



TECHNICAL REPORT
TR-NAVFAC-EXWC-EV-1703
JULY 2016

**WASTE-TO-ENERGY THERMAL DESTRUCTION
IDENTIFICATION FOR FORWARD OPERATING
BASES**

Tami Relph P.E.
Edwin Chiang P.E.
NAVFAC EXWC

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 01-July-2016		2. REPORT TYPE Technical Report		3. DATES COVERED (From - To) 2015-2016	
4. TITLE AND SUBTITLE Waste-to-Energy Thermal Destruction Identification for Forward Operating Bases				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Tami Relph, P.E. Edwin Chiang, P.E.				5d. PROJECT NUMBER WP-201521	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Facilities Engineering and Expeditionary Warfare Center 1000 23 rd Ave Port Hueneme, CA 93043				8. PERFORMING ORGANIZATION REPORT NUMBER TR-NAVFAC-EXWC-EV-1703	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Environmental Security Technology Certification Program 4800 Mark Center Drive, Suite 17D08, Alexandria, VA 22350-3605				10. SPONSOR/MONITOR'S ACRONYM(S) ESTCP	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This project was a follow-up to the SERDP FY 12 statement of need in search of W2E technologies at TRL 6 for demonstration. In addition, this project included compiling relevant DoD W2E progress in one document. A sources sought solicitation was issued and an industry day was conducted with the help of the JDW2E community in search of ready to demonstrate W2E systems. While the concept of W2E is desired, in reality, there are many challenges associated with W2E systems at a small scale impractical. The sub-processes of W2E are very well understood, but the challenge is successfully integrating the sub-processes together and meeting the expeditionary requirements of each service branch.					
15. SUBJECT TERMS Waste to Energy, Forward Operating Base, Solid Waste Reduction					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT U	18. NUMBER OF PAGES 45	19a. NAME OF RESPONSIBLE PERSON Tami Relph
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (805) 982-5548

Disclaimer:

This publication is intended to be informational and does not indicate endorsement of a particular product(s) or technology by the Department of Defense or NAVFAC EXWC, nor should the contents be construed as reflecting the official policy or position of any of those Agencies. Mention of specific product names, vendors or source of information, trademarks, or manufacturers is for informational purposes only and does not constitute or imply an endorsement, recommendation, or favoring by the Department of Defense or NAVFAC EXWC. Although every attempt is made to provide reliable and accurate information, the authors of this publication do not warrant or otherwise represent in any way the accuracy, adequacy, efficiency, or applicability of any product or technology discussed or mentioned herein, including the suitability of any product or technology for a particular purpose



FINAL REPORT

Waste-to-Energy Thermal Destruction Identification for Forward Operating Bases

ESTCP Project WP-201521

**Tami Relph P.E.
Edwin Chiang P.E.
NAVFAC EXWC**

Version 1

July 2016

This page is intentionally left blank.

ACRONYMNS

AFB	Air Force Base
AFCEC	Air Force Civil Engineering Center
AFIT	Air Force Institute of Technology
ARL	Army Research Laboratory
CFR	Code of Federal Regulations
CPD	Capability Production Document
DoD	Department of Defense
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FOB	Forward Operating Base
FPE	Force Provider Expeditionary
JDW2E	Joint Deployable Waste to Energy
MSW	Municipal Solid Waste
NAVFAC EXWC	Naval Facilities Engineering and Expeditionary Warfare Center
NECC	Navy Expeditionary Combat Command
NSRDEC	Army Natick Solider Research, Development and Engineering Center
OEBGD	Overseas Environmental Baseline Guidance Document
OSWI	Other solid waste incineration
PAX	Personnel
PERP	Portable Equipment Registration Program
PM FSS	Product Manager Force Sustainment Systems
SERDP	Strategic Environmental Research and Development Program
TCLP	Toxicity Characteristic Leaching Procedure
TPD	Tons per day
TRL	Technology Readiness Level
USAF	United States Air Force
USMC	United States Marine Corps
W2E	Waste to Energy
WEC	Waste to Energy Converter

EXECUTIVE SUMMARY

INTRODUCTION

This project is a follow-up to the (Strategic Environmental Research and Development Program) SERDP Fiscal Year 2012 statement of need in search of waste to energy (W2E) technologies at technical readiness level (TRL) 6 for demonstration. In addition, this project included compiling relevant Department of Defense (DoD) W2E progress in one document. A sources sought solicitation was issued and an industry day was conducted with the help of the Joint Deployable Waste-to-Energy (JDW2E) community in search of ready to demonstrate W2E systems. While the concept of W2E and its processes are mature, there are many challenges associated with W2E systems that make small scale deployment impractical such as successfully integrating W2E sub-processes together and meeting the expeditionary requirements of each service branch.

The project team believes that the way forward for successful deployment of a cost effective, safe and environmentally acceptable waste disposal strategy is to simplify the technology development goals. Specifically, the goal of reducing total net energy consumption to net zero is recommended. The minimum objective should be the lowest possible fuel consumption per unit of waste disposed. By shifting the focus from W2E to waste elimination and minimizing fuel usage, this path is more achievable than focusing only on W2E.

OBJECTIVES

There are two objectives to this project. The first objective is to identify waste-to-energy (W2E) thermal destruction system(s) (e.g. gasification, pyrolysis, etc.) that is suitable for use at small (300-1,999 personnel (pax); <2 TPD¹) base camps and at a technical readiness level of 7 or higher. This objective builds upon the SERDP statement of need issued in 2012 by seeking mature technologies to demonstrate under the Environmental Security Technology Certification Program (ESTCP). Although the project's primary focus is on gasifiers, the project team also looked at other thermal destruction technologies. The other primary categories of waste to energy systems (biological systems and plasma arc) are unsuitable for remote base camps. Biological systems take too long to setup and produce energy, and plasma-arc systems use too much energy. The second objective is to compile and evaluate relevant past and on-going DoD efforts related to W2E for small base camps. The purpose is to inform ESTCP and W2E community the progress of W2E and lessons learned.

¹ The small base size range is from ATP 3-37.10/ MCRP 3-17.7N Base Camps Page 1-2. The 2 Tons Per Day (TPD) is from Joint Deployable Waste to Energy (JDW2E) Working Group (WG).

TECHNOLOGY DESCRIPTION

W2E technology in the United States (U.S.) began as incinerators to process solid waste for cities in the mid-1800s. By the early 1990s, 15% of all U.S. municipal solid waste (MSW) was being combusted by the majority of non-hazardous waste incinerators recovering energy and employing pollution control systems. In the 21st century, many W2E technologies exist to convert municipal solid waste to energy with minimal use of landfills. While utilizing W2E on the municipal scale may be economically feasible (depending on utility rates and tipping fees), transferring the technology to a small, mobile Forward Operating Bases (FOB) is challenging. The common approaches for handling non-hazardous solid waste at FOBs are now either not desirable or not available.

There has been extensive research and development conducted within the DoD on the development and evaluation of W2E systems for the DoD over the past 7 years. This includes defining the military requirements, defining the test standards for evaluating W2E systems, reviewing past and current DoD efforts, searching the industry for available technologies that are ready for demonstration and addressing technology challenges. A compilation of the various projects (including projects from SERDP, ESTCP, Air Force Research Laboratory, Army Research Laboratory (ARL) and Natick Soldier Research Development and Engineering Center (NSRDEC)) into one document is included in this report to better assess the progress of W2E as a whole throughout DoD.

PERFORMANCE ASSESSMENT

In coordination with JDW2E, a sources sought solicitation was issued on FedBizOps in May 2015 (See Appendix A). The solicitation included the criteria in the W2E system being sought and the composition of the feedstock. The performance specification in the solicitation was too constraining because there was no appropriate vendor response to the solicitation after 3 months. Because of the lack of response, Naval Facilities Engineering Command (NAVFAC) Engineering and Expeditionary Warfare Center (EXWC) revisited the vendor list involved in the 2014 ARL “Study of Systems for Waste-to-Energy Conversion”. The goal of searching through the vendor list was to determine if any of the vendors developed new technology or upgraded equipment since the study. The vendors were individually contacted to gather additional information. In addition to using the vendor list, previous W2E studies were reviewed to find suitable, innovative W2E systems suitable for small base camps.

Industry Day 2016 was a NAVFAC EXWC sponsored event in collaboration with Pacific Command (PACOM) for the JDW2E community. The event was from February 25-26, 2016 via Adobe Connect On-line, and the goals of the industry day included:

- Finding new and different expeditionary W2E vendors
- Informing and updating the private industry about the DoD’s goals and progress with regards to expeditionary W2E

- Increasing private industry competition in the expeditionary W2E field

Industry Day was broken into two days: Day 1 was opened to the public with Government presentations, and Day 2 was one-on-one sessions with vendors by appointment only. The purpose of the one-on-one sessions was to allow open discussions with the vendors without the concern of revealing proprietary information to the public. Forty individuals participated in the teleconference on Day 1 and eight vendors participated in the closed door session. One vendor had the highest TRL and was selected by the JDW2E community for a follow-on site visit to determine the viability of the technology for demonstration.

COST ASSESSMENT

No cost assessment was performed in this project.

IMPLEMENTATION ISSUES

There were no implementation issues in this project.

RECOMMENDATION

The sub-processes or components of an expeditionary W2E system are very well understood and developed; however, the challenge is assembling all the sub-processes into one coherent system that works. Technology challenges were identified from the ARL *Study of Systems for Waste-to-Energy Conversion* report and from discussions with members of the JDW2E working group.

From discussions with NSRDEC and the operational manager of JDW2E, the way forward to providing a solution for solid waste elimination at small FOBs is to adjust the priorities for a viable solution. Instead of focusing primarily on waste-to-exportable electricity systems, the focus should be waste elimination systems that minimize the fully burdened cost of fuel. The fully burdened cost of energy includes the cost of the fuel itself, cost of labor to transport the fuel to the base camp, cost of the equipment involved in transport and the costs related to casualties inflicted during transport.

The next priority after reducing the fully burdened cost of energy for solid waste elimination is wastewater treatment. At small base camps, the use of portable toilets or burial for wastewater treatment is not always the best option. A system that eliminates both solid waste and wastewater while minimizing fuel usage is ideal.

W2E systems exporting hot water should be optional because there may not always be a need for hot water depending on the location of the base. Tentatively, in FY17 ARL and NSRDEC will investigate hot water usage from a W2E system.

W2E systems exporting electricity should not currently be pursued for small base camps because the systems tend to be very complex, expensive, large foot print and the amount of electricity exported may be negligible due to inefficiencies in engines. Similar to W2E systems that export hot water, there may not always be a need for exportable electricity, which would only burden

the end user to consume the electricity. At least two major W2E companies are not pursuing waste to electricity for extra-small and small size systems.

This page is intentionally left blank.

TABLE OF CONTENTS

Executive Summary	vii
1.0 Introduction.....	14
1.1 Background	14
1.2 Objective	15
1.3 Regulatory Drivers	15
2.0 Technology Development.....	16
2.1 Military Requirements.....	16
2.2 Test Standards	19
2.3 Market Research.....	28
2.4 Industry Day 2016.....	29
2.5 Past Efforts	29
2.6 Other Current DoD Efforts.....	34
3.0 Recommendation	36
4.0 Conclusion	38
5.0 REFERENCES	39
APPENDIX A: FED BIZ OPS SOLICITATIONS	A-1

TABLES

Table 2-1: Characteristics of 150 Pax and 600 Pax Modules.	17
Table 2-2: Standard and Challenge Recipes by Weight Percent.	20
Table 2-3: Breakout of Plastic Recipe by Weight Percent.	20
Table 2-4: Comparing Solid Waste Recipe to Other Waste Characterizations.	21
Table 2-5: Comparison of EPA Emission Standards for Incinerators Burning Less than 35 Tons Per Day to OEBGD.....	23
Table 2-6: Hazardous Waste Identification.	25
Table 2-7: Process Metrics [Ref. 7].	26
Table 2-8: Operational Metrics [Ref. 7].	27
Table 2-9: ESTCP and SERDP W2E Projects.....	32
Table 3-1: Technology Challenges.	37

1.0 INTRODUCTION

1.1 Background

The Department of Defense (DoD) is in need of a waste elimination system as an alternative to burn pits and incinerators at forward operating bases (FOB). Burn pits and incinerators are the most commonly used technologies for eliminating solid waste at remote bases. However, burn pits usage is severely restricted, and incinerators are inefficient in burning wet solid waste.

Running an incinerator may require large quantities of diesel fuel due to the high moisture content and quantity of the waste. To supply the high demand for diesel fuel at FOBs, the fuel needs to be transported over long distances. However, the transportation of diesel fuel over long distances increases the risks to military personnel and contractors. Because fuel is a limited resource at FOBs, diesel fuel consumption should be minimized. Other waste management practices are not always desirable or available such as burying non-hazardous solid waste could result in claims against the United States; hauling waste to a rear support area is a low priority due to the cost and logistical issues; or contracting with host nation for trash removal is not always available or preferable. A solution would be to use a waste-to-energy thermal destruction system to reduce the volume of the waste and supply its own energy source.

In October 2010, the Strategic Environmental Research and Development Program (SERDP) program issued a statement of need:

Develop innovative approaches to decrease the size and increase the efficiency of battalion-scale waste to energy converter (WEC) systems based only on gasification or pyrolysis processes. The performance criteria for a battalion-scale WEC, as established by Product Manager Force Sustainment Systems (PM FSS) and the Base Camp System of Systems Working Group, is to process 1–3 tons per day (TPD) of non-hazardous mixed solid waste into exportable energy in the form of fuel or electricity, with a residual waste of only non-hazardous char and ash. The threshold efficiency is for the system to be self-sufficient in processing the waste without adding fuel or power. The objective is for the system to be 50% efficient in terms of net chemical energy recovered, accounting for parasitic energy requirements in all subsystems.

Since issuing the statement of need, much progress has been made in the WEC field within the DoD and private industry. Because of many on-going parallel efforts, there may be a knowledge gap on the different findings. This project builds upon the SEDRP statement of need by compiling the relevant findings from recent DoD efforts, examining the benefits and limitations of the SERDP funded projects related to that statement of need, and finding and recommending innovative small WEC technologies for demonstration if any. This report provides the Environmental Security Technology Certification Program (ESTCP) and SERDP committee with WEC performance specifications and test standards as requested by the military community

and providing the committee technology challenges that are preventing the progress of WEC in the DoD. These challenges can be addressed by future SERDP statement of needs.

1.2 Objective

There are two objectives to this project. The first objective is to identify waste-to-energy (W2E) thermal destruction system(s) (e.g. gasification, pyrolysis, etc.) that is suitable for use at small (300-1,999 personnel (pax); <2 TPD²) base camps and at a technical readiness level of 7 or higher. This objective builds upon the SERDP statement of need issued in 2012 by seeking mature technologies to demonstrate under ESTCP. Although the project's primary focus is on gasifiers, the project team also looked at other thermal destruction technologies. The other primary categories of waste to energy systems (biological systems and plasma arc) are unsuitable for remote base camps. Biological systems take too long to setup and produce energy, and plasma-arc systems are too energy intensive. The second objective is to compile and evaluate relevant past and on-going DoD efforts related to W2E for small base camps. The purpose is to inform ESTCP and W2E community the progress of W2E and lessons learned.

1.3 Regulatory Drivers

There is significant interest by the DoD in using W2E technologies at contingency bases to offset the required fuel demand for heat and power generation, while protecting soldiers and minimizing waste management burdens. The following policies illustrate this desire:

- **DoD Instructions 4715.19 (July 2013)** prohibits plastic and other “covered waste” from burn pits and requires Combatant Commanders to use alternate means of disposal or justify to the Under Secretary of Defense for Acquisition, Technology and Logistics and Congress every 180 days why no alternatives are feasible [Ref. 2]. It applies to locations with activity levels over 100 personnel and over 90 days.
- **Government Accountability Office-11-63** asserts that DoD contingency waste disposal practices siphon security personnel and pose significant hazards for operations and neighboring communities [Ref. 3].
- **DoD Directive 3000.10 (January 2013)** directs that contingency basing pursue joint, scalable capabilities that use operational energy efficiently, minimize waste, manage environmental, health, safety, and pest risks, and minimize the logistics footprint [Ref. 4].
- The **Overseas Environmental Baseline Guidance Document** (OEBGD) covers the water quality, air quality, solid waste and hazardous waste standards that the system would have to meet overseas if the host nation's standards are not adequate.

² The small base size range is from ATP 3-37.10/ MCRP 3-17.7N Base Camps Page 1-2. The 2 Tons Per Day (TPD) is from Joint Deployable Waste to Energy (JDW2E) Working Group (WG).

2.0 TECHNOLOGY DEVELOPMENT

W2E technology in the United States (U.S.) began as incinerators to process solid waste for cities in the mid-1800s [Ref. 5]. By the early 1990s, 15% of all U.S. municipal solid waste (MSW) was being combusted by the majority of non-hazardous waste incinerators recovering energy and employing pollution control systems. In the 21st century, many W2E technologies exist to convert municipal solid waste to energy with minimal use of landfills. While utilizing W2E on the municipal scale may be economically feasible (depending on utility rates and tipping fees), transferring the technology to a small, mobile military camp is very challenging [Ref. 9]. The common approaches for handling non-hazardous solid waste at FOBs are now either not desirable or not available.

This section highlights the progress of the development and evaluation of W2E systems for the DoD over the past 5 years. This includes defining the military requirements, defining the test standards for evaluating W2E systems, reviewing past and current DoD efforts, searching the industry for available technologies that are ready for demonstration, and addressing technology challenges. By compiling the information into one document, the progress of W2E can be seen throughout DoD.

2.1 Military Requirements

Two detailed military requirements exist for W2E that can be discussed publically.

Requirement 1. Army Force Provider Expeditionary Capability Production Document - see Section 2.1.1

Requirement 2. *Expeditionary Energy, Water, and Waste Initial Capabilities Document (JROCM 140-12)* – Approved by Joint Capabilities Board for joint use on 14 September 2012 - no details on performance specifications. Publically available at:
<http://www.hqmc.marines.mil/Portals/160/Docs/USMC%20E2W2%20ICD.pdf>

This Joint Capabilities Board approval gives approval for any service to use.

2.1.1 Official DoD Requirement: Army Force Provider Expeditionary Capability Production Document

Currently, no official joint military performance requirements exist among the different services for W2E systems. The Army Force Provider Expeditionary (FPE) Capability Production Document (CPD) published in February 2014 the requirements to support highly modular and deployable systems for environmentally controlled billeting; food service; hygiene; power generation and distribution; petroleum and water storage and distribution; and shower water recycling. The CPD was issued for 150 pax and 600 pax base camps, and it is the only official DoD document that defines solid waste requirements useable for W2E. For solid waste management, this CPD has two options: 150 pax modules or add-on kit for four collocated 150-

man modules. Table 2-1 summarizes the CPD threshold and objective for both the 150 pax module and the 600 pax collocated modules with add-on capability.

Currently, the Army explicitly is not pursuing any W2E capture for the 150 pax module incinerator (Reference <https://www.fbo.gov> - Solicitation Number: EXPEDITIONARY-SOLID-WASTE-DISPOSAL-SYSTEM Modification July 2015 including Draft Performance Purchase Description July 2015 Expeditionary Solid waste Disposal System.

Table 2-1: Characteristics of 150 Pax and 600 Pax Modules.

MODULE CONFIGURATION	CHARACTERISTICS	DEVELOPMENT THRESHOLD	DEVELOPMENT OBJECTIVE
150 pax module	Weight of solid waste processed per day	1,000 pounds or more	No extra requirements
	Convert to Usable Energy	None	Converted to usable energy including fuel, heat or electric power.
600 pax module	Weight of solid waste processed per day	4,000 pounds or more	No extra requirements
	Convert to Usable Energy	None	Converted to usable energy including fuel, heat or electric power.

2.1.2 Estimated Requirements Per Service

The Joint Deployable Waste to Energy (JDW2E) working group comprises representatives from all four services to informally determine W2E requirements. The performance specifications for each service branch are expected to vary due to varying sizes of their remote base camps. For example, the Army's interests are solid waste management systems for extra small (50-299 personnel (PAX) minimum 1 ton per day) and small base camps (300-1,999 PAX minimum 2 TPD), while the Air Force (USAF) has its primary interests in systems for medium base camps (2,000-5,999 PAX minimum 3-5 TPD).

The Army is currently developing solid waste management system performance specifications for extra small and small base camps. For extra small base camps, the Army PMFSS is seeking solid waste elimination via incineration with no energy recovery but at least energy neutral systems for small base camps. For medium base camps, the Air Force Civil Engineering Center (AFCEC) will be developing formal W2E requirements for the USAF. Currently, there is no timeline for when the performance specifications and requirements will be completed.

The Navy (non-Marine Corps) is pending a decision on whether there is a need for W2E systems at small base camps. If the Navy does have a need to establish requirements for small base camps, the Navy is expected to adopt the Army's base standardization requirements pending approval from the Navy Expeditionary Program Office. The USMC will not determine any requirements for W2E systems until after 31 December 2016, pending the release of the "Contingency Waste Disposal and Energy Conversion Cost-Benefit Analysis".

By reviewing past W2E solicitations issued from the Army and Air Force and discussions among the JDW2E community, unofficial W2E performance specifications for the different services were compiled. Note, these performance specifications are not finalized, are part of a working draft and are subject to change. Because of varying missions and available equipment, each service branch has its own performance specifications for W2E systems. The Navy and Marine Corps' lack of available heavy equipment (i.e. rough terrain container handler that can lift 25,000 pound containers) and limited ship space reduce the maximum container weight capacity and container size. The Navy and Marine Corps do not expect to lift containers that are greater than 10,000 pounds because of the lift capacity of their forklifts. In addition, Navy and Marine Corps personnel expressed their interests in triple containers (TRICON) or quadruple containers (QUADCON). TRICONs have dimensions of 8 foot (length) by 8 foot (height) by 6 foot 5 9/16 inches (width), and QUADCONs have dimensions of 8 foot (length) by 8 foot (height) by 4 foot 9 3/8 inches (width). The Army and USAF do not have these restrictions, so their containers are limited to 8 foot (width) by 8 foot 6 inches (height) by 20 foot (length) International Standards Organization (ISO) containers weighing up to 25,000 pounds each.

2.2 Test Standards

While the military requirements drive the specifications of the technology, DoD test standards help evaluate different technologies on a comparable level. However, currently, there is no official DoD standard for testing W2E systems while multiple efforts of testing different W2E systems are on-going concurrently within the DoD. Without guidance on how to test the systems such as feedstock composition and the metrics for evaluation, comparing the performance among various W2E systems will be difficult or inconclusive. Although there is no official DoD standard, Leidos, Army Research Laboratory (ARL) and Army Natick Solidier Research, Development and Engineering Center (NSRDEC) released a report in August 2015 titled *Test Standards for Contingency Base Waste-to-Energy Technologies* that provides guidance on test standards (e.g. solid waste recipe, air quality standards, solid and liquid residual and performance metrics) as discussed below.

Individual commercial W2E companies were asked whether a commercial test standard existed in this industry, and they responded that currently there is none. The metrics included in the Leidos, ARL, NSRDEC report covers the typical metrics evaluated in the commercial industry such as feedstock, emissions analysis (solid, liquid, gas), net electricity production, consumables and process conditions. The general test standards issued by ARL, NSRDEC and Leidos are considered comprehensive and complete. The test plan for each system is expected to include additional unique test parameters for that system in addition to the general test standard.

2.2.1 Solid Waste Recipe

Knowing the realistic composition of the solid waste generated at FOBs is essential for demonstrating and evaluating the performance of W2E systems and for comparing the performance to other W2E systems. Many waste characterizations of remote bases have already been conducted by the DoD. American Society for Testing and Materials D5231 provides guidance on how to conduct a waste characterization study, and it breaks down solid waste into the following standard categories: cardboard, mixed paper, food waste, plastic (#1-7), wood, metals, glass, rubber and neoprene, textile and other. Some remote bases would have more food, plastic, wood etc. than others. Included in a standard solid waste recipe should be challenge recipes that reflect a higher proportion of a solid waste category such as wood, food and plastic. The solid waste test recipe and challenge recipes developed by Leidos, ARL and NSRDEC have been used by them for a W2E test in July 2015 (See Section 0) and for three more W2E systems testing in 2016. Note, these recipes are not official DoD standards, but they have the support of the JDW2E working group. The solid waste recipe and challenge recipes developed are found in Table 2-2. Because plastic and food waste are challenging waste to process in a W2E system, the challenge recipes can be used to test the capability of the W2E system (cardboard and wood challenge recipes were excluded from the table because they are not as challenging as food waste and plastics). The breakdown of the plastic challenge recipe is shown in Table 2-3.

Table 2-2: Standard and Challenge Recipes by Weight Percent.³

Category	Standard Recipe	Challenge Recipe Food	Challenge Recipe Plastic
Cardboard	15%	11%	10%
Mixed Paper	10%	7%	6%
Food Waste	32%	51%	21%
Plastic (Total)⁴	15%	11%	44%
Wood	14%	10%	9%
Metals⁵	6%	4%	4%
Glass	1%	1%	1%
Rubber and Neoprene	1%	1%	1%
Textile	3%	2%	2%
Miscellaneous Waste/Other	3%	2%	2%
Total	100%	100%	100%
Moisture Content	30%	42%	20%

Notes: Values were adjusted for round-off errors and percentages are provided as whole numbers. The numbers in bold represent the waste category that is being challenged.

Table 2-3: Breakout of Plastic Recipe by Weight Percent.⁶

Plastic Type	Standard Recipe	Challenge Recipe Plastic (Total)
Plastic (Total)	15%	44%
#1 PET	6.0%	17.7%
#2 HDPE	2.7%	7.8%
#3 PVC	0.9%	2.6%
#4 LDPE	2.7%	7.8%
#5 PP	0.3%	0.8%
#6 PS	1.8%	5.4%
#7 Other	0.6%	1.6%

³ Test Standards for Contingency Base Waste-to-Energy Technologies Report

⁴ Breakdown of plastic types is shown in

Table 2-3

⁵ Recommended breakdown of metal types is 60% ferrous, 36% aluminum, and 4% other metals.

⁶ Test Standards for Contingency Base Waste-to-Energy Technologies Report

While scrap wood can be reused in local markets in developing countries, due to the expeditionary nature of small base camps, they are typically destroyed. For Navy Construction Battalions, scrap wood is either hauled for future reuse or destroyed. Scrap wood and metal reuse in local markets are more appropriate for medium base camps, as they have more time to sort and provide the material to the local market. Table 2-4 compares the solid waste recipe to the solid waste characterization conducted in 2013 and 2014 in relevant environments. It can be seen that the solid waste standard recipe developed resembles the solid waste characterizations of U.S. installations. Because of the close resemblance to actual solid waste characterization and because the standard recipe has the support from many organizations in the DoD W2E community, it is recommended that this solid waste recipe should be used for future W2E system testing despite the recipe not being an official DoD standard. By using a standard recipe, the performance among different W2E systems can be better compared.

Table 2-4: Comparing Solid Waste Recipe to Other Waste Characterizations.

Waste Category	Standard Recipe	2013	2014
Cardboard	15%	20.3%	19.7%
Mixed Paper	10%	8.1%	14.3%
Food Waste	32%	29.9%	28.2%
Plastic (Total)	15%	24.8%	15.3%
Wood	14%	1.1 ⁷ %	6.9%
Metals	6%	7.5%	7.9%
Glass	1%	1.1%	0.35%
Rubber and Neoprene	1%	N/A ⁸	0.58%
Textile	3%	3.1% (Combined with textile)	1.1%
Miscellaneous Waste/Other	3%	Combined with textile	5.6%

⁷ Base operation and support contractor responsible to remove construction material waste.

⁸ Included in miscellaneous waste

2.2.2 Air Quality Standards

In addition to developing a standard feedstock, emissions standards such as air need to be developed. Protecting the environment and human health are the drivers for moving away from burn pits to cleaner solid waste management alternatives. Other than training exercises, the expected locations for deploying these W2E systems are in developing countries. It is also expected that the ambient air quality in these locations may be below World Health organization standards, but W2E systems should not significantly contribute to worsening the current environmental conditions. Therefore, emissions from W2E systems should meet applicable air emission standards.

Currently, there are no air quality standards specifically for gasification W2E systems with design capacities of 2-3 TPD. However, the closest applicable air quality standards within the continental United States are what the Environmental Protection Agency (EPA) has set for other solid waste incineration (OSWI) units or pyrolysis/combustion units burning less than 35 tons per day of municipal solid waste (40 Code of Federal Regulations (CFR) Part 60 Subpart EEEE) and the OEBGD for foreign nations. Neither of these standards cover all small W2E systems because the EPA standards for OSWI units do not include gasification, and the OEBGD does not cover 2-3 TPD W2E systems. The OEBGD does provide air quality standards for new incinerators (including gasifiers) of 35-250 tons per day capacity (lowest capacity available). An updated OEBGD is expected to be released that includes this lower limit; however, an actual release date has not been issued. Because the primary use of these systems is in developing countries, the small W2E systems should comply with OEBGD air quality standards at a minimum, and the EPA air emission standards can be used as performance goals. An air emissions study, with the EPA as a partner, is currently underway that analyzes the emissions from a gasification unit. The results from this study may influence future EPA air quality regulations concerning very small gasification units (See Section 2.6.1). Table 2-5 compares the air emission standards from EPA and OEBGD.

Table 2-5: Comparison of EPA Emission Standards for Incinerators Burning Less than 35 Tons Per Day to OEBGD.

Pollutant	EPA	OEBGD ^(1,2)	EPA Test Method
Particulate Matter	0.013 gr/dscf (30 mg/dscm)	24 mg/dscm	5 or 29
Opacity	10%	10%	9
NO_x	103 ppmdv	500 ppmv	7, 7A, 7C, 7D, or 7E
SO₂	3.1 ppmdv	80% reduction or 30 ppmv	6 or 6C
Dioxins/Furans	33 ng/dscm	13 ng/dscm	23
Cadmium	18 µg/dscm	20 µg/dscm	29
Lead	226 µg/dscm	200 µg/dscm	29
Mercury	74 µg/dscm	85% reduction or 80 µg/dscm	29
HCl	15 ppmdv	80% reduction or 30 ppmv	26A
Fugitive Ash	N/A	5% of hourly observation period	9
CO	40 ppmdv	50 ppmv ⁽³⁾	10, 10A, or 10B

N/A - Not applicable or not defined by requirement

dscf - dry standard cubic feet

dscm - dry standard cubic meter

ppm - parts per million

ppmdv - parts per million dry volume

ppmv - parts per million volume

¹Emission standards and operating limit values shown are for new incinerators of 35-250 tpd capacity (lowest size available).

²All standards (except for CO) are stated at 7% oxygen, dry basis at standard conditions (20°C, 1 atm).

³CO value is for modular starved-air type incinerator at 4-hr average.

While air permitting and meeting local air emissions standards may be of concern to operate these systems within the continental United States and in other allied countries, California's air quality resource board does exempt portable equipment including military tactical support equipment from obtaining air permits. The systems need to be mature to be registered in the Portable Equipment Registration Program (PERP). Under the PERP program, military tactical support equipment obtains a statewide permit and is thus exempt from obtaining individual permits in local air districts. In addition, the equipment cannot reside in one location for more than 12 months. A caveat is that the equipment must have an engine, which would exclude incinerators and waste elimination systems that do not export electricity. Until W2E systems are mature to be under the PERP, demonstration and validation of these systems require research permits or exemptions. Obtaining research permits or exemptions have been done for demonstrations in California and Florida; however, obtaining research permits or exemptions will vary per state. As of December 2015, Tyndall Air Force Base (AFB) has a research air permit in place that allows for them to conduct demonstrations of W2E systems. The permit is not specific to any system and allows up to 300 tons of waste processed per year. The Tyndall AFB has indicated that they are open to host future DoD W2E systems demonstrations under their research permit.

2.2.3 Solid and Liquid Residual

EPA guidelines on incinerators burning less than 35 tons per day only address air emissions but not disposal of solid waste, hazardous waste or liquid discharges that may be generated during the process. With regards to solid waste from W2E systems, the guidance is to determine whether they are hazardous wastes that may require special handling [Ref. 7]. However, the generation of hazardous waste depends on the feedstock. For example, toxic metals may be concentrated during processing.

The FPE CPD states that most of the waste from very small base camps is likely not hazardous waste, but solid waste characterization at other bases included a small percentage i.e. 1% of hazardous waste. In 2011, the ash generated from the incinerators at Camp Lemonnier was tested and deemed nonhazardous. The incinerators were used to dispose of solid waste except for aluminum and rubber. Therefore, a hazardous waste classification would not be expected. During testing in an operationally relevant environment, the solid and liquid residual should be tested for hazardous waste only if the feedstock contains materials that could reasonably be expected to concentrate hazardous substances during processing. For example, if the waste stream includes batteries, toxic metals are more likely to be observed in the process ash.

The following EPA sampling and analysis regulations can be used for hazardous waste identification:

- EPA Guidance for the Sampling and Analysis of Municipal Waste Combustion Ash for the Toxicity Characteristic
- EPA Waste Analysis at Facilities that Generate, Treat, Store, and Dispose of Hazardous Wastes; A Guidance Manual
- 40 CFR Part 261, Subpart C Characteristics of Hazardous Waste
- EPA SW-846 *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*

40 CFR Part 261 Subpart C defines hazardous waste as any waste that exhibits any of the following characteristics: corrosivity, ignitability, reactivity, or toxicity.

Table 2-6: Hazardous Waste Identification., lists the minimum constituents that should be tested and the corresponding sampling method.

Table 2-6: Hazardous Waste Identification.

Constituent	EPA Method
Toxicity Characteristic Leaching Procedure (TCLP) Volatile Organic Compound	1311 and 8260 (TCLP compounds only)
TCLP Semi-volatile Organic Compound	1311 and 8270 (TCLP compounds only)
TCLP Metals	1311, 6010, 7470 (Mercury only)
Corrosivity	9045
Ignitability	1010
Reactivity	40 CFR 261.23

2.2.4 Performance Metrics

Included in all test standards should be a set of metrics to evaluate the performance of a technology. To better compare the performance among W2E systems, the types of data collected should be similar among various testing. The *Test Standards for Contingency Base Waste-to-Energy Technologies* report by Leidos, ARL, NSRDEC provides guidelines on the minimum process and operational metrics to evaluate such systems (see Table 2-7 and Table 2-8 respectively). These metrics are comprehensive and covers the types of information needed to evaluate W2E systems. However, with limited time and funding, not all data can be collected. Modifications to this list include removing solid waste characterization in the operational field and quantifying gas emission, and adding user feedback. Solid waste characterization is time consuming, expensive (in terms of labor) and should be an optional item in the operational field.

While knowledge of the waste composition in an operational environment is useful for analysis, it is not always possible due to the mobile nature of small base camps.

In addition, the volume of gas emitted should not be an environmental or logistics issue so long as the process complies with the OEBGD. And, operator feedback should be included in the operational metrics. This qualitative metric is useful to know the difficulty of operating the system, and the feedback can be used to provide useful upgrades for the industry.

Table 2-7: Process Metrics [Ref. 7].

Process Data Item	Objective	Description
Solid Waste Feed	<p>Controlled Testing: Estimate any required deviations from the test standard simulated waste feed recipe for composition, moisture content, and heating value.</p> <p>Field Testing: Estimate the composition, moisture content, and heating value of the mixed waste materials used for testing.</p>	<p>Controlled: The moisture content and heating value of the test standard simulated waste feed materials are estimated to be 30% and 5,300 BTU/lb, respectively.</p> <p>Field Testing: The estimated waste composition using the 10 standard waste categories, moisture content (%), and heating value (BTU/lb) for the actual mixed waste materials used for testing.</p>
Waste Processed	Quantify the amount of waste that is processed per unit time so that a batch quantity or throughput can be calculated.	The volume and mass of waste processed, the processing cycle time, and the time between processing cycles.
Emissions	Quantify the amount of emissions (solid, liquid, and gas) generated per unit of time so that a comparison to the amount of waste fed can be calculated.	The volume and mass of emissions (solid, liquid, and gas) emitted during each phase of the operational cycle to include startup, operations, shutdown, and idle time (if applicable).
Fuel Consumption (if applicable)	Quantify the fuel consumption so that gallons/ton waste processed can be calculated.	The quantity of fuel consumed during each phase of the operational cycle to include startup, operations, shutdown, and idle time (if applicable).
Consumable Usage (if applicable)	Quantify the amount of consumables used so that a quantity/ton of waste processed can be calculated.	The quantity of all consumables used for the process to include water, process chemicals, and other materials.
Electricity Consumption	Quantify the total amount of electricity required to operate the equipment, excluding any electricity produced and returned to the process, so that KWh/ton waste can be calculated.	The electricity required to operate the equipment over the entire cycle. Electricity usage should be measured for each major equipment area (e.g., shredder, primary chamber, pollution abatement equipment) as a peak value and as an average.
Electricity Production (if applicable)	Quantify the total amount of electricity that can be produced from the process so that KWh/ton waste can be calculated.	The electricity produced from the process over the entire cycle that can either be returned to operate the equipment or exported for other uses. The calculated heating value of the waste materials needs to be clearly stated.
Heat or Hot Water Production (if applicable)	Quantify the total amount of heat or hot water produced from the process so that its quantity can be calculated on a per ton of waste basis.	The heat (e.g., facility heating) or hot water produced from the process during each phase of the operational cycle to include startup, operations, shutdown, and idle time (if applicable).
Process Conditions	Collection of critical process data to evaluate ability to operate within control limits.	The process data used to control or operate the equipment (e.g., temperature, pressure). The type of data is specific to each system.

Table 2-8: Operational Metrics [Ref. 7].

Operational Data	Objective	Description
Installation/ Demobilization	Identify the requirements for installation and demobilization of the equipment and compare the planned (design) verses actual performance.	Collect data regarding installation and demobilization activities to include weight and dimension of modules requiring placement, equipment and personnel required, site preparation work, any specialized equipment needed, and duration.
Permitting	Document the required process to permit the equipment (if required) at the test location.	Describe the permitting process to include any sampling and analysis requirements, operation restrictions, data collection/submission requirements, and estimated time required to obtain the permit.
Environmental Conditions	Document the external conditions in which the system was operated.	Collect data regarding the environmental conditions observed during testing to include temperature, humidity, and atmospheric pressure (altitude).
Safety	Identify any potential safety concerns not previously identified in the safety reviews.	Provide a description of any potential safety concerns with respect to operational personnel and surrounding area personnel that were not already identified during safety reviews (e.g., job hazards analysis, hazard operability study).
Number of Operators	Identify the number of personnel required to operate and maintain the equipment.	Describe the number of personnel required to perform each task (e.g., feed preparation, startup, normal operation, shut down, maintenance), and the observed durations for each task.
Operator Skills and Training	Identify the skill level and training requirements of the personnel required to operate and maintain the equipment.	Describe the skill level and training required for each personnel that perform individual tasks (e.g., feed prep, startup, normal operation, shut down, maintenance).
Specialty Equipment	Identify any specialty equipment needed to operate and maintain the equipment.	Describe any specialty equipment such as tools, machinery, and personal protective attire that are needed to operate and maintain the equipment.
Operational and Down Time	Document the observed operational time verses planned and unplanned downtime.	Record times during startup, normal operations, and shutdown to include feed preparation and handling times and residue removal times. Collect times for planned and unplanned maintenance activities along with a description of those activities.
Noise	Compare noise levels to industry standards.	Measure noise levels at various locations and times during operations.
Odor	Document observed odors from the process during operation.	Qualitatively assess any odors generated from the equipment during processing.
Residual Disposal	Identify the requirements for collecting and disposing solid and liquid process effluents.	Describe the operational requirements for removing, collecting, storing, and disposing solid and liquid wastes generated by the process. Include any additional waste treatment that may be required prior to disposal.
Video/Photo	Utilize visual media to augment test report narrative.	Collect video and still photos of key operational and maintenance activities to include the raw waste fed into the system and process effluents. Capture video/photos of stack (i.e., smoke) and any potential heat signature equipment during operation.
Post Test Inspections	Identify any wear or component fatigue that may have resulted prematurely from the test program.	Between test runs and at the conclusion of testing, inspect system components for corrosion or fatigue/failure. Collect measurements as appropriate.

2.3 Market Research

The primary objective of this study is to find and evaluate commercially available W2E systems that meet the solid waste needs of small base camps. Small base camp is defined as 300-1,999 persons and producing solid wastes 2-3 TPD. A sources sought solicitation was issued via FedBizOps requesting vendors to respond with information. The plan was to evaluate the vendors that responded and visit the facilities of the top three vendors to select the top vendor to recommend to ESTCP for demonstration.

2.3.1 Sources Sought Solicitation

In coordination with JDW2E, a sources sought solicitation was issued on FedBizOps in May 2015 (See Appendix A). The solicitation included the criteria in the W2E system being sought and the composition of the feedstock. The performance specification in the solicitation was too constraining because there was no appropriate vendor response to the solicitation after 3 months. Because of the lack of response, Naval Facilities Engineering Command (NAVFAC) Engineering and Expeditionary Warfare Center (EXWC) revisited the vendor list involved in the 2014 ARL *Study of Systems for Waste-to-Energy Conversion*. The goal of searching through the vendor list was to determine if any of the vendors developed new technology or upgraded equipment since the study. The vendors were individually contacted to gather additional information. In addition to using the vendor list, previous W2E studies⁹ were reviewed to find suitable, innovative W2E systems suitable for small base camps.

2.3.2 Vendor Evaluation

NAVFAC EXWC evaluated vendors according to the following criteria:

- Nonhazardous municipal solid waste feedstock
- Capacity 2-3 TPD
- Slightly net positive energy output
- Feedstock needs to comprise 20% plastics
- Handle 30% moisture
- Processes involving plasma and biology were dismissed due to high energy input and high setup time respectively
- TRL 7

⁹ United Nations *Converting Waste Plastic into a Resource*; Claudine Ellyin thesis *Small Scale Waste-to-Energy Technologies*; CSIRO Energy Technology Review of Small Scale Waste to Energy Conversion Systems; NAVFAC Engineering Service Center *Initiation Decision Report: Waste to Clean Energy*

After preliminary evaluation of the submitted technologies, none met the above criteria that are not already being investigated by JDW2E. Some vendors are recommended for future consideration.

2.3.3 Facility Site Visits

No site visits were conducted because none met our criteria.

2.4 **Industry Day 2016**

Industry Day 2016 was a NAVFAC EXWC sponsored event in collaboration with Pacific Command (PACOM) for the JDW2E community. The event was from February 25-26, 2016 via Adobe Connect On-line, and the goals of the industry day included:

- Finding new and different expeditionary W2E vendors
- Informing and updating the private industry about the DoD's goals and progress with regards to expeditionary W2E
- Increasing private industry competition in the expeditionary W2E field

The industry day solicitation was approved by the JDW2E community, and it was posted on FedBizOps on 19-November 2015 for 1 month (See Appendix A). The advertisement was more general than the first W2E sources sought advertisement to increase vendor participation. The original location was to be held in Honolulu, Hawaii in conjunction with Pacific Command's Science and Technology conference to increase vendor participation; however, due to logistical difficulties, the industry day was held via teleconference. Industry Day was broken into two days: Day 1 was opened to the public with Government presentations, and Day 2 was one-on-one sessions with vendors by appointment only. The purpose of the one-on-one sessions was to allow open discussions with the vendors without the concern of revealing proprietary information to the public. Forty individuals participated in the teleconference on Day 1 and eight vendors participated in the closed door session. One vendor had the highest TRL and was selected for a follow-on site visit to determine the viability of the technology for demonstration.

2.5 **Past Efforts**

JDW2E members have conducted numerous individual studies with regards to W2E. This section summarizes relevant past efforts in the DoD for easier accessibility and to minimize duplicating efforts. In addition, any lessons learned are discussed.

2.5.1 Study of Systems for Waste-to-Energy Conversion

ARL published *Study of Systems for Waste-to-Energy Conversion* in May 2014 that examined the state of technology offered by companies with functioning systems. The study was focused on small and medium sized base camps; identified a list of major vendors in the W2E industry; evaluated the W2E systems; and determined the limitations and potential areas for further research and development.

After the initial list of companies/systems applicable to the W2E industry was identified, screening factors were used to narrow down the list for potential independent engineering evaluations. The information gathering, screening process, phone calls, and meetings narrowed the list down to four companies for independent engineering evaluations. These systems were evaluated and compared to a baseline incineration technology. The companies selected for further evaluation were not considered the best four systems, but they were selected to compare a variety of W2E processes such as gasification, plasma arc, pyrolysis and combustion.

From the detailed evaluation of the companies, technology challenges can be inferred that are applicable to the W2E industry.

2.5.2 Test Standards for Contingency Base Waste-to-Energy Technologies

ARL, NSRDEC and Leidos published *Test Standards for Contingency Base Waste-to-Energy Technologies* in August 2015. This study identified test standards to provide universal criteria for measurement and evaluation during demonstration of potential W2E systems. The test standards include a solid waste test recipe and challenge recipes; air quality sampling and analysis standards; solid and liquid sampling and analysis standards; and process and operational metrics. These standards are not officially sanctioned by the DoD; however, DoD research organizations can use these standards to produce data that are more comparable. A discussion of the test standards is in Section 2.2.

2.5.3 AFRL Waste to Energy Selection Guide

The Air Force Research Laboratory (AFRL) developed and published a Waste-to-Energy Down Selection Guide to provide users information about W2E companies and available technologies. The original approach identified vendors, created a vendor database, developed a vendor survey to showcase their W2E systems, and transferred the information into a downloadable user guide tool which included a W2E system search engine and database. As of Feb 2014, the vendor survey was simple and thorough and the user guide was very user-friendly, but there were issues with low vendor involvement, incomplete survey entries, and potentially outdated information. Currently, the project has ended and the selection guide is not being further developed. This database can be useful in the future to keep track of W2E technologies of all sizes as the number of competitive W2E companies increase.

2.5.4 ESTCP/SERDP Projects

Table 2-9 shows past and on-going ESTCP and SERDP projects related to W2E. The first three SERDP projects are related to research and development of a component in the W2E system, and the fourth SERDP project is developing an innovative W2E system. The ESTCP projects have been funded by the Energy and Water platform, and the objectives seek to demonstrate and validate commercialized gasifiers at DoD installations. The SERDP principal investigators (PI) were contacted to collect information on their projects and the lessons learned. Valuable

information can be gleaned from these projects that further the progress of developing W2E systems suitable for FOBs. For example, SERDP project WP-2236 further substantiated the knowledge that systems involving plasma are not ready for use in deployable W2E systems. While the research project was innovative, further funding of plasma systems should be avoided.

SERDP project WP-2235 has overcome a hurdle in gasification technologies. Many gasification technologies require the feedstock to either be pelletized or briquetted. Pre-processing the feedstock increases complexity and energy demand to the overall system. In this project, a gasifier that accepts shredded feedstock was fabricated and tested successfully. It is expected that the findings from this project will be incorporated into future W2E products by MSW Power Corporation.

SERDP project WP-2210 has overcome the tar accumulation problem associated with countercurrent gasification systems. The findings from this project will provide more diverse options for W2E systems, especially because downdraft gasifiers are the common preference. This project does need further development such as air emissions characterization and long term performance evaluation. Although the PI stated that the syngas co-firing negatively affects the generator emissions, it is unclear whether the emissions still meet the OEBGD. Air pollution controls are not feasible for small W2E systems. Extended performance testing may also help determine the maintenance requirements such as catalyst lifetime.

SERDP project WP-2211 created a useable prototype that involves re-using tar in the engine, but the prototype needs to be operated for a longer duration to determine longer term performance and environmental emissions. Although the PI said that the engine has difficulties operating on syngas, he said that the fix would not be complicated. Also, more performance limitations (e.g. upper limit on plastics) need to be determined to improve the system. The prototype did meet SERDP's objective of 50% efficient in terms of net chemical energy recovered while processing 1-3 TPD.

Both ESTCP projects used installations as the demonstration site. While successful demonstration would show the technology capability on large or medium bases, translating the findings to small mobile bases is more challenging. System mobility, weight, equipment for setup and ease of use are factors that need to be taken into consideration. While the technology in project EW-200932 does work, it does seem too complicated and cost prohibitive for use on small base camps.

Table 2-9: ESTCP and SERDP W2E Projects.

Project Name	POC	Objective	Status
SERDP			
WP-2236 Investigating Efficient Tar Management from Biomass and Waste to Energy Gasification Processes	Patrick Scott Lockheed Martin pat.scott@lmco.com	Use an updraft gasifier to generate a tar rich gas stream and evaluate plasma and catalytic reformation of the tars in a pilot plant configuration to make a higher percent of the tars usable as fuel	<ul style="list-style-type: none"> • Completed 2015 • Experimental system is complex • Plasma or catalytic reactor system is probably too complex for a FOB waste to energy system • Light tars could be sent to the engine via the intake manifold if the scrubber and syngas stream is kept hot to keep the light tars from condensing
WP-2235 Shredded Waste Downdraft Gasifier for Overseas Contingency Operations Waste to Energy Conversion	Michael Cushman Infoscitex Corporation mcushman@infoscitex.com	Design, fabricate and characterize a downdraft gasification system capable of converting shredded mixed waste into a clean burning syngas suitable in spark ignition or diesel cycle generator set.	<ul style="list-style-type: none"> • Completed 2015 • Diverging downdraft gasifier designed and fabricated • Prototype demonstrated in a laboratory setting • Full-scale 2-3 TPD diverging gasifier designed
WP-2210 Thermal Catalytic Syngas Cleanup for High-Efficiency Waste-to-Energy Converters	Christopher Martin University of North Dakota Energy and Environmental Research Center cmartin@undeerc.org	Develop a robust, efficient, and compact syngas-cleaning technology that will complement distributed-scale countercurrent gasifier technology.	<ul style="list-style-type: none"> • Estimated project completion: 2015 • Prototype gasifier (50 lb/hr) and syngas cleanup system developed • The reformed syngas appears clean enough for extended generator operation with no sign of tar accumulation • Final stage combustion of the waste stream in the gasifier maximizes the volume reduction and it eliminates any hazardous potential associated with the ash • CO, particulates, unburned hydrocarbons found in emission when using syngas • Conversion efficiency at least 50% • Potentially commercialize system

WP-2211 Rotary Kiln Gasification of Solid Wastes for Base Camps	Stephen Cospers ERDC-CERL stephen.d.cospers@erdc.dren.mil	Develop a design for a deployable, rotary kiln, 1-3 TPD gasification system that is net energy positive and minimal pre-processing	<ul style="list-style-type: none"> • Project completed: 2016 • Functioning full-scale prototype • Re-use tar in gasifier; light tar sent to engine • Difficult to operate emission-controlled diesel engines on syngas • Upper limit on the fraction of plastics that the gasifier can process (30%-40% by weight) • Styrene not broken down and found in emission • Created 3D design to fit into 3 TRICONs
ESTCP			
EW-200932-Demonstration and Validation of a Waste-to-Energy Conversion System for Fixed DoD Installations	Michael Cushman Infoscitex Corporation mcushman@infoscitex.com	Demonstrate 3 TPD gasification technology that reduces energy cost, mitigates environmental impacts, improves energy security	<ul style="list-style-type: none"> • Completed 2013 • Permitting, interconnect agreement hurdles • 90% solid waste by weight reduction • Approximately 40 kWe net electric output • Acceptable levels of particulate matter, carbon dioxide but did not meet NO_x and non-methane hydrocarbon • Did not meet 5 year payback • Single operator, automated system • Mixed results for system operation and maintenance
EW-201334-Waste Gasification System for Fixed Installation On-Site Distributed Generation	Michael Hart Sierra Energy mhart@sierraenergycorp.com	Verify 10 TPD FastOx gasifier is a cost effective, environmentally-beneficial way to achieve energy resiliency and security.	<ul style="list-style-type: none"> • On-going • Permitting hurdles • System fabrication and installation • Demonstration in 2018

2.6 Other Current DoD Efforts

Concurrent efforts have been on-going among the different service branches of the military involving testing various W2E systems.

2.6.1 Air Force Institute of Technology Theses

The Navy Expeditionary Combat Command (NECC), DoD Transformative Reductions in Operational Energy Consumption program, and JDW2E sponsored two Air Force Institute of Technology (AFIT) students to complete their Masters theses on W2E. The theses have the following titles:

Thesis 1: *Waste Stream Characterization of a “Small” United States Marine Corps Expeditionary Base Camp in the Pacific Theatre.*

Thesis 2: *Identification and Comparison of Emissions Output Between Waste-to-Energy (WTE) Systems and Burn Pits Based on a Controlled Waste Stream*

This thesis had the following objectives:

- Demonstrate and evaluate the test standards developed by Leidos, ARL and NSRDEC
- Analyze emissions using the simulated solid waste recipe in a W2E system

In addition to the two NECC funded theses, the US Marine Corps (USMC) funded four AFIT theses that would together form a Cost Benefit Analysis (CBA) to inform USMC requirement decision for waste disposal systems. This is divided into two tasks described below with two theses per task.

Task 1: Cost-benefit analysis of contingency base solid waste disposal options – completed February 2015

- Literature review of waste disposal alternatives
- Data collection on complete life-cycle costs for each alternative
- Identification of “representative” expeditionary/austere sites for case study
- Identification of qualitative factors for CBA using value-focused thinking
- Estimate Return on Investment for USMC on W2E technology

Task 2: Development of decision trees and planning factors for contingency base planners, logisticians, and engineers – planned completion by 31 May 2016

- Identify typical mission categories to anticipate expected waste
- Assess current capabilities and determine constraints
- Develop Courses of Action for waste disposal at typical location types
- Identify and understand Contingency Base (CB) models [JOEI (Joint Operational Energy Initiative), MPEM (MAGTF Power and Energy Model MPEM)] for inclusion
- Analyze discriminators between categories of CBs
- Develop decision trees and planning factors to assist planners

3.0 RECOMMENDATION

The sub-processes or components of an expeditionary W2E system are very well understood and developed; however, the challenge is assembling all the sub-processes into one coherent system that works. Technology challenges were identified from the ARL *Study of Systems for Waste-to-Energy Conversion* report and from discussions with members of the JDW2E working group.

From discussions with NSRDEC and the operational manager of JDW2E, the way forward to providing a solution for solid waste elimination at small FOBs is to adjust the priorities for a viable solution. Instead of focusing primarily on waste-to-exportable electricity systems, the focus should be waste elimination systems that minimize the fully burdened cost of fuel. The fully burdened cost of energy includes the cost of the fuel itself, cost of labor to transport the fuel to the base camp, cost of the equipment involved in transport and the costs related to casualties inflicted during transport.

The next priority after reducing the fully burdened cost of energy for solid waste elimination is wastewater treatment. At small base camps, the use of portable toilets or burial for wastewater treatment is not always the best option. A system that eliminates both solid waste and wastewater while minimizing fuel usage is ideal.

W2E systems exporting hot water should be optional because there may not always be a need for hot water depending on the location of the base. Tentatively, FY17 Army Research Laboratory/Natick Soldier Research, Development and Engineering Center will investigate hot water usage from a Waste to Energy system.

W2E systems exporting electricity should not currently be pursued for small base camps because the systems tend to be very complex, expensive, large foot print and the amount of electricity exported may be negligible due to inefficiencies in engines. Similar to W2E systems that export hot water, there may not always be a need for exportable electricity, which would only burden the end user to consume the electricity. At least two major W2E companies are not pursuing waste to electricity for extra-small and small size systems.

Table 3-1: Technology Challenges.

	ARL, NSRDEC, Leidos Report	AFCEC	JDW2E
Size	System needs to fit into 20' ISO container (threshold) or TRICON (objective)		
Mobility	System components needs to be rugged so they will not be damaged during transport; Must be easy to assembly/disassembly	Minimal logistic, field-ready solutions, i.e. a better, standard burn box design that can be deployed and/or made on site	
Energy	Some components require consistent high energy load (fuel or electricity) to operate (e.g. shredder)	Plug and play inverter/transformer (One stop solution for power conditioning regardless of input)	Minimize fully burdened cost of fuel Sustainable
Pre-processing	System should include any pre-sorting or pre-processing.	<ul style="list-style-type: none"> • Small, deployable, rugged military grade non-mechanical pre-processing of waste, for use in variety of site applications (incineration, composting, volume reduction, anaerobic and aerobic digestion, food waste comminution etc.) • Upfront reduction in waste (i.e. biodegradable shipping materials) 	
Feedstock			System should be able to handle metals and live ammunition but not expected to continue to operate
O&M	Residual solids/ash must be removed manually. Some systems require forklifts to move waste containers out of gasifier module, which may not always be available		
Emissions	Char, ash, tar, wastewater produced need to be disposed offsite; gas emissions must meet OEBGD	Innovative incinerator ash disposal technology	
Conversion Technology		Starter kits for deployable biology W2E systems <ul style="list-style-type: none"> • Up-conversion of waste to value-added products 	

4.0 CONCLUSION

This project was a follow-up to the SERDP FY 12 statement of need in search of W2E technologies at TRL 6 for demonstration. In addition, this project included compiling relevant DoD W2E progress in one document. A sources sought solicitation was issued and an industry day was conducted with the help of the JDW2E community in search of ready to demonstrate W2E systems. While the concept of W2E is desired, in reality, there are many challenges associated with W2E systems at a small scale impractical. The sub-processes of W2E are very well understood, but the challenge is successfully integrating the sub-processes together and meeting the expeditionary requirements of each service branch.

After extensive market research, solicitations issued, and an industry day, we identified only one commercially available W2E technology at or above TRL 6, where the technology can be demonstrated in a relevant environment (as of 1 MAY 2016). There are other W2E systems still undergoing development that can potentially produce a viable product within 3 years.

The project team believes the way forward for successful deployment of a cost effective, safe and environmentally acceptable waste disposal strategy is to simplify the technology development goals. Specifically, we recommend a goal of reducing total net energy consumption to net zero. The minimum objective should be the lowest possible fuel consumption per unit of waste disposed. By shifting the focus from W2E to waste elimination and minimizing fuel usage, this path is more achievable than focusing only on W2E. A secondary goal should be recovering waste heat for productive uses to the maximum extent possible.

5.0 REFERENCES

1. Army Environmental Policy Institute (AEPI), “Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys,” Final Technical Report, September 2009.
2. DoDI 4715.19, Use of Open-Air Burn Pits in Contingency Operations, Incorporating Change 1, 8 February 2013.
3. GAO-11-63, United States Government Accountability Office, “Afghanistan and Iraq: DoD Should Improve Adherence To Its Guidance On Open Pit Burning and Solid Waste Management,” Report To Congressional Requesters, October 2010.
4. DODD 3000.10, Contingency Basing Outside the United States, 10 January 2013.
5. <http://www3.epa.gov/epawaste/nonhaz/municipal/wte/basic.htm>
6. Army Research Laboratory. *Study of Systems for Waste-to-Energy Conversion*. May 2014.
7. Margolin, J., Marrone, P., Randel, M., Allmon, W., McLean, R., and Bozoian, P. *Test Standards for Contingency Base Waste-to-Energy Technologies*. ARL-TR-7394. August 2015.
8. Rotty, L. *Solid Waste Characterization Study Updated Camp Lemonnier, Djibouti City, Djibouti*. SSR-NAVFAC-EXWC-EV-1317. August 2013.
9. Tseng, E. *Initiation Decision Report (IDR): Waste to Clean Energy*. TR-2367-ENV. September 2011.
10. Rand, T., Haukohl, J., Marxen, U. *Municipal Solid Waste Incineration: A Decision Maker’s Guide*. Washington D.C.: The International Bank for Reconstruction and Development, 2000.

APPENDIX A: FED BIZ OPS SOLICITATIONS

Scope: This solicitation is a sources sought, and there is no guarantee that a contract will be issued. NAVFAC EXWC is seeking vendors who have developed waste-to-energy equipment with a capacity between 0.25 to 2 tons/day that is suitable for expeditionary purposes. Acceptable technologies include incineration and gasification. The equipment should be able to fully process solid wastes typically found at expeditionary facilities and produce energy from waste destruction. Additionally, the technology should significantly reduce the volume of the waste and alter it in such a way that the conversion residuals (air, water, and solids) do not present health hazards for operators or surrounding personnel. The environmental conditions include extreme cold and heat, extreme low and high humidity levels, rugged terrain, sand storms, and intense rainfall.

NAVFAC EXWC is looking for the following criteria in the proposed equipment:

1. Ability to operate with no or very limited external power supplies.
2. Net energy production at least slightly positive with energy output as electricity.
3. Capable of operating in parallel with localized generator “grids.”
4. Capable of performing any required material preprocessing, presorting, and removal of any free liquids.
5. Capable of being operated unattended or with minimal personnel with limited English speaking operators.
6. Able to withstand extreme cold and heat, extreme low and high humidity levels, rugged terrain, sand storms, and intense rainfall.
7. Ability to process solid waste in the following composition(by dry weight) range:
 - a. 20 - 40% plastic
 - b. 20 - 40% paper
 - c. 20 - 40% cardboard
 - d. 0 - 5% metal
 - e. 0 - 10% wood
 - f. 0 - 35% organics including food waste
2. Handle up to 30% moisture
3. Fit into standard 20 foot long ISO shipping containers, or 10 foot long ISO shipping containers (BICON) or a 6' 5 & 1/2" length ISO shipping containers (TRICON). The preference is for equipment fitting within a TRICON. No single component can weigh more than 10,000 lbs.
4. Allow for setup without construction of concrete pads, proprietary equipment, or skilled personnel in less than 3 days. (e.g. plug-and-play)

Two types of Waste to Energy end items are unlikely to be selected for expeditionary use: (1) plasma-assisted gasification and (2) biological driven processes. Plasma assisted gasification uses too much energy and may require 4 or more gallons of cooling water. Biological driven processes depend on microorganisms, which cannot survive in the extreme military operation or military transport temperatures.

In your submission, include the following information:

- Model name
- Intellectual property owner/developer
- Description
- Type of technology e.g. gasifier
- DoD technology readiness level (TRL)
- Hours waste processed/day
- Container size and number of containers
- Loading capacity (lbs/batch)
- Load interval (hours between batches)
- External fuel or power used per day
- Footprint (ft²)
- Ash production (% weight of total waste input)
- Electricity/gas/heat output noting maximum, minimum and average
- Types of waste that can/cannot be handled
- Allowable water content
- Setup labor hours, number of people and duration
- Operating labor hours, number of people and duration
- Takedown operating labor hours, number of people and duration

Until 30 October 2015, providers can submit their technology by responding to Sources Sought - at FEDBIZOPS <https://www.fbo.gov/> or NECO <https://www.neco.navy.mil/> [click on Synopsis and type in solicitation number]. Responses received after this deadline may not be considered. Since this is a sources sought announcement, no evaluation letters will be issued to the participants. Respondents do not need to provide information already provided to the Joint Deployable Waste to Energy (JDW2E) Working Group (WG). However, respondents are encouraged to provide updated information with respect to that provided to the JDW2E WG. In addition, respondents do not need to provide information on significant RDT&E DoD waste-to-energy end item efforts within the last 10 years.

Joint Deployable Waste to Energy Industry Day

February 29-March 1, 2016

Location: Honolulu, HI

Providing energy and managing municipal solid waste (MSW) on small and medium sized contingency bases is a logistical burden and poses safety hazard to our warfighters. Primary Department of Defense (DoD) contingency waste disposal practices are no longer acceptable under new Congressional mandates and DoD policy. Contingency base waste contains useful energy not currently utilized. Technologies are available at various scales to manage and possibly convert MSW to energy, but they need to be developed for the specific requirements and concept of operations of our military's small and medium sized contingency bases.

The Joint Deployable Waste to Energy Community of Interest (JDW2E COI) is a community of government researchers, engineers, material developers, and operations specialist from across all U.S. military services who have their own individual programs in solid waste management and waste-to-energy. The JDW2E COI is a forum to share information and avoid duplication of efforts. At JDW2E COI Industry Day you will:

- Gain an understanding of the unique needs of the military for waste to energy systems
- Have an opportunity to meet one-on-one with government representatives

The JDW2E committee encourages companies that meet the following criteria to apply. Note that these needs are not officially sanctioned by the DoD and are subject to change at any time:

1. Prototype system can be validated in a simulated environment and capable to be demonstrated at full-scale in an operationally relevant environment in 2 years
2. Design waste capacity up to 5 tons per day
3. Maximize energy savings
4. Ability to process unsorted solid waste in the following composition (by dry weight) range:
 - a. 15 - 45% plastic (all resin codes)
 - b. 10 - 40% paper
 - c. 15 - 20% cardboard
 - d. 0 - 5% metal
 - e. 0 - 15% wood
 - f. 0 - 50% organics including food waste
5. Typically handle 30% moisture but capable of handling surges up to 50% moisture
6. Fit into multiple standard 20 foot ISO shipping containers (8'x8'x20')
7. No single container can weigh more than 25,000 pounds
8. Complete system i.e. includes any shredding, pre-processing equipment etc., if required
9. Ease of assembly with minimal heavy equipment

- 10. Minimal labor to operate
- 11. Minimal operator skill

JDW2E COI will brief participants and conduct an open question/answer session. You will also have the opportunity to sign up to a closed door meeting with the JDW2E COI. Publically available presentations from the previous industry day can be viewed at https://community.apan.org/wg/jdw2e_government_presentations. Interested companies must RSVP with the POC by 18-December 2015 or you will not be allowed to attend. A response to this request does not guarantee any future procurement actions. This event is subject to cancellation or a change in location.

POC: Edwin Chiang

edwin.chiang@navy.mil