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Contingency Waste Disposal and Energy Conversion Decision Support Model

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Abstract--**Managing solid waste is an enduring issue for many U.S. and combined force contingency operations. While various options have been explored to mitigate the problem, there are significant drawbacks and cost implications to many of these alternatives. Therefore, a systematic analysis of various expeditionary solid waste disposal options was conducted to develop a multi-objective decision model, which should aid decision-makers' planning for future operations and acquisition decisions. The decision model was built using the value-focused thinking approach and incorporated quantitative and qualitative values in conjunction with cost. This was accomplished by developing a hierarchy of waste management objectives, which improves performance utilization of scarce expeditionary resources. The research also included an economic analysis to evaluate each alternative compared to a baseline operation. The intent of the research was to increase the mission effectiveness of deployed military units, maintain Department of Defense environmental compliance, and strengthen the resilience of the U.S. military energy portfolio. The primary conclusion of the research is that current waste-to-energy (WTE) technologies represent a justifiable investment and contribute significant value in certain contingency environments if forward operating base processes are designed to accommodate and apply WTE technologies.**

I. INTRODUCTION

Expeditionary environments introduce challenges to planning across the range of military operations, as decision-makers must ensure that forces can operate without the support of permanent installations and a fleet of personnel and equipment. One of the challenges the Department of Defense (DoD) currently faces in expeditionary environments is planning for nonhazardous solid waste disposal operations. On average, each deployed service member produces 4.5-20 pounds of nonhazardous, solid waste per day and utilizes 3.5-22 gallons of fuel in camp [8, 9, 19, 20]. For expeditionary bases, this means that daily solid waste generation reaches 150 tons/day and daily fuel use reaches 105,000 gallons/day [20].

To combat the large amount of waste being generated, U.S. forces increasingly relied on open-air burn pits because of the relatively low logistical requirements and cost. However, studies over the last decade have increasingly expressed concerns about the health of service members working around burn pits. The emissions from burning trash in burn pits often go unreported to environmental agencies and are left out of many national inventories of air pollution [12]. This has led to language in the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2010 which directed the Secretary of Defense to prohibit the disposal of covered waste in open-air burn pits for all DoD contingency operations unless no other feasible disposal option is available. In response to the 2010 NDAA, the Secretary of Defense signed DoD Directive (DoDD) 3000.10 directing the DoD to increase the effectiveness and efficiency of contingency waste disposal operations. The main goals of the directive were to promote operational energy efficiency, integrate comprehensive risk management, and minimize the logistics footprint and adverse impacts on the environment.

The elimination of open-air burn pits, and the subsequent transition to more operational energy-efficient waste disposal methods, provides the much-needed opportunity to minimize health and safety risks to military forces. A number of other solid waste disposal methods are currently available to expeditionary forces: locally contracted hauling, base-maintained landfills, burying, and incineration. Additionally, waste-to-energy (WTE) systems are emerging as another potentially viable alternative. According to actual operating data collected by the US WTE industry, combusting 1 metric ton of solid waste in a modern WTE power plant generates a net of 600 kWh of electricity, thus avoiding importing one barrel of oil [4]. In addition, WTE solves the problem of solid waste disposal while recovering the energy from the waste materials, and the pollutant emissions can be controlled to low levels [6]. When determining which alternative to pursue, decision-makers need a proven method that accounts for the cost and different qualitative factors of each disposal alternative. The increase in the effectiveness of contingency waste disposal planning will result in better utilization of budget resources. Furthermore, decision-makers require an analysis that will incorporate their values and objectives to aid in the assessment of numerous solid waste disposal strategies to make the best selection for future contingency operations. However, selecting and recommending a specific solid waste management option for a contingency base is a complex task involving many internal and external factors. There are various methodologies and techniques that help decision-makers assess all the evidence and reach a defendable conclusion. Therefore, the objective of this paper is to present a combination of qualitative decision analysis and quantitative economic analysis of WTE technologies in contingency environments to better inform DoD decision-makers and planners.

II. BACKGROUND

WTE, a form of energy recovery, is the process of generating energy in the form of electricity and/or heat from the incineration of waste. Many WTE processes produce electricity and/or heat directly through combustion or gasification. WTE may provide the opportunity to simultaneously offset operational energy demands and improve nonhazardous solid waste disposal. WTE technology will be able to help the DoD repurpose waste, reduce waste volume, and potentially save on energy costs. Currently, the DoD is working with several WTE manufactures to evaluate the applicability of their respective technologies on extra-small and small contingency bases [2].

The WTE concept is being evaluated by the DoD from a requirement perspective to determine whether there are viable alternatives to current methods of waste disposal for contingency bases. A number of studies have used multi-criteria decision analysis methods to evaluate waste management and/or energy operations in municipal settings [5, 11, 15, 17, 18]. However, there have been no previous studies regarding the overall decision-making process or life-cycle costs associated with WTE technologies in DoD expeditionary applications. Furthermore, previous evaluations have not been tailored to the specific Joint Deployable Waste to Energy (JDW2E) requirements for extra-small and small bases situated in hostile and austere environments. JDW2E is a DoD multi-service initiative to develop, evaluate, and field a containerized, deployable, and semi-autonomous system that significantly reduces the volume of waste produced in austere or hostile contingency operations [2]. Therefore, the JDW2E community and the U.S. Marine Corps Expeditionary Energy Office are seeking to understand the cost implications and other key factors affecting decisions on solid waste disposal policies in these scenarios.

Decision analysis (DA) is a systematic process to transform challenging and unclear decisions into simpler and clearer decisions. DA is defined as, “A social-technical process to create value for decision-makers and stakeholders facing difficult decisions involving multiple stakeholders, multiple objectives, complex alternatives, important uncertainties, and significant consequences[13].” Since there are numerous objectives, a multiple objective decision analysis (MODA) approach was deemed appropriate; furthermore, the value-focused thinking (VFT) methodology was selected. VFT has four main concepts: start with values, generate better alternatives, create decision opportunities, and use values to evaluate alternatives [13]. To prevent limiting the decision, the research team identified the sponsor’s values and objectives regarding expeditionary waste disposal before examining any alternatives. The sponsor’s values and objectives can then be used to generate better alternatives. As Parnell [13] states, “If we have several crummy alternatives and fail to find improvements to any of them, the best analysis will only identify a crummy alternative.” Given the scope of the research though, only existing alternatives were evaluated. This research followed the ten-step decision support process outlined by Shoviak [17]: (1) Identify the Problem, (2) Develop Objectives Hierarchy, (3) Develop Evaluation Measures, (4) Create Value Functions, (5) Objective Hierarchy Weights, (6) Alternative Generation, (7) Alternative Scoring, (8) Deterministic Analysis, (9) Sensitivity Analysis, (10) Recommendations. To provide DoD planners with choices applicable to their specific situation, this MODA process produced deterministic results for hostile/austere and permissive/developed scenarios. Future research could provide probabilistic assessments based on the historic frequencies of each scenario; however, the fluid nature of warfare may limit the applicability of such historic trends. This overall methodology worked efficiently for the research due to a large number of alternatives, stakeholders, and multiple criteria. The primary decision-makers for the research were members of the Pacific Command (PACOM) Joint Engineers Working Group (JENWG), who ultimately develop strategies for regional disposal options used in contingency operations.

In addition to a VFT approach, an economic analysis (EA) was conducted to compare the costs and benefits of the multiple alternatives. The economic analysis, which followed the guidance set forth in AFMAN 65-506, generated key financial metrics such as Net Present Value (NPV) and Savings to Investment Ratio (SIR) for the disposal alternatives. The NPV method was used to calculate the capital investment, operating cost, and any WTE savings over an economic life of 10 years in terms of FY 2015 dollars. When comparable cost elements of the alternative WTE methods and the incinerator baseline were compiled, a cost summary was determined. The recommended waste management alternative was selected based on the NPV and SIR metrics. Sensitivity analysis was used to determine how the volatility of fuel prices in war, weather conditions, and discount rates would affect decision-making in hostile and austere environments.

III. QUALITATIVE DECISION ANALYSIS

A. Value Hierarchy Construction

The overarching objective to *evaluate expeditionary nonhazardous solid waste management* was developed after reviewing applicable DoD policies and directives and in consultation with senior decision-makers within the JDW2E community. To apply the evaluation across a range of military operations, two operational scenarios were assessed – hostile/austere and permissive/developed – which represent the extremes regarding conditions which may be encountered. An initial set of 22 decision factors were identified from gold and silver standard sources, [13]. Doctrinal guidance on deployed waste management, joint capabilities requirements, and journal articles provided gold standard inputs, documents which are already approved by decision-makers [13]. JDW2E leadership, along with tactical-level and operational-level stakeholders, provided silver standard inputs and was consulted to identify relevant waste planning issues. Silver standards sources are stakeholder representatives [13]. Similar planning issues were grouped, and a decision objective was established for each issue. Decision objectives were then grouped and organized into the hierarchy shown in Fig. 1. Completeness, nonredundancy, decomposability, operability, and conciseness were desired characteristics when developing the hierarchy [10]. The hierarchy was then presented to the PACOM JENWG for platinum standard review and approval [13]. The platinum standard is a measure of the value model's credibility, indicating that the model was primarily based on information from key stakeholders and senior decision-makers [13].

The expeditionary solid waste management evaluation is subdivided into two fundamental objectives: *maximize force protection* and *maximize deployability*. *Maximize force protection* addresses issues related to maintaining the health and safety of deployed DoD personnel and is divided into four sub-objectives: *minimize enemy threat to resupply*, *minimize escorted contractors*, *minimize health impacts*, and *minimize disease vectors*. Two specific health impacts were addressed: *health impacts by air emissions* and *noise pollution*. *Maximize deployability* is further divided into two sub-objectives which influence deployed mission readiness: *minimize time requirements* and *minimize logistic requirements*. *Minimize time requirements* includes five time-related sub-objectives: *training time*, *setup time*, *teardown time*, *operation man-hours*, and *maintenance downtime*. *Minimize logistic requirements* decomposes to address the disposal operation's *physical dimensions*, *capacity*, and *shipping and handling requirements*. In both acquisition and strategic planning, life-cycle cost is a significant factor which must be considered in conjunction with quantitative and qualitative values. However, to more directly focus on institutional values, the *minimize life-cycle cost* objective is not included in the value hierarchy.

B. Evaluation Measure and Single Attribute Value Function Development

Through discussions with JDW2E leadership and a review of scientific articles, measures were developed to objectively assess each value. Measures were chosen based on ease of understanding, applicability to widely varying disposal operations, and readily available information in the DoD and industry. In order to further enhance understanding and applicability by U.S. military planners, imperial units were used to for evaluation measures and planning factors, such as tons per day and square feet. Those measures are displayed in Table 1. When a direct measure did not exist, proxy measures were developed that were applicable to deployed waste disposal.

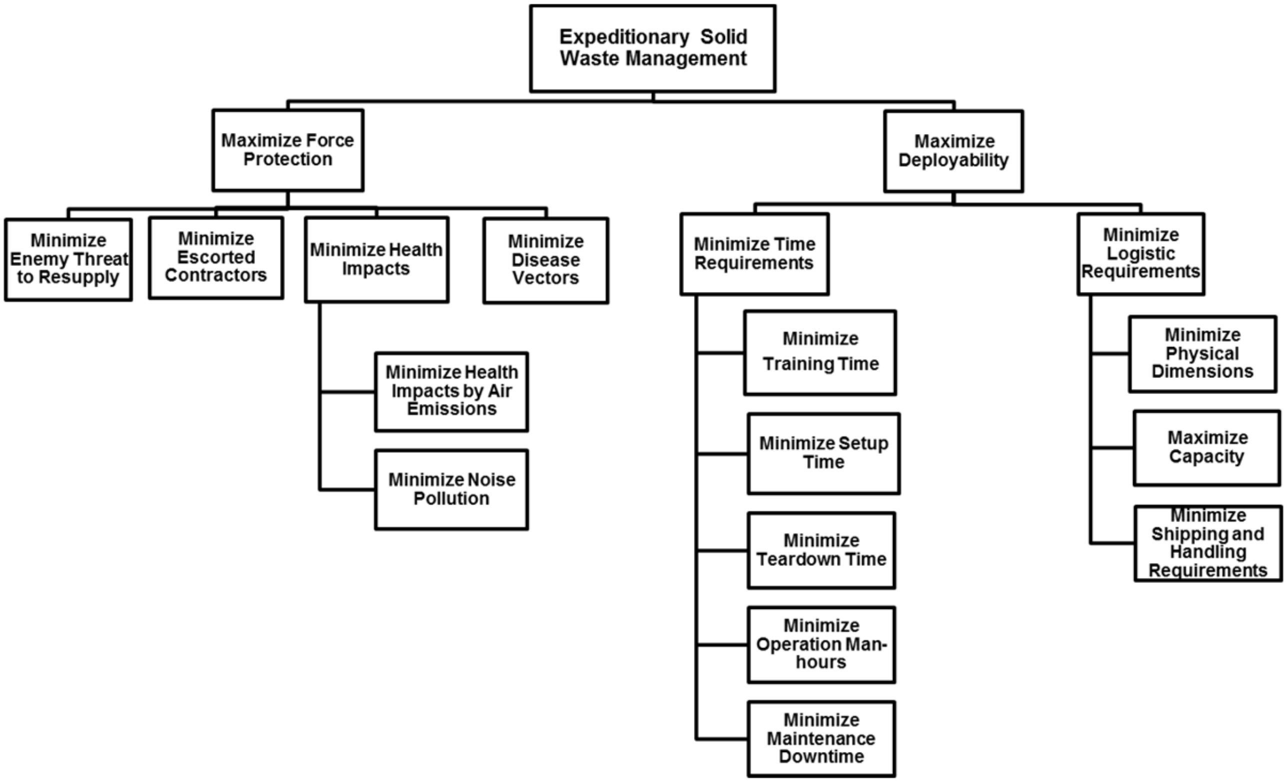

Fig. 1. Expeditionary Waste Disposal Value Hierarchy

TABLE 1. EVALUATION MEASURES

Fundamental Objective	**Sub-objective**	**Evaluation Measure**
Force Protection		
	Minimize Enemy Threat to Resupply	Total Fuel Requirements
	Minimize Escorted Contractors	Man-Hours
	Minimize Health Impacts by Air Emissions	Regulatory Compliance
	Minimize Disease Vectors	Volume Reduction and Treatment Method
	Minimize Noise Pollution	Decibels
Deployability		
	Minimize Training Time	Days of Training
	Minimize Set-up Time	Man-Hours
	Minimize Teardown Time	Man-Hours
	Minimize Operation Man-Hours	Man-Hours
	Minimize Maintenance Downtime	Percentage of Downtime
	Minimize Physical Dimensions	Square feet
	Maximize Capacity	Lbs/Square Foot/Day
	Minimize Shipping and Handling Requirements	TEUs and Level of Equipment Required

After establishing the evaluation measures, single attribute value functions (SAVFs) were developed to capture the subjective preferences of decision-makers and to convert the disparate evaluation measure scores to a single scale. Guided discussions were held with the JDW2E leadership to develop the SAVFs. After explaining the function of the SAVFs, the leaders were asked to consider each measure in the context of planning waste disposal options for a contingency base of 50 to 2,000 personnel with a mission duration of at least 90 days. The shape of each SAVF was established using the direct rating or bisection method [21]. Additionally, an Excel based tool was used to establish multidimensional value functions [16, 22].

Direct rating was used for the only categorical SAVF in the hierarchy – *minimize health impacts by air emissions*. Shown in Fig. 2, this SAVF is based on meeting standards established in 40 Code of Federal Regulations Part 60, Subpart EEEE, and the Overseas Environmental Baseline Guidance Document. With only three categories, the JDW2E leadership was able to easily assign specific preferences levels to each category. The bisection method was used for continuous value measures to assess value at regular intervals along the SAVF; a curve was then fitted to the elicited points. There are four basic curve shapes: linear, concave, convex, and S-curve [13]. *Minimize noise pollution* (Fig. 3) was represented by a convex SAVF, and nine other values were represented by linear SAVFs: *minimize enemy threat to resupply*, *minimize escorted contractors*, *minimize training time*, *minimize setup time*, *minimize teardown time*, *minimize operation man-hours*, *minimize maintenance downtime*, *minimize physical dimensions*, and *maximize capacity*.

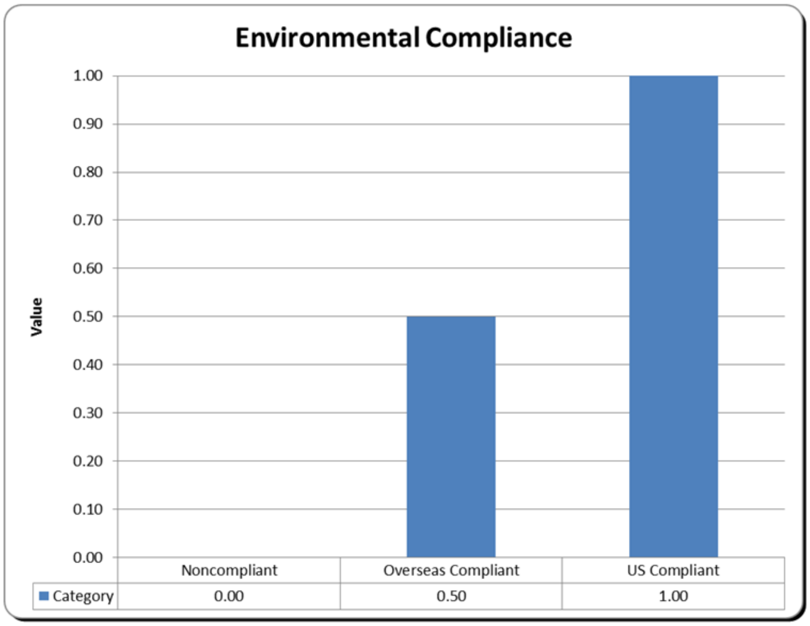

Fig. 2. Value Function for Minimize Health Impacts by Air Emissions

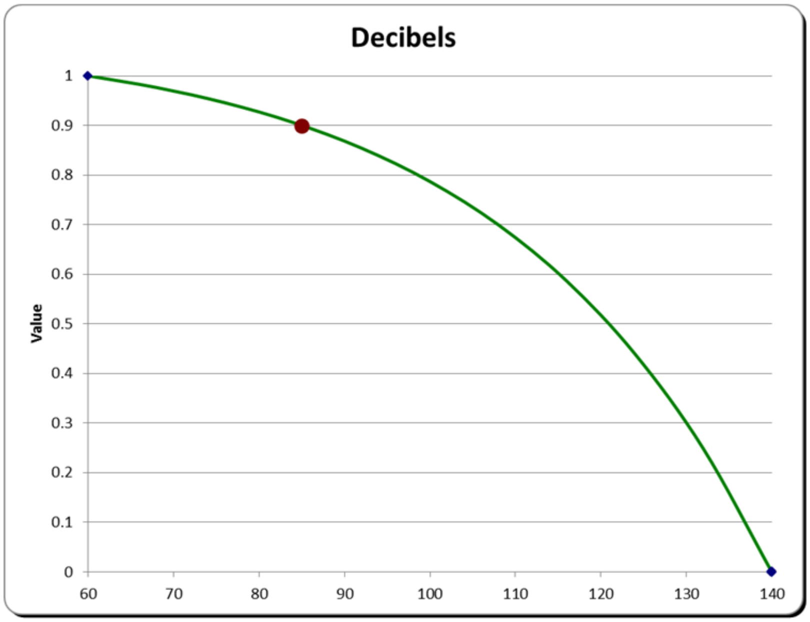

Fig. 3. Value Function for Minimize Noise Pollution

During discussions with JDW2E and JENWG members, it was determined that dependencies existed between some of the initial objectives. To assess these dependent values together, multidimensional value tables were developed. Two SAVFs utilized multidimensional tables: *minimize disease vectors* and *minimize shipping and handling requirements* (Fig. 4). *Minimize disease vectors* were assessed through the combined effects of waste volume reduction and waste treatment method. *Minimize shipping and handling requirements* combined twenty-foot equivalent units (TEUs) of shipping and the availability of equipment for disposal operations. All SAVFs were then checked to ensure consistency with JDW2E leadership preferences.

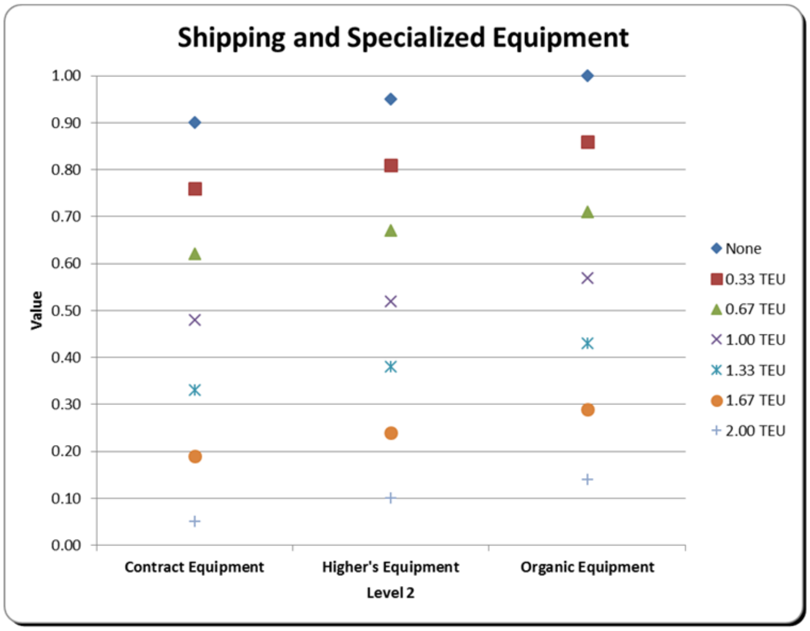

Fig. 4. Value Function for Minimize Shipping and Handling Requirements

C. Hierarchy Weight Determination

Although the value hierarchy has been constructed and decomposed into quantifiable objectives, weighting factors must be developed to determine value tradeoffs between all objectives. Senior decision-makers from the JENWG, which strategizes future use of disposal alternatives in contingency operations, were consulted to determine the weights, which indicated the decision-maker's strength of preference among the objectives [7]. To determine the weights, the decision-maker was first told that x is the hypothetical worst alternative, with each objective value set to its worst level. If they could swing one objective from its worst level to its best level, the decision-maker was then asked to identify which objective they would choose. After the first objective was selected, the decision-maker used a similar approach on the remaining objectives to determine the importance of each objective in descending order. Finally, the rank order of each attribute was converted to a weight using the Rank Order Centroid (ROC) formula in (1):

$$w_i = \frac{1}{n}\sum_{j=i}^{n}\frac{1}{j} \tag{1}$$

where n is the number of objectives being compared against each other, i is the rank order of each objective, and w_i is the weight of objective i. Table 2 represents an example of how weights were assigned to the sub-objectives located under the *maximize force protection* objective. The ROC weighting technique was performed on each branch of the hierarchy and came directly from the senior decision-makers.

TABLE 2. ROC WEIGHTING EXAMPLE

Sub-objective	Rank Order	Weight
Minimize enemy threat to resupply	1	0.457
Minimize escorted contractors	2	0.257
Minimize health impacts	3	0.157
Minimize noise pollution	4	0.09
Minimize disease vectors	5	0.04

D. Multiattribute Value Function Development

The next step was to develop an additive multiattribute value function (MAVF) to combine the SAVFs into a single aggregate value score for each alternative, using weighting factors to establish the relative importance of each value and each evaluation measure. During this process, it is important that all values must be preferentially independent [10]. Preferential independence exists if the decision-makers' preferences for any given measure are unaffected by the scores of other measures [21]. As previously discussed, JDW2E initially identified interactions regarding *minimize disease vectors* and *minimize shipping and handling requirements*. After the development of multidimensional tables for these two measures, senior decision-makers were asked to identify further dependencies; however, no other dependencies were noted. With preferential independence established for all measures, the MAVF may be written as in (2):

$$V(x_1,\ldots,x_n) = w_1v_1(x_1) + \ldots + w_nv_n(x_n) \tag{2}$$

where $V(x_1,\ldots,x_n)$ is the multiattribute value function score, x_i is the evaluation measure for attribute i, $v_i(x_i)$ is the single attribute value function score for attribute i, and w_i is the weight (scaling constant) for attribute i. The final value scores may then be used to compare decision alternatives.

E. Alternative Identification

The alternatives were subsequently scored using the MAVF to inform decision-makers about which waste disposal options provided the most value in hostile/austere and permissive/developed environments. The alternative that recorded the highest value would be considered the best option for that environment. Conversely, the alternative that recorded the lowest value would be considered the worst option for that environment. The alternatives included a burn pit, field burial, local contracted support, and an onsite landfill. Since contingency data were unavailable, characteristics for these alternatives were produced from an extensive literature review and in consultation with subject matter experts (SME) with experience in that arena. The remaining alternatives included six different tactical incinerators and five WTE disposal operations. The tactical incinerator alternatives' data came directly from a government report in 2012 that detailed the operational processes and characteristics of each incinerator. Finally, the WTE systems' data came from site visits with multiple manufacturers.

F. Scoring Procedure and Results

Once weighting factors were determined for the value tradeoffs, the weighted value scores were generated from the input characteristics of the different alternatives. The generated scores were produced from an Excel-based evaluation tool that represented the hierarchy and SAVFs previously mentioned. The generated scores attained for the hostile/austere and permissive/developed environments are shown in Fig. 5 and Fig. 6, respectively. Each figure has a legend at the bottom with a set of measurements with an associated color. The order of the legend measurements represents the importance to the decision-maker in order from left to right. For example in Fig. 5, the fuel usage measurement is listed first and represents the most important attribute for a decision-maker in a hostile/austere environment. The fuel usage is then followed by the second and third most important attributes which are the contractor presence on base and the environmental compliance respectively. This order continues on for all 13 attributes. Finally, the ideal alternative is included to represent the best possible alternative and to show where the real alternatives are lacking value. Typically, the ideal alternative is not possible.

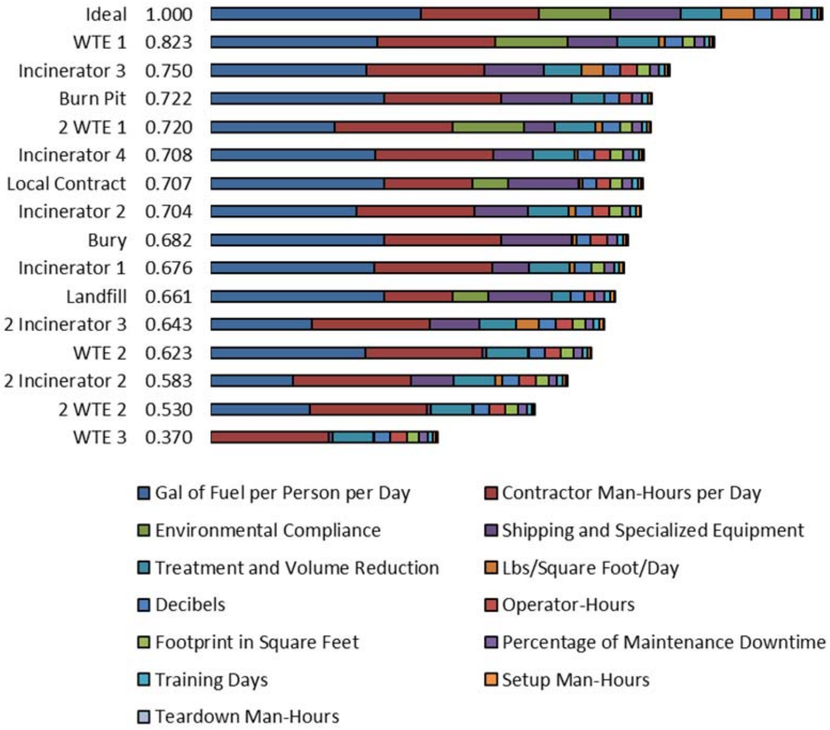

Fig. 5. Alternative Scores for Hostile/Austere Environment

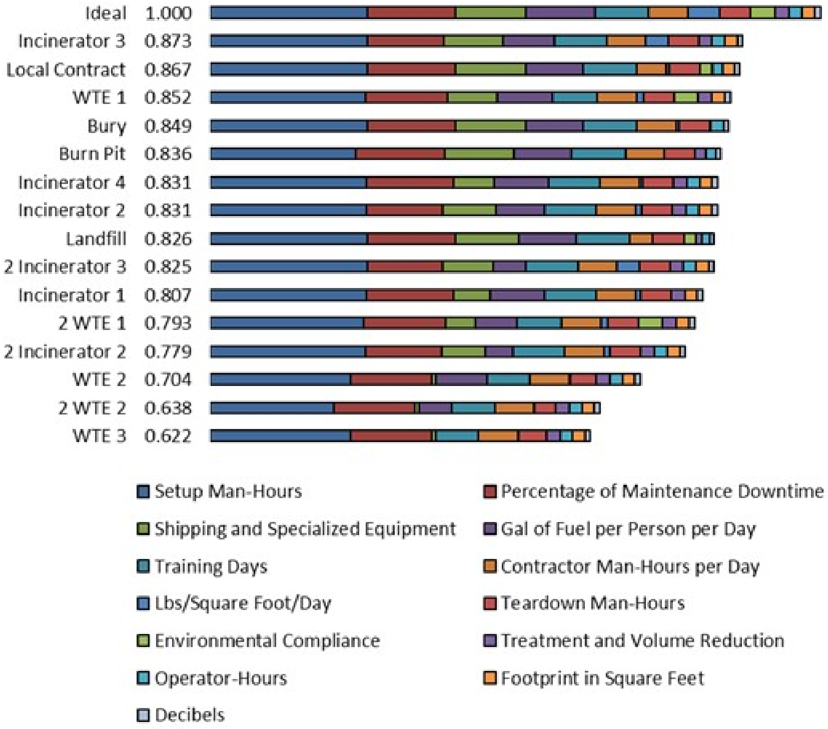

Fig. 6. Alternative Scores for Permissive/Developed Environment

IV. QUANTITATIVE DECISION ANALYSIS

A. Cost vs. Value

Fig. 7 and Fig. 8 show the available capital costs and calculated value scores for each alternative for the hostile/austere and permissive/developed environments, respectively. Decision analysts and decision-makers find this type of chart helpful in identifying dominated alternatives [13]. Being able to identify the dominated alternatives, which do not lie on the efficient frontier, helps decision-makers determine the additional cost required to improve their respective value [13]. In most cases, a dominated alternative should not be considered because the decision-maker would be paying more money for less value. Therefore, the primary focus should be on nondominated alternatives.

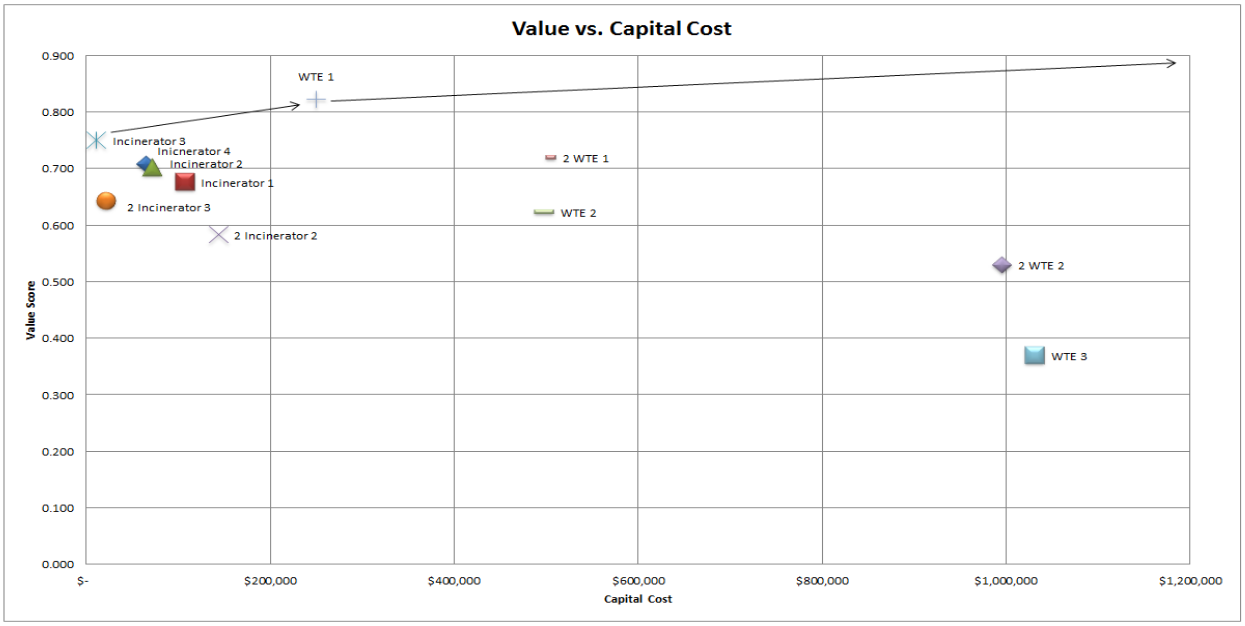

Fig. 7. Capital Cost vs. Value Chart for Hostile/Austere Environment

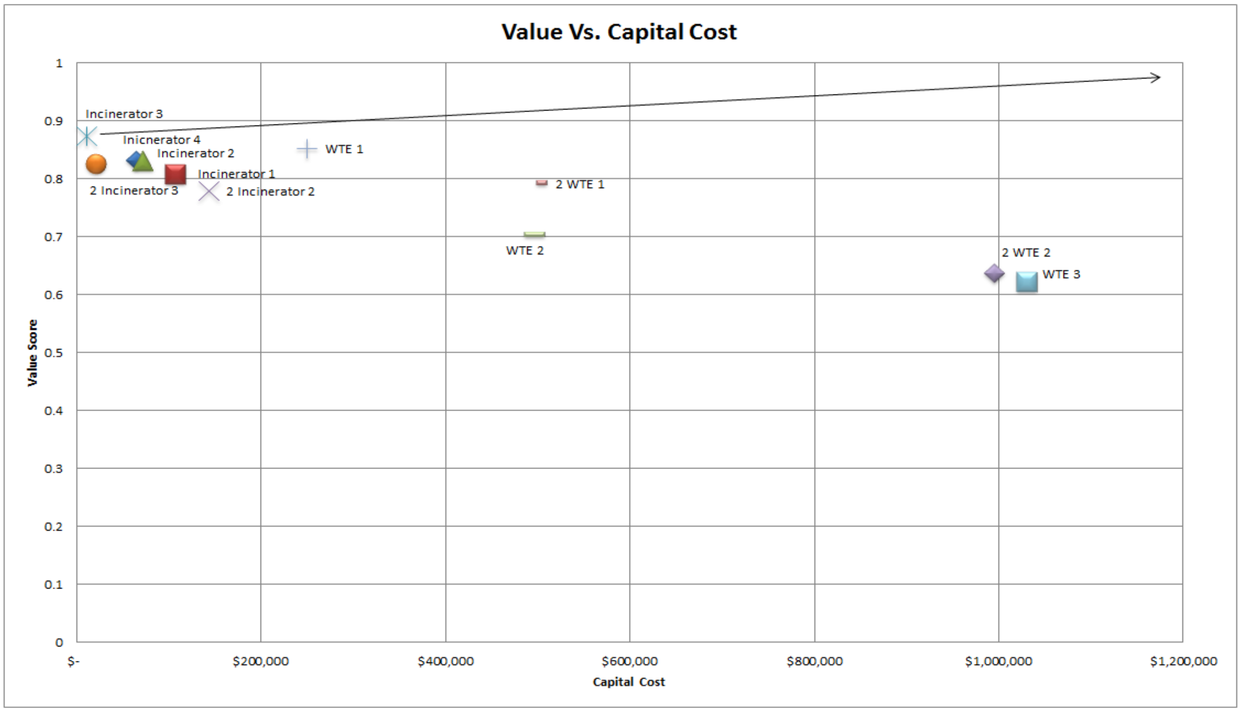

Fig. 8. Capital Cost vs. Value Chart for Permissive/Developed Environment

B. VFT Sensitivity Analysis

A sensitivity analysis was conducted to determine if varying the weights and attribute scores would affect the preferred set of alternatives. Sensitivity refers to changes in the results based on the changes of one input variable while the other variables are held constant. A decision is considered insensitive, or robust, if it is not affected by varying the input parameters. A sensitivity analysis demonstrates the stability (or instability) of the recommendation [1]. For this research, the JDW2E community was particularly interested in the conditions under which WTE system values exceed current expeditionary waste disposal practices, such as open-air burn pits and tactical incinerators. During the weighting process, there was consensus between five of six JENWG members regarding the weights on the fundamental objectives of *maximize force protection* and *maximize deployability* in both the hostile/austere and permissive/developed scenarios. Therefore, the sensitivity analysis was conducted on the second-tier weights. The weights for the sub-objectives *minimize time requirements* and *minimize logistic requirements* were varied locally within the tier (Fig. 9.) and was found to have minimal impact on the preferred set of alternatives. This indicates that the preferred alternatives will likely not change, despite the lack of consensus in weighting the time and logistic sub-objectives. Under hostile/austere conditions, there was consensus that *minimize enemy threat to resupply* should be the most heavily weighted single objective. Sensitivity analysis on the *minimize enemy threat to resupply* global weight (Fig. 10) revealed that traditional deployed disposal methods – burn pits, local contract, and burial – become the preferred alternatives as greater importance is placed on addressing the enemy threat. The alternatives displayed in Fig. 10 were limited to the highest ranking and those sensitive to weighting changes.

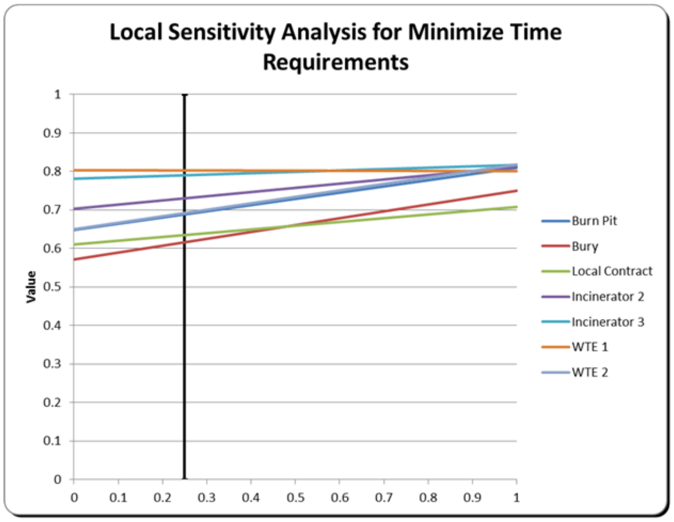

Fig. 9. Local Sensitivity Analysis for Minimize Time Requirements (Hostile/Austere)

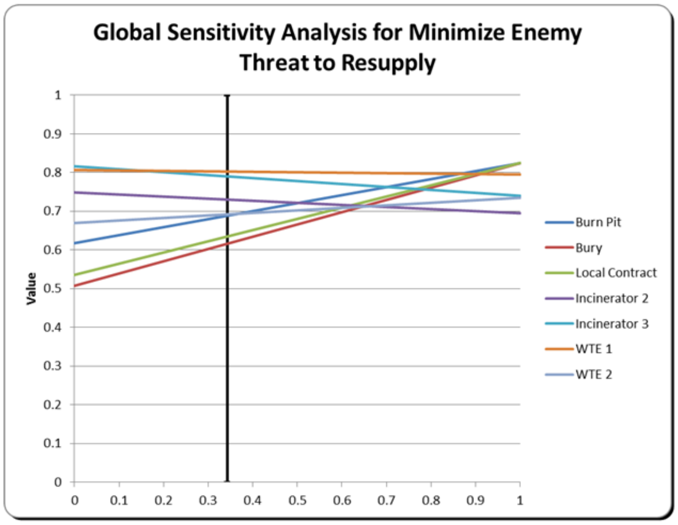

Fig. 10. Global Sensitivity Analysis for Minimize Enemy Threat to Resupply (Hostile/Austere)

Natural variation in both solid waste generation rates and composition of the deployed waste stream are sources of uncertainty in disposal planning [3]. These two factors greatly influence the amount of latent energy available for conversion. Therefore, sensitivity analysis (Fig. 11) was also conducted on the attribute scores for daily fuel use (*minimize enemy threat to resupply*) and pounds/square foot (*maximize capacity*), as each would be influenced by waste generation and characterization. With the exception of WTE 3 at low levels of fuel use, the small changes in value did not affect the preferred set of alternatives when compared to the disposal alternatives under consideration.

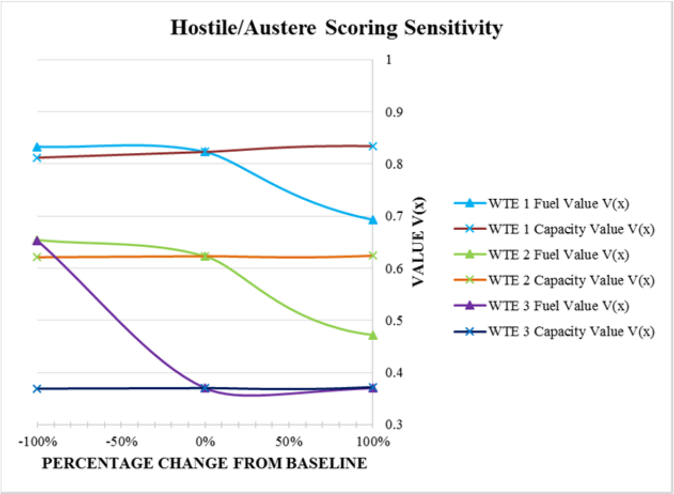

Fig. 11. Sensitivity Analysis for WTE Fuel Use and Capacity (Hostile/Austere)

C. Economic Analysis

While VFT focuses on qualitative and quantitative analysis of various factors, an economic analysis (EA) was conducted to provide a quantitative case study utilizing WTE technologies against a baseline incinerator. EA is a method of helping decision-makers decide among alternatives based on quantifiable benefits. Several financial concepts were used to measure the effectiveness of the capital investment to help DoD planners decide whether to invest in WTE technology at forward operating bases (FOBs). The first task compared the costs of the new WTE technologies against the existing incinerator operations using an EA. The financial metrics used were Savings-to-investment ratio (SIR), Net Present Value (NPV), and Payback Period (PP); these metrics offer three different perspectives on the financial value of projects. The second task used deterministic sensitivity analysis to pinpoint key cost parameters effect on the decisions. The sensitivity analysis helps to understand the impact of varied fuel prices and weather conditions on the WTE savings and whether the preferred alternatives changed using these parameters.

Overall, three alternatives were evaluated through EA. For the model, a 10-year economic life was assumed for each alternative and the first usable year was 2016. This analysis compared existing incinerator technologies with two WTE vendors and sought to understand whether WTE is justifiable from a cost perspective. Both technologies can support the waste processing requirement of 2 tons per day for a small 500-person FOB, based on output data provided by the vendors. This analysis used FY 2015 as the base year.

The cost elements were categorized into non-recurring and recurring costs. Non-recurring costs included equipment, training, installation, curing, and demobilization. Recurring costs included operating cost, utilities, transport, fuel, parts/maintenance, and heat/ electricity savings. Constant year 2015 was used for the cost input. In a constant dollar analysis, this required an adjustment from the year in which costs are incurred to the base year of the proposed project. Each alternative was compared side by side with the status quo with a 10-year cost summary for each option. Table 3 summarizes the key financial metrics from the EA for each alternative.

Additionally, three input factors were analyzed in a separate sensitivity analysis. From the literature review, the variability of fuel cost in hostile environments is significant enough to justify a sensitivity analysis on this cost input. The goal is to understand the cost of fuel's impact on NPV and if the rankings would change given different fuel costs. The fuel price of $10 per gallon in hostile environments was based on a Deloitte study [8]. Fuel price variation percentages were applied to determine if a 70% increase or decrease in fuel price had an impact on the overall rankings. A sensitivity of total present value analysis chart is documented in Fig. 12, which shows no impact on the rankings. Vendor C is still the preferred choice throughout the range of cost variation. Vendor C's equipment can save on both hot water and heating, thereby realizing a net fuel savings and a resulting savings in logistics costs. The greater the increase in fuel cost, the greater the savings Vendor C achieves. Both WTE operations have advantages over the baseline incinerator operations.

TABLE 3. SUMMARY OF KEY METRICS

	Net Present Value	Savings-to-Investment Ratio	Payback Period (yrs)
Vendor A	$3,373,743	NA	NA
Vendor B	$1,676,373	6.43	1.6
Vendor C	($4,016,346)	15.57	0.5

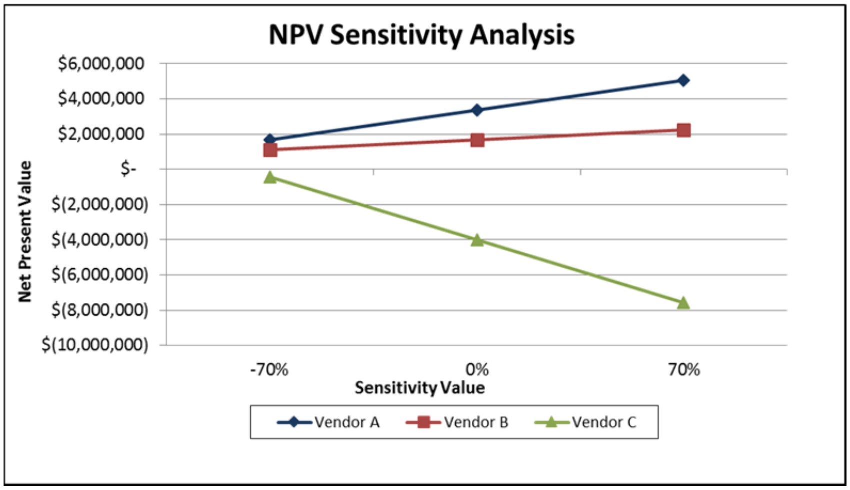

Fig. 12. NPV Sensitivity Analysis

The number of days each year that require heating is also a key assumption in determining the amount of fuel used to operate heaters at contingency bases. Some WTE technologies rely on this factor to realize the cost savings from the technology, so this is a critical assumption when determining savings. The baseline scenario assumes that heating is required for approximately a fourth of the year, or 90 days. This assumes the base experiences the standard four seasons per year. However, since contingency bases are also located in tropical and extremely cold areas, three scenarios were created for the heating requirement. Under tropical weather, such as locations in the Philippines, the annual average temperature is about 26.6 °C (79.9 °F). Cooler days are usually felt in the month of January with the temperature averaging at 25.5 °C (77.9 °F) [14]. Zero heating days are assumed in this scenario. Within the mountainous northern climate of Yechon Air Base in the Republic of Korea, the heating requirement could easily exceed 180 days.

A climate sensitivity impact chart is documented in Fig. 13. The number of heating days has a significant impact on the net present value of Vendor C. Without the heating requirement, Vendor B is the preferred alternative, which has a net present value of $1,676,373. Vendor C can save substantially more as the number of heating days are increased. Specifically, if the number of days heating is required exceeds 26 days, Vendor C becomes the preferred choice; therefore, Vendor C would be the preferred choice when considering deploying WTE in a cold climate. If the number of heating days exceeds 57 days, then Vendor C can realize a net fuel savings. At approximately 67 days of heating requirement, the WTE by Vendor C realizes twice as much as the savings compared to Vendor B.

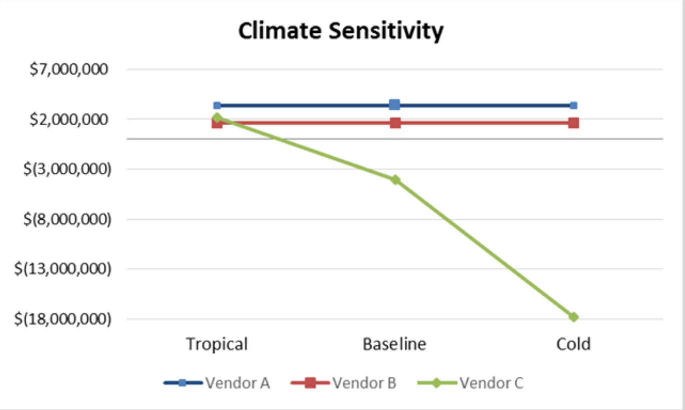

Fig. 13. Climate Sensitivity Analysis

The discount rate is another variable that can be subject to sensitivity analysis. The net present values were calculated using discount rates representing the government's cost of borrowing. The rates used in the calculations were the interest rates on Treasury notes and bonds with 10-year maturity durations. The model's baseline assumption was of a discount rate of 0.9% with a 10-year economic life. The AFMAN 65-506 suggests sensitivity analysis on the discount rate should be conducted at plus and minus roughly 25% of the rate used [1]. Therefore, a lower discount rate of 0.7% and a higher rate of 1.1% were used to calculate the NPV for all alternatives.

V. CONCLUSIONS

Through VFT analysis, a robust set of alternatives emerged under both the hostile/austere and permissive/developed scenarios. For both operating environments, WTE 1 and Incinerator 3 provide stakeholders with the greatest value, barring active hostilities which necessitate an exemption for burn pit use. Locally contracting waste disposal also joins the preferred set alternatives in permissive/developed settings. Due to the greater importance placed on reducing air emissions, equipment requirements, and enemy threats, both inside and outside the camp, analysts should focus initial improvements in the areas of air emissions, physical dimensions, and fuel consumption to improve stakeholder value. Fuel use and coordinating equipment are constant issues for military planners, and it is appropriate that these issues emerged as primary design factors, which should affect the DoD's planning decisions. Air emissions have become a high visibility issue due to burn pits, and this research qualitatively demonstrates that open-air burning of solid waste is inferior to containerized systems when comprehensively evaluated for all of the stakeholder values measured, not for air emissions alone. Due to inherent battlefield complexity, there will be situations where the simplicity of burn pits remains appropriate. However, the tactical incinerators and WTE systems evaluated in this study represent only a small portion of the emerging options available for extra-small and small contingency bases, and more systems should be evaluated to replace burn pits in more situations.

Under the baseline condition (90 days heating, and $10 per gallon fuel cost), the EA revealed the greatest total net present value savings is $4,016,346 offered by Vendor C. Varying the fuel price does not affect the baseline assumption that Vendor C is the most economical choice. However, under tropical conditions, where no heating days are required, the best net present value is $1,676,373 offered by Vendor B's system. When the number of heating days is greater than approximately 26 plus days, Vendor C becomes the preferred choice.

Based on the two different approaches, VFT and EA, WTE has significant stakeholder value and the potential for life-cycle cost savings. This suggests that WTE technologies are becoming the future of expeditionary disposal for the DoD. This direction of development is not only policy driven, but it also constitutes an environmentally and fiscally responsible choice. The primary conclusion of this research is that current WTE technologies present a justifiable investment and offer significant value for extra-small and small contingency environments, if FOB processes are designed to accommodate and apply WTE technologies.

However, there is currently a gap between what is desired for a contingency environment and the products available. To reduce the logistical footprint, further weight reduction in WTE systems is needed for application in contingency environments; additionally, WTE technologies vary widely in capability and the means by which they convert waste into energy. Near-term advancements in these areas will ultimately determine the extent of DoD savings through WTE adoption. To spur industry development, the DoD should take a leading role in partnering with private enterprises to develop a DoD-specific, deployable WTE product based on contingency scenarios.

The use of appropriate planning factors is vital to the examples illustrated in this research. Assumptions sometimes differ between the manufacturers' estimates and force provider planning factors. As the DoD collects further field testing data, this model needs to be updated for key data assumptions through standardized testing procedures, and informed decision-makers should take into account operational data in specific environments. These updates will help DoD decision-makers use the analysis determining the most feasible, suitable, and sustainable options given specific base requirements. Finally, there needs to be an overall FOB energy strategy, of which the Waste to Energy solution would be just one component. The holistic energy solution for fuel supplies, food supplies, packaging, water, and other materials required on base needs to be designed, planned, and streamlined so that optimal logistic efficiency can be achieved.

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DISCLAIMER

The views expressed in this article are those of the authors and do not reflect the official policy or position of the U.S. Air Force, U.S. Marine Corps, Department of Defense, or the U.S. government.

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