF	Spray Polyurethane Foam
sq ft	square foot
SSA	Source Selection Authority
USD	Under Secretary of Defense

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—Capt. Stephen D. Gerry

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—LT Steven L. Caballero

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—LCDR Robert J. Marsh

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I. INTRODUCTION

A. BACKGROUND

The Department of Defense (DOD) is the single largest consumer of energy in the United States and accounts for approximately 90% of the petroleum-based products used by the U.S. government (U.S. Government Accountability Office [GAO] 2008a). In fiscal year (FY) 2013, the DOD consumed approximately 89.9 million barrels of fuel, at the cost of $14.8 billion, to sustain military operations worldwide. In FY 2014, DOD projected consumption levels to increase to approximately 104.6 million barrels of fuel, costing $16 billion—a 16.4% increase in quantity consumed and an 8% increase in cost from FY 2013 levels (Department of Defense [DOD], 2014). Although operational energy fuel costs compose only 3% of the proposed $529.9 billion DOD FY 2014 Base Budget request, energy demands remain a significant factor to military readiness, force planning, and capability. Global energy price volatility and increases in operational energy costs complicate the budget processes, resulting in additional appropriations and trade-offs required to cover funding shortfalls. In 2007, near oil's peak price per barrel, the DOD estimated that for "every $10 increase in price per barrel, operating costs increase by approximately $1.7 billion" (GAO, 2008a, p. 4).

In 2011, the DOD consumed nearly 5 billion gallons of fuel, costing approximately $17.3 billion, to support global U.S. strategic interests and military operations (GAO, 2012). In Afghanistan alone, DOD officials stated, "more than 43 million gallons of fuel (781,818 barrels), on average, were supplied each month" (GAO, 2012, p. 6) to support ongoing combat operations (see Figure 1). According to the Defense Science Board Task Force (DSBTF), a team established to identify opportunities arising from new technology, fuel logistics represent "approximately 70% of U.S. Army tonnage" (DOD, 2008, p. 23) transported throughout the battlefield. Large fuel requirements create significant risks to personnel, property, and mission during the transportation and delivery phases of fuel to forward-deployed locations. As such, increased fuel efficiency results in less risk and increased operational endurance time, which equates to more efficient and effective use of combat power.

Figure 1. Three-mile backup of fuel delivery trucks and other supply vehicles inside Afghanistan along the Northern Passage from Pakistan (from GAO, 2008a).

1. DOD Action to Address Forward-Deployed Fuel Consumption

In 2006, United States Marine Corps Major General Richard Zilmer, Commander of Multinational Forces-West (MNF-W) in Iraq's Al-Anbar Province, recognized fuel demand as an emerging threat to combat operations in his area of responsibility. He submitted a Joint Urgent Operational Needs Statement (JUONS) requesting a "renewable and self-sustainable energy solution to support forward operating bases, combat outposts and observation posts throughout MNF-W's battlespace" (Eady, Siegel, Bell, & Dicke, 2009, p. 1). The request went on to say that "by reducing the need for [petroleum-based fuels] at our outlying bases, we can decrease the frequency of logistics convoys on the road, thereby reducing the danger to our marines, soldiers, and sailors" (p. 1).

As seen in Al-Anbar Province, Iraq, high demand for fuel results in a significant burden on U.S. forces tasked with the transportation and protection of fuel convoys. According to the DOD, "44 trucks and 220,000 gallons of fuel were lost due to attacks or other events" (GAO, 2009, p. 8) in June 2008 in Afghanistan. At the 2008 Defense Energy Support Center (DESC), standard price of \$2.83 per gallon for Jet Propulsion Fuel, Type 8 (JP-8), a fuel commonly used for tactical vehicles and generators, the loss equates to $622,600 in fuel costs; not including costs associated with vehicle damage/loss, loss of life, and reduction of combat readiness and capability.

In response to Major General Zilmer's JUONS, the U.S. Army, through the Army Rapid Equipping Force (REF), created the Power Surety Task Force (PSTF) to explore material and nonmaterial solutions to the problem. The PSTF is charged with supporting and developing programs and/or initiatives that provide solutions to urgent needs requests that are deployable within 18 months (GAO, 2008a). The resulting efforts culminated in the analysis of two technologies—foam insulated tents and biodegradable dome structures—intended to reduce the number of generators and decrease fuel consumption for power generation at forward-deployed locations (GAO, 2008a).

2. Introduction of Spray Foam Insulation to Forward-Deployed Structures

In 2007, the Army began applying closed-cell spray foam (CCSF) insulation to nonexpeditionary structures to increase heating and cooling efficiencies, and to decrease associated electrical and fuel demands. Since the project's inception, $130 million in external insulation of temporary structures (EITS) contracts were awarded to apply foam to approximately 13.5 million square feet of nonexpeditionary structures in Iraq (Foulkner & Wilke, 2010) (see Figure 2). As of July 2009, 4 million square feet of CCSF insulation was applied to approximately 1,200 structures within United States Central Command (CENTCOM) AOR (Foulkner & Wilke, 2010).

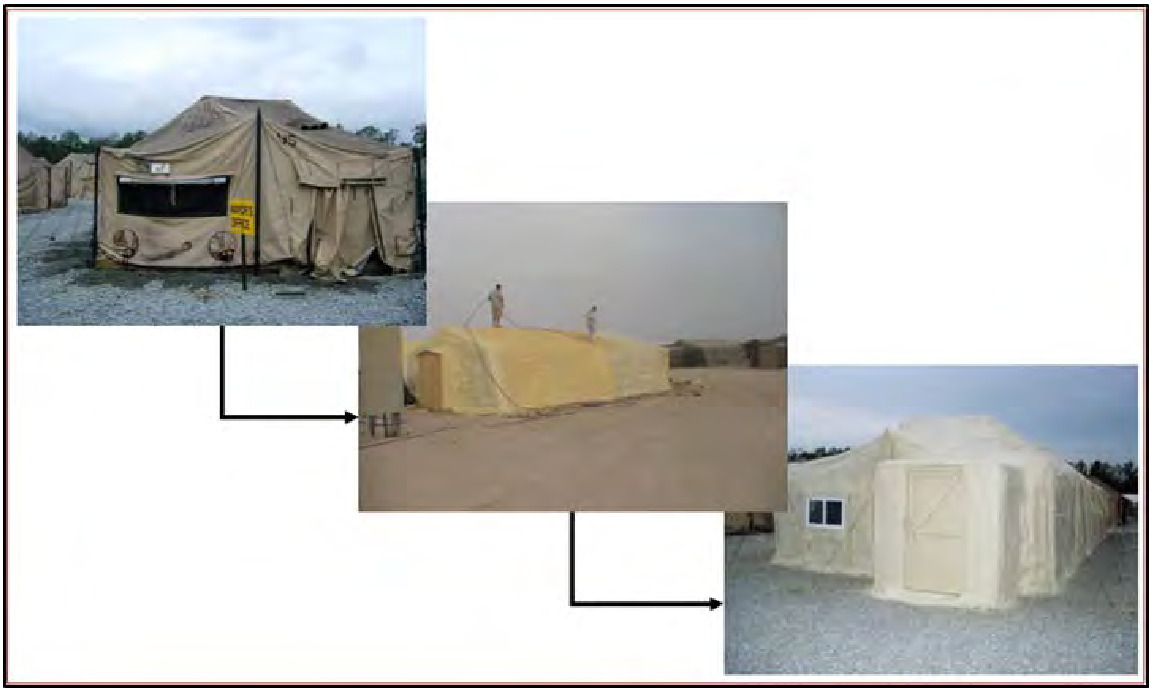


Figure 2. General-purpose-medium (GP-M) tent before, during, and after closed-cell foam insulation application (from Foulkner & Wilke, 2010).

In 2009, the Department of the Army's Director of Operations and Logistics Readiness tasked the U.S. Army Materiel Systems Analysis Activity (AMSAA) with conducting an analysis of energy and cost savings related to CCSF insulation application to nonexpeditionary structures in Iraq. The AMSAA conducted an engineering and cost analysis, based on "heat-transfer principles," to determine the annual cost savings related to fuel reduction from increased heating and cooling efficiencies gained from the foam application. Five types of structures, commonly used throughout forward operating bases (FOBs) in Iraq, were studied at four Iraq locations utilized by the United States and coalition forces. The structures analyzed were the Southwest Asia Hut, frame tent, general-purpose-medium (GP-M) tent, general-purpose-large (GP-L) tent, and barrel structures. The analysis calculated fuel savings from a sample of 794 structures that were applied with CCSF insulation. Fuel savings were translated to dollars saved, payback period, and fuel convoy reduction (Foulkner & Wilke, 2010).

Results analysis determined that the application of CCSF insulation to tent structures in Iraq yielded "approximately 50%" in fuel savings and calculated the "average payback period as less than 75 days using the Fully Burdened Cost of Fuel (FBCF) price of $13.80 per gallon" (Foulkner & Wilke, 2010, p. 1). The AMSAA further extrapolated the individual structure savings and applied it to FOB-level infrastructures, based on the awarded EITS contracts, yielding an estimated fuel savings of 4.7 million gallons, or $65 million annually (2009 budget year [BY] dollars). AMSAA translated the 4.6 million gallons saved into 5,000 gallon fuel trucks, commonly used by U.S. military forces to transport fuel in forward-deployed locations, resulting in approximately 940 fuel tanker trips avoided.

While the AMSAA study captures the initial cost savings from CCSF insulation, it does not account for other relevant costs and benefits associated with its application due to the time constraints under which the AMSAA study was conducted. Other costs and benefits applicable to CCSF insulation use include reduction in generator size requirements, loss of life, loss of equipment due to transportation, disposal costs, health and/or safety concerns, structure life-cycle costs, and structure replacement costs. True cost savings related to the application of CCSF insulation, when factoring in the above benefits, yield a significantly shorter payback period and greater value in cost savings over the anticipated life of the structures.

B. PURPOSE

The purpose of this Master of Business Administration (MBA) project is to conduct a cost benefit analysis (CBA) on the application of CCSF insulation to nonexpeditionary structures commonly used at forward-deployed locations and provide recommendations regarding future integration, use, and employment. Emphasis will be placed on the relevant, quantifiable, and non-quantifiable costs and benefits associated with the insulation's use. This project will provide relevant cost formulas associated with three types of structures (i.e., a frame tent, a GP-M tent, and a GP-L tent) dependent on other associated variables that will yield total cost savings associated with CCSF insulation's integration into each respective structure's construction. Additionally, this project will provide recommendations on possible procurement and acquisition strategies (e.g., in-time contract and program of record) and other areas of applicable use or methods of employment.

C. METHODOLOGY

The following methodology was implemented for this research:

- Review DOD operational energy policies, regulations, and strategies.
- Review DOD operational energy use.
- Review current DOD forward-deployed construction practices.
- Review current DOD forward-deployed structure characteristics.
- Review available data associated with forward-deployed structure energy consumption use.
- Review CCSF insulation use regulations and directives.
- Conduct a CBA on CCSF insulation application and use.
- Provide recommendations on future and alternative uses of CCSF insulation to the U.S. Army Corps of Engineers and Department of Defense and Office of Acquisition, Technology, and Logistics (AT&L).

II. DOD OPERATIONAL ENERGY FRAMEWORK

A. DEFINING DOD OPERATIONAL ENERGY

Operational energy, defined by U.S. Code 10, Section 138c, as “energy required for training, moving, and sustaining military forces and weapons platforms for military operations” (Assistant Secretary of Defense for Operational Energy Plans and Programs [ASD OEPP], 2015, p. 1), is a major cost driver of global U.S. military operations and a component of the DOD’s annual operating budget estimates. Operational energy encompasses a broad spectrum of fuel sources and types to include nuclear, wind, solar, geothermal, coal, natural gas, and petroleum-based products. The inefficient use of operational energy can have a significant impact on the conduct of worldwide military operations by increasing the costs in a fiscally restricted environment. Additionally, mismanagement of operational energy creates a logistics burden while conducting military operations in forward-deployed locations.

Petroleum-based products, the major component of operational energy, are not solely used to power combat weapons systems. Petroleum-based energy sources, however, *are* required in significant amounts to power base support activities in forward-deployed locations that rely on spot generation in the absence of established power grids or energy infrastructures. Forward-deployed locations, consisting of contingency operating bases (COBs) or FOBs, are commonly comprised of numerous temporary and/or semipermanent structures that satisfy support infrastructure requirements such as berthing, offices, sewer, water, and messing. Fuel requirements for base support activities are those associated with base vehicle use and generators providing power for communication, information technology systems, air conditioning, heating, lighting, and other infrastructure equipment. According to the Government Accountability Office (GAO), base support activities’ fuel consumption, as a percentage of total fuel consumption, can range from 13% at large, forward-deployed air bases such as Bagram Air Field, Afghanistan, to 78% and 73% in locations such as Camp Arifjan, Kuwait and COB Adder, Iraq, respectively (GAO, 2009) (see Figure 3).

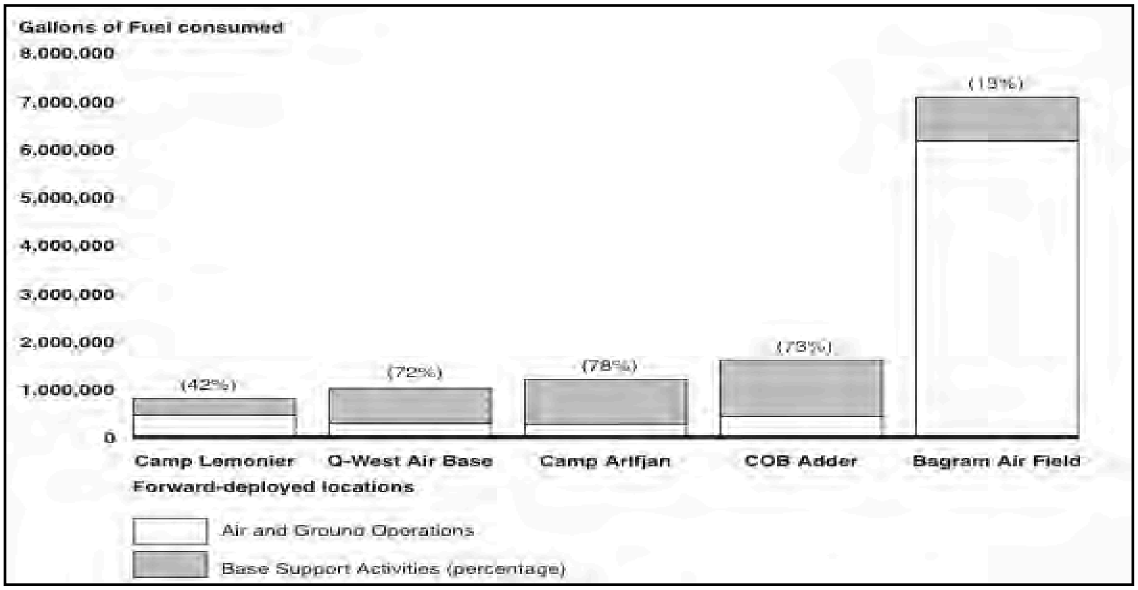
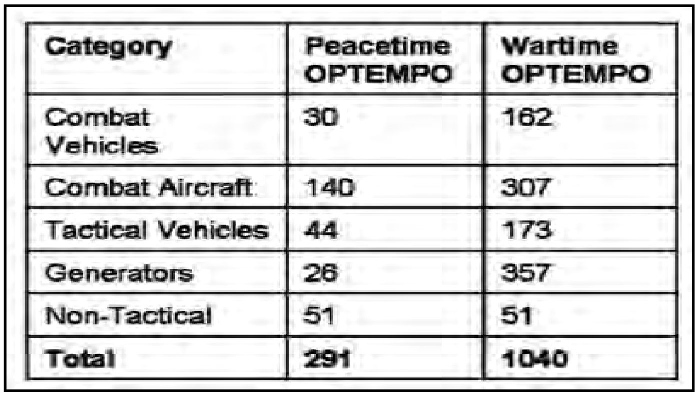


Figure 3. Proportion of fuel consumption reported for base support activities and for air and ground operations by selected, forward-deployed locations for June 2008 (from GAO, 2009).

In 2001, the Defense Science Board (DSB) found that “of the top ten battlefield fuel users, only two were combat systems; the rest were support systems” (DOD, 2008, p. 29). The DSB also found that fuel demand generated by a water heater for messing use was greater than that of an AH-46D attack helicopter.

In 2008, the DSB conducted an analysis on-base support activity fuel use. The study concluded that the fuel consumption levels and proportions were relatively unchanged since 2001. Of the base support activities in forward-deployed locations, energy production by generators was the largest battlefield consumer of fuel and consumed more than combat vehicles, combat aircraft, and tactical vehicles (see Table 1) (DOD, 2008). The United States Air Force calculated that up to 65% of fuel convoys at certain forward-deployed locations were transporting fuel for generators and that 80% of power generated at these locations was to power environmental control units (ECU) for FOB structures (Department of the Air Force Civil Engineer Support Agency [AFCESA], 2010).



Category	Peacetime OPTEMPO	Wartime OPTEMPO
Combat Vehicles	30	162
Combat Aircraft	140	307
Tactical Vehicles	44	173
Generators	26	357
Non-Tactical	51	51
Total	**291**	**1040**

Table 1. Army fuel consumption in peacetime and wartime (million gallons per year) (from DOD, 2008).

B. OVERVIEW OF PAST DOD OPERATIONAL ENERGY POLICY

1. Past DOD Operational Energy Studies and Findings

The DOD has made significant efforts to better understand operational energy issues by initiating and sponsoring studies conducted by organizations within the Office of the Secretary of Defense (OSD). In addition to the numerous GAO and Congressional Research Service (CRS) studies and reports summarizing DOD actions needed to reduce fuel demand, the below studies have served as catalysts for continuing action and reform with regard to policy and organizational changes within the DOD and the respective service branches.

In 2001, the Under Secretary of Defense for Acquisition, Technology & Logistics (USD [AT&L]) tasked the DSB to conduct a study on actions needed to improve the fuel efficiency of weapons platforms. The study's major conclusions were:

- Although significant warfighting, logistics and cost benefits occur when weapons systems are made more fuel-efficient, these benefits are not valued or emphasized in the DOD requirements and acquisition process.
- The DOD resource allocation and accounting processes (Planning, Programming, and Budgeting System (PPBS), DOD Comptroller) do not reward fuel efficiency or penalize inefficiency.
- Operational and logistics wargaming of fuel requirements is not cross-linked to the Service requirements development or acquisition program processes.

- High payoff, fuel efficient technologies are available now to improve warfighting effectiveness in current weapon systems through the retrofit and in new systems acquisition. (Truly & Alm, 2001, p. ES3-ES5)

In 2006, the Office of the Director, Defense Research and Engineering enlisted the resources of The JASONs, an independent defense advisory group, to "assess ways to reduce DOD's dependence on fossil fuels" (GAO, 2008a, p. 8). The group examined technological options to reduce dependence on fossil fuels or increase efficiency of current and future weapon systems able to meet military capability performance requirements. Additionally, the study highlighted overall consequences related to fossil fuel dependence and provided recommendations and areas of focus for DOD improvement. Major conclusions were:

- Fuel use is characterized by large multipliers and co-factors: at the simplest level, it takes fuel to deliver fuel.
- Fuel use imposes large logistical burdens, operational constraints and liabilities, and vulnerabilities: otherwise capable offensive forces can be countered by attacking more-vulnerable logistical-supply chains.
- Because of the long life cycle of DOD systems, uncertainties about an unpredictable future make it advisable to decrease DOD fuel use to minimize exposure and vulnerability to potential unforeseen disruptions in world and domestic supply (Dimotakis, Lewis, & Grober, 2006, p. iv)

In May 2006, at the same time that The JASONs' study was underway, the USD (AT&L) directed the DSB to examine the DOD's energy strategy, focusing efforts towards finding areas in which to reduce energy demands, identify "institutional obstacles" to their implementation, and assess "potential commercial and security benefits to the nation" (DOD, 2008, p. 3). The final report was released in February 2008 and cited the following findings:

- The recommendations from the 2001 Defense Science Board Task Force Report "More Capable Warfighting Through Reduced Fuel Burden" have not been implemented, with one being for the DOD to re-engineer its business processes to make energy a factor in the key Departmental decisions that establish requirements, shape acquisition programs and set funding priorities.
- The Department lacks the strategy, policies, metrics, information, and governance structure necessary to properly manage its energy risks. (p. 4)

- There are technologies available now to make DOD systems more energy efficient, but they are undervalued, slowing their implementation and resulting in inadequate future S&T investments.
- Operational risks from fuel disruption require demand-side remedies; mission risks from electricity disruption to installations require both demand- and supply-side remedies. (DOD, 2008, pp. 3–5)

In 2007, the Logistics Management Institute, a private, not-for-profit corporation that provides management consulting, research, and analysis to government organizations, was contracted by the OSD, Office of Force Transformation and Resources to assist in establishing a DOD framework for a comprehensive energy strategy. The Logistics Management Institute identified "disconnects" where the DOD has the opportunity to change its views that would enable achieving the strategic goals of a comprehensive energy strategy. These disconnects are listed below:

- Incorporate energy considerations (energy use and energy logistics support requirements) in the department's key corporate processes: strategic planning, analytic agenda, joint concept and joint capability development, acquisition, and planning, programming, budgeting, and execution (PPBE).
- Establish a corporate governance structure with policy and resource oversight to focus the department's energy efforts.
- Apply a structured framework to address energy efficiency, including alternate energy sources, to the department's greatest energy challenges— those areas consuming the most fuel, requiring the most logistics support, or having the most negative impact on the warrior. (Crowley et al., 2007, p. iv)

As the above studies highlight, there are major obstacles to the DOD's management of operational energy. Common themes include the lack of organizational hierarchies at the department and service level; the lack of directive policy with regard to reporting, management, conservation, efficiency; and lack of value and/or consideration operational energy has within the requirements and acquisition management systems.

2. Past DOD Operational Energy Policy Implementations

Since the release of the above studies, the DOD has taken steps to improve upon its management positions, policies, directives, and the value that it places on operational energy. In 2006, the OSD created the DOD Energy Security Task Force to address and oversee energy security concerns (GAO, 2008a). This task force also monitors the progress of various service-level research and development (R&D) projects that can potentially decrease operational energy demands. It operates as an integrated project team (IPT), consisting of members of the military service branches, defense agencies, Office of the USD (AT&L), Office of the USD for Policy, OSD's Program Analysis and Evaluation Office, and the DOD Comptroller's Office. Working groups are used to disseminate information and deliberate on ideas and efforts to reduce fuel demands of current and future weapons systems.

In 2007, the Deputy Secretary of Defense, the Honorable Mr. Gordon England, added energy to the DOD's list of the "top 25 transformational priorities" for the department "as part of its initiative to pursue targeted acquisition reforms"(GAO, 2008a, p. 2). Also in 2007, the Honorable John J. Young, Jr., the USD (AT&L), directed that the fully burdened cost of fuel (FBCF) be included in the acquisition strategies of all tactical systems that have energy demands associated with their operation (GAO, 2008b). Using the FBCF allows the DOD to capture the true fuel cost of a weapon system over its anticipated life cycle and better captures the impact of fuel prices on DOD operations.

In 2009, the DOD increased focus on operational energy issues and established Office of the Assistant Secretary of Defense for Operational Energy Plans and Programs (ASD [OEP&P]). In addition to overseeing department-wide efforts, the ASD (OEP&P) Current Operations Division is focused on supporting combatant commanders in the areas of rapid fielding of energy initiatives, technology, and contingency basing (Office of the Secretary of Defense [OSD], Historical Office, 2014).

Following the establishment of the ASD (OEP&P), U.S. Forces-Afghanistan (USF-A) created an Operational Energy Division to oversee and manage U.S. Central Command's fuel consumption and alternative fuel initiatives. Due to large fuel consumption levels caused by generators, the USF-A Operational Energy Division initiated efforts to transition from generators to centralized power grids by securing $108 million (2011FY$) in investment funding for power-efficient generation, distribution, and infrastructure improvements (GAO, 2012). The DOD estimated that the investment would remove approximately "545 generators," yielding an annual savings of approximately 17.5 million gallons of fuel, or the removal of “7,000 fuel trucks from the roads in Afghanistan” (GAO, 2012, p. 12). Furthermore, USD (AT&L) issued a memorandum to reprogram overseas contingency operations (OCO) funds “to expedite the deployment of more efficient generators, centralized power projects, and shelter modification kits to forward- deployed locations in Afghanistan” (GAO, 2012, p. 12).

In FY2009, the Duncan Hunter National Defense Authorization Act, Public Law 110–417, “introduced the concept of energy as a Key Performance Parameter (KPP)” (Bohnwagner 2013a, p. 1) to ensure energy demand of weapons systems are optimized to manage the expected fuel burden throughout the program’s life cycle. A KPP is “a characteristic or attribute of a system that is considered critical or essential to the development of an effective military capability” (Defense Acquisition University [DAU], 2015, p. 1). Codifying the requirement, The National Defense Authorization Act of 2009 mandated adding the energy KPP to the requirements development process, updating the Joint Capabilities Integration and Development System (JCIDS), and classifying energy as a required KPP. This KPP requires “fuel efficiency and logistic resupply risk considerations” (Chairmen of the Joint Chiefs of Staff [CJCS], 2009, p. B-6) are analyzed as part of the design process to mitigate fuel requirements associated with employment of the weapon system.

On June 14, 2011, the DOD released its Operational Energy Strategy, thus setting the direction and framework for DOD operational energy efforts within OSD, Office of the Chairmen, Joint Chiefs of Staff and the Joint Staff, (CJCS), combatant commands, and military departments and agencies. The strategy outlines three ways, focused on the warfighter, to ensure that the armed forces have the energy resources required to meet current and future threats and challenges. Strategic goals and priorities were established within each of the three principles, listed below, thereby defining the objectives of the operational energy efforts.

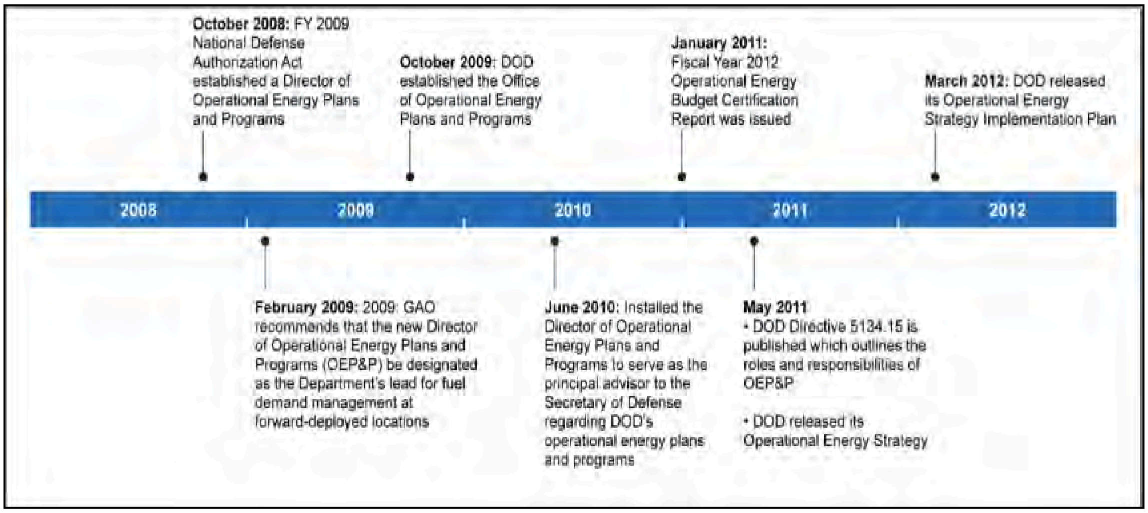
- More fight, less fuel: Reduce the demand for energy in military operations.
- More options, less risk: Expand and secure the supply of energy to military operations.

- More capability, less cost: Build energy security into the future force. (DOD, 2011, p. 1)

To put the strategy into action, ASD (OEP&P) released the *Operational Energy Strategy: Implementation Plan* in 2012, which established targets to achieve the strategic goals of overall reduced consumption, increased energy efficiencies to enhance effectiveness, and reduced cost and mission risk. The targets directed the measurement of current DOD operational energy use to better identify and understand areas of improvement by establishing standardized performance metrics. Additionally, the targets assessed and analyzed fuel use for conducting combat operations and training, as well as departmental efforts to improve efficiencies. Other targets include a focus on operational energy innovation, energy security, the viability and development of alternative fuels, and the inclusion of energy security considerations in the acquisition process. The Operational Energy Strategy Implementation Plan targets are:

- Target 1: Measure Operational Energy Consumption.
- Target 2: Improve Energy Performance and Efficiency in Operations and Training.
- Target 3: Promote Operational Energy Innovation.
- Target 4: Improve Operational Energy Security at Fixed Installations.
- Target 5: Promote the Development of Alternative Fuels.
- Target 6: Incorporate Energy Security Considerations into Requirements and Acquisition.
- Target 7: Adapt Policy, Doctrine, Professional Military Education, and Combatant Command Activities. (DOD, 2012a, p. 3-7)

Along with the above targets, the implementation plan set milestones, reporting requirements, and assigned responsibilities and accountability for achieving the strategic initiatives. According to the ASD (OEP&P) FY2012 budget report, the military services anticipate spending approximately $4 billion in operational energy initiatives through FY2017 to improve overall energy management and decrease operational consumption (GAO, 2012). Figure 4 summarizes the ASD (OEP&P)'s key operational energy milestones since the office's inception, as a result of the numerous studies mentioned above.



October 2008: FY 2009 National Defense Authorization Act established a Director of Operational Energy Plans and Programs

October 2009: DOD established the Office of Operational Energy Plans and Programs

January 2011: Fiscal Year 2012 Operational Energy Budget Certification Report was issued

March 2012: DOD released its Operational Energy Strategy Implementation Plan

February 2009: 2009: GAO recommends that the new Director of Operational Energy Plans and Programs (OEP&P) be designated as the Department's lead for fuel demand management at forward-deployed locations

June 2010: Installed the Director of Operational Energy Plans and Programs to serve as the principal advisor to the Secretary of Defense regarding DOD's operational energy plans and programs

May 2011
- DOD Directive 5134.15 is published which outlines the roles and responsibilities of OEP&P

- DOD released its Operational Energy Strategy

Figure 4. Timeline of key events in OEP&P efforts to manage operational energy issues (from GAO, 2012).

C. DOD OPERATIONAL ENERGY PRICING FOR FUEL

1. Standard Price

The Defense Logistics Agency (DLA), through the DESC within the DLA-E office, is responsible for the purchase, storage, distribution, and sale of energy to various military buyers worldwide. The DESC buys petroleum-based products from global suppliers, financed through a defense working capital fund, and sells it to DOD customers to fulfill their energy requirements. To reduce transportation costs, fuel is purchased from suppliers in close proximity to their customers. DLA-E maintains, stores, and distributes fuel from over 600 fuel depots located in strategic locations worldwide (Schwartz, Blakeley, & O'Rourke, 2012).

Due to transportation-associated costs, the DLA-E purchase price of fuel varies. To account for this variation, DLA-E established a global-level set price, or standard price, for each specific fuel type that is for sale to its DOD customers. Standard prices are usually set and published every 18 months or shorter, depending on market volatility, to provide predictability for DOD budgetary or operational planning purposes. To set the standard price, DLA-E averages the cost of fuel purchased and adds a surcharge to account for their operating costs associated with the fuel's storage and transportation. Once set, the standard price for each respective fuel type is the price paid by their customers, regardless of the customer's location (Schwartz et al., 2012).

2. Fully Burdened Cost of Fuel

As defined under Section 332 of the FY2009 National Defense Authorization Act, the fully burdened cost of fuel is "the commodity price for fuel plus the total cost of all personnel and assets required to move, and when necessary, protect the fuel from the point at which the fuel is received from the commercial supplier to the point of use" (Bohnwagner, 2013b, p. 1).

Because the DOD purchases and sells fuel based on a "wholesale" or averaged price, the DESC standard price does not include nor account for the delivery costs from the point of distribution/sale to the end user. Not accounting for such costs diminishes the accuracy of the true cost of fuel.

FBCF, referred to as the fully burdened cost of energy (FBCE) when applied to all fuel sources, is calculated by the summation of a number of elements accounting for costs incurred from the point of distribution or sale. As seen in Table 2, determining the FBCF is highly dependent on tangible and intangible costs. Tangible costs include miles traveled, transportation assets required, and protection. Intangible costs include those associated with environmental and regulatory compliance. Because of these varying elements, there is no standardized FBCF estimating methodology applicable to all situations.

Element #	Price Element	Burden Description
1	**Fuel Commodity Price**	DLA Energy capitalized cost to purchase, transport, store, and manage fuel to the Point of Sale at the edge of the scenario battlespace.
2	**Tactical Delivery Assets Burden***	Includes all of the following:
	Fuel Delivery O&S Price	Per gallon price of operating service-owned fuel delivery assets including the cost of military and civilian personnel dedicated to the fuel mission.
	Depreciation Price of Fuel Delivery Assets	Measures the decline in value of fuel delivery assets with finite service lives using straight-line depreciation over total service life.
	Infrastructure, environmental, and other miscellaneous costs over/above and distinct from the DLA Energy capitalized cost of fuel	Per gallon price of fuel infrastructure, regulatory compliance, tactical terminal operations, and other expenses as appropriate.
3	**Security/Force Protection Assets Burden***	Per gallon price associated with delivering fuel, such as route clearance, convoy escort and force protection. Includes the manpower, O&S, and asset depreciation costs of the force protection.

Table 2. Fully Burdened Cost of Energy (FBCE) Elements (from Bohnwagner, 2013a).

In 2006, the Energy and Security Group (ESG) designed and developed the Sustain the Mission Project (SMP) methodology used to calculate the FBCF associated with U.S. Army missions. The resulting SMP Decision Support Tool has been used by the U.S. Army Logistics Innovation Agency to support operational, logistic, and requirements planning. In 2012, the ESG further expanded the scope and capabilities of the SMP Decision Support Tool; now renamed the fully burdened cost (FBC) tool (Energy and Security Group, 2015a). The current version of the FBC tool (version 4.0), effective in 2012, provides FBCF cost and (benefits) estimates for fuel supply convoy casualties (avoided), fuel resupply convoy soldier threat exposure (hours avoided), fuel consumption (gallons saved), fuel supply truck miles (freed up for other missions), aviation fuel transport hours (freed up for other missions), convoy protection gun truck miles (freed up for other missions), convoy protection aviation system hours (freed up for other missions), and dollars (avoided) (Energy and Security Group, 2015b).

To illustrate the price impacts of the FBCF elements, initial estimates done by OSD Program Analysis and Evaluation (PA&E) and the Institute for Defense Analyses (IDA) calculated that the price for delivering fuel to the battlefield was around $15 per gallon, not including costs associated with force protection for convoys. Other estimates include $42 per gallon for fuel delivered in-flight, and “several hundreds of dollars per gallon for fuel delivered to isolated F.O.B.s deep in the battlespace” (DOD, 2008, p. 30). The AMSAA study used the initial version of this tool (the Sustain the Mission Project Tool) to calculate a range of FBCF prices for analysis during their Tent Foam Insulation Cost Benefit Analysis conducted in 2009, yielding a FBCF range from $13.80 per gallon to $30 per gallon (Foulkner & Wilke, 2010).

III. CLOSED-CELL SPRAY FOAM INSULATION FOR ENERGY REDUCTION

A. CLOSED-CELL SPRAY FOAM DEVELOPMENT

The development of polyurethane, a component of CCSF insulation, is credited to Doctor Otto Bayer. The U.S. military began using polyurethane during World War II as a replacement for scarce rubber resources. As the versatility of the organic polymer was further developed, it was used in other military applications such as chemical warfare resistant garments, aircraft finishes, and chemical and corrosion-resistant coatings (American Chemistry Council Inc., 2015e). As a result of the war, polyurethane's characteristics became applicable to the civilian sector throughout various commercial industries. Polyurethane was used to manufacture cushioning flexible foams used in the upholstery and auto industries. Today, polyurethanes are found in various everyday products such as household items, furniture, clothing, and home construction materials (American Chemistry Council Inc., 2015e).

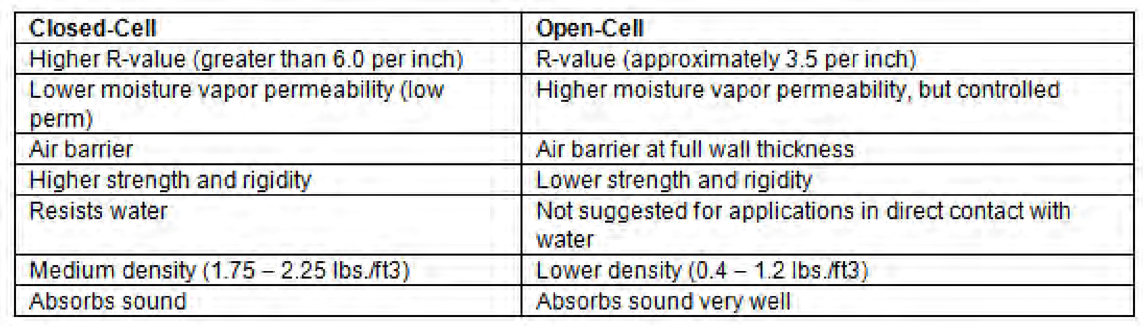
In the 1950s, the invention of the "blendometer" by Walter Baughman expanded polyurethane's commercial use. The blendometer mixed various chemicals, yielding a new type of material known as polyurethane foam (Polyurethane Foam Association, 2010), which did not see wide-scale use until the early 1960s. In 1963, after the development of spray technology, polyurethane foam was able to be applied as a home insulation material and is currently used in modern construction practices (InovateUs Inc., 2013).

Significant energy savings are realized through the application of spray foam due to the material's insulating properties and its ability to conform to a wide variety of irregular insulation application sites. According to the American Chemistry Council, spray foam provides a superior weatherproof sealant and seamless layer of insulation in current construction practices. The versatility of spray foam insulation allows it to be used during new construction as well as in preexisting structures.

B. CLOSED-CELL SPRAY FOAM PHYSICAL PROPERTIES

1. R-Values/Moisture/Vapor/Air/Sound

R-value is one of the most significant characteristics of spray foam when choosing among alternative insulation products. R-value relates to the insulating material’s ability to resist heat flow. Higher R-values provide a greater degree of insulating properties, yielding lower energy costs and fuel consumption. Table 3 compares CCSF and open cell spray foam (OCSF) material properties, most notably showing CCSF with an R-value almost twice that of OCSF, clearly indicating that CCSF is superior to OCSF in most applications.



Closed-Cell	Open-Cell
Higher R-value (greater than 6.0 per inch)	R-value (approximately 3.5 per inch)
Lower moisture vapor permeability (low perm)	Higher moisture vapor permeability, but controlled
Air barrier	Air barrier at full wall thickness
Higher strength and rigidity	Lower strength and rigidity
Resists water	Not suggested for applications in direct contact with water
Medium density (1.75 – 2.25 lbs./ft3)	Lower density (0.4 – 1.2 lbs./ft3)
Absorbs sound	Absorbs sound very well

Table 3. Side-by-side comparison between closed cell and open cell spray foam (from American Chemistry Council Inc., 2015c).

2. Ballistic Protection

Protection of military personnel is often achieved through installation construction, perimeter control, structure standoff distances, and antiterrorism force protection measures and training. The unified facilities criteria for “Non-Permanent DOD Facilities in Support of Military Operations,” which establishes the construction criteria for military structures, acknowledges that most expeditionary structures cannot be sufficiently retrofitted or hardened to counter higher threats. In the absence of adequate standoff distances, expeditionary structures may not comply with unified facilities criteria standards listed in the *DOD Antiterrorism Standards for New and Existing Buildings* (DOD, 2012b). Expeditionary force forward operating base (FOB) locations are often dictated to ground force commands (GFCs) from higher command, with locations chosen for strategic, operational, or tactical advantage over site placement. Because FOB locations vary based on operational requirements, compliance with force protection standards and practices is not always feasible. Therefore, cost-effective measures should be employed when possible.

Traditional, forward-deployed building materials do not provide much in terms of ballistic protection. As such, additional ballistic protection has to be erected to provide adequate protection for structures such as the addition of Hesco barriers or construction of concrete T-walls. In 2008, at a FOB near Baqubah, Iraq, CCSF displayed an unproven ballistic protection characteristic during an enemy attack, preventing shrapnel from an enemy round from penetrating a CCSF-coated structure. Personnel discovered that shrapnel thrown by the round hit several structures and vehicles, causing external damage (see Figure 5). Military personnel on the ground later assessed the round to be a 107-millimeter rocket. Despite the damage to the surrounding area, the spray-foamed structure—approximately 80–100 yards away from the round's impact zone—appeared to prevent the shrapnel from penetrating the structure (see Figure 6) (Mason Knowles Consulting LLC, 2015).

Figure 5. Damage to a metal building and the tailgate of a pick-up truck approximately 50 yards from the impact site of the 107mm rocket (from Mason Knowles Consulting LLC, 2015).

Figure 6. CCSF-sprayed military tent resists shrapnel penetration; October 17, 2008 (from Mason Knowles Consulting LLC, 2015).

3. Chemical Components

The two chemical components of CCSF remain separated in equal amounts, commonly referred to as side-A and side-B. According to the Environmental Protection Agency (EPA), the side-A component is comprised of very reactive chemicals known as isocyanates, while side-B is primarily comprised of a polyol that reacts with the isocyanates of side-A to create the polyurethane. Other chemicals are added, such as flame-retardants, blowing agents, and surfactants, to complete the reactive process (Environmental Protection Agency [EPA], 2015b). CCSF isocyanates present a significant chemical exposure concern, as minimal contact can result in breathing-related complications that could be fatal.

4. Cure Times

The cure time for CCSF insulation is the duration it takes for the foam components to reach a fully hardened state once applied and depends on various factors, such as temperature and humidity. Estimates vary from as little as one hour for single component spray foams, to as much as 8 to 24 hours for OCSF or CCSF. Due to the significant health hazards, the EPA stresses to err on the side of caution and consult with a product application contractor and manufacturer for reentry periods (EPA, 2015c).

5. Shipping/Storage

Spray foam chemical component’s shipping and storage requirements must be satisfied in accordance with manufacture instructions in addition to U.S. military, United States Department of Transportation, Occupational Safety and Health Administration, and EPA requirements, as applicable. Failure to follow proper storage and transportation requirements could result in fire, explosion, the components being rendered unusable, or adverse health effects from chemical exposure. Side-A and side-B chemical components have specific warnings related to each. The storage of the components should ensure that an appropriate distance is maintained before, during, and after use to prevent contact with water, acids, or reactive chemicals. Additionally, the user should ensure that containers are sealed when not in use to prevent moisture infiltration and off gassing (American Chemistry Council Inc., 2010).

6. Disposal

The disposal of spray foam components and containers should be done in accordance with current federal, state, and local laws and regulations. Additionally, users should comply with the chemical container safety data sheet and consult with the manufacturer regarding proper waste disposal. Currently, cured spray foam can be disposed of as nonhazardous waste by incineration or burial (American Chemistry Council Inc., 2015b).

7. Health Hazards and Concerns

The EPA has indicated that there are serious health risks associated with the airborne aerosols, mists, and vapors that result from spray foam application. During the application process, workers and others in the immediate area can be exposed to chemicals that could result in irritation and chronic lung disease. In addition, exposure to the eye and the skin of unprotected areas of the body can also be potentially hazardous. Manufacturer-recommended, personal protective equipment is required during application (EPA, 2015d). To reduce the health risks resulting from exposure, the EPA outlines several workplace ventilation best practices and principles. By incorporating these practices and principles, personnel are less susceptible to chemical exposure. Additional measures should be taken to ensure that personnel not directly involved in the application process, but in close proximity to the application site, are aware of the hazards and chemical exposure risks.

C. CLOSED-CELL SPRAY FOAM COMMERCIAL APPLICATION

There are three types of spray foam insulation available on the commercial market. The first is one-component foam, typically used by do-it-yourself nonprofessionals or homeowners for small job applications such as weatherizing a home. The one-component foam is premixed, ready to use, and comes prepackaged in a 12–24 ounce can similar to spray paint. This foam is typically used to seal around pipes; windows and door seals; and heating, ventilation, and air conditioning duct work (see Figure 7). The one-component foam can also be used in repair work or applications similar to those pictured below.

Figure 7. One-component spray polyurethane foam application options (from American Chemistry Council Inc., 2015d).

Larger-scale projects require different material characteristics satisfied by either a two-component, OCSF or CCSF insulation. Both variations provide unique environmental protection properties and characteristics. OCSF, as the nomenclature indicates, consists of an open cell-structure filled with air, resulting in a soft, low-density product (Spray Polyurethane Foam Alliance, 2013). The low-density characteristic results in a more aggressive expansion during application and curing, resulting in a thicker end product.

OCSF provides increased benefits over other insulation systems by providing a more capable barrier to moisture, vapor, sound, and external climate variations (see Figure 8). The OCSF is applied with a low-pressure system, typically less than 250 pounds per square inch (psi), and provides greater ability to resist conductive heat transfer, with an R-value of approximately 3.5 per inch of spray foam (American Chemistry Council Inc., 2015a). R-value is the measure of the material's thermal resistance used in the building and construction industry. Thicker application of low-density OCSF may be required to meet desired insulating requirements.

Figure 8. Open-Cell Spray Foam (from EPA, 2015a).

The CCSF contains a closed-cell structure that traps insulating gases, called blowing agents, which have a lower thermal conductivity than air and increases the product's R-value (Spray Polyurethane Foam Alliance, 2013). CCSF is a denser and more expensive material than OCSF that expands less aggressively, requiring less material during application to meet desired insulation properties and characteristics (see Figure 9). CCSF is applied with a high-pressure system, typically 800–1,600 pounds per square inch, providing R-values of 6 per inch. Additionally, CCSF components are packaged in 55-gallon drums for larger applications (EPA, 2015a). CCSF provides significant cost savings over OCSF, when used in large volumes, due to its increased insulation properties and ability to procure in larger quantities.

Figure 9. CCSF two-component, professional, high-pressured system foam application (from EPA, 2015a).

D. CLOSED-CELL SPRAY FOAM MILITARY APPLICATION (ENERGY/FUEL REDUCTION)

Since the July 2006 JUONS the DOD has used foam insulation throughout the U.S. Central Command and U.S. Africa Command areas of responsibility, both in controlled testing environments and under field conditions in forward-deployed locations. Synovision Solutions conducted the initial testing and demonstration of external foam application at Fort Benning, Georgia in December 2006. Gaco Western 193 foam, a low-density, rigid polyurethane insulation, was applied to a single tent, yielding a "92 percent reduction in energy" (Sprayfoam.com Inc., 2015, p. 1) used power heating and cooling systems (see Figure 10). The Fort Benning demonstration showed that EITS foam application "can reduce the number of generators by 50%" and that the "insulated tents require 75–90% less power than non-insulated tents" (AFCESA, 2010, p. 5). Reduced energy demand for the insulated tents resulted from the removal of half of the environmental control units needed to maintain predetermined interior temperatures (GAO, 2009). In addition to the reduction in energy demand, the foam insulation increased indoor air quality from the reduction in dust, dirt, and other debris. The foam insulation also reduced exterior noise penetration, providing better quality of life characteristics for the tents' inhabitants (GAO, 2009).

Figure 10. GP-L tent before and after external application of spray foam insulation, Fort Benning, Georgia, 2007 (from GAO, 2009).

1. National Training Center – Net Zero Plus – Project Eskimo

In 2007, the U.S. Army Rapid Equipping Force conducted a Joint Capability Technology Demonstration (JCTD) at the National Training Center (NTC), Fort Irwin, California. The demonstration analyzed available renewable energy technologies with a goal of achieving military installation energy independence from established power grids. One technology tested was the application of spray foam insulation to expeditionary military berthing tents to determine the effects on temperature regulation and energy use. This effort, termed Project Eskimo, was deployed throughout Iraq, Afghanistan, Djibouti, and Kuwait for field demonstration purposes and became the proof of concept for future foaming contracts. The aim of the project was to cover 79 temporary structures to measure energy efficiencies gained with the application of foam insulation (Null, 2010). According to U.S. Army officials, the project yielded a 40%-75% energy savings, reached fiscal break-even point in 178 days, and saved over $194 million from initial deployment through February 2010 (Null, 2010).

2. Employment of Foam Insulation in Forward-Deployed Locations

In 2007, the U.S. Army Developmental Test Command approved spray foam insulation for use, enabling the U.S. Army Rapid Equipping Force to solicit and award contracts for foam application. In May 2007, the Army conducted a demonstration in Kuwait by spray foaming semipermanent berthing tents and other base support structures. Foam application resulted in an approximately 20%-40% reduction in energy use (see Figure 11) (AFCESA, 2010).

Figure 11. Foam insulation applied to tents in Kuwait (from AFCESA, 2010).

In 2006, leadership at Combined Joint Task Force-Horn of Africa, Camp Lemonier, Djibouti, requested assistance from the U.S. Army with an increasing energy demand due to ongoing camp expansion projects. In July 2007, the REF awarded a contract to Glencoe Roofing Company to apply spray foam insulation to the external surface of the base gym at Camp Lemonier, Djibouti (see Figure 12) (McCarty, 2015). Prior to the foam's application, the gym required five ECUs to maintain internal gym temperatures, averaging 95 to 100 degrees Fahrenheit (F) (GAO, 2009). After application, two of the five ECUs were removed and internal temperatures averaged 72 degrees F, resulting in a fuel savings of approximately 40% (GAO, 2009).

Figure 12. Exterior foam application to Camp Lemonier Gym, Djibouti (from Nolan, 2015).

In coordination with the U.S. Army REF, Synovision Solutions was asked to provide project leadership and services to conduct initial testing at Camp Victory in Baghdad, Iraq. A large gym, formerly an aviation maintenance facility, was picked to conduct the initial application due to its high-energy demand. Prior to the foam's application, the gym required eight ECUs, running 24 hours a day, to maintain an internal temperature of approximately 92 degrees F, depending on the time of day. After application, six of the eight ECUs were removed and the remaining two maintained an internal temperature of approximately 72 degrees F. As a result of the successful testing, in April 2008, the U.S. Army authorized $95 million in contracts to foam up to nine million square feet of external structure surface area throughout Iraq (Sprayfoam.com Inc., 2015). Brigadier General Anderson, the U.S. Army Deputy Chief of Staff, Logistics

(G-4), stated that the U.S. military was saving “$2 million a day” (Osborn, 2009, p. 1) in Iraq from the 1,200 structures that were foamed. The foam application was said to drop the average internal temperature of a tent in Iraq by 22 degrees F (Osborn, 2009). Honeywell International was contracted by Multi-National Corps-Iraq to apply spray foam insulation to approximately 900 existing base structures, costing $12.5 million, to further increase overall fuel efficiency and reduce the energy demand (see Figure 13) (Urethanes Technology International, 2009).

Figure 13. Honeywell employee applies terra strong foam to structures in Iraq (from Urethanes Technology International, 2009).

After successful performance demonstrations, Relyant, LLC, formally the Critical Mission Support Services, was awarded a $32 million contract, with an additional $7 million extension, to provide spray foam application services in Afghanistan (Sprayfoam.com Inc., 2010). Relyant began applying Gaco Western Polyfoam System 193 from late 2008 through 2009 to semipermanent structures at FOBs spread throughout Afghanistan, as well as at Bagram Air Field (see Figure 14). In January 2009, Synovision Solutions and Honeywell International were contracted to supply insulation materials to foam 500 to 600 semipermanent structures in a continuing effort to further lessen fuel dependence (Osborn, 2009).

Figure 14. Relyant, LLC employee applies spray foam insulation to a tent structure in Afghanistan (from Sprayfoam.com Inc., 2010).

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IV. CCSF COST BENEFIT ANALYSIS

A. INTRODUCTION

This chapter includes a detailed look at the following issues:

- The steps of the CBA
- The factors that create value or cost to the military
- The decision criteria evaluation process

It also evaluates the utility of CCSF insulation for military structures; specifically, three tent types. The eight-step CBA process quantifies the numerous costs and benefits of the military's use of CCSF insulation and suggests decision-making criteria and weighting for alternative selections. The CBA was conducted from the DOD perspective and does not account for societal externalities.

The CBA process is used by the various branches of the government and military to determine the benefit of acquiring items for military use. The total cost of closed-cell spray foam implementation goes beyond procurement and associated life-cycle costs. Placing a monetary value on the costs and benefits of CCSF implementation requires an analysis of how various stakeholders value the item. The CBA is critical to monetizing the costs and benefits of CCSF insulation for military use and aids in the decision-making process.

1. Application of Cost Benefit Analysis

The Army's eight-step CBA process was used to evaluate the feasibility of CCSF insulation application for the military. It also provides an accepted method used by military and government officials to make critical procurement decisions for future expenditures. Additionally, the CBA process allows decision makers to comprehend the methodology used in this analysis.

The eight-step CBA process ensures that all factors are evaluated to determine the overall costs and benefits of acquiring CCSF.

- Step 1 defines the problems or potential opportunities associated with CCSF procurement and implementation. The main problem addressed in this analysis is the exorbitant fuel use required for berthing and office area climate control.
- Step 2 identifies the facts, assumptions, and constraints used to evaluate the costs and benefits.
- Step 3 identifies possible alternatives for the procurement and use of CCSF insulation for semipermanent, deployed structures. These alternatives provide decision makers with different options to evaluate the implementation of CCSF use.
- Step 4 develops the total quantifiable and nonquantifiable cost estimates for each of the alternatives. These costs are evaluated and analyzed to determine the true cost of each alternative.
- Step 5 identifies the quantifiable and nonquantifiable benefits produced from each alternative. In order to properly weigh the benefits against the costs, nonquantifiable benefits will have to be monetized by placing a dollar value on the benefit. The dollar value will represent the value to the end user and the military's willingness to pay for that benefit.
- Step 6 identifies weighting criteria used for decision making when selecting alternatives.

The final two steps of the CBA process determine an actual value of each alternative and provide selection recommendations.

- Step 7 combines the costs and benefits of each alternative, yielding an overall net value or benefit.
- Step 8 is a sensitivity analysis of each alternative due to factors such as fluctuating fuel prices, the cost of CCSF materials, and time. This final step of the CBA reports the results of the analysis and provides a recommendation to decision makers on the procurement of CCSF.

B. STEP 1: DEFINE PROBLEM/OPPORTUNITY AND SCOPE

1. Problem Statement

The DOD's legacy forward-deployed structure construction practices and materials require an exorbitant amount of energy, in the form of petroleum products, to maintain base support activities and acceptable living and operating conditions for deployed U.S. military personnel. Wartime generator use, required to power essential base support activities, consumes more energy than combat vehicles, tactical vehicles, and combat aircraft. According to a 2010 study conducted by the U.S. Air Force Civil Engineering Support Agency (AFCESA), approximately 80% of the energy produced by generators is used to power the ECUs necessary to heat and cool berthing, office, and messing structures (AFCESA, 2010). During the construction process, the application of energy efficient materials into legacy structures can reduce operational energy demand throughout the battlefield, thus yielding significant fuel savings, an increase in operational effectiveness and endurance, and reducing casualties associated with fuel transportation and protection.

2. Objective

The objective of this CBA is to determine and analyze the costs and benefits associated with CCSF application for use on new or existing forward-deployed, semipermanent structures. CCSF implementation can significantly alter forward-deployed construction practices within the DOD and reduce operational energy demand and related costs. This research identifies, through case study and cost comparison, whether CCSF application to forward-deployed structures will achieve the desired outcome of reduced costs, increased stability, and protection for military forward-deployed structures.

Specific objectives include:

- Identify CCSF quantifiable and nonquantifiable costs and benefits.
- Compare costs and benefits between the status quo and alternative(s).
- Calculate the CCSF application annual net benefit (e.g., return on investment [ROI], net present value [NPV], and the break-even period [BEP]).
- Develop a CCSF net benefit formula per structure (three tent types).
- Demonstrate how CCSF application fits into current DOD operational energy initiatives.
- Provide CCSF usage recommendations.

3. Voice of the Stakeholders

Stakeholders, as defined by the *U.S. Army CBA Guide*, are those “customers, functional process owners, or end users” of the product or services that have a voice in the decision-making process or are directly affected by the CBA results. For this CBA, stakeholders are broken down into the following functional categories:

- CCSF requirements stakeholders;
- CCSF solicitation and selection stakeholders;
- CCSF user stakeholders; and
- other CCSF stakeholders. (Department of the Army [DoA], 2013, p. 14)

a. CCSF Requirements Stakeholders

The primary requirements stakeholder, and key decision maker, identified for this CBA is the Secretary of Defense, who is the final approval authority for program of records submitted to the Congress for authorization and appropriation. Requirements codified at this level are applicable to the respective service branches or the DOD as a whole. Policies governing and/or mandating CCSF use and application will be disseminated to the respective users and providers.

Other key requirements stakeholders are the respective combatant commanders, who identify combat-related needs and requirements to fulfill capability gaps. Once capability gaps are identified, joint and service-specific stakeholders are involved in the capabilities-based assessment. Decisions from this assessment lead to an analysis of alternatives during the material solution analysis phase of the JCIDS process. Specific requirements stakeholders include:

- Secretary of Defense
- USD (AT&L)
- Service Secretaries
- Joint Chiefs of Staff
- Service Chiefs

- Component Acquisition Executive – Assistant Secretary of the Army (AT&L)
- Program Executive Office (PEO) – U.S. Army PEO Soldier, Joint Committee on Tactical Shelters

b. CCSF Solicitation and Selection Stakeholders

The primary solicitation and selection stakeholder and decision maker is the USD (AT&L). For joint programs, the office of the USD (AT&L) is the final solicitation and selection decision authority unless delegated to a service material command. For CCSF contracts, the U.S. Army Material Command is the likely designated executive agent responsible for contractor solicitation and selection. Once the requirement is approved, the U.S. Army Material Command will designate a Source Selection Authority (SSA) responsible for reviewing and selecting the contractor(s) who provide the best value, based on the requirements specified in the solicitation. Specific solicitation and selection stakeholders include:

- USD(AT&L)
- U.S. Army Material Command
- Service SSA

c. CCSF User Stakeholders

CCSF user stakeholders are those associated with the product’s end use. In forward-deployed locations, user stakeholders span the spectrum from combatant commanders to the individual warfighter. Combatant commanders are the primary stakeholders, due to CCSF’s ability to reduce fuel demand, increase warfighter quality of life, and reduce mission risk associated with fuel transport, storage, and protection. Reduction of fuel demand also enables greater combat endurance and more efficient use of combat power, as combat power previously used to protect fuel convoys can now be assigned to support other mission objectives. Combatant commanders are ultimately responsible for CCSF’s successful implementation on the battlefield to achieve theater energy efficiency goals.

Individual warfighters are the ultimate end users of CCSF products and are the direct beneficiaries of the foam’s environmental control properties and fuel reduction capabilities. Improved quality of life, realized by CCSF’s application, translates into better performance and more effective and enduring warfighting capabilities at the tactical level. Less fuel translates into reduced warfighter risk associated with convoy protection and escort missions. Specific user stakeholders include:

- Combatant commanders
- Coalition commanders
- Component commanders
- Battlespace owners/commanders
- FOB/COB commanders
- Logistics battalions
- Individual warfighters

d. Other CCSF Stakeholders

Other stakeholders are those affected by CCSF’s employment throughout the battlefield, but are not customers, end users, or anyone involved in the functional processes. The largest stakeholders affected by CCSF’s use are those associated with fuel purchase, storage, and transport to the end user. The DESC, which is responsible for managing and satisfying DOD’s fuel requirements, is directly affected by major changes in battlefield fuel demand; specifically, volume. Other fuel-associated stakeholders include those responsible for its storage and transportation to the end user; including both domestic and international providers.

From a budgetary perspective, all levels of the DOD are stakeholders due to fuel consumption’s effect on the overall DOD budget. Volatility and instability of global fuel prices may require additional appropriations from Congress to fund anticipated fuel demand. Major changes in DOD budget requests affect Congressional appropriations previously authorized for other DOD programs of record.

From a material perspective, commercial suppliers and manufactures of forward-deployed structures used for base infrastructure (e.g., expeditionary tents, construction materials, etc.) are stakeholders of CCSF's employment. Because CCSF application changes the useful life and functionality of the structure it is applied to, suppliers will realize a change in material demands for their products. Other stakeholders include:

- DLA
- Military equipment manufacturers
- Contracted construction-related labor forces (domestic and international)
- Contracted fuel-related labor forces (domestic and international)
- Host-nation-provided services
- Ancillary base support equipment providers (e.g., ECUs, generators, etc.)
- U.S. taxpayers (who are also stakeholders and are affected by the implementation of CCSF's use in DOD construction practices)

C. STEP 2: FORMULATE BOUNDARIES, ASSUMPTIONS, AND CONSTRAINTS

1. Boundaries

CBA boundaries are critical towards finding feasible and practical results for all alternatives within a given analysis (DoA, 2013). Setting boundaries minimizes the difficulties associated with alternative(s) comparison and allows for a more focused look at the primary criteria prioritized by decision makers. Unbounded CBAs could result in numerous alternatives, costs, and benefits that may have little to no effect on the CBA's results (DoA, 2011). The boundaries used during this CBA keep the focus on the major costs and benefits of CCSF implementation, which are listed below:

- This CBA only analyzes the costs and benefits that CCSF provides to U.S. military berthing structures; specifically, frame tents, GP-M tents, and GP-L tents.
- CCSF-insulated structures analyzed are those anticipated to be occupied for a minimum of one year due to the availability of published annual fuel consumption figures for the respective structures that are analyzed.

- CCSF-insulated structures analyzed are those at forward-deployed locations. This CBA does not analyze CCSF use at current military posts with permanent structures.

2. Assumptions

The *Army CBA Guide* defines assumptions as "conditions that must exist or events that must occur in order for the recommended COA to be successfully implemented" (DoA, 2013, p. 26). Assumptions used during this CBA are:

- The U.S. military will continue to use assets in existing inventories—specifically frame, GP-M, and GP-L tents—as expeditionary structures in forward-deployed locations due to their existing integration in military doctrine. The procurement costs associated with the three tents are treated as sunk and irrelevant in the cost and benefit calculations because they are included in an operational unit's standard Mission Table of Organization and Equipment (MTOE). This assumption is required in order to provide the cost benefit analysis of CCSF's effect on fuel reduction and other benefits associated with current and projected military berthing structures.

- The U.S. military will continue to employ semipermanent expeditionary structures in forward-deployed locations for berthing purposes to support mobility requirements dictated by mission requirements. Semipermanent structures have flexible, useful field lives, enabling their use for a variety of missions and mission durations. Due to the unknown duration of military operations, semipermanent structures offer flexibility to deployed forces. This assumption is required to reflect the temporary and varying nature of expected future military operations.

- Generator sets are assumed to be the primary source of power generation due to the unreliable nature or absence of local power sources or infrastructures in forward-deployed locations. The U.S. military will continue to use fossil fuels, specifically JP-8, in generator sets because of its universal use to power combat vehicles, aircraft, or auxiliary base support equipment. This assumption allows the CBA to remove the effects of outside power sources (i.e., local power grids) to focus the analysis on CCSF's effect on fuel reduction and other corresponding second- and third-order effects (i.e., reduced convoy operations, casualty reduction, mission effectiveness, etc.).

- Future CCSF service is assumed to be provided by commercial contractors due to the lack of organic military skill sets. Contractors also present a more cost-effective solution than creating an organic military capability. CCSF-related components are assumed to be readily available in the public/private markets to fulfill U.S. military demands when called on. This assumption allows the cost benefit analysis to focus on one method of CCSF implementation that is assumed to be used in future projects due to the significant costs related to establishing and maintaining an organic military capability.

3. Constraints

Data used for the CBA is constrained by available information retrieved from historical studies and/or past field employment. The ability to test CCPF on berthing areas for the sole purpose of this CBA is not feasible due to lack of available funding, time, and industry support. The data analyzed for this CBA only addresses the use of CCSF on berthing areas (three types) in Asia and the Middle East. As such, climate conditions and structure type may vary depending on employment location. The lack of CCPF testing in diverse climates, locations, and weather constrains this study from providing a general analysis for all forward-deployed structures and locations. Constraints used during the analysis are:

- Structure (three tent types) fuel consumption data is only available from historical CCSF use in Afghanistan, Iraq, Kuwait, and Djibouti.
- Foam contract costs are based on historical awarded contracts executed in Asia and the Middle East. Obtaining current CCSF prices from possible suppliers is impossible due to the DOD’s unauthorized commitment policy.
- CCSF insulation application can only be conducted by contracted personnel.
- DOD fuel prices used during the analysis are retrieved from historical DESC fuel standard prices for JP-8.
- MBA project completion time frame is constrained to six months, thereby limiting the scope of research time.

D. STEP 3: DEFINE ALTERNATIVES

1. Introduction

This analysis compared the costs and benefits of three structures—a frame tent, a GP-M tent, and a GP-L tent—versus the alternative course of action: the three tent structures with foam insulation applied externally. Each unfoamed structure was compared to its foamed counterpart to determine costs and benefits from the foam application and structure size and characteristics. The characteristics chosen to compare foamed versus unfoamed structures are based on characteristics that differ between the status quo and the alternative (see Table 4). The characteristics chosen are key decision factors when deciding which structure best suits operational needs and field situations.

Category	Status Quo: Uninsulated Tent Structures	Alt: CCSF-Insulated Tent Structures
Structure Purpose	Berthing	Berthing
Employment Location	Forward-deployed	Forward-deployed
Personnel Requirements	Military	Military and contractor
Set-Up Time	Less than 24 hours	More than 24 hours
Mobility	Mobile	Semipermanent
Disposal	None. Redeployment	Disposal required
Field Useful Life	Three years	Five years and greater
Structure Capital Outlay	None; structures in existing inventory	None; structures in existing inventory
Quality of Life	Low	Improved (nonquantifiable)
Energy Efficiency	Low	Approximately 50% greater
Maintenance	Low	Low
Health Factors	Dust, noise, humidity intrusion; drastic temperature variation; semipermeable material	Large reduction in dust, noise, and humidity; constant temperature; nonpermeable material
Structural Rigidity	Acceptable	Improved structural integrity
Implementation	No changes required	Requires additional policy and training

Table 4. Alternative comparison.

2. The Status Quo

Current military structures employed throughout the battlefield consist of uninsulated tents, wooden structures (e.g., Barracks Hut, Southwest Asia Hut), barrel structures, and containerized living units (CLUs). These structures are erected uninsulated and may or may not incorporate thermal shading, in the form of a camouflage netting system, installed above the structure's roofing. The status quo for this analysis is the three unfoamed tent structures (frame tent, GP-M, and GP-L). These structures provide a representative snapshot of the standard berthing structures currently employed throughout forward-deployed locations.

The three status quo structures are current DOD inventory items, utilized by all services and commonly employed during the initial and follow-on phases of military operations. They meet current military specifications for use as dictated by the DOD 4120.24-M established by the USD (AT&L). These structures are incorporated into the *Joint Forward Operations Base (JFOB) Survivability and Protective Construction Handbook* (Ground Test Article 90–01-011), which dictates their recommended use and employment during FOB establishment. Military personnel responsible for expeditionary operations are routinely trained on tent construction during the training and work-up phases of their respective deployment training cycles.

3. Documenting the Status Quo

a. Material Costs

Status quo structure material costs per unit were retrieved from the DLA – Defense Logistics Information Service (DLIS), found at www.dlis.dla.mil/webflis, using their respective national stock numbers (NSNs). Tent component costs were also retrieved from the DLIS website to account for replacement costs associated with standard tent use, maintenance, and component's operational field life. Tent component NSNs were extracted from the respective technical manuals.

b. Fuel Consumption Associated With ECUs

Fuel consumption amounts associated with each tent were retrieved from the U.S. Army Material Systems Analysis Activity engineering analysis conducted in 2009 under battlefield conditions. The engineering analysis used "principles of heat transfer and historical weather data to predict the amount of energy required to heat and cool the interior of the respective status quo structures located in multiple locations throughout Iraq" (Foulkner & Wilke, 2010, p. 7). Using the average change in fuel consumption in gallons per year, and percentages realized from the foam insulation application (see Table 5) provided by the AMSAA engineering analysis, this original, unfoamed, annual fuel consumption in gallons per year was calculated as seen below:

- **Formula 1:** Average change in fuel consumption (gal/yr)/percentage change = unfoamed fuel consumption (gal/yr)

- **Formula 2:** Unfoamed fuel consumption (gal/yr)–Average change in fuel consumption due to foam application (gal/yr)=Annual fuel consumption (gal/yr) with foam application

Annual Average Fuel Consumption per Tent (Iraq and Afghanistan)			
	Unfoamed Structure (gal)	**Foamed Structure (gal)**	**Fuel Consumption Reduction (gal)**
Frame Tent	10,573	4,652	5,921 (56%)
GP-M	10,600	4,664	5,936 (56%)
GP-L	14,488	5,215	9,272 (64%)

Table 5. Average annual fuel consumption per tent (after Foulkner & Wilke, 2010).

c. Fuel Convoy Requirements

Fuel convoy requirements are calculated by dividing the annual fuel use in gallons per year of each respective status quo structure by the standard 2,500-gallon and 5,000-gallon U.S. Army fuel tanker trucks (see Table 6).

Annual Fuel Truck Requirement per Tent			
	Fuel Consumption (gal.)	**2,500-gal. Fuel Trucks**	**5,000-gal. Fuel Trucks**
Frame Tent	10,573	4.23	2.11
GP-M	10,600	4.24	2.12
GP-L	14,488	5.80	2.90

Table 6. Annual fuel truck requirement per tent (after Foulkner & Wilke, 2010).

4. Define Alternative Course(s) of Action

For this analysis, there are two courses of action considered: the status quo (unfoamed structures) and the alternative (foamed structures). These courses of action are compared using the characteristics outlined previously in Table 4.

a. Alternative – Foamed Structures

The alternative course of action is defined as the three status quo structures, with foam insulation applied externally. Current DOD policy requires that foam insulation is applied by "factory authorized and trained contractor personnel" (AFCESA, 2010, p. 6) to ensure correct application and responsible use of the material. DOD personnel were not considered to apply CCSF insulation during this analysis. CCSF insulation is only applied to the external surface of the three structures, utilizing the original structure's framework for support. CCSF application increases energy efficiency, provides additional structural integrity, and provides a barrier from environmental conditions. Additionally, the application of foam insulation removes the expeditionary characteristics of the structure, rendering the exterior tent cover unrecoverable. Because of this, consideration is required when determining which structures to foam. As of 2010, three commercial-off-the-shelf foam products are authorized for use by the U.S. military: Gaco Western Polyfoam System 193, BASF Spraytite System 158 with BASF TERRAStrong Acrylic Coating 7261, and Baysystems Bayseal 2.0 Foam System (AFCESA, 2010). Additional safety considerations are required when employing CCSF due to the chemical characteristics of the foam material. Considerations include two exits of egress from the structure, installation of smoke detectors, a wait time prior to occupancy, minimum air volume exchange rates, and specific electrical safety standards. Disposal considerations need to be accounted for prior to its application, due to the foam's one-time use characteristics.

5. Identify Second and Third Order Effects (Alternative)

Second and third order effects are those that arise from the implementation of the alternative course of action and must be considered during the decision process. These effects may have financial or operational consequences for other DOD agencies or departments whose procedures may require modification when choosing the alternative course of action. Despite the cost savings from CCSF insulation, implementation of the alternative may result in contractor dependence, increased disposal costs, acquisition budget opportunity costs, loss in combat force mobility, and contractor retainer related costs and agreements.

a. Contractor Dependence

Contractor dependence from CCSF use increases due to the technical requirements associated with product application. Current military personnel do not possess the applicable skill sets or the organic equipment required for CCSF application or handling.

b. Disposal Costs

The U.S. military will incur additional disposal costs associated with the disposal or removal of CCSF structures. Current disposal costs for unfoamed structures are minimal, due to their ability to be turned over to the host nation or redeployed with U.S. forces due to their expeditionary nature. Tents become semipermanent when foamed, requiring disposal in accordance with host nation environmental policies and regulations.

c. Acquisition Budget Opportunity Cost

Funds associated with the procurement and sourcing of CCSF contracts remove funding resources available from other DOD programs of record. Prioritization of program requirements is necessary to offset the resulting impacts to other programs competing for funding. Despite the expected cost savings resulting from the decrease in fuel demand, fuel savings will not be directly reallocated to the acquisition budget.

d. Lost Mobility

CCSF application removes the expeditionary functionality of the structure (e.g., frame tents, GP-M, GP-L). As a result, additional tents are required to be held in reserve to meet expeditionary requirements of the respective units. Additionally, foamed structures are unable to be redeployed and/or reused once established. CCSF implementation will increase the overall DOD procurement and on-hand inventory levels of tents required by expeditionary forces.

e. Contractor Retainer

CCSF component shelf life and storage requirements mandate just-in-time sourcing, making inventory stockpiling and prepositioning of materials impractical. Additionally, specialized CCSF application equipment is required and thus does not justify the capital expenditures for the DOD. Due to these reasons, it is cost beneficial to the DOD to maintain CCSF contractors on a retainer to provide needed services to support mission requirements, as they arise.

f. CCSF Safety Training

Current military doctrine and training does not cover the hazards associated with CCSF-insulated structures. CCSF requires specific safety precautions during application and while occupying the structures. As such, additional time and resources are required to ensure safe and proper use of the foamed structures.

E. STEP 4: IDENTIFY AND ESTIMATE QUANTIFIABLE AND NONQUANTIFIABLE COSTS

This section examines the quantifiable and nonquantifiable costs associated with the alternative course of action: the application of CCSF insulation to the three tent structures. Costs are categorized as quantifiable and nonquantifiable. Market valuation methods are used to determine quantifiable financial costs. Examples of quantifiable financial costs include structure and structure component costs, and CCSF foam application costs. Nonquantifiable costs are those that cannot be measured numerically, but are incurred at the expense of CCSF implementation and integration into existing construction practices.

1. Quantifiable Costs

Quantifiable costs associated with CCSF implementation include the material, application, and structure replacement costs. Material costs are determined by the quantity of CCSF materials, stipulated by the CCSF contract, and the market valuation of the materials such as price per square foot. Application costs are those that include the transportation, labor, and physical application of CCSF insulation associated with the designated structures. Structure replacement costs are those that result from the anticipated or planned duration of use of the tent structures in the combat environment. If combat use exceeds the structure's useful life, structure replacement is necessary and incurs additional costs to meet the combat requirements.

a. Material Costs

Structure material expenditures are included as a quantifiable cost due to their unrecoverable nature and need for replacement after CCSF application. Including structure material costs into the CBA ensures that maximum costs are analyzed representing a worst-case scenario. Structure material costs per unit were retrieved from the DLA–DLIS, found at www.dlis.dla.mil/webflis, using their respective NSNs. Tent component costs were also retrieved from the DLIS website to account for replacement costs associated with standard tent use, maintenance, and the component's operational field life. Tent component NSNs were extracted from their respective technical manuals. Tent costs are summarized in Table 7.

Tent Component Costs		
Component	**NSN**	**Cost (2015BY$)**
Frame Tent (Complete)	8340-00-880-2622	$1,365
Frame Tent (Cover)	8340-00-753-6570	$964
GP-M (Complete)	8340-01-329-7478	$2,579
GP-M (Cover)	8340-01-477-9567	$1,250
GP-L (Complete)	8340-01-329-7479	$4,003
GP-L (Cover)	8340-00-285-5596	$2,280

Table 7. Tent component costs
(after Defense Logistics Agency [DLA], 2015).

Once foamed, the original tent cover material becomes permanently bonded to the CCSF insulation, rendering it unusable. The original internal framing components of the respective tents can be reused and are unaffected by the foam application. Thus, the only consumable component expended during foam application is the respective tent covering.

b. Foam Application Costs

Foam application costs were derived from AMSAA Cost Analysis Study data, using the 2009 EITS contract of $95 million (2008BY$) to foam approximately 13.5 million square feet of external structure surface area (Foulkner & Wilke, 2010). Foam cost per square foot is calculated as:

- Foam cost/sq ft = 2009 EITS contract price (2008BY$)/Contract-stipulated square footage to be applied with CCSF insulation = Price/sq ft (2008BY$).
- Foam cost/sq ft = $95,000,000 (2008BY$)/13,500,000 sq ft = $7.04/sq ft (2008BY$).

Adjustment for inflation from 2008 BY dollars to 2014 BY dollars was calculated using the joint inflation calculator (JIC) from the Naval Center for Cost Analysis. The calculation utilized the Military Construction Army Appropriation/Cost Element, converting from 2008 BY dollars to 2014 BY dollars yielding and an inflation factor of 1.1212. Foam price per square foot equaled $7.90 (2014BY$). Foam costs per square foot include those associated with transportation (air, sea, and ground), material storage, application, and project management. Foam costs per tent were based on the total external surface area requiring application (see Table 8).

Tent Structure Types and Characteristics			
Structure Type	**Material Type**	**Internal Footprint (sq ft)**	**Total External Surface Area (sq ft)**
Frame Tent	PVC Fabric	660	1,533
GP-M	PVC Fabric	666	1,575
GP-L	PVC Fabric	999	2,193

Table 8. Tent Structure Types and Characteristics (after Foulkner & Wilke, 2010).

Calculating foam application cost per tent structure is accomplished by multiplying the cost per square foot of foam, $7.90, by the respective external surface areas of the three tents. Foam application costs range from $12,111 for a frame tent, to $17,325 for a GP-L. Table 9 summarizes the foam application costs per structure.

CCSF Application Costs per Structure			
Structure Type (each)	**Internal Footprint (sq ft)**	**Total Surface Area (sq ft)**	**Foam Application Cost (2014BY$)**
Frame Tent	660	1,533	$12,111
GP-M	666	1,575	$12,443
GP-L	999	2,193	$17,325

Table 9. CCSF application costs per structure (after Foulkner & Wilke, 2010).

c. Structure Replacement Costs

The useful life of the three tent structures analyzed during this CBA can vary, depending on deployment locations, environmental factors, and anticipated use. This analysis assumed a three-year useful life for unfoamed tents and a five-year useful life for foamed tents. Useful life duration assumptions are required to conduct an analysis of the potential quantifiable financial benefits associated with CCSF application. CCSF insulation application extends the useful life of the tent structure by covering the exterior material with a weather-resistant, elastomeric coating. Once fully cured, CCSF insulation materials are relatively inert, yielding negligible changes in physical properties over time. CCSF insulation reduces damage and degradation commonly caused by direct sun and ultraviolet exposure, moisture intrusion (liquid and gas form), extreme temperature fluctuations, and airborne hazards such as soil, sand, rock, and other materials. Additionally, CCSF insulation adds structural rigidity to the existing structure, making it less susceptible to failure from high wind forces. Useful life extension reduces replacement costs associated with the tent cover and/or structural members.

Table 10 shows a comparison of the cumulative replacement costs between the unfoamed and foamed tents over a 12-year period. The 12-year analysis period is chosen to show the total cumulative replacement costs based on historical Iraq and Afghanistan mission durations. Replacement costs of unfoamed tents include the tent covering and internal structural components. Replacement costs for the foamed tents include the tent covering and the cost to reapply the CCSF insulation. Internal structural components are assumed to be recoverable and reusable for foamed structures. Foam costs are based on the tent’s external square footage, multiplied by the cost per square foot of foam insulation. From a structure materials cost perspective, unfoamed tents are less expensive to replace than their foamed counterparts, despite the increase in useful life of the foamed variant.

Cumulative Structure Replacement Material Costs (2015FY$)					
Tent Type (each)	**1-Year Replacement Costs**	**3-Year Replacement Costs**	**6-Year Replacement Costs**	**9-Year Replacement Costs**	**12-Year Replacement Costs**
Frame Tent - Unfoamed	$0	$1,365	$2,730	$4,095	$5,460
GP-M - Unfoamed	$0	$2,579	$3,944	$5,309	$6,674
GP-L - Unfoamed	$0	$4,003	$5,368	$6,733	$8,098
Frame Tent - Foamed	$0	$12,111	$25,186	$25,186	$38,261
GP-M - Foamed	$0	$12,443	$25,850	$25,850	$38,925
GP-L - Foamed	$0	$17,325	$35,614	$35,614	$48,689

Table 10. Cumulative structure replacement material costs (2015BY$) – 12-year analysis.

2. Nonquantifiable Costs

Nonquantifiable costs associated with CCSF implementation include location-specific disposal costs, construction time and design modification-related costs, costs associated with loss of structure mobility, DOD-wide safety and training implementation costs, and opportunity costs that arise from alternative use of financial resources. Since these costs are situationally dependent, they cannot be accurately determined at the time of implementation but require consideration during the decision-making process.

a. Disposal Costs

Disposal costs may constitute the largest cost burden associated with CCSF insulation application. These costs are based on structure location at the time of disposal and local regulations and/or capabilities (e.g., landfill or incinerator), thus making them only quantifiable when location and corresponding environmental regulations are known. Disposal costs, if not conducted organically by the U.S. military, depend on host-nation disposal fees. If CCSF material is organically disposed of, costs associated with the operation of the incinerator represent the disposal costs. Such costs may be irrelevant if the existing CCSF structures are turned over to host-nation representatives for future use.

The semipermanent nature of the CCSF insulated tents also incurs costs associated with deconstruction. Costs such as additional labor and equipment (i.e., front loaders, cutting equipment, dump trucks, etc.) are required for their disassembly and removal if conducted by nonorganic, nonmilitary sources, such as government-contracted companies or host-nation personnel.

b. Construction Time/Design Modifications

CCSF insulation requires dedicated substrate preparation, application, and cure time, depending on the desired insulating properties of the end product. Application times vary depending on the structure size and the desired foam thickness, which is driven by R-value requirements. Additional temporary structures are required for personnel berthing during CCSF application, due to a minimum 24-hour wait time required prior to structure occupancy. The additional structure requirement increases inventory and maintenance costs associated with CCSF implementation.

Traditional tent structures also require modification prior to CCSF application. When cured, the foam’s rigidity prevents the use of the tent’s standard egress doors. As such, two wooden vestibules with traditional doorways are installed prior to foam application to meet military fire safety standards, which increases construction costs. Specific structure modification costs depend on the materials used (e.g., vestibule and door materials) and the type of tent structure employed. Due to the different materials required by each type of structure, and various sourcing options of those materials in forward-deployed locations, definitive cost numbers are unavailable.

c. Structure Mobility

Traditional military tents are designed to be erected and disassembled in a 24-hour period, yielding a highly mobile and temporary structure. Because CCSF insulation bonds to the substrate to which it is applied (i.e., the outer tent lining), foamed tents become semipermanent once constructed and the outer tent lining becomes unusable for future use. Units may require a reserve of spare tents to maintain mobility requirements in the event that operations dictate relocation to an area without established, suitable berthing and operating structures. The requirement for redundant structures increases the inventory and holding costs associated with the increase in the unit's MTOE.

d. Implementation Costs – Safety, Training, and Doctrine

Safety: CCSF creates inherent safety hazards for the end user that must be considered. After the application, all exterior panels of the tent structure become rigid making fire safety, egress, and air quality and inspection requirements similar to those of a permanent-type structure. This requires DOD components to implement safety standards and training measures to mitigate the additional risk, while ensuring compliance with structure occupancy regulations and standards. DOD components utilizing CCSF structures must incorporate safety and health quality measures that meet minimum standards, as outlined in the applicable Safety of Use Messages (SOUM) (U.S. Army Corps of Engineers [USACE], 2010). Additionally, SOUMs require that quarterly, or force turnover, inspections are conducted and records maintained for two years; but, it does not stipulate the required qualifications of inspecting personnel. Additional personnel requirements to inspect compliance with published standards may incur additional costs associated with CCSF implementation. While SOUMs provide general guidance regarding safety, air quality, inspection, and record-keeping requirements, several variables present difficulties in quantifying the costs associated with safety standards implementation and training.

Monitoring: The EPA and OSHA have clearly identified health concerns associated with CCSF application, primarily focused on component chemical exposure and reentry periods after the application. While there are laws, rules, and regulations in place to address health concerns associated with CCSF exposure, long-term exposure health impacts have yet to be determined. These variables prohibit determining the costs associated with long-term monitoring for health and safety.

Use Training: Individual DOD components will be required to develop appropriate training in compliance with the policy governing CCSF use. A reasonable expectation would be to utilize online training venues such as Navy Knowledge Online and Army Knowledge Online, in the same manner that personnel are required to complete annual general military training (GMT) and predeployment training requirements. Until official policy is established incorporating CCSF as part of the DOD's energy policy, the costs associated with additional training are difficult to quantify.

e. Opportunity Costs

Decreased budget flexibility for operational commanders represents a major opportunity cost if policy directs CCSF implementation in forward-deployed locations. Foam application to forward-deployed structures requires upfront costs that reduce fiscal resources from other mission-related expenditures. CCSF opportunity cost may increase, as DOD budgets decrease, forcing commanders to make trade-offs.

Despite the fact that CCSF implementation reduces total fuel expenditures, financial resources saved may not be reprogrammable due to congressional appropriations and authorization constraints (i.e., the "color of money"). DESC purchases fuel for the DOD under separate budget appropriations; therefore, saved financial resources may not be reallocated to operational DOD budgets or be recouped by the operational commanders implementing CCSF insulation. Additionally, this may deter upfront investment in CCSF implementation. Without increased funding for CCSF usage, operational commanders are required to weigh the opportunity costs based on mission needs, and not the overall benefits from CCSF.

Opportunity costs also exist beyond the financial affect. In both Iraq and Afghanistan, host-nation contractors regularly provide labor forces to build semipermanent berthing structures for deployed forces, creating jobs for the local populace, which injects money into the local economy. Host-nation contractor employment builds goodwill and support for U.S. troops with local communities. If CCSF installation is U.S.-contractor sourced, it may reduce the need for host-nation support and affect goodwill and overall host-nation support of U.S. activities. Removal of certain host-nation support may impact the effectiveness of U.S. military objectives in the localized AORs. This lost opportunity cost may escalate wherever U.S. presence is a divisive issue within the host-nation populations.

F. STEP 5: IDENTIFY AND ESTIMATE QUANTIFIABLE AND NONQUANTIFIABLE BENEFITS

This section examines the quantifiable and nonquantifiable benefits associated with the alternative course of action—the application of CCSF insulation to the three tent structures. Market valuation methods are used to determine quantifiable financial benefits. Examples of quantifiable financial benefits include cost savings and/or avoidance, and productivity improvements. Nonquantifiable benefits are those that cannot be captured numerically, but provide an overall identifiable benefit as a result of the chosen course of action.

1. Quantifiable Benefits

Quantifiable benefits associated with CCSF implementation include the financial saving realized from the reduction in fuel use, transportation, and storage, and the reduction in required generator quantities and sizes. These benefits can be measured in financial terms and projected over that anticipated duration of CCSF use and employment on the battlefield.

a. Fuel Savings

Reduced fuel use is the major quantifiable benefit realized by the application of CCSF insulation. Increased R-values provided by CCSF reduces energy loads associated with the ECUs necessary to maintain internal temperatures and air-flow requirements of the respective tent structures. Table 11 summarizes the average annual fuel consumption of the three respective tents without CCSF insulation and the annual fuel costs dependent on the price per gallon of fuel. Annual fuel consumption in gallons is 10,573, 10,600, and 14,488 for frame tents, GP-M tents, and GP-L tents, respectively (Foulkner & Wilke, 2010).

Annual Average Fuel Consumption Costs per Tent (2014BY$)				
	Annual Fuel Consumption (gal)	**Standard Price of $3.70/gal JP-8**	**FBCF Price (Low End) of $16.00/gal JP-8**	**FBCF Price (High End) of $34.90/gal JP-8**
Frame Tent	10,573	$39,120	$169,168	$368,997
GP-M	10,600	$39,220	$169,600	$369,940
GP-L	14,488	$53,606	$231,808	$505,631

Table 11. Annual fuel consumption cost per tent (after Foulkner & Wilke, 2010).

The standard price of JP-8 was retrieved from the FY2015 DESC website, http://www.energy.dla.mil/customers/standard_prices/Pages/default.aspx, under "DLA Energy Standard Prices." This price is the standard price charged to DOD customers regardless of the transportation requirements and costs to the end user.

The low-end FBCF price of $13.80 (2008BY$) was derived from the AMSAA Study (Foulkner & Wilke, 2010). The adjustment for inflation from 2008 to 2014 BY dollars was calculated using the JIC from the Naval Center for Cost Analysis. The calculation utilized the drop-down category "Fuel for all services (OSD Cost Element)," yielding an inflation factor of 1.1619. The FBFC equaled $16.00 in 2014 BY dollars.

The high-end FBCF price was also derived from the AMSAA study, which recommended an FBCF range from $10.00 to $30.00 (2008BY$) (Foulkner & Wilke, 2010). This analysis used the $30.00 FBCF price as the high-end fuel cost. The adjustment for inflation from 2008 to 2014 BY dollars was also calculated using the JIC from the Naval Center for Cost Analysis. The calculation utilized the drop-down category "Fuel for all services (OSD Cost Element)," yielding an inflation factor of 1.1619. The FBFC equaled $34.90 in 2014 BY dollars.

Table 12 compares the average annual fuel consumption of the three tent structures prior to and after CCSF application. CCSF insulation resulted in an average fuel consumption savings of approximately 59.25% from the uninsulated structures. Assuming that fuel is transported in 5,000-gallon tankers, the annual fuel savings from a single-frame, or GP-M, tent equates to the removal of one fuel truck from resupply convoys annually, and two for a GP-L tent. Fuel truck removal corresponds to the number of convoys required to support combat operations in forward-deployed locations.

Annual Average Fuel Savings per Tent (Iraq and Afghanistan)			
	Tent w/o Foam Consumption (gal)	**Foamed Tent Consumption (gal)**	**Fuel Consumption Savings (gal)**
Frame Tent	10,573	4,652	5,921 (56%)
GP-M	10,600	4,664	5,936 (56%)
GP-L	14,488	5,215	9,272 (64%)

Table 12. Average fuel consumption change due to foam application (after Foulkner & Wilke, 2010).

Fuel consumption savings, in 2014 BY dollars, are directly related to the price of fuel. Annual fuel savings from CCSF-insulated tents ranged from approximately $22,000 to $35,500 dollars per structure, using the 2014 standard price of JP-8 (see Table 13). The DOD uses the standard price of fuel during budget formulation; therefore, these savings will directly affect the budgeted line items associated with fuel cost and consumption. When using the FBCF price, which includes all costs associated with delivery to the end user, the savings translate to those realized by the operational commanders in forward-deployed locations.

Average Annual Fuel Savings per Foamed Tent (2014BY$)				
	Fuel Consumption Savings (gal)	**Standard Price of $3.70/gal JP-8**	**FBCF Price (Low End) of $16.00/gal JP-8**	**FBCF Price (High End) of $34.90/gal JP-8**
Frame Tent	5,921	$21,907	$94,736	$206,643
GP-M	5,936	$21,963	$94,976	$207,166
GP-L	9,272	$35,416	$148,352	$323,593

Table 13. Annual cost savings per foamed tent (after Foulkner & Wilke, 2010).

2. Net Present Value

NPV represents the current value of money saved, as a result of fuel savings, over the assumed useful lives of the tent structures. Expected useful life and deployment durations of the tent structures are assumed to be between three and seven years. In accordance with the published *2014 Discount Rates for OMB Circular No. A-94*, –0.03% three-year and 0.0% five-year discount rates were used to calculate NPVs for the three- and five-year employment durations. In this calculation, “cash flow” represents the annual fuel cost savings, depending on the fuel price (e.g., standard price, FBCF low end, and FBCF high-end).

NPV (annuity) = (CF/r) * (1- $(1/(1+r)^t)$ – initial foam application cost

NPV = Net present value (2014BY$)

CF = Cash flow (fuel savings in dollars) (BY$)

r = Discount rate

t = Time period in years

Table 14 shows the net present value of savings per structure over a three-year period. Three-year useful life is chosen to represent the low-end expected use of foamed tents in forward-deployed locations. Using the FY 2014 standard price of JP-8, NPV savings ranged from $54,008 to $86,215, per structure, over a three-year period. From an operational standpoint, the NPV savings realized by using the high-end FBCF resulted in a savings ranging from $611,556 to $959,307, per structure, over a three-year period.

Three-Year NPV at –0.03% Discount Rate					
	Fuel Consumption Savings (gal)	**Foam Application Costs**	**NPV of Annual Savings at Standard Price of $3.70/gal JP-8**	**NPV of Annual Savings at FBCF of $16.00/Gal JP-8 (low end)**	**NPV of Annual Savings at FBCF of $34.90/Gal JP-8 (high end)**
Frame Tent	5,921	$12,111	$54,008	$273,811	$611,556
GP-M	5,936	$12,443	$53,844	$274,203	$612,804
GP-L	9,272	$17325	$86,215	$430,415	$959,307

Table 14. NPV of fuel savings per foamed tent (over a three-year period).

Table 15 shows the net present value of savings per structure over a five-year period. Five-year useful life is chosen to represent the average expected use of foamed tents in forward-deployed locations. Using the FY 2014 standard price of JP-8, NPV savings ranged from $97,428 to $154,207, per structure, over a five-year period. From an operational standpoint, the NPV savings realized by using the high-end FBCF resulted in a savings ranging from $1,021,104 to $1,600,639, per structure, over a five-year period

Five-Year NPV at 0.0% Discount Rate					
	Fuel Consumption Savings (gal)	**Foam Application Costs**	**NPV of Annual Savings at Standard Price of $3.70/gal JP-8**	**NPV of Annual Savings at FBCF of $16.00/Gal JP-8 (low end)**	**NPV of Annual Savings at FBCF of $34.90/Gal JP-8 (high end)**
Frame Tent	5,921	$12,111	$97,428	$461,569	$1,021,104
GP-M	5,936	$12,443	$97,373	$462,437	$1,023,389
GP-L	9,272	$17325	$154,207	$724,435	$1,600,639

Table 15. NPV of fuel savings per foamed tent (over a five-year period).

a. Fuel Delivery Reduction and Associated Fuel Savings

Fuel-demand reduction resulting from CCSF will reduce fuel truck deliveries needed to sustain operations. Historically, 2,500-gallon- and 5,000-gallon-capacity fuel trucks are used to transport fuel to various locations throughout the battlefield. This analysis looked at two types of commonly used U.S. Army fuel trucks: the M978 A4 Heavy Expanded Mobility Tactical Truck (HEMTT) and the Medium Tactical Vehicle Replacement (MTVR) Mk 31, a seven-ton tractor truck with a fuel tank (see Figures 15 and 16). Table 16 summarizes the vehicles' characteristics and unit costs.

Figure 15. M978 A4 Heavy Expanded Mobility Tactical Truck (HEMTT); a 2,500-gallon tanker (from Basic Concepts Inc., 2015).

Figure 16. Oshkosh Wheeled Tanker (Medium Tactical Vehicle Replacement (MTVR) Mk 31 7-Ton Tractor Truck with Tank) (from Military-Today.com, 2015).

	NSN	Unit Cost (2015BY$)	Normal Operating Range	Miles per gallon (mpg)
M978 A4 (HEMTT)	2320-01-097-02490	$396,130	300 miles	~2
MK 31 (MTVR)	2320-01-552-2762	$181,000	300 miles	~3.8
MTVR 5,000-gal fuel trailer	2330-01-155-0048	$90,610	None	None

Table 16. U.S. Army Fuel Truck Characteristics (after Cooke, 2008; after Jean, 2011).

Table 17 summarizes the annual fuel truck reduction per structure from the application of CCSF insulation. To demonstrate the potential effect of CCSF insulation on fuel-truck reduction, the living requirements of a standard deployed combat unit, a U.S. Army infantry company, were analyzed. Maximum personnel occupancy per tent was determined using the CENTCOM “Sand Book,” which dictates a minimum berthing requirement of 80 square feet per soldier in the CENTCOM AOR. Assuming that a typical U.S. Army infantry company is comprised of 100 personnel, nine GP-L tents are required for berthing. CCSF application to the nine tents reduces fuel consumption by 16.65 (9 x 1.85) 5,000-gallon fuel trucks or 33.4 (9 x 3.71) 2,500-gallon fuel deliveries annually.

Individual Structure Annual Fuel-Truck Reduction from CCSF Insulation			
	Fuel Consumption Savings (gal)	**# of 2,500-gal Fuel Deliveries Reduced (i.e., HEMTT)**	**# of 5,000-gal Fuel Deliveries Reduced (i.e., MTVR)**
Frame Tent	5,921	2.37	1.18
GP-M	5,936	2.37	1.19
GP-L	9,272	3.71	1.85

Table 17. Individual structure annual fuel-truck reduction from CCSF insulation.

The decrease in fuel deliveries translates to fewer miles traveled and less fuel required for fuel-transporting assets (i.e., fuel trucks). The savings depends on the type of structures used, number of structures employed, miles traveled to FOB locations, and miles per gallon of the transporting asset. Based on an average, 300-mile, normal operating range of the MTVR and HEMTT, maximum one-way travel distance was limited to 120 miles during the analysis, while reserving 20%, or 60 gallons, to account for unexpected travel and/or combat circumstances. Tables 18 and 19 show the approximate fuel savings from reduced fuel deliveries, depending on the transportation asset, a maximum distance from the origin of 120 miles, and a JP-8 standard price of $3.70 (FY 2014) per gallon.

Estimated Cost Savings from Fuel-Delivery Reduction (2014 BY dollars) - HEMTT						
Tent Type (each)	**# of 2,500-gal Fuel Deliveries Reduced**	**Round Trip Distance (miles)**	**Total Miles Saved**	**Total Gallons Saved (3.9 mpg)**	**Savings per Tent ($3.70/gal - Std. Price)**	**Savings per Tent ($34.90/gal - FBCF)**
Frame Tent	2.37	240	568.8	145.8	$540	$5,090
GP-M	2.37	240	568.8	145.8	$540	$5,090
GP-L	3.71	240	890.4	228.3	$845	$7,968

Table 18. Estimated annual cost savings from fuel-delivery reduction (2014BY$) – HEMTT.

Estimated Annual Cost Savings from Fuel-Delivery Reduction (2014 BY dollars) – MTRV						
Tent Type (each)	**# of 5,000-gal. Fuel Deliveries Reduced**	**Round Trip Distance (miles)**	**Total Miles Saved**	**Total Gallons Saved (2 mpg)**	**Saving per Tent ($3.70/gal - Std. Price)**	**Saving per Tent ($34.90/gal - FBCF)**
Frame Tent	1.18	240	283.2	141.6	$524	$4,942
GP-M	1.19	240	285.6	142.8	$528	$4,984
GP-L	1.85	240	444	222	$821	$7,748

Table 19. Estimated annual cost savings from fuel-delivery reduction (2014BY$) – MTVR.

b. Generator Reduction/Right Sizing

Generator sets are the largest fuel consumers at forward-deployed locations, with ECUs drawing the largest energy demand. As a result, ECU reduction leads to load and power reduction. Generator fuel inefficiencies arise from numerous variables that include varying demand loads, under-loading, overloading, number of start-ups, operating altitudes, ambient temperatures, and fuel type. Under-loaded generators run inefficiently; therefore, matching the generator set size to the expected load is necessary to maximize fuel efficiencies. Additionally, higher load demands require larger generator sets, which increase associated fuel costs and generator procurement costs.

Reduced energy demand resulting from ECU reduction enables localized power grids to operate with fewer and smaller generators at optimal load levels. Reduction in generator size and amounts has additional cost savings related to their operation, maintenance, and transportation requirements.

Based on performance data from Iraq and Afghanistan, the AMSAA analyzed energy loads required by the three foamed and unfoamed structures, and calculated that the fuel consumption rates for “10kW, 15kW, 30kW, 60kW, 100kW, and 200kW sized tactical quiet generators” (Foulkner & Wilke, 2010, p. 15). Generator size requirements per structure are determined from the maximum electrical demand in kilowatts (kW), accounting for mission and start-up loads, as seen in Table 20 (Foulkner & Wilke, 2009). CCSF application reduced the size of the generators required to power the respective tent structures. For example, a single, unfoamed frame tent requires one 30kW generator, based on the maximum load of 22.6kW. The comparable foamed frame tent only requires a 10kW generator, based on a maximum load of 4.3kW, as a result of reduced ECU power demand. The decrease in ECU power demand equates to smaller generators required to power berthing structures.

Structure Type	Average Unfoamed Generator Set Requirements			Average Foamed Generator Set Requirements		
	Maximum kW	Average kW	Generator Set	Maximum kW	Average kW	Generator Set
Frame Tent	22.6	6.7	30kW	4.3	3.0	10kW
GP-M	23.0	6.8	30kW	4.4	3.1	10kW
GP-L	32.1	9.3	60kW	6.0	4.1	10kW

Table 20. Tent generator size requirements (after Foulkner & Wilke, 2009).

In addition to smaller generator size, CCSF application reduced the quantity of generators required to power berthing structures. Table 21 shows the quantity of generators required to power the unfoamed and foamed tent structures. Based on maximum-kW, an unfoamed frame tent requires 2.26 10kW generators to provide adequate power, compared to its foamed counterpart that only requires 0.43 10kW generators. As the example shows, one 10kW generator can support the electrical demand of two foamed frame tents, compared to its single, unfoamed counterpart, which requires a minimum of one 30kW generator. CCSF application allows for either the reduction in generator size or an increase in the number of tent structures supported by an individual generator.

Structure Type	Generator Set Requirements – Unfoamed				Generator Set Requirements – Foamed			
	Maximum kW	10kW	30kW	60kW	Maximum kW	10kW	30kW	60kW
Frame Tent	22.6	2.26	0.75	0.38	4.3	0.43	0.14	0.07
GP-M	23.0	2.30	0.77	0.38	4.4	0.44	0.15	0.07
GP-L	32.1	3.21	1.07	0.54	6.0	0.60	0.20	0.10

Table 21. Tent generator requirements (after Foulkner & Wilke, 2009).

The reduction in both generator size and generator quantity equates to greater generator configuration options and a reduction in overall procurement costs. Table 22 shows the procurement costs (2015FY$) of 10kW, 30kW, and 60kW Tactical Quiet Generator sets from the DLIS website.

Generator Set	Generator Set Cost (2015FY$)	
	NSN	Cost
10kW	6115-00-033-1389	$12,102
30kW	6115-01-462-0290	$24,334
60kW	6115-01-274-7390	$25,073

Table 22. Generator set procurement costs (after DLA, 2015).

To show cost savings from generator reductions, the berthing requirements of a standard deployed combat unit, a U.S. Army infantry company comprised of approximately 100 personnel, was chosen again. Table 23 shows the maximum load demanded by the required nine GP-L tents in kW. The number of 10kW, 30kW, and 60kW generators required to power both the unfoamed and foamed tents were calculated by dividing the maximum kW by the generator size in kW. The number of generators required was then multiplied by the respective generator procurement costs to arrive at a total generator cost to power the nine tents. For the unfoamed tents, the most economical quantity and size of generators equaled five 60kW generators costing $125,365 (2015FY$). For the foamed tents, one 60kW generator, costing $25,073 (2015FY$), is capable of meeting the reduced energy demand of the nine tents due to CCSF application. This example shows the cost savings that CCSF insulation has on generator configurations needed to support berthing structures.

	Gen. Set Requirements - Unfoamed				Gen. Set Requirements - Foamed			
	Max kW	10kW Gen. Required	30kW Gen. Required	60 kW Gen. Required	Max kW	10kW Gen. Required	30kW Gen. Required	60kW Gen. Required
GP-L	288.9	28.89	9.63	4.82	54.0	5.40	1.80	0.90
Generator Cost		$349,627	$234,336	$120,726		$65,351	$43,801	$22,566
GP-L (rounded)	288.9	29	10	5	54.0	6	2	1
Generator Cost		$349,627	$243,340	$125,365		$72,612	$48,668	$25,073

Table 23. Generator configuration and procurement costs for nine GP-L tents.

3. Nonquantifiable Benefits

Nonquantifiable benefits associated with CCSF implementation are those that cannot be represented in financial terms and depend on the situational employment of CCSF insulation. They include increased quality of life and morale for combat personnel, increased structure physical protection characteristics, reduced fuel transportation asset requirements, reduced convoy operations, and reduced convoy-related casualties. Identifying and considering these nonquantifiable benefits during the decision-making process enables leadership to determine the best course of action that will satisfy their operational requirements or goals.

a. Quality of Life/Morale

Quality of life increases overall morale for deployed units and provides important benefits to commanders. Deployed personnel are exposed to battlefield stress stemming from mission hazards, separation from family, and lack of sleep. CCSF provides a vast improvement in the quality of life for deployed personnel through improved air quality, temperature control, and noise reduction.

Typical military GP tents provide limited protection to personnel from environmental elements such as wind, rain, dust, and drastic temperature variation. CCSF application minimizes the penetration of airborne particulates and hazards, thus increasing the overall air quality inside the structure. Improved indoor air quality gives deployed military commanders personnel that are rested and less susceptible to adverse health risks.

While forward-deployed structures utilize ECUs to control internal temperatures, military tents struggle to maintain stable interior temperatures. In extreme heat or cold, ECUs operate at capacity to maintain livable environments. CCSF application enables efficient ECU operation, temperature regulation, and stability for the structures' inhabitants, thereby significantly improving the quality of life for deployed personnel.

Ambient noise can be a major inhibitor to personnel sleep cycles in deployed environments. Current military tent structures provide very little to no protection from ambient noise. CCSF insulation provides a barrier from ambient noise, limiting disruption of rest and recovery periods. Increased sleep and rest is a significant quality of life improvement, resulting in more combat-effective and ready personnel.

b. Structure Protection (Ballistic)

The increasing casualty rates suffered by U.S. personnel during the early years of the Iraq campaign resulted in the acquisition of various personnel protective technologies. While the focus of this research project is on energy savings related to CCSF, this product offers additional benefits related to ballistic protection, as described in Chapter II.

Honeywell International, Inc. has developed, and is currently seeking patent protection for, several blast mitigation and suppression systems that incorporate the use of TERRAStrong II spray polyurethane foam the trademarked product owned by Honeywell and used during the 2008 Iraq EITS contract. The CCSF product is described in the patent application as a material that helps dissipate the effects of explosive blast waves when applied to the undercarriage of armored vehicles. Possible CCSF blast mitigation properties warrant further research as to how they would apply to forward-deployed berthing structures.

c. Reduced Fuel Truck Inventories and Associated Life-Cycle Costs

Reduction in fuel consumption to support base activities may reduce the inventory of fuel trucks required in forward-deployed locations. Additionally, CCSF application may also reduce the required number of fuel trucks carried in the current DOD inventory. Less fuel consumption translates to fewer assets required. The reduction in the DOD fuel truck inventory will decrease the costs associated with vehicle storage, operation, transportation, maintenance, and future replacement costs (i.e., life-cycle costs).

d. Convoy Reduction

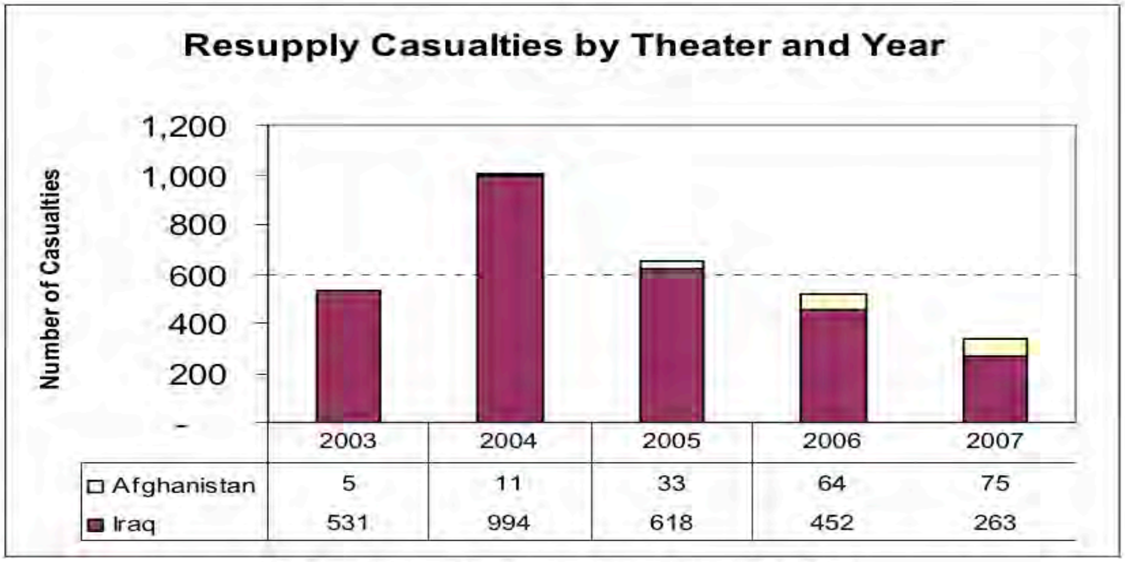
CCSF application reduces the amount and size of fuel convoys necessary to support base activities, thereby reducing the overall costs of convoy operations. Fuel convoy costs include purchase, operation, and maintenance of the transportation assets, protection assets (personnel and combat equipment), and personnel required to support and coordinate the movements. Many of these costs are only quantifiable when mission-specific details are identified. Some examples of benefits relating to convoy reduction are:

- Reduced asset base required to conduct convoys (i.e., fuel trucks, maintenance, deprecation, replacement, etc.).
- Reduced manpower associated with convoy planning, coordination, and control.
- Reduction of soft targets on the battlefield (i.e., targets of opportunity).
- Reduced risk to military personnel and mission.
- Reduced reliance on contracted support (i.e., contracted vehicles and drivers).
- Reduced security assets and personnel tasked with convoy security.

e. Convoy Personnel Casualty Reduction

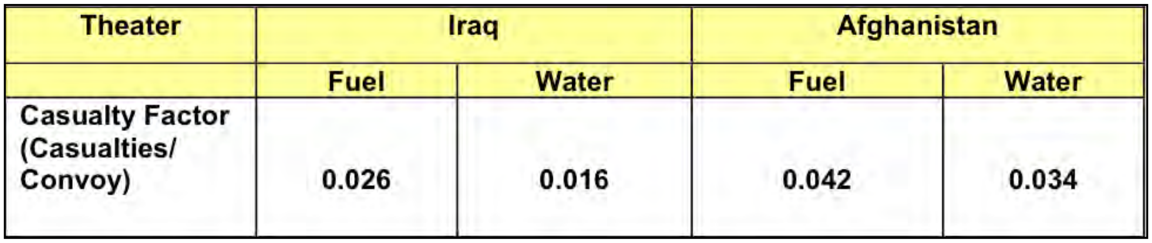
Casualties resulting from attacks on fuel convoys are related to the frequency of convoys conducted within a battlespace. According to the Center for Army Lessons Learned (CALL), "resupply casualties have historically accounted for about 10–12% of total Army casualties—the majority related to fuel and water transport" (Siegel, Bell, Dicke & Arbuckle, 2008, p. 9). The reduction of a single fuel convoy reduces the number of casualties associated with fuel use and its transportation to various outstations or FOBs. Although convoy casualties can be calculated based on historical data, it is difficult to predict convoy casualties associated with future operations. Such casualties depend on the nature of conflict, projected operating environment (permissive versus nonpermissive), distance traveled, levels of security assigned, and seasonal factors (i.e., weather, daylight duration, etc.).

In 2009, the AEPI conducted a study of historical casualty data from 2003 through 2007 to determine the casualty factors associated with fuel and water supply convoys (see Figure 17). Casualty factors were calculated using field data from convoy attacks and their resulting casualties in Iraq and Afghanistan. The analysis concluded that every fuel convoy removed from the road reduces the possible wartime casualties by 0.042 personnel in Afghanistan and 0.026 personnel in Iraq (see Table 24) (Siegel et al., 2008).



(Source: Center for Army Lessons Learned (CALL))

Figure 17. Resupply casualties by theater and year (from Siegel et al., 2008).



Theater	Iraq		Afghanistan	
	Fuel	Water	Fuel	Water
Casualty Factor (Casualties/ Convoy)	0.026	0.016	0.042	0.034

Table 24. Casualty factors Iraq and Afghanistan (2007) (from Siegel et al., 2008).

Situational variables surrounding convoy operations prevent the derivation of accurate quantifiable financial benefits resulting from convoy reduction. Further complicating the issue is the large variation in published fiscal estimations of the value of lives lost in combat. Despite the challenges to accurately capturing the financial benefits from loss of life, a rudimentary example can be made to show the generic effect that convoy reduction has on fuel convoy casualties. Since FOB sizes vary throughout the battlefield, a FOB located in Iraq consisting of 300 personnel (approximately three U.S. Army infantry companies) was chosen to demonstrate the possible effects of CCSF. Tent requirements were also calculated using the 80-square-foot-per-soldier requirement dictated by the CENTCOM “Sand Book.” The GP-L was again chosen as the preferred berthing structure to keep the analysis consistent with previous examples used during this CBA. Dividing the internal footprint of a GP-L (999 square feet) by the 80-square-foot-per-soldier requirement equated to a maximum occupancy of 12 personnel per tent. Twenty-five GP-L tents are required to satisfy the berthing requirements of the 300 FOB personnel.

Casualty numbers were determined by first calculating the annual fuel consumption of the 25 GP-L tents with and without CCSF. To determine the number of trucks required for fuel transport, the annual fuel consumption of the 25 tents was divided by 5,000 gallons, the capacity of a standard U.S. Army fuel truck. Using a worst-case scenario, it was assumed that each 5,000-gallon fuel truck requires its own convoy. Casualty numbers were determined by multiplying the number of convoys by the Iraq convoy casualty factor of 0.026 (from Table 24). From the above example, CCSF application results in a fuel convoy casualty reduction from 1.9 personnel for unfoamed structures to 0.7 personnel for foamed structures; a 63% casualty reduction. Tables 25 and 26 show the annual fuel convoy casualty numbers for the three tent structures (unfoamed and foamed), based on the calculations in the example above:

Estimated Annual Fuel Convoy Casualties (without CCSF)						
Tent Type (each)	**# of Tents Required**	**Annual Fuel Consumption/ Tent (gal.)**	**Total Annual Fuel Consumption (gal.)**	**# of 5,000-gal. Tankers Required**	**# of Convoys Required**	**Annual Casualties**
Frame Tent	38	10,573	401,774	80	80	**2.1**
GP-M	38	10,600	402,800	80	80	**2.1**
GP-L	25	14,488	362,200	72	72	**1.9**

Table 25. Estimated annual fuel convoy casualties, based on a 300-person unit (without CCSF).

Estimated Annual Fuel Convoy Casualties (with CCSF)						
Tent Type (each)	**# of Tents Required**	**Annual Fuel Consumption/ Tent (gal.)**	**Total Annual Fuel Consumption (gal.)**	**# of 5,000-gal. Tankers Required**	**# of Convoys Required**	**Annual Casualties**
Frame Tent	38	4,652	176,776	35	35	**0.9**
GP-M	38	4,664	177,232	35	36	**0.9**
GP-L	25	5,215	130,375	26	26	**0.7**

Table 26. Estimated annual fuel convoy casualties, based on a 300-person unit (with CCSF).

To provide a theater-wide example, the AEPI determined that, in 2007, 502,110,368 gallons of fuel was transported in Iraq to support combat operations (Eady, Siegel, Bell & Dicke, 2009). Of the total fuel transported, generators consumed approximately 65% or 326,371,739 gallons (502,110,368 gal. x 0.65) (AFCESA, 2010). Of the total fuel consumed by generators, approximately “80%” of fuel is used to power ECUs (AFCESA, 2010, p. 5), or 261,097,391 gallons (326,371,739 gal. x 8). AEPI calculated that the average fuel-carrying capacity of a convoy in Iraq in 2007 was approximately 97,818 gallons (16 trucks) (Eady et al., 2009), equating to 2,670 convoys (261,097,391 gal./97,818 gal./convoy) required to supply fuel solely to power ECUs. Using the casualty factor of 0.026 for fuel resupply convoys in Iraq, 69.42 casualties (2,670 convoys x 0.026) resulted from transporting fuel to power ECUs.

To show CCSF insulation’s effect on casualty reduction, the fuel used to power ECUs in the previous example is cut by 56%; the approximate average fuel savings realized by CCSF application to the three structures analyzed. This calculation assumes that all structures running ECUs equate to the same reduction in fuel consumption as the three tent structures analyzed during this study. The resulting total fuel consumption used to power ECUs was reduced to 114,882,852 (261,097,391 gal. x 0.56) gallons, requiring 1,175 fuel convoys (114,882,852 gal./97,818 gal./convoy). Using the casualty factor of 0.026 for fuel resupply convoys in Iraq, 30.54 casualties (1,175 convoys x 0.026) are attributed to fuel transportation to power ECUs. In this example, CCSF application resulted in a 56% reduction in casualties associated with fuel convoys.

Available published data regarding the Value(s) of a Statistical Life (VSL) vary. In 1993, Kip Viscus, from Duke University, estimated the VSL to be approximately $7,500,000 (Viscusi, 1993). In 2010, The U.S. Food and Drug Administration estimated the value of a life to be approximately $7,900,000 (Appelbaum, 2011). During the Bush Administration, the EPA published estimates ranging from $6,800,000 to $9,100,000 (Appelbaum, 2011). In 2014, the U.S. Department of Transportation provided their value of a life estimate of approximately $9,200,000 (U.S. Department of Transportation [DOT], 2014). Although various U.S. government agencies publish VSL estimates, the DOD refrains from publically assigning and publicizing dollar amounts to soldier's lives due to the sensitivity of the issue.

As the above data suggests, accurately determining the VSL is both complex and varying, depending on the factors involved in calculating a VSL. To show the hypothetical cost savings from convoy casualty reduction, the above estimates were used as the data set yielding a low-end estimate of $6,800,000, a high-end estimate of $9,200,000, and a mean VSL of $8,100,000. These estimates were used to calculate possible cost savings in human life, based on casualty reductions from CCSF implementation. Table 27 summarizes the possible cost savings resulting from casualty reduction using the above using 2007 Iraq fuel consumption and casualty factor data.

Casualty Cost Savings				
	Casualty Numbers	**Low-End Cost**	**Mean Cost**	**High-End Cost**
Without CCSF	69.42	$472,056,000	$562,302,000	$638,664,000
With CCSF	30.54	$207,672,000	$247,374,000	$280,968,000
Total Savings	38.88	$264,384,000	$314,928,000	$357,696,000

Table 27. Casualty cost savings.

G. STEP 6: DEFINE ALTERNATIVE SELECTION CRITERIA

This step identifies and describes the alternative selection criteria for the decision-making process. The chosen alternative selection is based on the assumed importance factors of a geographic combatant commander or joint force commander in forward-deployed combat zones. Selection criteria include both financial and nonfinancial factors, tailored to the problem statement, as they relate to the two courses of action: the status quo and the alternative.

1. Financial Selection Criteria

ROI, NPV, and BEP were chosen as financial selection criteria for this analysis due to their ability to capture the financial benefits from CCSF implementation. All three financial measures analyze the financial benefits over varying time durations, fluctuations in material and fuel prices, and changes in discount rates dictated by the Office of Management and Budget.

a. Return on Investment

For this analysis, ROI is the amount saved in fuel costs in relation to the initial CCSF material expenditures per tent structure over a one-year period. ROI is dependent on commodity and material prices, as well as the geographic location in which the structure is employed. Volatility in global fuel prices will either increase or decrease the ROI, depending on the direction of the price fluctuation. Foam material prices will vary depending on the size and scope of the contract, contractor capabilities, and CCSF component material price. Employment location also factors into ROI as it drives energy efficiency, fuel consumption levels, and material amounts needed to satisfy specific R-value insulating requirements. Fuel consumption is expected to increase in locations experiencing large temperature variations, compared to those with static climates.

b. Net Present Value

NPV calculations represent the present value of the annual savings in fuel costs from CCSF application. NPV provides an upfront estimation of future dollars saved used to compare initial investment decisions. Additionally, it provides savings values for varying durations, based on the expected useful life of the foamed structures and the anticipated duration of structure employment.

c. Breakeven Period

The BEP is the duration of time required for the initial investment in CCSF to match the savings in fuel costs resulting from CCSF application. This BEP enables decision makers to identify the minimum time required for CCSF application to yield financial benefits, based on the structure’s anticipated employment and use time horizon. Similar to ROI, breakeven periods are subject to the same sensitivities inherent in fuel and CCSF material prices at the time of implementation.

2. Nonfinancial Selection Criteria

Nonfinancial selection criteria used during this analysis include combat effectiveness, unit mobility, ease of CCSF integration and use, ease of CCSF disposal, and fuel dependence. These criteria are assessed to be of critical importance to combatant and operational commanders when making decisions regarding CCSF implementation on the battlefield and for future forward-deployed combat operations.

a. Combat Effectiveness

Combat effectiveness includes factors associated with increases in quality of life, health and safety, structural benefits, and convoy reduction. The combat effectiveness of CCSF implementation, or that of any employed weapon system, is a major consideration of any geographic combatant or joint force commander during course of action selection. The combat effectiveness selection criteria is broken down into its integral parts during the alternative comparison step, yielding an overall combat effectiveness based on the weights that the decision maker assigns to its various components relating to his/her specific needs. Assuming typical battlefield berthing requirements, CCSF implementation provides overall benefits to combat effectiveness.

b. Mobility

The semipermanent properties of CCSF-insulated berthing structures require consideration when selecting the appropriate course of action. CCSF-insulated structures provide favorable benefits in conditions not requiring relocation of equipment or personnel, but are detrimental when mobility is required for mission execution. CCSF should be implemented when a location’s (i.e., the FOB) employment duration can be accurately determined. The status quo, or the unfoamed structure, is more beneficial when mobility is required.

c. Ease of Implementation/Integration

CCSF implementation and integration into existing DOD construction practices requires additional personnel, training, coordination, and costs compared to the employment and use of unfoamed tents. This criterion takes into account the ability/feasibility of the decision maker to commit the additional resources (i.e., time and money) required for CCSF implementation. Implementation and integration into existing construction practices requires directing policy in addition to personnel training in regards to the construction, use, and maintenance associated with CCSF-insulated tents.

The status quo, or the unfoamed tent, is more beneficial when ease of integration is required or desired.

d. Disposal

Disposal costs associated with CCSF insulated structures are dependent on employment location and host-nation environmental regulations. Upfront disposal costs should be determined prior to CCSF implementation to determine the overall net benefit or cost from CCSF use. Besides the costs associated with the material’s disposal, CCSF may require nonorganic personnel and equipment support. Assuming that CCSF disposal incurs costs and is not turned over to host nation forces, the unfoamed tent is more beneficial due to its ability to be redeployed incurring no disposal costs.

e. Fuel Dependence

Current U.S. government and DOD initiatives identify goals to reduce weapons systems’ dependence on and use of fossil fuels, shifting towards integrating a greater amount of renewable energy sources as a percentage of total DOD operational fuel consumption. Reduction of fossil fuel use reduces fuel dependence. Remote and land-locked combat locations, such as Afghanistan, highlight the logistic and financial effects of high fuel consumption, such as increased risk to mission and required resources. Additionally, combat location geopolitical pressures and constraints increase risks to mission, military personnel, and political objectives when fuel requirements are pivotal to operations.

H. STEP 7: COMPARE ALTERNATIVES

1. Decision Matrix Design

The comparison of courses of action is driven by the viewpoints and priorities of the decision maker. As such, generic selection criteria, and their related ratings and weights, do not provide value added to the decision-making process. This analysis provides a decision matrix, tailored to the courses of action, which can be used to aid leadership in determining the possible costs and benefits associated with the two courses of action.

a. Selection Criteria

Selection criteria are based on the priorities and desired end state of the decision maker. Once determined, the selection criteria are broken into measures of performance (MOPs) used to determine the financial and nonfinancial benefits of the respective courses of action under consideration. The number of selection criteria should be minimized to focus on the decision-making process. When applicable, the decision matrix should include criteria that are quantifiable, usually financial, and nonquantifiable (DoA, 2013). Nonquantifiable selection criteria are subjective in nature and thus require consensus among decision makers in regards to their importance. The following list shows the selection criteria, MOPs, and their rationale, which are used to evaluate the courses of action:

Financial Selection Criteria

- **1: Return on Investment –** ROI was chosen to measure the efficiency of the use of financial resources. The "return" for this ROI calculation is the savings from reduced fuel consumption. ROI only applies to the CCSF alternative, but depends on its anticipated duration of employment. If ROI is negative, CCSF implementation should be rated low.

- **2: Net Present Value –** NPV was chosen to determine the viability or benefit of CCSF implementation and associated opportunity costs. Opportunity costs represent the other options that the decision maker can dedicate financial resources to if CCSF is not implemented. A positive NPV tells the decision maker that the financial benefits, in this case savings, outweigh the financial costs of CCSF implementation. NPV only applies to the CCSF alternative, but depends on its anticipated duration of employment. If NPV is negative, CCSF implementation should be rated low.

- **3: Break-Even Period –** BEP was chosen to determine the respective time period(s) required for CCSF to become cost beneficial. BEP only applies to the CCSF alternative, but depends on its anticipated duration of employment. Depending on the current cost of fuel and CCSF contract price, decision makers can compare the expected BEP with the anticipated duration of a military operation to determine if it is cost beneficial to employ CCSF. If the BEP is longer than the anticipated duration of employment, CCSF implementation should be rated low.

Nonfinancial Selection Criteria

- 1: Combat Effectiveness
  - **MOP 1.1: Quality of Life –** Soldier effectiveness is directly attributable to his or her quality of life outside of combat operations. It includes comfort, cleanliness, and factors that influence rest, recovery, and sleep periods that affect soldier stress levels and combat performance.
  - **MOP 1.2: Health and Safety –** This MOP accounts for the health and safety benefits provided by the course of action and includes factors such as physical protection from environmental or combat conditions that may adversely affect soldier short-term or long-term health-related issues.
  - **MOP 1.3: Structural Durability –** In areas of adverse and varying environmental conditions, structural integrity is an essential factor when choosing berthing structures. Structural integrity determines structure useful life in forward-deployed locations and minimizes replacement and repair costs.
  - **MOP 1.4: Convoy Operations –** This MOP was chosen to address the benefits of casualty reduction associated with reduced convoy operations. If convoy operations are assessed to be protected, or operate in a permissive environment, this MOP will not vary between the two courses of action due to the low risk of convoy-related casualties.
- **2: Structure Mobility –** Structure mobility was chosen to address the course of action's ability to satisfy unit or desired mobility requirements. CCSF application reduces the structure's mobility characteristics and may not be feasible for employment under specific battlefield conditions or for units requiring mobility.
- **3: Implementation/Integration –** This MOP addresses the course of action's ease of implementation and integration into current military doctrine, training curriculums, and operating procedures.
- **4: Disposal –** This MOP addresses the course of action's ease and expected costs of disposal after termination of its useful life or redeployment time. Disposal options depend on the host-nation's willingness to accept custody of the structure (i.e., host-nation turnover), or on their environmental regulations.
- **5: Fuel Dependence –** This MOP addresses the course of action's ability to contribute to reduced battlefield fuel consumption. Reduced fuel dependence mitigates battlefield risks to mission and personnel.

b. Objectives

Objectives describe the desired end state of the respective MOPs within each selection criteria. They are used as a benchmark when assigning ratings to specific MOPs. Objectives may vary, depending on the decision maker's priorities or mission criteria. Below are the selection criteria and measure of performance objectives used to evaluate the courses of action:

- Financial Selection Criteria Objectives
  - **1: Return on Investment –** A positive ROI over the anticipated period of employment (applies only to CCSF alternative)
  - **2: Net Present Value –** A positive NPV over the anticipated period of employment (applies only to CCSF alternative)
  - **3: Break-Even Period –** A breakeven point shorter than the anticipated period of employment (applies only to CCSF alternative)
- Nonfinancial Selection Criteria Objectives
  - 1: Combat Effectiveness
- **MOP 1.1: Quality of Life –** Increased quality of life translating to increased personnel combat performance.
- **MOP 1.2: Health and Safety** – Reduction in health and safety costs, and risks to personnel.
- **MOP 1.3: Structural Durability –** Increased structural integrity and stability.
- **MOP 1.4: Convoy Operations –** Decreased convoy operations, associated risks, and costs.
  - **2: Structure Mobility –** Relocate the structure within a predetermined timeframe.
  - **3: Implementation/Integration –** Minimize costs and time associated with implementation into DOD practices.
- **MOP 4: Disposal –** Minimize disposal costs associated with structure removal.
- **MOP 5: Fuel Dependence –** Reduced fuel demand and associated risks and costs.

c. Ratings

A rating is the numerical value assigned to selection criteria that identifies the course of action's ability to achieve the criteria's objective. Rating ranges depend on the decision maker's level of fidelity and/or sensitivity desired. Ratings are subjective for both quantifiable and nonquantifiable criteria. For this CBA, a rating range of 1 to 9 is used, providing a middle point of 5. A rating of 1 represents a course of action that does not, or is unlikely to provide any benefit towards meeting the objective of the specific selection criteria. A rating of 9 represents a course of action that is highly likely to, or fully meets or exceeds, the objective of the selection criteria. For the decision matrix, a rating column is created for each course of action. Below lists the ratings ranges and values used to evaluate the courses of action.

- **Rating Range 1–2:** Represents a rating that either does not, or is unlikely to, achieve the objective of the MOP.
- **Rating Range 3–4:** Represents a rating that is may possibly achieve the objective of the MOP.
- **Rating 5:** Represents the midpoint rating or rating that is likely to achieve the objective of the MOP.
- **Rating Range 6–7:** Represents a rating that is highly likely to achieve the objective of the MOP.
- **Rating Range 8–9:** Represents a rating that is near certain or will achieve the objective of the MOP.

c. Weight

Weight, or weighting, is the numerical value that identifies the level of importance of each selection criteria to the decision maker or desired end state. Weights for both quantifiable and nonquantifiable selection criteria should individually sum to 1.00 to maintain an equal effect on the final scoring. Because the weights are required to sum to a final value of 1, individual weights must be distributed among the respective number of selection criteria, which may vary. Weights display their level of importance when compared to the weights assigned to the other selection criteria. For example, a weight of 0.4 assigned to MOP 1 represents a selection criterion of higher importance than MOP 2, with a weight of 0.05. As such, there is no defined weighting range that corresponds to a specific level of importance (i.e., a weight of 0.4 translates to level of "great" importance). Assigning weights are also subjective and depend on the decision maker(s) and the desired end state of the courses of action. It is important that weights are agreed on by all involved in the decision-making process to ensure continuity when assigning values. As such, weighting decisions should be included in the planning process when constructing decision matrices.

d. Weighted Score

The weighted score for each selection criteria is the multiplication of the criteria's respective rating and weight assigned. Scores for all selection criteria are then added together within the same category to produce a final score for the course of action (i.e., quantifiable and nonquantifiable). The course of action, or alternative, with the highest score provides the most benefit to the desired end state and should be chosen.

- **Weighted Score – Status Quo:** The weighted score for each MOP of the status quo are added together, resulting in a final score for both financial and nonfinancial selection criteria.
- **Weighted Score – CCSF Alternative:** The weighted score for each measure of performance of the CCSF alternative are added together resulting in a final score for both the financial and nonfinancial selection criteria.

The scoring of the two courses of action are based on a hypothetical example of a FOB commander in Afghanistan desiring to minimize costs and risk to personnel by reducing fuel consumption, while maintaining combat effectiveness. The FOB commander is looking to determine if CCSF insulation should be implemented on berthing structures required to house an incoming battalion consisting of 1,000 personnel. To satisfy the battalion's berthing requirements, 84 GP-L tents (1,000 personnel divided by 12 personnel per GP-L) are required and are part of the battalion's MTOE. For this analysis, combat employment of the incoming battalion is expected to last a minimum of one year. Ratings and weights assigned represent the subjective views of the authors of this CBA. The following summarizes the results of the assigned ratings and weights given to each selection criteria and measures of performance:

- **The Status Quo Course of Action:** The status quo's financial selection criteria yielded a final weighted score of 1 because the course of action does not achieve any of the financial objectives and does not provide any financial benefit. The status quo's final financial criteria score of 1 means the course of action satisfied approximately 11% of the desired financial selection criteria's objectives. Despite the mathematical score of 11%, this course of action actually satisfied 0% of the desired objectives because it does not provide any financial benefit. This disparity represents the errors that are inherent in a decision matrix and is due to the subjective rating values used in the comparison.

The status quo's nonfinancial selection criteria yielded a final score of 4.55. This course of action ranked above the CCSF alternative in MOPs 2, 3, and 4. The status quo's final score of 4.55 means that the course of action satisfied approximately 51% of the desired nonfinancial selection criteria's objectives (4.55 divided by 9, with 9 representing a score that achieves all desired objectives)

- **The CCSF Course of Action:** The CCSF's financial selection criteria yielded a final weighted score of 8 due to positive ROI, NPV, and a BEP shorter than the expected duration of employment. The CCSF's financial criteria score of 8 means that the course of action satisfied 89% of the financial criteria objectives (8 divided by 9, with 9 representing a score that achieves all desired objectives).

NPVs were calculated using both the standard price of $3.70/gallon, representing a low-end estimate, and using the FBCF price of $34.90/gallon, representing a high-end estimate. Both calculations resulted in a positive NPV. The high-end NPV, $25,661,445, was calculated using a discount rate of 0.24 % (current one-year U.S. Treasury Bill interest rate), a cash flow of $27,181,795 (the one-year fuel cost savings at $34.90/gal [high-end FBCF]), and cash outflow of $1,455,300 (84 * $17,325) representing the cost of CCSF application to the 84 tents. CCSF's NPV, using the standard price of $3.70 per gallon, equated to an NPV of $1,419,538 for the CCSF.

ROI was calculated using the cost of CCSF application to the 84 tents, or $1,455,300 (84 * $17,325), as the investment cost of the course of action. The return was calculated using the one-year fuel savings from the CCSF application; a low-end estimate of $2,881,738 (using the standard price of $3.70/gallon) and a high-end estimate $27,181,795 (using the FBCF price of $34.90/gallon). Low-end ROI equated to $1,426,438, or a 98% ROI. High-end ROI equated to $25,726,495, or a 1,803% ROI in one year.

The BEP was calculated by determining the daily savings amount by dividing the total annual fuel savings by 365 days. The low-end total one-year savings, equating to $2,881,738, yielded a daily savings amount of $7,895 and a BEP of 185 days. The high-end total one-year savings, equating to $27,181,795, yielded a daily savings amount of $74,471 and a BEP of 20 days. Both BEPs are shorter than the expected duration of employment and satisfy the BEP's objectives. Table 28 shows the one-year fuel savings, based on the number of required tents.

One-Year Fuel Savings (2014TY$)					
	# of Tents	**Fuel Consumption Savings**	**Total Fuel Savings at Std. Price of $3.70/gal JP-8**	**Total Fuel Savings at FBCF Price of $16.00/gal JP-8**	**Total Fuel Savings at FBCF Price of $34.90/gal JP-8**
GP-L	84	9,272	$2,881,738	$12,461,568	$27,181,795

Table 28. One-year fuel savings.

The CCSF's nonfinancial selection criteria yielded a final score of 6.25. This course of action ranked above the status quo in MOPs 1 and 5 only, but resulted in a higher final score due to the weightings assigned. This decision matrix valued MOP 1 (combat effectiveness, with a total weighting of 0.4) and MOP 5 (fuel dependence, with a total weight of 0.25) higher than the other MOPs due to the FOB commander's desired end state of "reducing risk to personnel by reducing fuel consumption while maintaining combat effectiveness" as stated above. The final, weighted, nonfinancial score of 6.25 means the course of action satisfied approximately 70% of the desired nonfinancial selection criteria's objectives (6.25 divided by 9, with 9 representing a score that achieves all desired objectives).

The resulting total weighted scores, shown in Tables 29 and 30, depicts that the CCSF alternative course of action does a better job in accomplishing the FOB commander's desired end state, based on the chosen selection criteria, ratings, and weights, and thus should be chosen as the preferred alternative.

Selection Criteria	**Objective**	**Status Quo**	**Alternative**	**Weight**	**Weighted Score: Status Quo**	**Weighted Score: Alternative**
Nonfinancial Selection Criteria						
MOP-1 Combat Effectiveness						
MOP-1.1 Quality of Life	Increased quality of life that translates to increased personnel combat performance	5	7	0.15	0.60	1.05
MOP-1.2 Health and Safety	Reduction in health and safety costs and risks to personnel	3	6	0.05	0.15	0.30
MOP-1.3 Structural Durability	Increased structural integrity and stability	3	8	0.05	0.15	0.40
MOP-1.4 Convoy Operations	Decrease in required convoy operations and associated risks and costs	1	7	0.25	0.25	1.75
Combat Effectiveness Total				0.40	1.15	3.5
Selection Criteria	**Objective**	**Status Quo**	**Alternative**	**Weight**	**Weighted Score: Status Quo**	**Weighted Score: Alternative**
Nonfinancial Selection Criteria						
MOP-2. Structure Mobility	Ability to relocate structure in predetermined time frame	9	2	0.05	0.45	0.10
MOP-3 Implementation/Integration	Minimize costs and time associated with implementation into DOD practices	9	3	0.10	0.90	0.30
MOP-4 Disposal	Minimize disposal costs associated with structure removal	9	3	0.20	1.80	0.60
MOP-5 Fuel Dependence	Reduction in fuel demand and associated risks and costs	1	7	0.25	0.25	1.75
				Total:	4.55	6.25

Table 29. Nonfinancial selection criteria COA decision matrix.

Selection Criteria	**Objective**	**Status Quo**	**Alternative**	**Weight**	**Weighted Score: Status Quo**	**Weighted Score: Alternative**
1. Financial Selection Criteria						
MOP-1.1 ROI	A positive ROI over the anticipated period of employment (applies only to alternative)	1	8	0.25	0.25	2
MOP-1.2 NPV	A positive NPV over the anticipated period of employment (applies only to alternative)	1	8	0.25	0.25	2
MOP-1.3 BEP	A BEP shorter than the anticipated period of employment (applies only to alternative)	1	8	0.50	0.50	4
Totals				1.00	1.00	8

Table 30. Financial selection criteria COA decision matrix.

I. STEP 8: SENSITIVITY ANALYSIS

This sensitivity analysis addresses two main cost drivers, fuel prices and CCSF application prices. Variation in these factors will affect the BEP, NPV, and ROI calculations applicable to CCSF's implementation. NPV and ROI sensitivity analysis used only quantifiable costs and benefits. Factoring in nonquantifiable benefits, such as generator, fuel truck, and casualty reductions, will increase the value of the ROIs and NPVs associated with the respective tent structures. To demonstrate the hypothetical effects of casualty reduction from CCSF implementation, the BEP analysis includes the savings from casualty reduction based on the mean VSL of $8,100,000 from Step 5. All calculations conducted during this analysis are based on the berthing requirements of a 1,000-person battalion-sized element, equating to 125 frame tents, 125 GP-M tents, or 84 GP-L tents, respectively, depending on the desired berthing type, to stay consistent with the COA decision example in Step 7.

1. Cost Drivers

Fuel price and CCSF material and application costs are the two cost drivers associated with CCSF implementation. Fluctuations in these cost drivers will alter the respective BEPs, ROIs, and NPVs depending on the chosen time frame for analysis.

a. Fuel Price (Standard and FBCF)

Two types of JP-8 fuel prices were varied during the sensitivity analysis, the standard price of fuel, based on historical data from fiscal years 2009 through 2015, and the FBCF, based on ranges from previous published research. Standard price-per-gallon use ranged from $1.60/gal to $5.00/gal, representing an approximate 50% decrease and 50% increase in price from the historical mean of $3.28/gal (FY2009-FY2105), respectively. The price per gal was varied by $0.10 increments to show the marginal effects on the financial measures.

As stated in Chapter III, FBCF depends on the various costs attributed to getting the fuel to its final destination and end user. This analysis used an FBCF range of $10.00 to $100.00 per gallon to show the plausible range of FBCF prices, independent of a specific operating environment. A low-end ground FBCF price of $16.00/gal was chosen to correspond with the previous examples used during this analysis and may represent shorter transportation distances to the end user, a permissive to semipermissive environment, and shipment via ground assets. A high-end ground FBCF price of $34.90/gal was chosen to again remain consistent with previous examples and account for increased transportation distances to the end user, a semi to nonpermissive environment, and shipment via ground assets. A high-end, air-transported FBCF price of $100.00/gal was chosen to provide a hypothetical cost for fuel transportation to remote combat outposts via rotary wing or fixed wing aircraft in semi or nonpermissive combat environments. For more accurate FBCF price determination, the specific combat environment and transportation details relating to the end user’s location should be entered into the FBC Tool (version 4.0), managed by the U.S. Army G-4 LIA. This tool requires the user to request access permissions through the LIA.

b. CCSF Material and Application Cost

CCSF application costs were varied during the sensitivity analysis to account for the variable effects of CCSF materials and contractor services. Cost variation takes into account the expected effect of economies of scale resulting from universal implementation throughout the DOD and CCSF contract service and application variables, depending on the physical location of CCSF application. It is assessed that CCSF application in forward-deployed locations with semi to nonpermissive environments will increase the CCSF contract price, translating to a higher price per square foot, due to the security and logistic costs associated with delivery. A low-end CCSF price of $5.00 per square foot (a ~30% reduction from the median price) was used to represent a situation with a permissive or semipermissive environment and minimal transportation and contractor costs. A price of $7.00 per square foot was used as the median CCSF price per square foot, as it represents the approximate price of the EITS contract used in Iraq, Afghanistan, Kuwait, and Djibouti from 2009 through 2010. For a high-end estimate, $9.00 per square foot (an ~30% increase from the median price) was used to represent the unit cost associated with delivering the end product to more remote, forward-deployed locations in a semi to nonpermissive environment, requiring increased logistic and security costs.

2. Sensitivity Analysis

Sensitivity analysis was conducted on the three financial measures for CCSF implementation: the breakeven period, the net present value, and the ROI. The BEP analysis is applicable to military planners with defined mission time frames who are faced with decisions that require weighing cost savings with the associated risks to mission and force. BEP analysis allows an operational commander to determine if CCSF application is beneficial to mission accomplishment and if the upfront investment costs are recoverable within the anticipated duration of combat operations or employment. NPV analysis allows financial planners, military program offices, and budget experts to determine the financial viability and net benefits of CCSF implementation. ROI analysis is a measure that allows the decision makers to determine the extent of financial benefits received from CCSF implementation within a specified or desired time frame.

a. Break-Even Period

BEP sensitivity analysis was conducted by varying the standard price per gallon of JP-8, while holding constant the CCSF material and application cost of $7.90 per square foot. Analysis indicates that a higher standard price per gallon yielded a shorter

BEP, as shown in Figure 18. The historical average price of $3.28/gal yielded BEPs of 226, 232, and 207 days for frame, GP-M, and GP-L, respectively. The low-end price of $1.60/gal yielded BEPs of 467, 478, and 426 days. The high-end price of $5.00/gal yielded BEPs of 149, 153, and 136 days for frame, GP-M, and GP-L, respectively. The average BEP over the entire fuel price range for the respective tents equaled 252, 258, and 230 days.

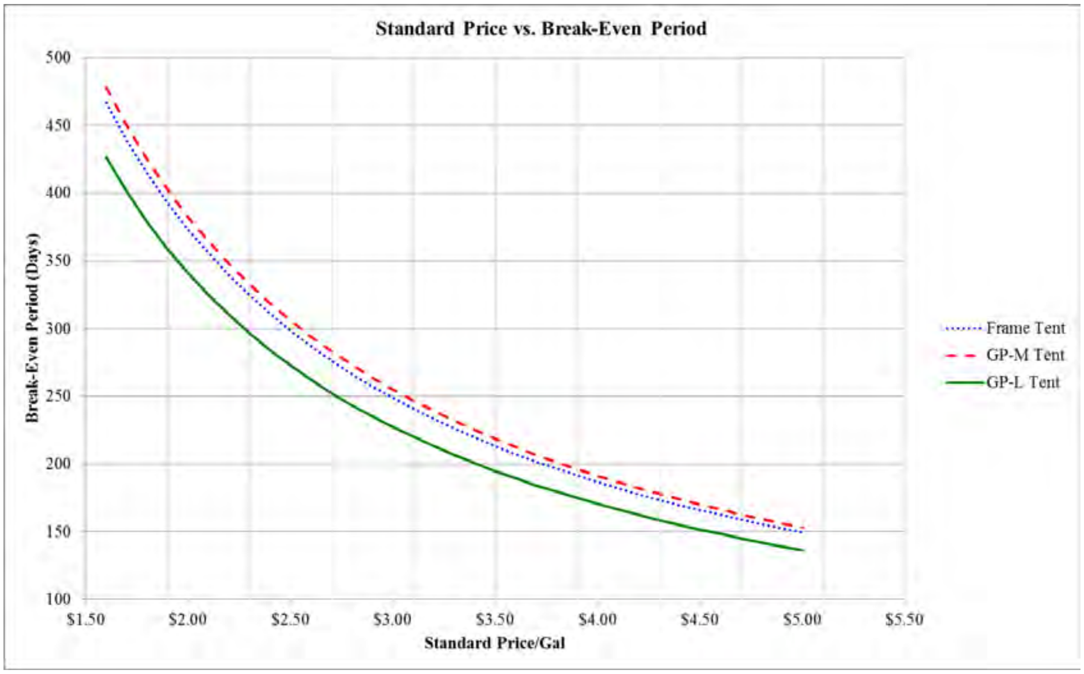


Figure 18. Standard price per gal vs. break-even period (at $7.90/sq ft CCSF).

When casualty reduction savings are factored into the analysis, the BEPs for the respective tents shortened drastically (Figure 19). The low-end price of $1.60/gal yielded BEPs of 17, 17, and 16 days. The high-end price of $5.00/gal yielded BEPs of 16, 16, and 14 days for frame, GP-M, and GP-L, respectively. The drastically shortened BEPs, when added to the casualty savings, are due to the large VSLs in comparison to the small fuel price range.

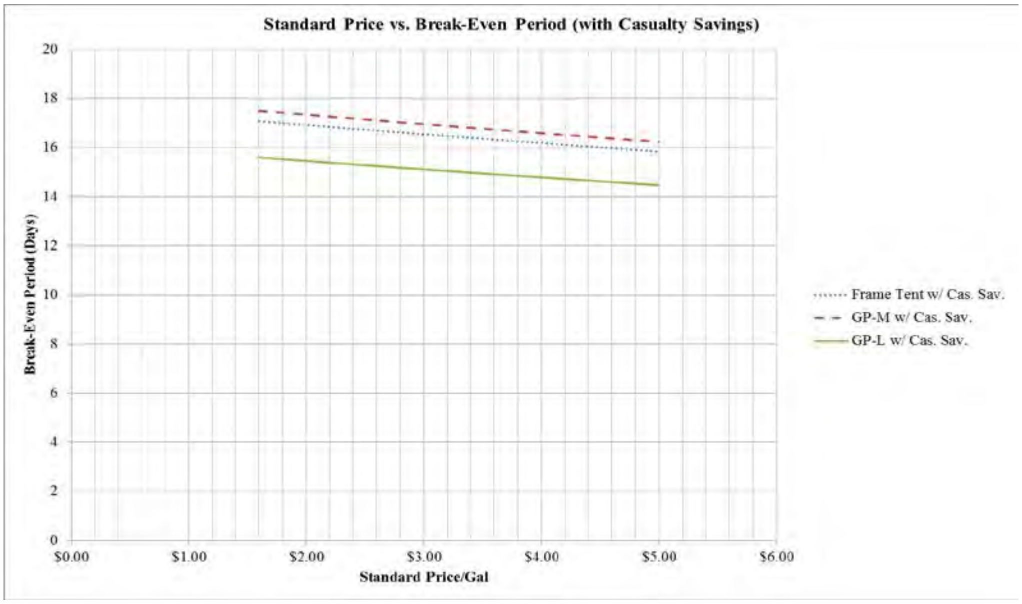


Figure 19. Standard price per gallon vs. break-even period (at $7.90/sq ft CCSF) including casualty savings.

Breakeven period sensitivity analysis was also conducted by varying the fully burdened cost of fuel price per gallon of JP-8, while holding the CCSF material and application cost of $7.90 per square foot constant. Analysis indicates that when using the FBCF price per gallon, breakeven periods were drastically shortened, as shown in Figure 20. The low-end ground FBCF estimate of $16.00/gal yielded BEPs of 47, 48, and 43 days for frame, GP-M, and GP-L, respectively. A high-end FBCF estimate of $34.90 yielded BEPs of 21, 22, and 19 days for frame, GP-M, and GP-L, respectively. The average BEP between the low- and high-end FBCF estimates for the respective tents equaled 31, 32, and 28 days. The hypothetical FBCF estimate of $100.00/gal yielded drastically short BEPs of 7, 8, and 7 days for frame, GP-M, and GP-L, respectively.

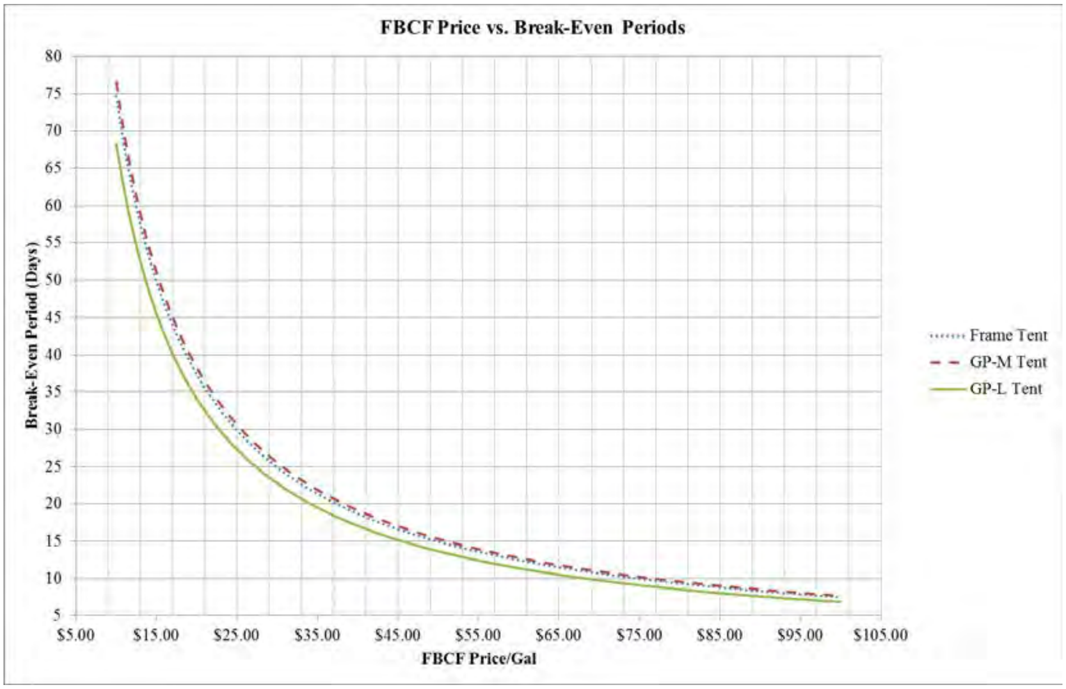


Figure 20. FBCF price per gal vs. break-even period (at $7.90/sq ft CCSF).

When casualty reduction savings are factored into the FBCF analysis, the BEPs for the respective tents ranged from 15 to 5 days (see Figure 21). The low-end price of $1.60/gal yielded BEPs of 14, 15, and 13 days. The high-end price of $5.00/gal yielded a BEP of 5 days for the frame, GP-M, and GP-L tents. The effect of casualty savings yielded BEPs for all structures of approximately two weeks or less.

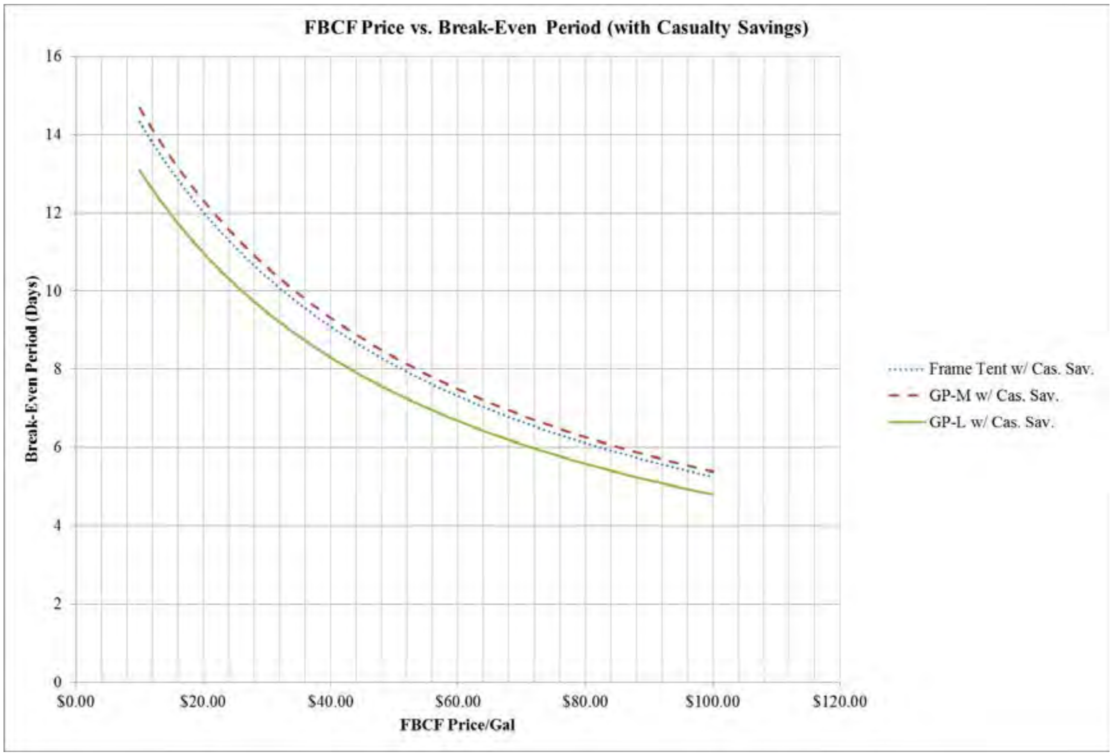


Figure 21. FBCF price per gal vs. break-even period (at $7.90/sq ft CCSF) including casualty savings.

To account for the other cost driver, CCSF application and material price per square foot was varied to show their effect on BEPs, while holding the standard price and FBCF constant. The historical average standard price of $3.28/gal, and average of the low-end and high-end ground FBCF price of $25.45, was held constant to show CCSF cost effects on BEPs. Holding the standard price constant, BEPs equated to 144, 148, and 132 days for the frame, GP-M, and GP-L tents, respectively at the low-end of $5.00 per square foot of CCSF. The high-end CCSF price of $9.00 per square foot yielded BEPs of 259,266, and 237 days. At the average cost of $7.00 per square foot of CCSF, BEPs equated to 202, 207, and 184 days (see Figure 22).

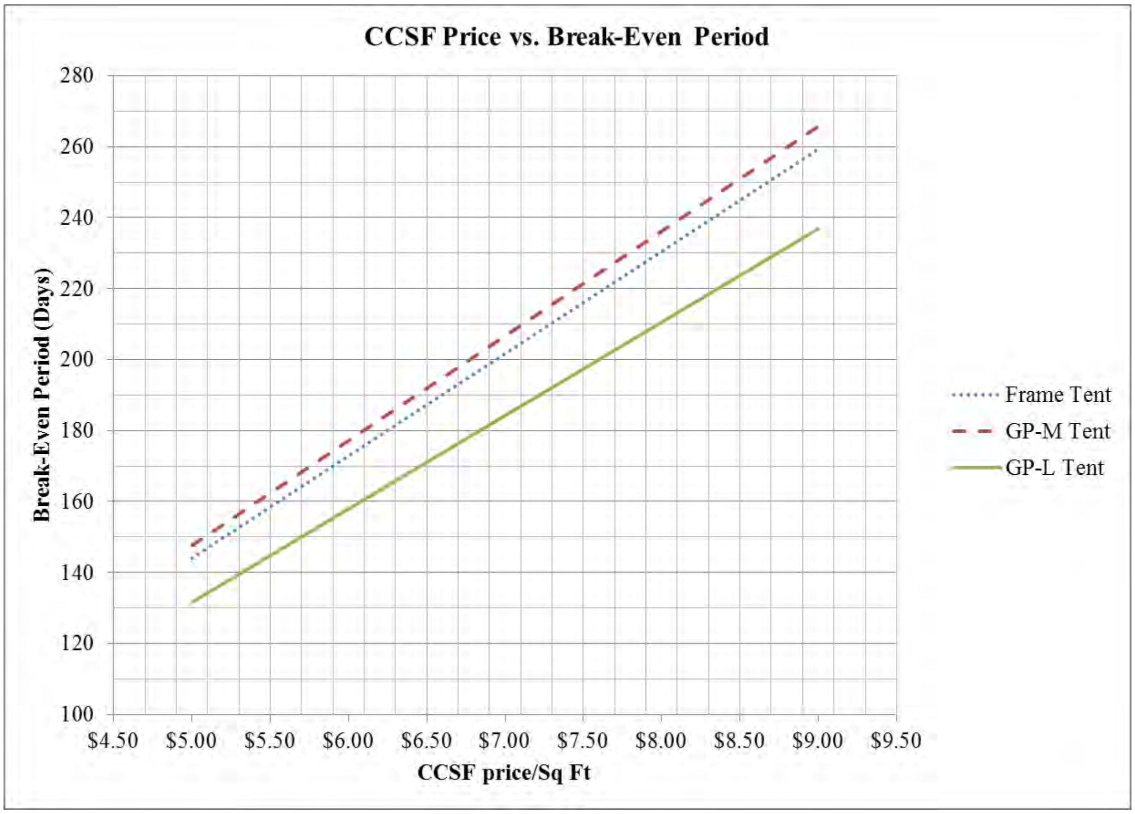


Figure 22. CCSF price per square foot vs. break-even period (at the standard price of $3.28/gal).

Sensitivity analysis was repeated, holding the average FBCF price of $25.45/gal constant. BEPs equated to 19, 19, and 17 days for the frame, GP-M, and GP-L tents, respectively at the low-end price of $5.00 per square foot of CCSF. The high-end CCSF price of $9.00 per square foot yielded BEPs of 33, 34, and 31 days. At the average cost of $7.00 per square foot of CCSF, BEPs equated to 26, 27, and 24 days (see Figure 23).

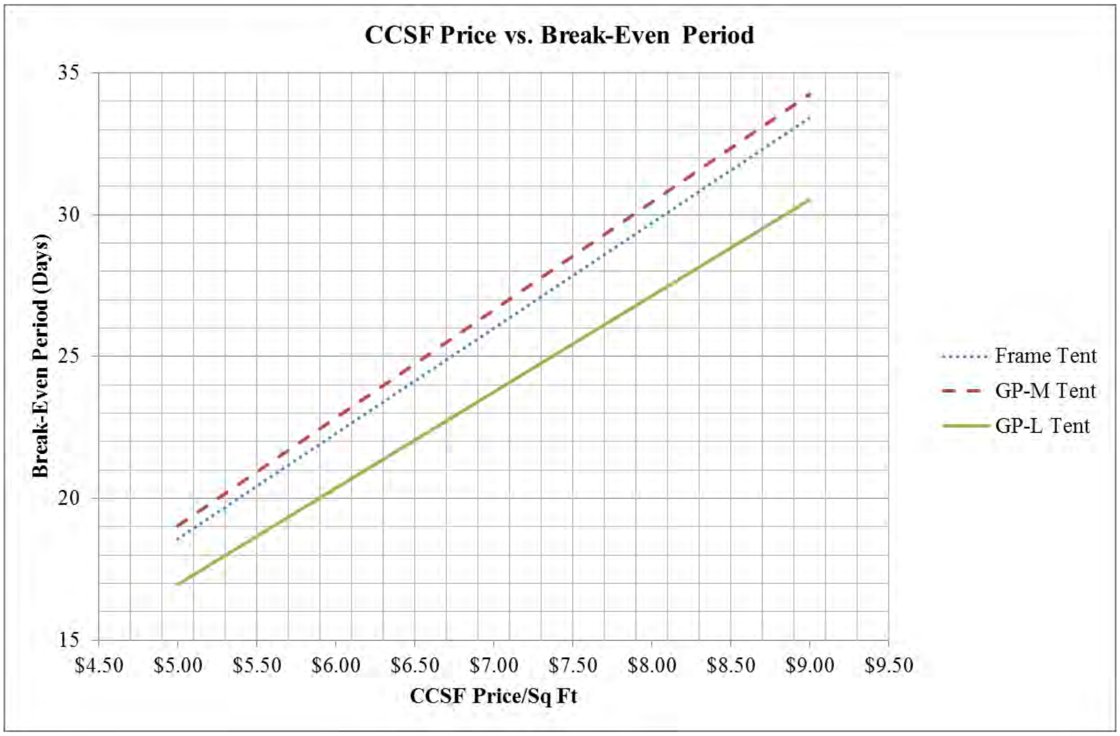


Figure 23. CCSF price per square foot vs. break-even period (at the FBCF price of $25.45/gal).

b. Net Present Value

Sensitivity analysis was conducted on NPV by varying the Office of Management and Budget (OMB)-published FY2014 discount rates. Discount rates were varied to reflect the variations in U.S. Treasury Bill interest rates; rates commonly used when quantifying financial benefits of government-funded projects, and expected project employment durations. For example, for projects expected to last for five years, the five-year U.S. Treasury Bill interest rate should be used as the project's discount rate to determine the financial benefits. To keep the analysis consistent with published government guidance, 2014 OMB discount rates of –0.3% (3-year), 0.0% (5-year), and 1.0% (10-year) were used as published by the Office of Management and Budget *Circular No. A-94 Revised* last updated February 7, 2014. The *2014 Discount Rates for OMB Circular No. A-94* does not include a specific, one-year discount rate, so –0.6% was used as an estimated value (Office of Management and Budget [OMB], 2014).

To show the effects of changing discount rates, CCSF material and application costs and fuel prices were held constant. NPV calculations were conducted using a CCSF price per square foot of $7.90, a standard price of fuel of $3.28/gal, and an FBCF price of $25.45/gal. NPVs were calculated over 1-, 3-, 5-, and 10-year periods to correspond with the feasible project durations, as seen in Tables 31 through 34.

One-Year NPV at a –0.6% Discount Rate					
	# of Tents	**Annual Fuel Savings (gal)**	**Foam Application Costs**	**NPV at Standard Price of $3.28**	**NPV at FBCF Price of $25.45/gal**
Frame Tent	125	740,125	$1,513,875	$928,389	$17,436,006
GP-M	125	742,000	$1,555,375	$893,076	$17,442,512
GP-L	84	778,848	$1,455,300	$1,114,742	$18,486,030

Table 31. One-year NPV of cost savings at a –0.6% discount rate.

Three-Year NPV at a –0.3% Discount Rate					
	# of Tents	**Annual Fuel Savings (gal)**	**Foam Application Costs**	**NPV at Standard Price of $3.28**	**NPV at FBCF Price of $25.45/gal**
Frame Tent	125	740,125	$1,513,875	$5,812,871	$55,335,423
GP-M	125	742,000	$1,555,375	$5,789,933	$55,437,942
GP-L	84	778,848	$1,455,300	$6,254,778	$58,368,327

Table 32. Three-year NPV of cost savings at a –0.3% discount rate.

Five-Year NPV at a 0.0% Discount Rate					
	# of Tents	**Annual Fuel Savings (gal)**	**Foam Application Costs**	**NPV at Standard Price of $3.28**	**NPV at FBCF Price of $25.45/gal**
Frame Tent	125	740,125	$1,513,875	$12,138,050	$94,180,906
GP-Medium	125	742,000	$1,555,375	$12,168,800	$94,419,500
GP-Large	84	778,848	$1,455,300	$12,773,107	$99,108,408

Table 33. Five-year NPV of cost savings at a 0.0% discount rate.

Ten-Year NPV at a 1.0% Discount Rate					
	# of Tents	**Annual Fuel Savings (gal)**	**Foam Application Costs**	**NPV at Standard Price of $3.28**	**NPV at FBCF Price of $25.45/gal**
Frame Tent	125	740,125	$1,513,875	$21,478,759	$176,889,334
GP-M	125	742,000	$1,555,375	$21,495,507	$177,299,793
GP-L	84	778,848	$1,455,300	$22,740,298	$186,281,883

Table 34. Ten-year NPV of cost savings at a 1.0% discount rate.

Sensitivity analysis of varying discount rates resulted in positive NPVs for the 1-, 3-, 5-, and 10-year employment durations, indicating that CCSF implementation is financially beneficial using the above fuel and CCSF material prices.

c. Return on Investment

The sensitivity analysis of the fuel price per gallon (both standard and FBCF), versus the one-year ROI, yielded significant results (see Figures 24 and 25). Holding the price per square foot of CCSF constant at $7.90, the ROI was only negative over a one-year period when the fuel price was below $2.10/gal for frame and GP-M tents, and $1.90 for GP-L tents. Large FBCF ROIs are the result of the relatively cheap costs associated with CCSF application, compared to the anticipated savings in fuel consumption over the one-year period of analysis. If the FBCF is used to price fuel, the lowest estimate of $10.00/gal yielded an ROI of 389%, 377%, and 435% over a one-year period for frame, GP-M, and GP-L tents, respectively.

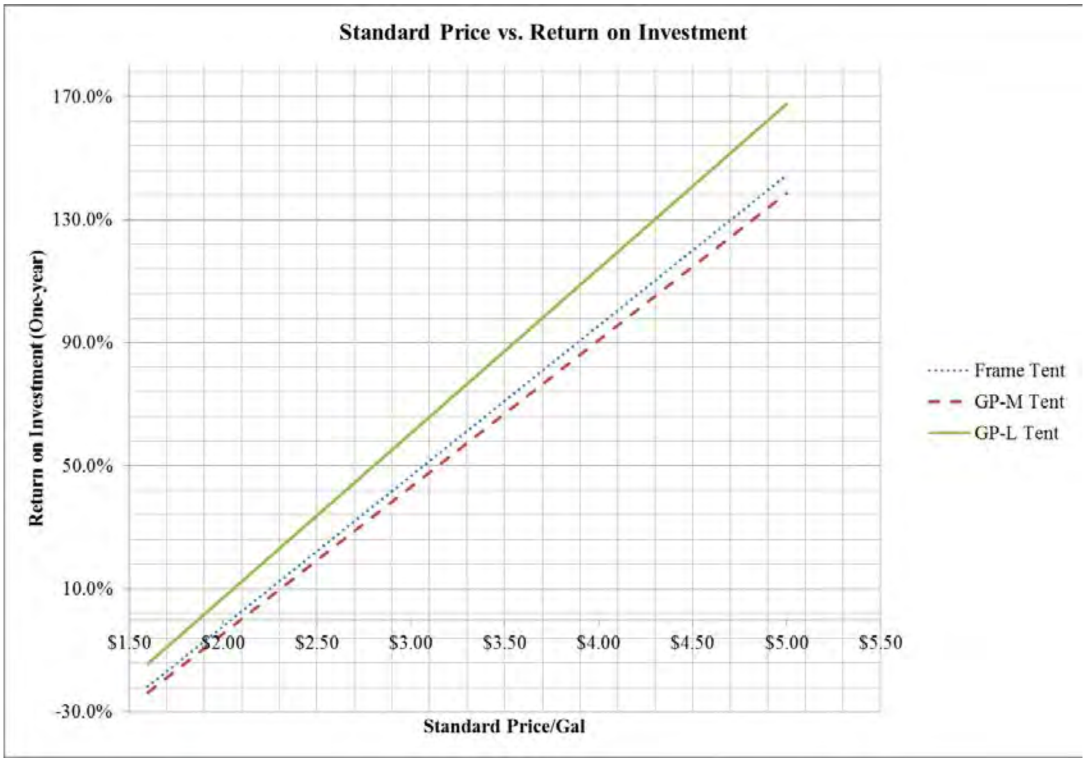


Figure 24. Standard price per gallon vs. return on investment (at $7.90/sq ft CCSF).

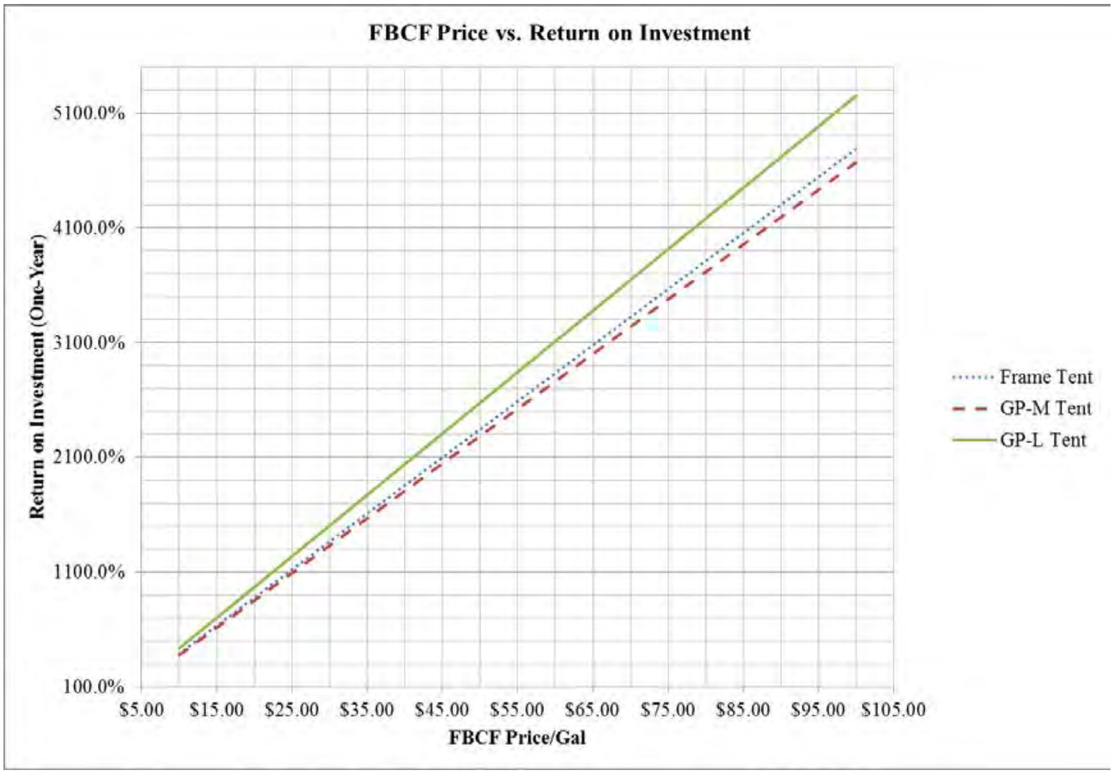


Figure 25. FBCF price per gallon vs. return on investment (at $7.90/sq ft CCSF).

Sensitivity analysis was also conducted to demonstrate the effects of CCSF price per square foot variations on ROI. In this analysis, two models were constructed holding both the standard price and FBCF price of fuel constant, with the historical average standard price of $3.28/gal and the average FBCF price of $25.45/gal. Holding the standard price constant, one-year ROIs ranged from 153% to 41% for frame tents, 147% to 37% for GP-M tents, and 177% to 54% for GP-L tents. Holding the FBCF price constant, one-year ROIs ranged from 1,865% to 992% for frame tents, 1,818% to 965% for GP-M tents, and 2,052% to 1,095% for GP-L tents (see Figures 26 and 27).

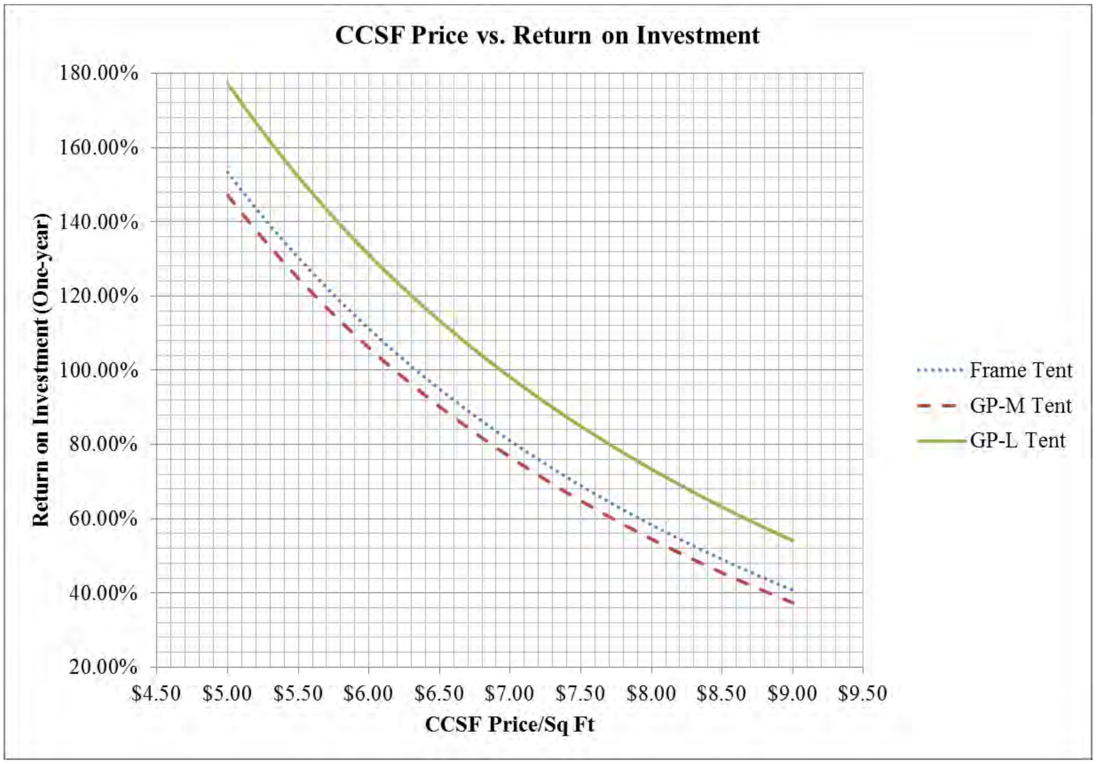


Figure 26. CCSF price per sq ft vs. return on investment (at the standard price of $3.28/gal).

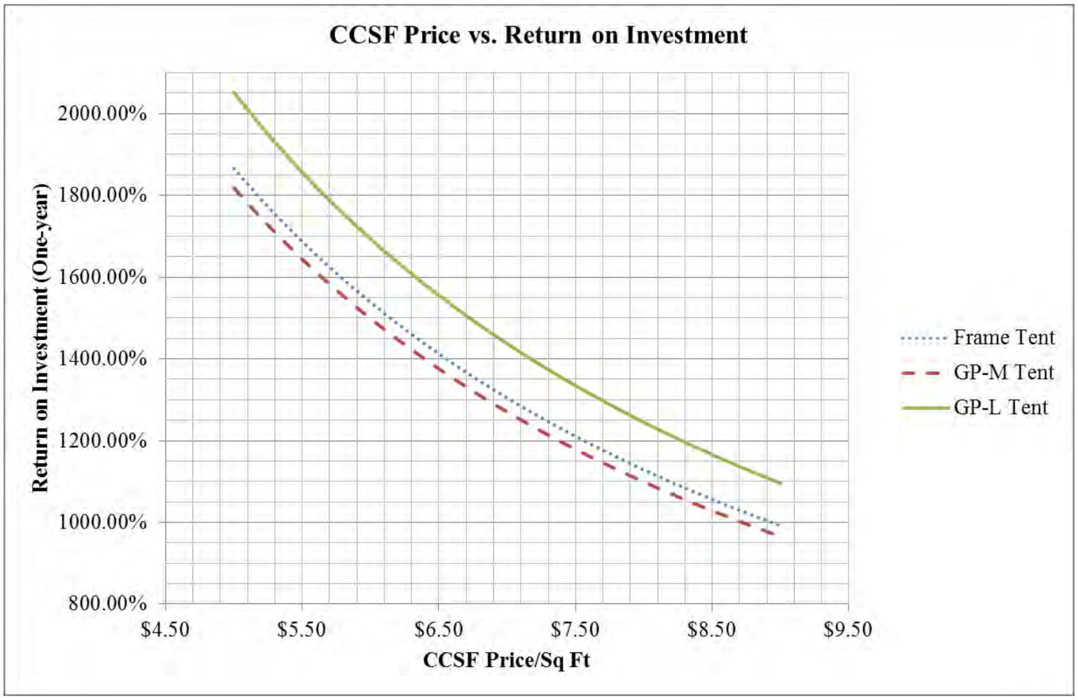


Figure 27. CCSF price per sq ft vs. return on investment (at the FBCF price of $25.45/gal).

J. STEP 9: CONCLUSION AND RECOMMENDATIONS

1. Conclusion

Recent DOD efforts aimed at reducing energy consumption and increasing weapon platform fuel efficiencies have been focused towards lowering fuel costs, while moving away from fossil-based fuels. Fuel price volatility has added substantial unexpected operating costs to DOD budgets, forcing department-wide efforts to provide viable solutions to reduce fossil fuel consumption. One readily available solution is the implementation of insulating technologies for structures in forward-deployed locations to reduce the fuel burden of combat operations.

This cost benefit analysis found that CCSF implementation is capable of providing a drastic reduction in forward-deployed operational energy demand and significant fuel cost savings. Financial analysis indicated CCSF's ability to return the upfront investment costs early, and within historical employment durations, despite variations in the cost drivers. Based on projected annual fuel savings analyzed during this CBA, universal CCSF implementation may yield exponential cost savings when conducting forward-deployed military operations. Besides the measureable financial benefits, CCSF implementation provides numerous nonquantifiable benefits to mission and personnel that may increase combat effectiveness and endurance, while lowering overall risk.

CCSF's proven combat effectiveness in Iraq, Afghanistan, Kuwait, and Djibouti make it a viable option for easy implementation into existing DOD forward-deployed practices. The previous deployed application of CCSF insulation can be used as a baseline on which future employment can be structured. CCSF's success on the battlefield warrants continued efforts to explore its use in future combat operations and implementation into similar energy reduction projects.

2. Recommendations

There are three recommendations that will benefit both the DOD and federal government with regard to future use of CCSF for forward-deployed, semipermanent structures. These recommendations may require some further analysis to ensure plausible and effective implementation into current DOD systems and policies.

- The DOD Director of Operational Test and Evaluation should conduct further tests to assess CCSF's viability for future use on deployed structures. This testing will provide the DOD with documented and projected costs and benefits associated with future use.
- The DOD should implement CCSF on existing expeditionary structures in forward-deployed locations with enduring footprints to begin capturing savings from fuel reduction, while CCSF implementation assessments are considered.
- The USD (AT&L) should explore CCSF contract support options for current and future deployment operations. Contract exploration will provide data for analysis in regard to best practices for future CCSF sourcing and contracts.

Consideration of the recommendations above will be critical to decisions regarding the future use of CCSF insulation for sustained combat operations.

3. Areas of Further Research

There are several potential areas of further research for CCSF application and associated benefits. These pertain to all military service branches that conduct expeditionary military operations in areas that require robust logistic infrastructures and fuel resources.

- CCSF performance on other commonly used expeditionary structures beyond those considered during this CBA.
- Research, analysis, and identification of relevant costs associated with creating an organic military capability to provide both CCSF materials and services for ready employment and deployment.
- CCSF's integration with energy efficient generators, power grids, or alternative energy sources currently undergoing military research and development efforts.
- Further research regarding CCSF ballistic protection capabilities and alternative uses.

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