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Total Resource Utilization (TRU) Habitat

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Tami Relph
NAVFAC EXWC

Gene Griffin
NAVFAC EXWC

Hunter Klein
NAVFAC EXWC

James Pilkington
NAVFAC EXWC

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James Pilkington
Gene Griffin
Hunter Klein
Tami Relph

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NAVFAC EXWC
1000 23rd Ave
Port Hueneme, CA 93043

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9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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14. ABSTRACT

The Total Resource Utilization (TRU) Habitat solution integrates two technologies to reduce liquid and solid waste streams at FOBs, while providing thermal energy and clean treated water. These technologies are the Micro Auto Gasification System (MAGS) and Wastewater Electrochemical Treatment Technology (WETT). The team from the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC), Terragon, and Sustained Turn demonstrated the TRU Habitat system at the Marine Corps Spring 2021 Weapons and Tactics Instructor (WTI) course at their expeditionary field site in Yuma, Arizona. The four-week demonstration measured the system's solid and liquid waste reduction, effluent water quality, water recovery ability, energy use, transportability, suitability for military operations, and assessed the payback period in different use cases.

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Table of Contents

Table of Contents iii
List of Figures vi
List of Tables vii
List of Acronyms x
DISCLAIMER xii
ACKNOWLEDGEMENTS xiii
Abstract xiv
Executive Summary xv
1 INTRODUCTION 1
1.1 Background 1
1.2 Objective of the Demonstration 2
1.3 Regulatory Drivers 3
2 DEMONSTRATION TECHNOLOGY 5
2.1 Technology Description 5
2.1.1 MAGS 5
2.1.2 WETT 7
2.2 Technology Development 11
2.3 Advantages and Limitations of the Technology 12
2.3.1 MAGS 12
2.3.2 WETT-G 15
2.3.3 WETT-S 16
2.3.4 TRU Habitat 16
3 PERFORMANCE OBJECTIVES 18
3.1 Solid Waste Reduction 19
3.2 Liquid Waste Reduction 19
3.3 Water Quality 19
3.4 Water Recovery 22
3.5 Thermal Energy Production 22
3.6 Energy Use 23
3.7 Transportability 24
3.8 Payback Period 24

3.8.1 MAGS 25
3.8.2 WETT 26
3.9 Ease of Use 27
3.10 Suitability for Operating Environment 27
4 SITES/PLATFORM DESCRIPTION 29
4.1 Test Platforms/Facilities 29
4.2 Present Operations 31
4.3 Site-Related Permits and Regulations 34
5 TEST DESIGN 36
5.1 Conceptual Experimental Design 36
5.2 Pre-Demonstration Testing 37
5.3 Design and Layout of Technology Components 38
5.4 Field Testing 41
5.4.1 Week 1 (3/7/21 – 3/13/21) 43
5.4.2 Week 2 (3/14/21 – 3/20/21) 47
5.4.3 Week 3 (3/21/21 – 3/27/21) 47
5.4.4 Week 4 (3/28/21 – 4/3/21) 48
5.5 Measurement/Monitoring Plan 51
6 PERFORMANCE ASSESSMENT 56
6.1 Solid Waste Reduction 56
6.2 Liquid Waste Reduction 57
6.3 Water Quality 58
6.4 Water Recovery 63
6.5 Thermal Energy Production 64
6.6 Energy Use 65
6.7 Transportability 66
6.8 Payback Period 67
6.9 Ease of Use 67
7 COST ASSESSMENT 68
7.1 Cost Model 68
7.2 Cost Analysis and Comparison 69
7.2.1 Solid Waste Reduction 69

7.2.2 Liquid Waste Reduction 69
7.2.3 Water Quality 70
7.2.4 Water Recovery 70
7.2.5 Thermal Energy Production 71
7.2.6 Energy Use 71
7.2.7 Transportability 71
7.2.8 Payback Period 72
8 IMPLEMENTATION ISSUES 77
8.1 Performance Objectives 77
8.1.1 Water Quality 77
8.1.2 Water Recovery 78
8.1.3 Energy Use 79
8.1.4 Payback Period 79
8.1.5 Ease of Use 79
8.2 Implementation Impacts 79
8.3 Design and Proprietary Information 80
8.4 Transition 80
9 REFERENCES 81
10 APPENDICES 82
Appendix A: Points of Contact 82
Appendix B: Health and Safety Plan 83
Appendix C: ANSI and TB MED Testing Criteria 89
Appendix D: WETT System Test Results 92
Appendix E: MAGS System Test Results 98
Appendix F: TRU Habitat Acquisition Package 109
F.1 Overview 110
F.2 Activity Need and TRU Habitat Benefits 110
F.3 Solicitation 111
F.4 Operations and Maintenance 111
F.5 Procurement 112
F.6 Performance 113
F.7 Regulations and Approvals 113

F.8 Additional Support 114
Appendix G: Lessons Learned 115
G.1 Accurate Information on Waste Streams 115
G.2 Dedicated Water Quality Sampling Personnel 115
G.3 Demonstration Duration 115
G.4 Utilizing MAGS Thermal Heat 116

List of Figures

Figure 0-1. TRU Habitat System Overview Diagram xvi

Figure 0-2. AUX II Site Location at MCAS Yuma xvi

Figure 0-3. USMC Personnel Examining the TRU Habitat During Commissioning xvii

Figure 1-1. TRU Habitat Components 2

Figure 2-1. Simplified Schematic of the Auto Gasification Process 6

Figure 2-2. Configuration of MAGS in Two Tricons 6

Figure 2-3. Containerized MAGS at Field Demonstration 7

Figure 2-4. WETT-G Process Diagram 8

Figure 2-5. Containerized WETT-G at Field Demonstration 9

Figure 2-6. WETT-S Process Diagram 10

Figure 2-7. Containerized WETT-S at Field Demonstration 11

Figure 3-1. Inside TRU Habitat during WTI Demonstration 28

Figure 4-1. AUX II Site Layout at MCAS Yuma 29

Figure 4-2. AUX II Facility Layout for WTI 31

Figure 4-3. WTI Fuel Delivery Truck and Filling Process 31

Figure 4-4. Unitized Group Rations 32

Figure 4-5. Solid Waste Collected for MAGS Influent 32

Figure 4-6. Expeditionary Field Kitchen Scullery 33

Figure 4-7. Blackwater Storage Totes 33

Figure 4-8. Transfer Pumps Used to Move Liquids 34

Figure 5-1. TRU Habitat Component Physical Dimensions 38

Figure 5-2. TRU Habitat Component Stream Diagram 39

Figure 5-3. WTI Layout at MCAS Yuma AUX II Site 40

Figure 5-4. Marines Examining the TRU Habitat during Setup 43

Figure 5-5. SuperCLU Workstation and Mobile Testing Lab 44

Figure 5-6. Field Lab Setup inside SuperCLU 44

Figure 5-7. Electrode and Wiper Blade for the WETT System 45

Figure 5-8. Marines Filling SIXCON from Supply Truck 46

Figure 5-9. Delivery of the Flush Toilet Trailer 46

Figure 5-10. MAGS Used Filter Bag after Removal 49

Figure 5-11. Emptying of Toilet Trailer 50

Figure 5-12. MAGS Char Buckets 50

Figure 5-13. WETT-G Electrodes after the Demonstration 51

Figure 6-1. MAGS Influent and Effluent Streams 57

Figure 6-2. WETT-G Coliforms after Disinfections 60

Figure 6-3. MAGS Thermal Energy Removal 3-28-2021 64

Figure 6-4. Fuel Resupply (Background) and Water Resupply (Foreground) 66

Figure 6-5. Marines Positioning TRU Habitat Tricons at WTI 67

Figure 8-1. Green Chemical Additive Found in Toilet Trailer Holding Tank 78

List of Tables

Table 0-1. ESTCP Project Demonstration Performance Objectives xvii

Table 3-1. Project Performance Objectives 18

Table 3-2. Excerpt from ANSI 350-2018 Effluent Criteria 20

Table 3-3. Excerpt from TB MED 577 Regarding Graywater Quality – Laundry and Shower Recycling 20

Table 3-4. WETT-G Consolidated Graywater Reuse and Discharge Requirements 21

Table 3-5. WETT-S Consolidated Blackwater Discharge Requirements 21

Table 3-6. MAGS Discharge Requirements 21

Table 3-7. WTI Demonstration of TRU Habitat Energy Use Summary 23

Table 3-8. Future Transition TRU Habitat Energy Use Summary 24

Table 3-9. Cost Savings of MAGS System versus Alternate Means using Closed Loop Heat Exchanger for Heat Recovery 25

Table 5-1. Laboratory Testing Performed Prior to Delivery 36

Table 5-2. Sampling Plan Schedule by Week 42

Table 5-3. Water Quality Testing Parameters 52

Table 5-4. WTI Exercise Baseline Data 53

Table 5-5. TRU Habitat Influent/Effluent Data Collection Sheet 53

Table 5-6. Laboratory Testing for WETT-G Discharges 54

Table 5-7. Laboratory Testing for MAGS Discharges 54

Table 5-8. Field Testing for WETT-G Discharges 54

Table 5-9. Field Testing for WETT-S Discharges 55

Table 6-1. WETT-G Graywater Treatment Results 58

Table 6-2. WETT-S Blackwater Treatment Results 61

Table 6-3. MAGS Daily Thermal Energy Output Summary 65

Table 7-1. Total Costs Incurred for Demonstration of TRU Habitat 68

Table 7-2. TRU Habitat Demonstration Costs 72

Table 7-3. WTI Demonstration Recurring TRU Demonstration Costs 72

Table 7-4. Spring 2021 WTI Four-Week Demonstration Payback Period 73

Table 7-5. Payback Period for Two WTI Events per Year 74

Table 7-6. Payback Period for 48-Week Operation 74

Table 7-7. WETT System Consumables Cost Information 75

Table 7-8. MAGS System Consumables Information 76

Table C-10-1. Excerpt from TB MED 577 Regarding Graywater Quality – Laundry and Shower Recycling..... 89

Table C-10-2. Excerpt from ANSI 350-2018 Effluent Criteria..... 89

Table C-10-3. ANSI 350-2018 Influent Water (Base Water Supply) 89

Table 10-4. ANSI 350-2018 Influent Water (Bathing Source Water)..... 90

Table C-10-5. ANSI 350-2018 Influent Water (Laundry Source Water) 90

Table C-10-6. ANSI 350-2018 Influent Water (Bathing and Laundry Source Water Combined) 90

List of Acronyms

AFIT	Air Force Institute of Technology
AUX II	Auxiliary Landing Field 2
BDD	Boron Doped Diamond
BOD	Biological Oxygen Demand
CD&I	Capabilities Development and Integration
CO	Carbon Monoxide
COD	Chemical Oxygen Demand
CONUS	Contiguous United States
COVID-19	Coronavirus Disease 19
DFAC	Dining Facilities
DLA	Defense Logistics Agency
DoD	Department of Defense
DRDC	Defense Research and Development Canada
EA	Environmental Affairs
EC	Electrocoagulation
EO	Electro-Oxidation
ESWDS	Expeditionary Solid Waste Destruction System
EXWC	Engineering and Expeditionary Warfare Center
FOB	Forward Operating Base
GPD	Gallons per Day
GPM	Gallons per Minute
kW	Kilowatt
LWPS	Light Weight Water Purification System
MAGS	Micro Auto-Gasification System
MARFORPAC	Marine Forces Pacific
MAWTS-1	Marine Aviation Weapons and Tactics Squadron One
MCAGCC	Marine Corps Air Ground Combat Center
MCAS	Marine Corps Air Station
MCI	Marine Corps Installation
MEPS	Mobile Electric Power Systems
MWSS	Marine Wing Support Squadron
NAVFAC	Naval Facilities Engineering Command
NPDES	National Pollutant Discharge Elimination System
NSF	National Sanitation Foundation
OECIF	Operational Energy Capability Improvement Fund
ONR	Office of Naval Research
OPS	Operations
PM FSS	Product Manager Force Sustainment Systems
PMES	Program Manager Engineer Systems
POL	Petroleum, Oils, and Lubricants
RO	Reverse Osmosis
SDTC	Sustainable Development Technology Canada
SF	Square Feet
SWRS	Shower Water Reuse System

TB MED	Technical Bulletin Medical
TDS	Total Dissolved Solids
TIR	Test Incident Report
TRL	Technology Readiness Level
TSS	Total Suspended Solids
US	United States
USAF	United States Air Force
USMC	United States Marine Corps
VFD	Variable Frequency Drive
WETT	Wastewater Electrochemical Treatment Technology
WTE	Waste to Energy

DISCLAIMER

This publication is intended to be informational and does not indicate endorsement of particular product(s) or technology by the Department of Defense (DoD) or the Naval Facilities Engineering Systems Command (NAVFAC), 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 DoD or NAVFAC.

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Abstract

The Environmental Security Technology Certification Program (ESTCP) Weapons Systems and Platforms program area expressed a need to demonstrate technologies that reduce or eliminate waste streams at Forward Operating Bases (FOBs) and have the potential to generate useful resources, including thermal energy and clean water.

The Total Resource Utilization (TRU) Habitat solution integrates two technologies to reduce liquid and solid waste streams at FOBs, while providing thermal energy and clean treated water. These technologies are the Micro Auto Gasification System (MAGS) and Wastewater Electrochemical Treatment Technology (WETT). MAGS is an energy system fueled by waste. It is a patented technology that thermally breaks down hydrocarbons into solid carbon and synthesis gas and uses the synthesis gas to fuel the process. All combustible waste is converted into thermal energy (up to 120 kW), biochar (<6%), and water. The WETT technologies are designed to treat a variety of wastewater streams, including graywater using the WETT-G system and sewage/blackwater using the WETT-S system. These systems use advanced electrochemistry through electrocoagulation (EC) and electro-oxidation (EO) to treat wastewater streams to produce reusable water without the use of filters, membranes, biological treatment, or chemical addition. The objective of this project is to demonstrate two unique technologies that combine to form the TRU Habitat, which addresses liquid and solid waste streams at FOBs. This eliminates the need for hazardous burn pits and inefficient incinerators, which greatly reduces the requirements for water and wastewater transportation, improves self-sustainability, decreases costs, and reduces security risks.

The team from the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC), Terragon, and Sustained Turn demonstrated the TRU Habitat system at the Marine Corps Spring 2021 Weapons and Tactics Instructor (WTI) course at their expeditionary field site in Yuma, Arizona. The four-week demonstration measured the system's solid and liquid waste reduction, effluent water quality, water recovery ability, energy use, transportability, suitability for military operations, and assessed the payback period in different use cases.

The TRU Habitat system met the solid and liquid waste reduction, thermal energy production, and transportation project performance objectives. However, during the demonstration, the project team identified multiple areas that impacted the TRU Habitat system performance and led to not meeting the water quality, water recovery, energy use, payback period, and ease of use performance objectives. Numerous field conditions including highly concentrated waste streams, staffing priorities, and unexpected chemical additions prohibited meeting all of the performance objectives. The project team concluded that these performance objectives could be met if the lessons learned highlighted in this report were implemented. Based on the demonstration, the team concluded that the TRU Habitat system is most applicable for generator run remote operations that need to limit resupplies, conserve water, and cannot readily dispose of generated waste. The system ROI is between 3.43 and 1.36 years based on a 48-week run time, with the variance coming from the treatment of sewage as well as utilizing the MAGS thermal output for water or air heating.

Executive Summary

The objective of this Environmental Security Technology Certification Program (ESTCP) project is to demonstrate the Total Resource Utilization (TRU) Habitat solution in an expeditionary environment for the purpose of reducing or eliminating solid and liquid waste streams at Forward Operating Bases (FOBs) with the potential of generating usable clean water and thermal energy.

The Department of Defense (DoD) needs a waste elimination system to increase self-sustainability at FOBs. Burn pits and incinerators are the most commonly used technologies at remote bases. However, burn pit usage is severely restricted and incinerators are inefficient in burning wet solid waste and require large quantities of diesel fuel, which is a limited and valuable resource at FOBs. Water is another expensive commodity for FOB operations, with nearly all water needs being met by trucking in potable water. The use of potable water for some activities such as dust suppression, vehicle cleaning, and firefighting are not necessary and instead could be met through the reuse or recycling of treated wastewater via on-site water treatment, which would significantly reduce the amount of potable water intake.

The TRU Habitat solution integrates two technologies: the Micro Auto Gasification System (MAGS) and Wastewater Electrochemical Treatment Technology (WETT) to process both solid and liquid waste streams (Figure 0-1). The MAGS and WETT systems are both developed by Terragon and patented under their wholly owned subsidiary, Proterrgo Inc. MAGS is an energy system fueled by solid waste that thermally breaks down hydrocarbons into solid carbon and synthesis gas and uses the synthesis gas to continue fueling the process. All combustible waste is converted into thermal energy (up to 120 kW), biochar (<6%), and water. Terragon's suite of WETT technologies are designed to treat a variety of wastewater streams, including graywater using the WETT-G system and sewage/blackwater using the WETT-S system. These systems use advanced electrochemistry through electrocoagulation (EC) and electro-oxidation (EO) to treat wastewater streams to produce reusable water without the use of filters, membranes, biological treatment or chemical addition. The reject stream produced is approximately 5% of the influent wastewater volume treated. This reject stream is dewatered and sent to the MAGS unit for gasification. These combined processes produce a char waste of 0.25% of the influent volume. If processed correctly, WETT effluent can be used for non-potable activities, such as toilet flushing, laundry, cleaning, vehicle cleaning, dust suppression, firefighting, and even shower water for military contingency operations. The TRU Habitat is also highly transportable, consisting of four Tricon containers – two for MAGS and one for each of the WETT system.

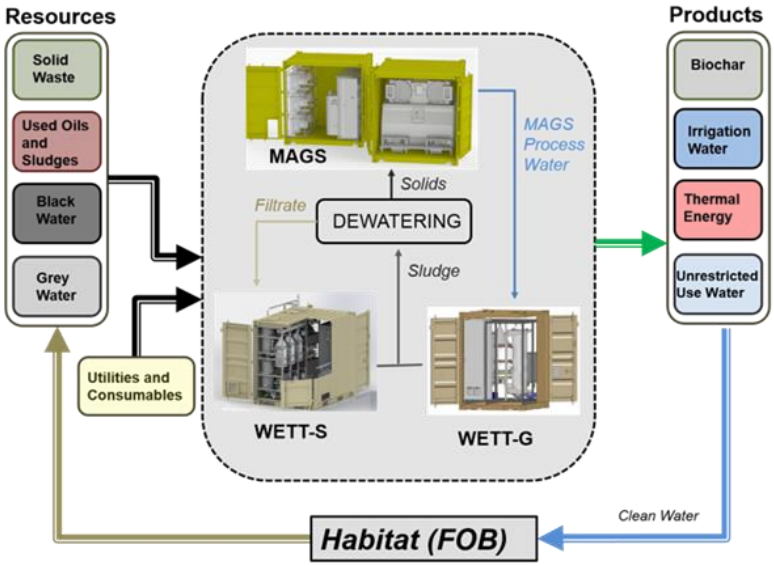

Figure 0-1. TRU Habitat System Overview Diagram

The TRU Habitat was demonstrated for four weeks at the US Marine Corps Weapons and Tactics Instructor (WTI) course held at the Marine Corps Air Station (MCAS) Yuma, Arizona AUX II site, approximately 8 miles southeast of MCAS Yuma (Figure 0-2). The WTI event was hosted by Marine Aviation Weapons and Tactics Squadron One (MAWTS-1). The test site was selected to demonstrate the TRU Habitat in an environment closely resembling FOBs where there are no permanent facilities and both water and fuel resources are at a premium value for mission support.

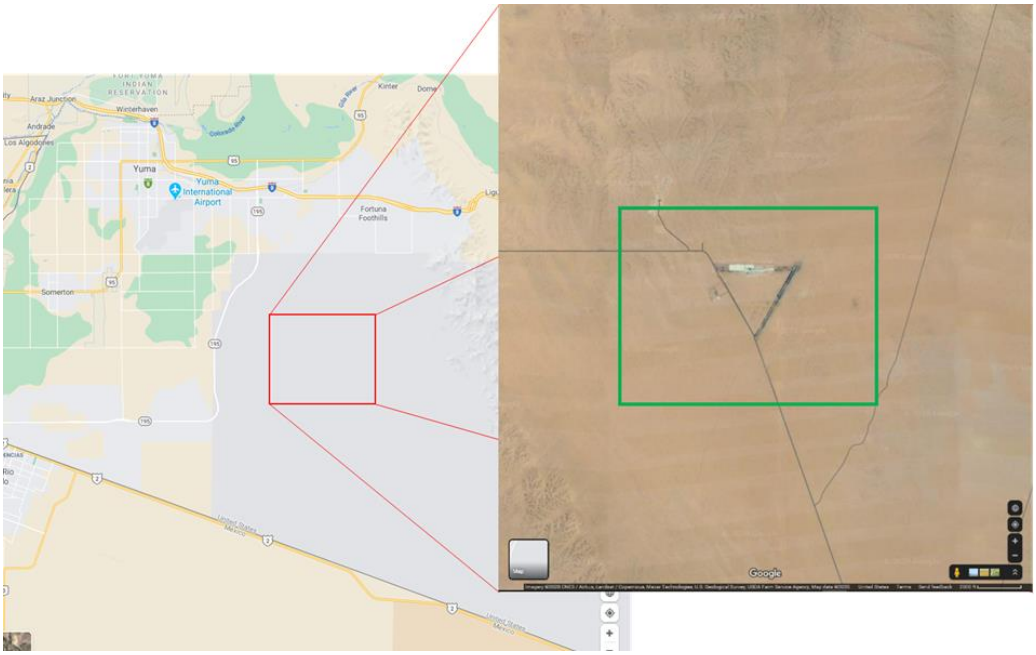

Figure 0-2. AUX II Site Location at MCAS Yuma

The demonstration was conducted by Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC), Terragon, and Sustained Turn Inc. with support from MAWTS-1 and Marine Wing Support Squadron (MWSS) 371 (Figure 0-3). Terragon was the primary operators of the TRU Habitat during the WTI event. The system was used to treat shower and laundry water with the WETT-G, kitchen and sewage blackwater with the WETT-S, and solid waste with the MAGS. Water quality testing was performed both by EXWC and Terragon personnel on site, as well as a local laboratory in Yuma for tests that could not be performed in the field.

Figure 0-3. USMC Personnel Examining the TRU Habitat During Commissioning

The TRU Habitat subsystems were each evaluated against performance objectives based upon National Sanitation Foundation (NSF) / American National Standards Institute (ANSI) 350, TB MED 577, and US Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) standards for their respective waste streams. These objectives, along with the results from the demonstration testing performed during the WTI, are presented in Table 0-1 below:

Table 0-1. ESTCP Project Demonstration Performance Objectives

Performance Objective	Data Requirements	Success Criteria	Objective Met?
Quantitative			
Solid Waste Reduction (MAGS)	% volume reduction (combustible waste)	>90%	Yes
Liquid Waste Reduction (WETT)	% volume reduction (wastewater)	>90%	Yes
Water Quality	Treated effluent characteristics (COD, BOD_5, TSS, TN, TP, pH, Total Coliform, E. Coli, TDS, turbidity, hardness, free available chlorine residual)	<u>For GW:</u> Meet NSF/ANSI 350 standard Meet TB MED 577 standard <u>For BW:</u> Meet US EPA NPDES standard	No

Performance Objective	Data Requirements	Success Criteria	Objective Met?
Water Recovery	% of wastewater (graywater) made available for reuse by site	60%	No
Thermal Energy Production (MAGS)	in kWh/h	>100kWh/h	Yes
Energy Use	Assess kWh/m^3 overall for site for solid waste, water and wastewater management	<50% of existing fuel consumption as determined during baseline measurements	No
Transportability	System size and compactness	Fit each MAGS and WETT system into Tricons or 20 ft. Intermodal container	Yes
Payback Period	CAPEX/OPEX costs	<12 months	No
Qualitative			
Ease of Use	Feedback from users on the system operability and maintenance requirements as documented by logs. Survey of technically skilled Military Occupational Specialties (MOS) after demonstration of custodial duties.	WETT systems do not require operators to be present during operation, minimal maintenance requirements MAGS is operated by service members, incidental to their normal duty with only brief (< 5 minute) familiarization. Custodial duties within skillset of on hand military Occupational Specialties.	Not Demonstrated
Suitability for operating environment	Recorded issues related to temperature, humidity, and dust.	Data collected to enhance ruggedness of follow-on iterations	Yes

The project performed a cost analysis to calculate the operational cost, payback period, and return on investment (ROI) of the system. The initial capital cost of the TRU Habitat is $766,160 with an operational cost of $49,926 annually (48-weeks of operation). The payback periods of the system were calculated for different operational scenarios over a 48-week run time:

- 3.43 years – No sewage treatment and no MAGS thermal reuse.
- 1.44 years – With sewage treatment and no MAGS thermal reuse.
- 1.39 years – With sewage treatment and MAGS thermal reuse for water heating.
- 1.36 years – With sewage treatment and MAGS thermal reuse for air heating.

The report recommends follow-on efforts for further testing and transitioning of the technology with end-users and interested agencies. During the exercise, EXWC identified valuable lessons learned to improve the performance of the TRU Habitat system. This includes gathering accurate information on the use locations waste streams, utilizing the thermal heat from MAGS, and additional items for further demonstrations of the system. An Acquisition Guidance document is included in the report Appendices to serve as a procurement guide to end-users interested in the TRU Habitat.

1 INTRODUCTION

1.1 Background

The Environmental Security Technology Certification Program (ESTCP) Weapons Systems and Platforms program area expressed a need to demonstrate technologies that reduce or eliminate waste streams at Forward Operating Bases (FOBs) and have the potential to generate useful resources, including thermal energy and clean water.

The Department of Defense (DoD) needs a waste elimination system to increase self-sustainability of FOBs. Burn pits and incinerators are the most commonly used technologies for eliminating solid waste at remote bases. However, burn pit usage is severely restricted, and incinerators are inefficient in burning wet solid waste. Incinerators also require large quantities of diesel fuel which needs to be transported over long distances, increasing the risk 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, which could result in legal claims against the United States; hauling waste to a rear support area, which is a low priority due to the cost and logistical issues; or contracting with the host nation for trash removal which is not always available or preferable. A solution is to use a waste-to-energy thermal destruction system to reduce the volume of the waste and supply thermal energy to the base.

Water is another expensive commodity for FOB operations. Nearly all water needs at FOBs are met by trucking in potable water for drinking, food preparation, laundry, and hygiene needs. Additional uses for water include dust suppression, vehicle cleaning and maintenance, and firefighting. The use of potable water for some of these requirements is not necessary, and the volume of potable water intake can be reduced considerably by recycling or reusing treated wastewater. Current wastewater solutions for FOBs must accommodate a fluctuating, inconsistent influent of water, which requires the systems to be sized to accommodate the highest volume of process water, and consequently, remain oversized for small influent or even periods of non-operation. Advanced sanitation and water management solutions must be implemented to reduce the water demand, wastewater generation, and to optimize the operational activities of FOBs. Solutions include on-site wastewater treatment for reuse or safe discharge to the environment.

The Total Resource Utilization (TRU) Habitat solution integrates two technologies to reduce liquid and solid waste streams at FOBs, while providing thermal energy and clean treated water. These technologies are the Micro Auto Gasification System (MAGS) and Wastewater Electrochemical Treatment Technology (WETT). MAGS is an energy system fueled by waste. It is a patented technology that thermally breaks down hydrocarbons into solid carbon and synthesis gas and uses the synthesis gas to fuel the process. All combustible waste is converted into thermal energy (up to 120 kW), biochar (<6%), and water. Terragon's suite of WETT technologies was designed to treat a variety of wastewater streams, including graywater (GW) using the WETT-G system and sewage/blackwater (BW) using the WETT-S system. These systems use advanced electrochemistry through electrocoagulation (EC) and electro-oxidation (EO) to treat wastewater streams to produce reusable water without the use of filters, membranes, biological treatment or chemical addition. The reject stream produced is approximately 5% of the influent wastewater volume treated. This reject stream is sent to the MAGS unit for gasification, after it is dewatered

to the required solids content. Treated WETT effluent can be used for non-potable activities, such as toilet flushing, laundry, cleaning, vehicle cleaning, dust suppression, firefighting, and even shower water for military contingency operations.

1.2 Objective of the Demonstration

The objective of this project is to demonstrate two unique technologies that combine to form the TRU Habitat (Figure 1-1), which addresses liquid and solid waste streams at FOBs. This eliminates the need for hazardous burn pits and inefficient incinerators, which greatly reduces the requirements for water and wastewater transportation, improves self-sustainability, decreases costs, and reduces security risks.

The TRU Habitat integrates two technologies to reduce liquid (WETT) and solid waste streams (MAGS) at FOBs, while providing thermal energy and non-potable water. The TRU Habitat provides the DoD with a safe and sustainable method for reducing solid and liquid waste streams at FOBs. Integrated solid and liquid waste treatment technology with the reuse of water and thermal energy provide high energy efficiencies and the potential for short payback periods due to the very high cost of energy and fresh water at the tactical edge. The Force Protection (FP) benefits are incalculable, as this approach reduces the convoys delivering fuel and water to the FOB and hauling waste products from the FOB. The TRU Habitat is applicable to combat, contingency, humanitarian and training missions, as well as the ill-defined distinction between fixed and temporary facilities on training ranges. The technology, enabled by absence of chemical reactants or biological processes, allows for quick start up, immediate shut down and makes it well suited to programs such as the US Air Force (USAF) Basic Expeditionary Airfield Resource, US Army Force Provider, and US Navy (USN)/US Marine Corps (USMC) Maritime Prepositioning Force.

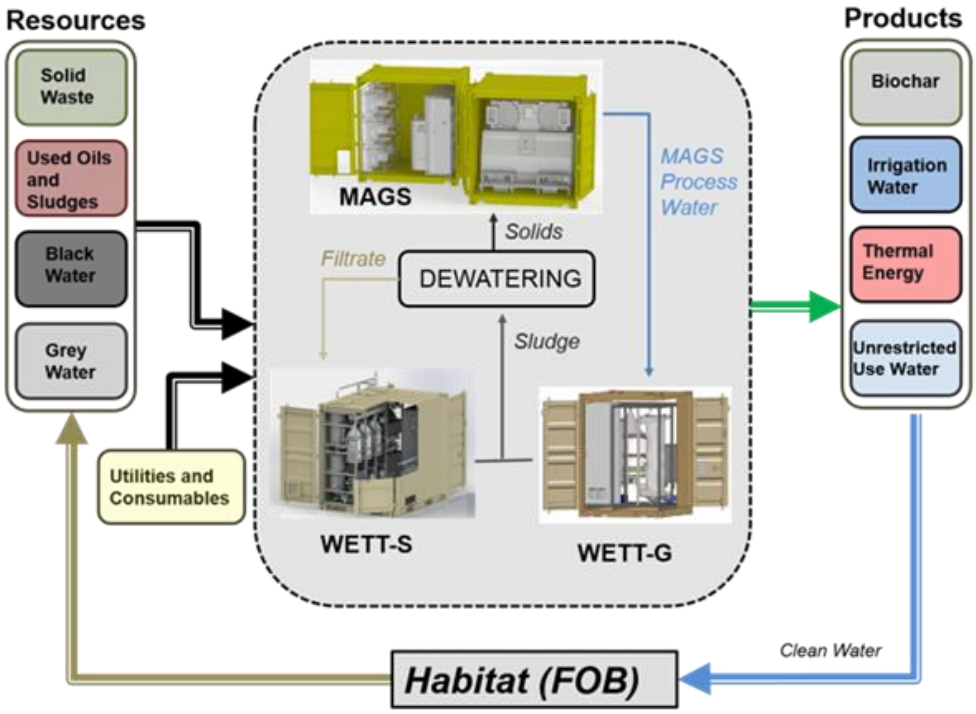

Figure 1-1. TRU Habitat Components

During this ESTCP project, the TRU Habitat was tested for four weeks at the USMC Weapons and Tactics Instructor (WTI) course in Yuma, Arizona. This full-scale testing replicated conditions expected in an expeditionary field environment. The system treated shower and laundry water with the WETT-G, kitchen and sewage blackwater with the WETT-S, and solid waste with the MAGS.

1.3 Regulatory Drivers

The dangers of burn pits are some of the most well-known adverse impacts on the health of military personnel who served in southwest Asia in the period 1990 – 2020. Regulations and directives pertaining to solid waste management are evolving as the human costs of the mismanagement of solid wastes have become political issues. Reuse and treatment of water resources are less covered by regulation, but are regarded as logistically valuable by the military and are covered by a few forward looking guides. Civilian standards are listed when relevant. The following regulations and directives pertain to the thermal treatment of solid and liquid waste.

DoD Instruction (DoDI) 4715.19 Use of Open-Air Burn Pits in Contingency Operations, Nov 13, 2018. In accordance with the authority in DoD Directives (DoDDs) 5134.01 and 4715.1E, and the July 13, 2018 Deputy Secretary of Defense Memorandum, this issuance establishes policy, assigns responsibilities, and provides procedures regarding the use of open-air burn pits and the prohibition of the disposal of covered waste in open-air burn pits during contingency operations, except in circumstances in which no alternative disposal method is feasible.

The DoDI 4715.22, Environmental Management Policy for Contingency Locations, 18 Feb 2016. Disposal of covered waste in open-air burn pits is prohibited unless it is determined that no alternative disposal method is feasible in accordance with DoDI 4715.19. Open-air burning must be authorized and conducted in accordance with DoDI 4715.19 and supplementary requirements as outlined in the Contingency Location Environmental Standards (currently under development) and environmental management plan.

DoD Directive 3000.10, Contingency Basing Outside the United States, 10 Jan 2013. Directs organizations to pursue joint, scalable capabilities that use operational energy efficiently, minimize waste, manage environmental health risk, and minimize the logistics footprint.

US Central Command (CENTCOM) Regulation 200-2, Environmental Quality – Contingency Environmental Standards, 23 May 2013. Provides environmental guidance and best management practices for U.S. base camps operated by CENTCOM personnel engaged in contingency operations within the CENTCOM area of responsibility.

US Army TB MED 593, Guidelines for Field Waste Management, 15 Sep 2006. This bulletin provides technical guidance to the preventive medicine community on the proper management of waste in field settings. This guidance will ensure waste is managed in a manner that is protective of human health and the environment, and is consistent with Army requirements.

US Army TB Med 577, Sanitary Control and Surveillance of Field Water Supplies, Dec 2005. This publication details the appropriate uses for potable and non-potable waters.

US Army Public Health Command Technical Guide 364a, Water Reuse in Contingency Operations, Mar 2014. This technical guide facilitates decision making on the part of materiel

and combat developers who seek to leverage water reuse in the field as a solution to reducing the burden of liquid logistics on the modern expeditionary battlefield.

US EPA Other Solid Waste Incinerator Emissions Regulations 40 CFR Part 60 Subpart EEEE. This regulation sets emissions limits for incinerators.

US EPA National Pollutant Discharge Elimination System sets water quality standards for discharge into the waters of the United States.

ANSI / NSF 350, Onsite residential and Commercial Water Reuse Treatment System, 03 Apr 2020. The purpose of this standard is to establish minimum material, design, construction, and performance requirements for onsite residential and commercial water reuse treatment systems.

Executive Order (EO) 13693 released in 2015, "Planning for Federal Sustainability in the Next Decade" requires DoD installations to take measures to reduce water loss.

2 DEMONSTRATION TECHNOLOGY

2.1 Technology Description

The TRU Habitat integrates two different technologies, the MAGS and WETT, into one combined waste management system. The TRU Habitat can process graywater and blackwater, as well as combustible waste streams, to greatly reduce the waste output and accompanying logistical support required by expeditionary exercises and FOBs.

2.1.1 MAGS

MAGS is a simple and extremely compact energy appliance fueled by waste. The system is designed to recover energy contained in solid waste and use it as the fuel for the process, minimizing its requirement for additional fuel (such as diesel), all while delivering thermal energy in the form of hot water and/or warm air for beneficial use by the site. Because of its low utility requirements and minimal operator training requirements, MAGS is well suited for various waste generation sites, such as FOB's, ships, ports, bases, hospitals and other buildings.

MAGS consists of two gasifiers, similar in size to conventional 55-gallon drums. The system (Figure 2-1), which is batch loaded, is capable of treating up to 110 lbs. of mixed, as-received, waste per hour. Each gasifier is constructed in a way that allows for the indirect heating of the waste inside the drum by the exhaust gases from the combustion chamber which circulate in a thermally insulated shell enveloping the bottom of the drum. Waste is loaded into the gasifier and heated to about 650˚C (1,200 ºF). A controlled amount of pre-heated air is fed into the gasifier and brought in contact with the waste. The oxygen in the air reacts with the waste in a reducing environment to convert all organic molecules to a synthesis gas, or syngas, composed primarily of Carbon Monoxide (CO) and Hydrogen (H_2), which is combusted in the combustion chamber.

The combustion chamber is a thermally insulated reactor, maintained at 1,100 ºC (2,012 ºF) through the combustion of either syngas or diesel during start-up. The hot exhaust gases from the combustion chamber serve as the heat source for the gasifiers. Leaving the gasifiers, the exhaust gases are quenched with water to a temperature of approximately 80 ºC (176 ºF) and are cleaned to remove particulates, acid gases and moisture prior to discharge.

The residue, which is mostly inorganic carbon in the form of char may contain any incidental metal and glass found in the original waste. Because a significant amount of the carbon contained in the waste is collected as char, the MAGS technology allows for the reduced emission of greenhouse gases as compared to competing practices such as landfilling, burn pits, and conventional incineration.

Although waste gasification has been the subject of much research worldwide, the MAGS technology is very innovative as it is designed to operate as a small-scale appliance rather than a large waste processing facility. The innovative features of MAGS include its ease of operation (load and push to start button) and its use of the syngas generated as the fuel source for the process.

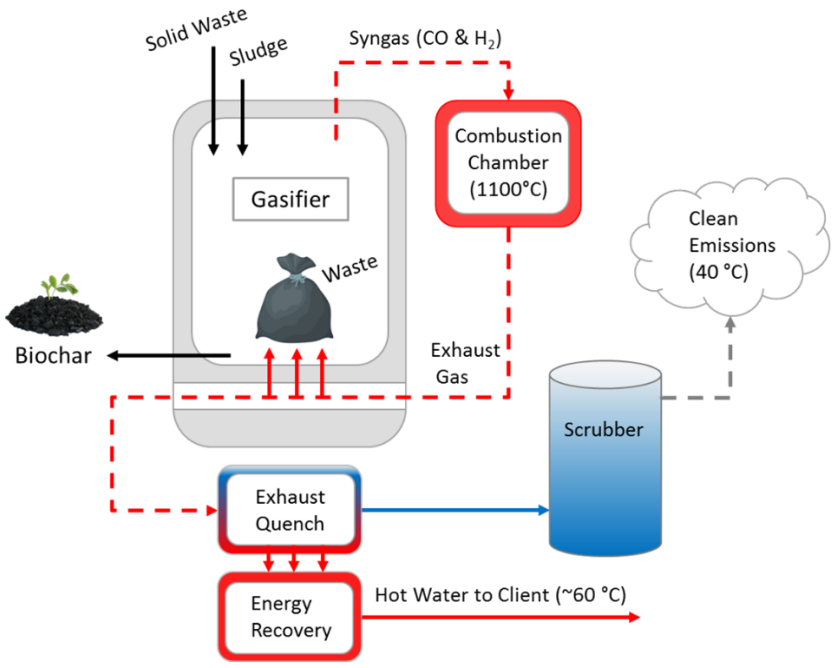

Figure 2-1. Simplified Schematic of the Auto Gasification Process

MAGS fits in two (2) Tricons weighing less than 7,000 lbs. each. The Tricon shipping weights for the demonstration were 6,996 lbs. and 6,615 lbs. The gasifier, combustion chamber, and quench are installed within one Tricon, while the off-gas cleaning system and air-cooling fans are in the second Tricon (Figure 2-2). MAGS is installed within the Tricon allowing for easy access to the waste loading doors, as seen in Figure 2-3. Once deployed, set up is simple and the system does not need to be removed from the Tricons, allowing for a rapid redeployment. The two Tricons can be separated up to 10 feet, if necessary, and do not need to be mated; hoses are used to connect the two parts of the system together. Additionally, there is no smoke stack, which also contributes to the ease of set-up and redeployment.

Figure 2-2. Configuration of MAGS in Two Tricons

Figure 2-3. Containerized MAGS at Field Demonstration

2.1.2 WETT

At their core, Terragon's innovative WETT technologies have a patented non-passivating electrocoagulation (EC) unit. EC is used to remove contaminants present in the wastewater using aluminum electrodes to which a current is applied. Trivalent aluminum ions (Al^{3+}) are released by the EC anode while hydroxide ions (OH^-) are released from the cathode during electrocoagulation. These ions serve to destabilize and coagulate the suspended solids, organics, colloids, and metal ions contained in the wastewater. These coagulated contaminants move upwards with the flow in the EC reactor and flocculate into larger, fluffier aggregates.

Gas bubbles produced electrolytically at the EC cathode attach to the flocs and float them to the cone-shaped top of the EC reactor where they are periodically discharged to the sludge tank. The EC typically removes 75% of Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD), and 90% of Total Suspended Solids (TSS).

The suite of WETT technologies was designed to treat a variety of wastewater streams, including graywater (WETT-G) and sewage/blackwater (WETT-S). During this demonstration, the WETT-G (Figure 2-5) and WETT-S (Figure 2-7) technologies were used, each housed within a separate Tricon.

WETT-G (Figure 2-4) is composed of an EC unit, a novel turbidity removal unit (removes remaining TSS), and a polishing stage (removes residual COD & BOD). A disinfection unit (disinfects and provides an oxidant residual) was added to determine its efficiency in providing the required effluent disinfection. It is an automated system that generates all that is required for treatment in-situ, without operator attendance. The system was designed to have low maintenance requirements and be remotely monitored. As well, the system automatically starts and stops, and can be programmed to operate during selected time periods as desired. The unit fits in one (1) standard Tricon (Figure 2-5).

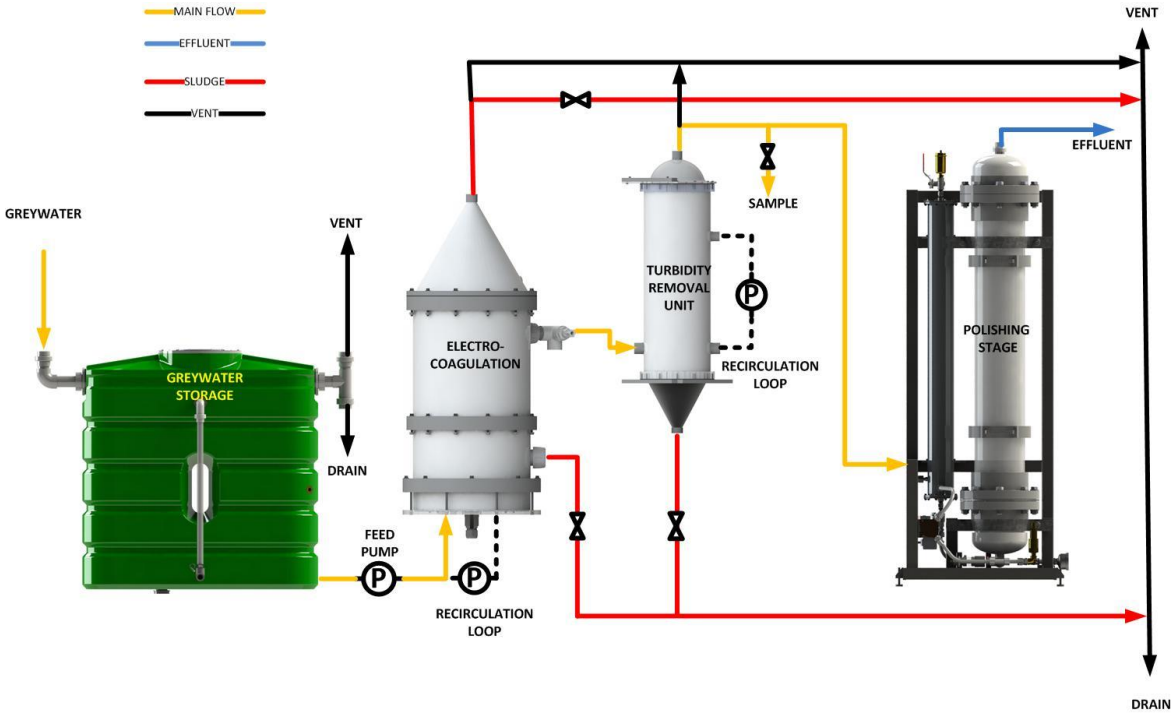

Figure 2-4. WETT-G Process Diagram

Figure 2-5. Containerized WETT-G at Field Demonstration

Typically, graywater is defined as the wastewater generated by showers, baths, bathroom sinks, and laundry (hygiene facilities); it does not include toilet or urinal wastewater (latrines), or water from kitchen sinks and dishwashing (Military Dining Facilities [DFAC] or Expeditionary Field Kitchens [EFK]). Graywater contains significant concentrations of detergent, soaps, suspended particles, organic compounds, oils, nitrogen, phosphorus, and pathogens, such that treatment prior to discharge is required (i.e. NPDES regulations). Treated graywater produced by WETT-G can be used for various non-potable activities, such as toilet flushing, laundry, cleaning, dust suppression, irrigation, and even shower water for military contingency operations. Additionally, treated graywater is more easily purified to potable standards through reverse osmosis (RO) than seawater or most surface water.

The system was designed to minimize maintenance requirements by incorporating an automated system cleaning process, which is performed during shutdown with no potable water requirement for cleaning. Replacement of consumables is required every 1-3 months depending on the application and involves a 15-30 minute procedure. The electrical consumption of the system is <2 kW, which can be provided by standard generators, hybrid or renewable power.

WETT-S is also based on the self-cleaning passivation-resistant EC unit, however, also includes an electrochemical oxidation (EO) unit. Unlike graywater that has been treated by EC, sewage or blackwater still contains a high concentration of COD and BOD after this stage. Thus, in WETT-S, EC is followed by an EO unit to destroy dissolved organics and convert them to CO_2 which is harmlessly discharged. EO is based on Boron Doped Diamond (BDD) electrodes, which are robust

and can withstand the harsh conditions required to treat concentrated sewage. The EO process produces highly reactive hydroxyl radicals that have the advantage of providing complete disinfection of treated effluent, along with destruction of pharmaceuticals found in the wastewater as well as chemical or biological warfare agents. With the addition of the EO unit, power required increases to 15 kW.

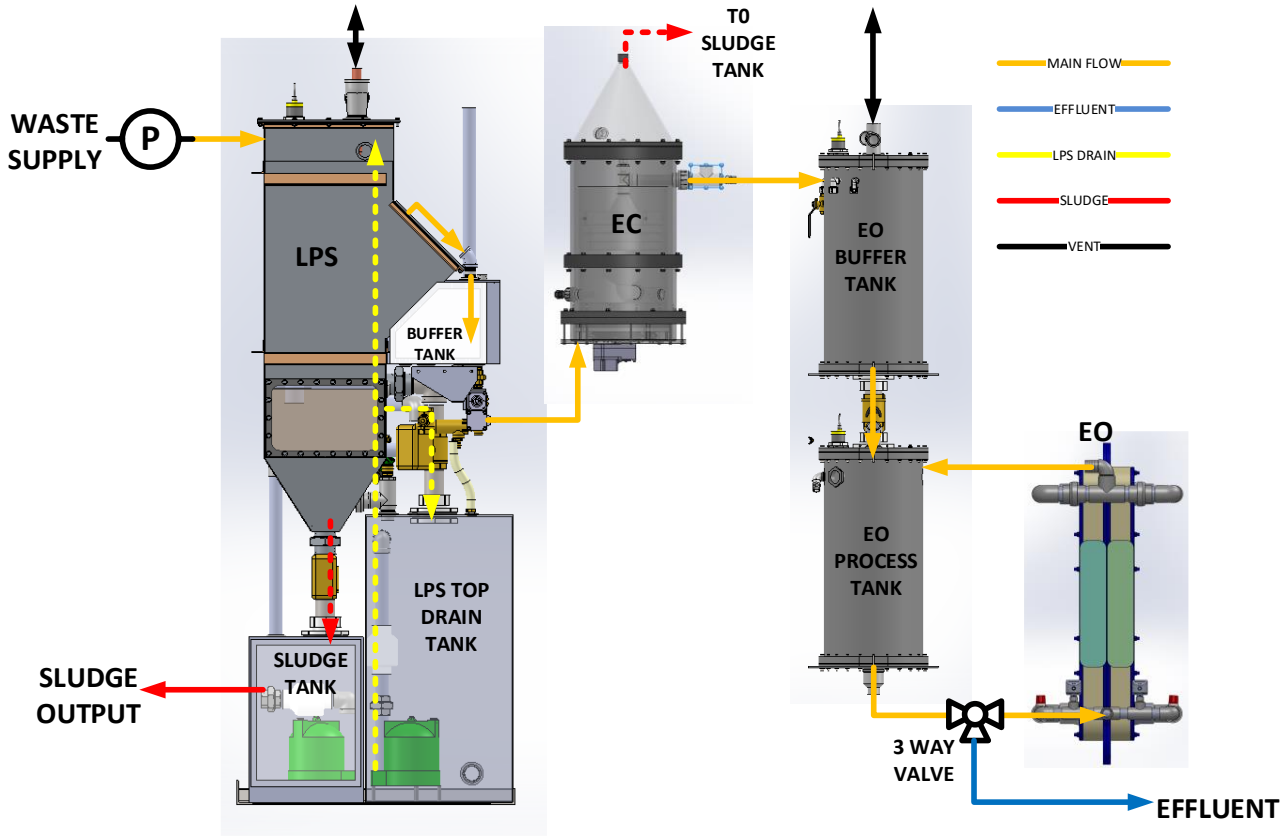

Figure 2-6. WETT-S Process Diagram

The WETT systems are compact, containerized and modular. Base units having a treatment capacity of 7.2 m^3/day (1,900 gpd); WETT-G and WETT-S systems with capacities that are multiples of the base capacity can be designed to meet the needs of the targeted application. The WETT systems can provide high quality water for reuse or safe discharge, are fully automated for 24/7 unattended operations after commissioning, are self-cleaning, and provide 5 times less reject volume than systems based on RO. The reject stream produced is approximately 5% of the influent wastewater volume treated. This stream is sent to the MAGS unit for gasification, after it is dewatered to the required solids content.

Figure 2-7. Containerized WETT-S at Field Demonstration

2.2 Technology Development

The development of MAGS began in 2005, with financial support from the US Office of Naval Research (ONR), Defense Research and Development Canada (DRDC), and Sustainable Development Technology Canada (SDTC) resulting in design iterations of the technology, numbered as versions 1 to 8 (V1 to V8). Throughout this period, MAGS was successfully developed and tested in Terragon's laboratory, following which, several engineered MAGS prototypes were demonstrated in the field, in various sites, including a Canadian Navy ship (V4), US military sites (US Marine Corps V5 and MAGS-in-a-Box V6), a commercial ship (Maersk V7), amongst others, for the purpose of validating the technology.

US Marine Forces Pacific (MARFORPAC) tested MAGS V5 and V6 prototypes with ONR funding from 2011 to 2013. This effort validated the promise of gasification as a treatment alternative to burn pits for expeditionary solid waste, measured the systems emissions (Appendix E: MAGS System Test Results) and waste reduction metrics, and provided insight to waste characterization for expeditionary operations. The MAGS V6 prototype was also used for a 2015 TROPEC funded and managed experiment to develop and validate test procedures and waste recipes for evaluating expeditionary waste destruction systems.

The MAGS V8, Terragon's commercial model, is now operating successfully onboard commercial ships, cruise ships, and in industrial applications. In 2018, Terragon won a competitive award from the US Army for 12 MAGS systems in the Central Command Theater of Operations (W56KGZ-18-P-0003 CJTF-OIR Mobile Incinerators). Due to an internal US Army contracting error discovered during a GAO protest, the Army terminated the contract for the convenience of the Government. The award was a validation of the value of MAGS.

Following the same path, the WETT technologies were also supported by ONR, NAVSEA, DRDC, SDTC, POLAR Knowledge Canada, and Build in Canada Innovation Program and underwent extensive laboratory testing with various types of wastewater influents starting in 2008. Several WETT demonstration projects were conducted in the 2012 to 2017 period in remote dwellings, on ships, as well as trials with the US military as part of a development effort for FOBs. The WETT-G technology is in its pre-commercial phase of development, while WETT-S is commercially available for both land-based and marine applications. The technology received its marine certification from USCG and Class Societies in October 2021.

2.3 Advantages and Limitations of the Technology

The TRU Habitat is a system-of-systems offering the primary advantage of recovering usable resources from solid and liquid waste streams and a secondary advantage of treating its own process waste streams. The system is producing usable resources and reducing unusable material, which together yields large savings in logistics effort and energy currently dedicated to producing and importing raw commodities and disposing unusable material. This in turn increases the resiliency of the FOB operation by reducing supply vulnerability and increases force protection through the reduction of exposure to enemy action outside the FOB during convoy operation and the exposure to harmful waste byproduct.

The explanation of the overall TRU's benefits and limitations are best described by first examining the individual components before exploring the synergistic properties of the overall system.

2.3.1 MAGS

MAGS is the first waste to energy system developed with the key attributes enabling expeditionary operations. The system was designed from the outset to be used in remote locations to harvest energy resources safely and efficiently while reducing the impact on people and the environment. The advantages brought by this design philosophy will be compared to the current FOB operations of burn pits, transportation, and other technologies.

2.3.1.1 MAGS vs Burn Pits

The clear advantage of MAGS is the safe destruction of combustible material via a gasification process with emissions controls, which prevents the formation and discharge of the toxins that can create grave health hazards to the operators and inhabitants of the FOB. The dangers of burn pits are well documented and the DoD has restricted burn pit use to a narrow set of conditions. When burn pits are allowed, they are restricted to burning "non-covered wastes." Non-covered wastes are items that don't produce large concentrations of highly toxic gasses when burned in an uncontrolled manner. Essentially this limits burn pits to food waste, paper, wood, and cardboard. MAGS has the advantage of cleanly gasifying non-covered and other common covered waste

streams such as plastics, Meals Ready-to-Eat (MREs), Petroleum, Oil, and Lubricants (POL), and medical waste.

2.3.1.2 MAGS vs Transportation

Employment of MAGS is commonly compared to standard waste transportation processes. The common argument is, "There are trucks bringing supplies in, why send them back out empty?" This is a short sighted argument, but gives a good basis to the discussion of MAGS advantages in logistics manpower requirements, energy use, and Force Protection.

MAGS is less manpower intensive than transportation when viewed in total. MAGS by virtue of its clean emissions and safe operations can and should be placed as close as practical to the waste/resource generation. In this demonstration MAGS was placed adjacent to the EFK and DFAC. In this way, waste can be carried by the "worker" directly from the workspace to MAGS. The batch loading process is akin to, and a direct labor burden substitute for, placing the waste in a dumpster or FOB collection site. With MAGS, the manpower burden for the waste essentially stops. For transportation, however, it is only the first step. From the collection site, it is periodically loaded by a work crew onto trucks. The waste is transported to a rear area, where it is offloaded by additional workers. This process may be repeated multiple times until the waste arrives at a place where additional manpower will ultimately destroy the waste, or the DoD will pay to transfer the waste outside of the accountable manpower structure. Added to this burden is the safety oversight, typically a spotter at each end of a truck as it moves through a camp, and the cleanup time to reset the trucks from waste haul to clean haul. This manpower burden is clear to the unit commanders on the FOB who must give up personnel for these housekeeping tasks.

Also, MAGS offsets or displaces energy demand. Harvested MAGS thermal energy offsets the additional fuel used to operate MAGS. When used to displace fuel used for heating water in an M80 water heater, typical of showers, MAGS has a greater than 7:1 ratio of waste mass treated to mass of fuel consumed. This directly reduces the amount of fuel imported to the FOB. Freeing the trucks of waste hauling load lowers the fuel consumption of the trucks as well.

Any reduction of transportation of fuel into the FOB or waste out of the FOB reduces the exposure of logistic personnel to enemy action. And the reduction of waste handling in general reduces the exposure to injury via modes such as muscle strains, puncture wounds, falls, debris in eyes, bacterial and fungal exposure, etc.

A limitation to MAGS is the inability to process certain waste streams which still require transportation off the FOB for proper disposal. This includes all non-combustible material, batteries, and large combustible items that are not practical for resizing to fit MAGS, such as large dunnage and tires. However, these items are relatively inert compared to the high priority waste streams such as food or medical wastes which become more dangerous over time.

2.3.1.3 MAGS vs Other Technology

MAGS hold significant advantage to other solid waste processing systems in terms of energy efficiency, treatment capacity, emissions performance, energy return, manpower requirement, size, and signature, and operational flexibility.

Regarding energy efficiency, MAGS treats 5 mass units of waste for every mass unit of fuel it consumes, a 5:1 ratio. This accounts for fuel burned in MAGS and in the generators to supply the electricity to power MAGS. When the energy MAGS harvests from waste is used to displace fuel burned in the M80 water heater, the mass ratio increased to greater than 7:1. MAGS has an operational day of 16 hours, or a duty cycle of 2:3. The capacity of MAGS in that 16 hours is 2/3 ton, with a surge capacity of a 24 hours operational day treating up to a full ton.

MAGS emissions controls curtail the formation of dioxins and furans, neutralize acid gasses, scrub particulate matter, and cool the exhaust gasses before they leave the appliance. The concentrations of emissions meet the US EPA OSWI standard. Those limits, however, only tell part of the story. Total emissions (mass) equals concentration multiplied by the emissions flow rate. Incinerators combusting waste directly have high oxygen demands and require flow rates many tens of times higher than MAGS, which combusts only the fuel derived from gasification. The difference is so stark, the US EPA has granted waivers exempting MAGS from the regulatory framework for incinerators. The emissions performance of MAGS allows the system to be placed within the FOB immediately adjacent to the living and working spaces. As stated previously, MAGS harvests thermal energy from waste through the quench and scrub processes of the emissions controls. This by-design element ensures energy extraction is not at the expense of emissions performance, as it is in incinerators. In practice, the reuse of this energy also reduces emissions of the displaced combustion processes in space and water heaters. Other incinerators without active emissions controls must maintain high exhaust temperatures until the emissions sampling point at the exit of the stack. Extracting energy from exhaust gasses cools them and allows the formation of dioxins and furans within the system where they can be measured. Formation of these persistent, harmful substances beyond the stack exit is not regulated.

MAGS returns useful thermal energy at a rate averaging between 80 kW and 120 kW. This energy is easy to incorporate into the FOB due to the proximity of MAGS to other camp infrastructure. For instance, MAGS can directly heat the air inside a maintenance shelter or aircraft hangar, simply by placing MAGS within the structure and allowing the cooling fans to heat the tent environment while exhausting the combusted syngas through an exhaust stack outside of the tent. This displaces fuel burned in space heaters or in generators powering electrical heaters. MAGS can heat water for shower and laundry, via an integrated water to water heat exchanger, displacing the fuel burned in water heaters. There is a simplicity of the physical connection to the water infrastructure without need for any control interface that make using the energy a negligible impact on the complexity of the camp logistics.

Manpower, as previously stated, is greatly reduced across the greater solid waste enterprise by both systems compared to burn pits and transportation. The advantages to MAGS include the access of the system adjacent to the work station of the originator of the waste. A MAGS custodian is required to attend to daily system start up and routine maintenance tasks, however in this operational construct the custodian is not full time assigned to operating MAGS, they only monitor the operations. The proximity of MAGS to the other infrastructure relieves the need for a constant presence at the appliance. The skill set to maintain MAGS is that of a mid-level generator technician. The overall labor burden of MAGS is equivalent to other electro-mechanical systems maintained by this Military Occupational Specialties (MOS). In summary, MAGS holds advantage to lower manpower burden during operations.

MAGS cool dry emissions have no visual signature during operations. The infrared (IR) signature was not measured during this demonstration, but is assessed to be indistinguishable from the FOB's overall IR signature. MAGS exhaust gas temperature is less than that of the generators in the FOB, and all exposed surfaces are safe for unprotected human touch.

2.3.2 WETT-G

Wastewater in expeditionary operations currently represents great promise for reclamation and reuse. Army publication TB MED 577 delineates the acceptable uses for non-potable water as a replacement for potable water when potable water is not available. The use of disinfected non-potable water is acceptable for field laundry and showers. In practice to date, there have been no simple, efficient, and low maintenance appliances to reliably generate this high quality disinfected non-potable water without the need of a separate storage and conveyance network to prevent cross contamination with potable supplies. This leads to potable water overproduction to meet the non-potable needs. On the flip side of the argument, every drop of water reclaimed and reused offsets the energy and logistics burden to make potable water. There is great opportunity for energy and logistics savings by a system that negates the aforementioned burden, and this is the advantage of WETT-G.

WETT-G receives graywater discharge from shower, laundry and shave stations. This immediately removes the need for a disposal pit or surface discharge. This water is cleaned and disinfected using far less energy than the production energy for RO systems to lift, clean, pump, store, transport, distribute, and maintain. The treated water is immediately available for reuse within the shower and laundry water supply storage. The high efficiency of WETT-G, around 95% return rate, maximizes the reuse potential of the water. Losses elsewhere in the water cycle, water removed with the clothing at the laundry for example, are made up with smaller potable water "top offs" to the storage bladders. In this way, the infrastructure dedicated to shower and laundry serve as both supply and collection, simplifying the overall handling of water.

Compared to other technological approaches, electrochemical treatment in the methodology of WETT has the advantage of accepting a wider variance of input water quality. Common pollutants in shower and laundry water include sand, hair, lint, soaps, and detergents. These substances quickly clog filters and RO membranes in filter based solutions. The addition of different pre-filtering strategies add size, weight, power, and consumables, lowering the logistics gain for using such as system. WETT-G's EC module efficiently flocs, floats, and removes these impurities by design. The 5% reject rate from WETT-G creates a lower burden, and when integrated in the TRU Habitat it is destroyed in MAGS. WETT-G is also an efficient pretreatment process for RO systems such as the Light Weight Water Purification System (LWPS). Pre-processing raw water in WETT-G allows LWPS operations without the first stage of the system, reducing energy, consumption of filters, and increasing processing rate.

A limitation of WETT-G is the removal of ammonia, NH_3, sometimes detected in shower water. The EC removes roughly 30%, but not all, of the NH_3. The GAC unit is able to handle a majority of the remaining ammonia. This is addressed at the human factors and education level. WETT-S is able to completely destroy ammonia.

2.3.3 WETT-S

Blackwater currently represents a logistic burden and Force Health Protection vulnerability. There are a few filter based and biological expeditionary systems in the research and development pipeline. The comparative advantage of WETT-S includes:

WETT-S is a rapid start, rapid shut down, system that does not need to balance biological processes. The Lamella Plate Separator and EC module do the work of the many settling and rough filtering processes of filter based and biological approaches in a compact and efficient manner. WETT-S's small form factor and scale-by-numbers approach makes it applicable to the smallest FOBs to the largest.

WETT-S EO stage disinfects the effluent without chemical addition. The simple interface with FOB wastewater discharge makes integration with FOB operations quick, easy, and flexible. With lightly contaminated blackwater, WETT-S can reduce the pollutants to a surface discharge standard in a single pass. For highly contaminated blackwater, WETT-S can cycle the water until the desired standard is met. The treated effluent from WETT-S can meet NPDES discharge standards. It would be acceptable for uses within the TB MED 577 Fresh Water (Non-potable) list to include construction, vehicle wash, and dust control. WETT-S can also be used for graywater water recycling, disinfection, and pretreatment of raw water from RO systems in the same manner as WETT-G.

Limitations of WETT-S were shown during this demonstration including the need for a second pass through the system due to very highly contaminated blackwater produced at the Marine's EFK with very low pH (2.5). This is solved either with pre-treatment dilution with graywater (treated or untreated) or acceptance of a multi-pass approach. Another limitation of WETT-S observed was the presence of sewage treatment chemicals in the toilet waste collection tank. These chemicals expedite the breakdown of waste and accelerate biological decomposition which interferes with WETT-S's primary EO mechanism. In practice, there is no need for these chemicals and the limitation experienced during the demonstration was artificially introduced by the use of commercial infrastructure for the human waste collection process. WETT-S creates a non-reusable sludge stream of solid and liquid contaminants which must be disposed outside the WETT system, such as with MAGS in the TRU Habitat.

2.3.4 TRU Habitat

The strengths of the individual systems comprising the TRU Habitat are valuable stand-alone tools for FOB efficiency, resiliency, and safety. Together, these tools have a cross compatibility that further strengthens the value proposition. Each individual system, as efficient as they are, produce a non-reusable waste stream that requires further treatment or disposal. For WETT-S and WETT-G that is the reject sludge produced in the water cleaning process. Within TRU, this stream is disposed entirely within MAGS, leaving zero disposal burden on logistics from the water reuse and remediation processes. MAGS harvests water during the emissions control process, technically clean but containing a small particulate matter residue. This water is sent to WETT-S for remediation, eliminating the need for discharge. As a result, the only non-reusable component of the FOB's combustible waste and wastewater is a small quantity of inert char.

The operational flexibility and resiliency of TRU is a strength. The TRU Habitat subsystems can be operated independently of each other, but will result in minor additional waste streams (filter bags, sludge, etc.) that would normally be treated within the TRU Habitat when all systems are interconnected. The system can be flexibly assembled in phases as the FOB establishes, expanded or replicated as capacity dictates, and retrograded in the same fashion. Maintenance of one subsystem has no effect on the others, and none of the individual components negatively affect the larger camp processes they support.

The TRU Habitat opens the possibility of increasing warfighter comfort. The ability of the TRU Habitat to treat human waste and reuse water would allow for efficient flush toilets to be part of the FOB utility kit. The human factors component of accessible toilets was demonstrated in the Auxiliary Airfield Number 2 (AUX II) WTI exercise. Without the flush toilets available immediately adjacent to the shower, service members faced the temptation to urinate in the shower rather than walk over 100 yards through sand to get to a porta-potty. This is the source of NH_3 sometimes detected in shower wastewater. With the flush toilet adjacent to the shower station, the temptation was greatly reduced. Within the exercise, the flush toilet trailer was the most popular and identifiable feature of the demonstration. While we did not do a "with and without" test to support the ammonia hypothesis, NH_3 was not significant in our findings as it was with other ESTCP shower water results (ESTCP Project ER-201636).

3 PERFORMANCE OBJECTIVES

The TRU Habitat system consists of multiple subsystems: the MAGS, WETT-G, and WETT-S. The quantitative and qualitative performance objectives for all subsystems are presented in Table 3-1.

Table 3-1. Project Performance Objectives

Performance Objective	Data Requirements	Success Criteria	Objective Met?
Quantitative			
Solid Waste Reduction (MAGS)	% volume reduction (combustible waste)	>90%	Yes
Liquid Waste Reduction (WETT)	% volume reduction (wastewater)	>90%	Yes
Water Quality	Treated effluent characteristics (COD, BOD_5, TSS, TN, TP, pH, Total Coliform, E. Coli, TDS, turbidity, hardness, free available chlorine residual)	For GW: Meet NSF/ANSI 350 standard Meet TB MED 577 standard For BW: Meet US EPA NPDES standard	No
Water Recovery	% of wastewater (graywater) made available for reuse by site	60%	No
Thermal Energy Production (MAGS)	in kWh/h	>100kWh/h	Yes
Energy Use	Assess kWh/m^3 overall for site for solid waste, water and wastewater management	<50% of existing fuel consumption as determined during baseline measurements	No
Transportability	System size and compactness	Fit each MAGS and WETT system into Tricons or 20 ft. Intermodal container	Yes
Payback Period	CAPEX/OPEX costs	<12 months	No
Qualitative			
Ease of Use	Feedback from users on the system operability and maintenance requirements as documented by logs. Survey of technically skilled Military Occupational Specialties (MOS) after demonstration of custodial duties.	WETT systems do not require operators to be present during operation, minimal maintenance requirements MAGS is operated by service members, incidental to their normal duty with only brief (< 5 minute) familiarization. Custodial duties within skillset of on hand military Occupational Specialties.	Not Demonstrated
Suitability for operating environment	Recorded issues related to temperature, humidity, and dust.	Data collected to enhance ruggedness of follow-on iterations	Yes

Each performance objective listed in Table 3-1 is necessary to evaluate the effectiveness of the TRU Habitat system to:

- reduce the costs of transporting fuel;
- reduce required potable water delivered; and
- reduce the solid/liquid wastes removed from the demonstration area.

Reductions in solid waste, energy usage, and water consumption directly translates into lower transportation costs and fuel consumption which would impact the payback period. To fully capture the performance of the TRU Habitat, inputs and outputs must be characterized quantitatively and/or qualitatively.

3.1 Solid Waste Reduction

Solid waste reduction is an important metric in determining the efficacy of the MAGS subsystems and will result in significant avoidance costs for the transportation of such waste streams off site. The performance metric was originally defined as percent (%) volume reduction, but the actual waste collected was measured by weight using a hand scale. The weight of the material fed into MAGS and the weight of the biochar output was logged by the operator. Based on this data, the percent weight reduction was calculated. It should be noted that although the bulk density measurements of the waste and biochar were not measured, typically the percent volume reduction is higher than the percent weight reduction. MAGS reduced solid waste by 94% by weight, we can confidently conclude that the performance objective reduction goal of 90% by volume was met.

3.2 Liquid Waste Reduction

Liquid waste streams such as sludge and concentrated brine present disposal challenges for bases. Liquid waste stream disposal requires labor hours and fuel costs. Similar to the solid waste stream, the cost savings are calculated based on the costs of liquid waste disposal on a per-unit basis. Both WETT system's sludge volume is considered a liquid waste and was analyzed during this project.

For WETT, the volume of wastewater fed into WETT-G and WETT-S was measured. However, the sludge volume from the WETT systems was not measured since it was sent to MAGS for gasification. The foam sludge produced needs to be dewatered and is then sent directly to MAGS. Since all liquid waste sludge is handled within the TRU Habitat environment, the reduction percentage is effectively 100%. This performance objective highlights the process efficiency of the TRU Habitat. In past studies, Terragon measured the WETT-G and WETT-S sludge volume to be 5% of the influent volume. The sludge for WETT-G contains 2% solids, and 6% solids for WETT-S. This data shows the WETT systems reduced liquid waste volume by 95%, meeting the performance objective of a greater than 90% reduction.

3.3 Water Quality

Water quality is a necessary performance objective that must also be met in conjunction with the liquid waste reduction performance objective. In the continental United States (CONUS), the standard for water reuse is set by the National Sanitation Foundation (NSF) and American National Standards Institute (ANSI) standard NSF/ANSI 350: On-site Residential and Commercial Water Reuse Treatment Systems (Table 3-2). Overseas the Technical Bulletin, Medical (TB MED) 577

standard (Table 3-3) guides the commander on the acceptable risk levels for water reuse. The combined NSF/ANSI 350 and TB MED 577 requirements for WETT-G are included in Table 3-4. For WETT-S, they are located in Table 3-5, and in Table 3-6 for MAGS. US Military RO water purification units are capable of treating almost any water to a potable standard, though at appreciable energy costs. The water quality standards achieved by the WETT units will inform the calculation of energy savings, if any residual treatment is required, and the overall cost savings.

Table 3-2. Excerpt from ANSI 350-2018 Effluent Criteria

Measurement	Class R (Residential Output)		Class C (Commercial Output)		Units of Measure
	Test Average	Single Sample Max	Test Average	Single Sample Max	
$CBOD_5$	10	25	10	25	(mg/L)
TSS	10	30	10	30	(mg/L)
Turbidity	5	10	2	5	(NTU)
E. Coli[1]	14	240	2.2	200	(MPN/100mL)
pH	6.0 - 9.0	N/A	6.0 - 9.0	N/A	(SU)
Storage Vessel Disinfection	≥0.5 - ≤2.5	N/A	≥0.5 - ≤2.5	N/A	(mg/l)[2]
Color	MR	N/A	MR	N/A	
Odor	Non-Offensive	N/A	Non-Offensive	N/A	
Oily Film and Foam	ND	ND	ND	ND	
Energy Consumption	MR	N/A	MR	N/A	

N/A: Not Applicable
ND: Non-Detectable
MR: Measured and Reported Only

1 Calculated as geometric mean
2 See sections 8.6.2.6 or 8.6.3.6 in ANSI 350-2018

Table 3-3. Excerpt from TB MED 577 Regarding Graywater Quality – Laundry and Shower Recycling

Constituent	Acceptable Range or Maximum Allowable Limit	Unit
pH	5 - 9	-
Turbidity	1	NTU
Hardness	500	mg/L
TDS	1500	mg/L
Coliforms	Absent	Detection
FAC Chlorine Residual	1	mg/L after 30 min

Table 3-4. WETT-G Consolidated Graywater Reuse and Discharge Requirements

Constituent	Acronym	Test Method	Discharge Limit		Units	Pass/ Fail
			Avg.	Max		
Biochemical Oxygen Demand	BOD	SM 5210B	< 10	25	mg/L	Fail
Chemical Oxygen Demand	COD	SM 5220D	< 10	25	mg/L	Fail
e. Coli by MD/MTF	e. Coli	SM 9221F	Absence		Detection	Fail
Free Chlorine Residual (Field)	Free Cl	SM 4500Cl G	0.2 - 2		mg/L	Fail
pH	pH	SM 4500H+ B	6 – 9			Pass
Total Coliform by MD/MTF	Tot. Coli	SM 9221B	Absence		Detection	Fail
Total Dissolved Solids	TDS	SM 2540C	< 1500		mg/L	Pass
Total Hardness Package	Hardness	varies	< 500		mg/L	Pass
Total Nitrogen Package	TN	varies	< 3	5	mg/L	Pass
Total Phosphorus	TP	SM 4500P B E	< 1	4	mg/L	Pass
Total Suspended Solids	TSS	SM 2540D	< 10	30	mg/L	Fail
Turbidity	Turb	SM 2130 B	< 1		NTU	Fail

Table 3-5. WETT-S Consolidated Blackwater Discharge Requirements

Constituent	Acronym	Test Method	Discharge Limit		Units	Pass /Fail
			Avg.	Max		
e. Coli by MD/MTF	e. Coli	SM 9221F	Absence		Detection	Pass
Total Coliform by MD/MTF	Tot. Coli	SM 9221B	Absence		Detection	Pass
Total Suspended Solids	TSS	SM 2540D	< 50	100	mg/L	Fail

Table 3-6. MAGS Discharge Requirements

Constituent	Acronym	Test Method	Discharge Limit	Units	Pass/Fail
Total Solids (Moisture %)	Tot. Solids	SM 2540G	5 - 10	Percentage	Pass

WETT-G effluent met a total of five constituent standards for reuse (nitrogen, phosphates, dissolved solids, pH, and hardness) and WETT-S effluent met two standards for reuse (e. coli and total coliforms) when treating kitchen wastewater and met no standards when treating toilet trailer sewage. Processed effluent water did meet some constituent metrics for reuse, but did not meet all of the constituent levels for these reuse cases for laundry, dust suppression, toilet flushing, vehicle washing, construction, and/or firefighting. A detailed breakdown of reuse constituents is included in Section 6.3.

Overall, the TRU Habitat did not meet the water quality performance objective for this demonstration. The principal reason for not meeting this objective was higher concentrated influent streams than anticipated and longer than anticipated influent stream holding times. The WETT systems were factory calibrated for typical commercial concentrations of graywater and blackwater. Calibration can be field adjusted by personnel after attending an equipment training session.

3.4 Water Recovery

The amount of water recovered for reuse or treated to standards that ensure safe discharge directly translates into water that does not need to be transported to the operational site. Such water requires labor hours and fuel to transport which translates into a per-unit cost. Similarly, this affects the costs associated with transporting waste water off site.

Quantifying the amount of water recovered for reuse allows for the quantification of cost savings from reductions in total water consumption. Wastewater captured from graywater discharge sources could, upon meeting treatment standards, be recycled by graywater applications (i.e. laundry) or reused for blackwater applications (latrines). Wastewater from blackwater applications could be recycled for further blackwater use (latrines) or reused for vehicle cleaning, dust suppression, or discharge. Thus, graywater and blackwater that is processed to be safe for reuse is also safe for surface and/or sump pit discharge. The safe discharge of treated water is a direct savings against the cost of wastewater backhaul and treatment by a contracted service provider.

Neither of the wastewater streams were reused or recycled during the TRU Habitat demonstration, but the water quality testing verifies the technology and the degree at which the waste streams are reusable or recyclable. Also, the reduced transport of the treated waste streams, due to reuse, provides both environmental and risk reduction benefits. Comparing influent and treated effluent volumes, WETT-G and WETT-S did not produce any treated water that fully met non-potable water reuse standards. However, some constituents in the effluent did meet individual constituent levels for reuse, such as TDS for graywater. Section 6.4 lists the specific constituents that were met for non-potable reuse. The principal reason for not meeting this performance objective was higher concentrated influent streams than anticipated and longer than anticipated influent stream holding times, which both led to decreased final effluent water quality.

3.5 Thermal Energy Production

The MAGS subsystem of the TRU Habitat produces usable thermal energy which can be recovered for other processes. This metric for thermal energy production, measured in kWh/h, is very important in that it can be compared to an equivalent fuel load, after considering conversion efficiencies and thermodynamic losses, which can be translated into fuel cost savings. The thermal

energy production from MAGS was determined by measuring the temperature of the inlet and outlet of the cooling fans and the flowrate going through the fans. MAGS records this differential which is then calculated to determine the average power recovered during the operating period. Based on average run time of 5.93 hours per day, MAGS produces 69.9 kWh/h of thermal energy. However, MAGS is able to produce over 120 kWh/h of energy with the right influent material, and this was verified during the system demonstration. The system met the performance objective of producing >100 kWh/h in the field. Section 6.5 provides more detail and graphs of the energy production from the TRU Habitat system.

3.6 Energy Use

The TRU Habitat system requires electricity for operation (MAGS, WETT-G and WETT-S), as well as supplemental diesel fuel (MAGS). However, MAGS produces a significant amount of thermal energy, thereby offsetting the energy footprint of the overall system. During the demonstration period, MAGS produced 407.6 kWh of energy per day with an average daily run time of 5.9 hours. Diesel fuel used for start-up and operation of the MAGS can be compared with the costs associated with typical solid waste disposal for a field operation or training exercises.

Overall, the total energy footprint of the system must be quantified in order to compare with existing energy and fuel costs to determine a cost-savings. Data provided by MWSS 371 was used to calculate the existing baseline energy use conditions. However, this data lacked information on the amount of solid waste produced by the site, and the volume of blackwater (kitchen and sewage waste) generated by the site, so these two values were estimated. The total water consumed for shower and laundry water was included in the MWSS 371 data sheet, so the team used this value to determine the convoy fuel usage to supply this amount of water. The fuel usage was calculated to kWh using a MEPS 1050 15kW generator gallon per hour fuel consumption. From there, the team calculated how much energy was required to deliver one cubic meter of water for showering and laundry (8.47 kWh/m^3). This water could theoretically be replaced by treated WETT-G effluent. The graywater energy use was multiplied by 1.5 for blackwater to account for the energy require to transport the blackwater off site and dispose of it properly (12.7 kWh/m^3), and the solid waste was estimated to be 0.5 times the graywater energy waste since it only required transport off site and proper disposal (4.24 kWh/m^3). At WTI, no thermal energy from MAGS was used and the WETT effluent did not meet non-potable reuse standards, so these values are excluded from Table 3-7.

Table 3-7. WTI Demonstration of TRU Habitat Energy Use Summary

Parameter	MAGS	WETT-G	WETT-S	TRU
Electricity Consumed (kWh)	1,237.8	107.2	217.3	1,562.3
Fuel Consumed	111.7 gal	-	-	111.7 gal
Volume Treated	3,125 lbs. (6.8 m^3)	10,514 gal (39.8 m^3)	4,649 gal (17.6 m^3)	64.2 m^3
Energy Use	1.09 kWh/lb.	0.010 kWh/gal	0.047 kWh/gal	-
TRU Energy Use (kWh/m^3)	501.9	2.6	12.4	**516.9**
Existing Energy Use (kWh/m^3)	4.2	-	12.7	**16.9**

In order to meet the performance objective (<50% of existing fuel consumption as determined during baseline measurements), the energy required for the operation of the MAGS should be compared to the typical energy-use figures that a FOB exercise would use for the disposal for their solid waste (burn pit, trucking, fuel, etc.). The fuel required for the WETT systems should be compared to the fuel costs of disposal of the waste streams treated by the WETT system. If treated WETT effluent is reused, this also represents a fuel cost savings by reducing the amount of potable water needed on-site. At the WTI demonstration, thermal energy from MAGS was not captured, and no treated effluent was cleared for reuse. Therefore, the energy use performance objective was not met during the demonstration with the principal reason for failure being the lack of full reuse of the TRU Habitat output streams.

In a future use case, thermal energy and treated WETT effluent could be used at the location. These reuse factors greatly reduce the energy costs of the TRU Habitat and do meet the performance objective. This scenario would reduce energy consumption by 1,623% showing the importance of utilizing all TRU Habitat outputs.

Table 3-8. Future Transition TRU Habitat Energy Use Summary

Parameter	MAGS	WETT-G	WETT-S	TRU
Electricity Consumed (kWh)	1,237.8	107.2	217.3	1,562.3
Electricity Produced (kWh)	6,114.4	-	-	6,114.4
Fuel Consumed	111.7 gal	-	-	111.7 gal
Volume Treated	3,125 lbs. (6.83 m^3)	10,514 gal (39.8 m^3)	4,649 gal (17.6 m^3)	64.2 m^3
Energy Use	-0.86 kWh/lb.	0.010 kWh/gal	0.047 kWh/gal	-
TRU Energy Use (kWh/m^3)	-397.3	2.6	12.4	**-412.3**
Existing Energy Use (kWh/m^3)	4.24	8.47	12.7	**25.4**

3.7 Transportability

The TRU Habitat is designed to fulfill a technological niche available at FOBs. By its nature, transporting equipment to FOBs is logistically difficult and expensive. Transportability includes metrics such as volume and weight, as well as ease of movement, manpower requirements, equipment costs, and time requirements for set up and tear down, and the effort to make ready for prolonged storage. The TRU Habitat successfully fit into four Tricons measuring 8’ x 6’ x 8’. No damage occurred during transportation from Canada to Port Hueneme, CA, and to/from Yuma, AZ. The system was transported over sand and placed by USMC personnel and equipment without issue meeting the performance objective.

3.8 Payback Period

The cost savings and payback period for the TRU Habitat system is a function of each performance objective listed in Table 3-1. This payback period first considers the individual TRU subsystems and then the synergistic effects which make the whole greater than the sum of the individual subsystems. Metric units are used throughout this effort, with imperial units occasionally made available to facilitate common comparisons. Payback period comparisons are made based on the Operations and Maintenance costs, with direct operational energy costs accounted for and indirect

manpower costs annotated for consideration. Unquantifiable Force Protection and environmental benefits are subjective but will also be highlighted for consideration.

Assumptions used in the payback period calculations:

- Fuel is JP-8 yielding 9.74 kWh /L (37.12 kWh/g) at density 0.81kg/L.
- Fuel cost is $0.72/L ($2.74/gal) DLA unburdened, $2.63/L ($10.00/gal) burdened at FOB (Deloitte 2009). For the purposes of our test, we used a 2023 projected diesel cost of $1.07/L ($4.06/gal) cite in June 2022 from the US Energy Information Administration.
- Electricity will be provided by MEPS generators greater than or equal to 30 kW, with a conversion factor of 3.34 kWh/L (12.7 kWh/gallon)
- Water heating is accomplished in military water heaters at 81% efficiency, 7.89 kWh/L
- Air heating reference system is the USAF Polar BEAR 130, 4.54 kWh/L.

3.8.1 MAGS

Direct costs for MAGS include electricity, fuel, and manpower. Direct cost avoidances include fuel displaced by recovered energy, fuel used by alternate means, and solid waste disposal and transportation costs. Indirect cost avoidances include labor hours saved using MAGS versus alternate means. The alternate thermal destruction technology used is a generic incinerator at a 2.5:1 waste mass to fuel mass ratio sought by PM FSS in Expeditionary Solid Waste Destruction System (ESWDS) Industry Day without energy recovery. For the payback period calculations, MAGS is assumed to be operating at 75% duty cycle to account for loading delays, wet waste, and preventative maintenance, and outputting an average of 100 kW of thermal energy.

As shown in Table 3-9, MAGS generates significant daily savings in fuel (249 L/day) and cost versus the alternative technology, while operating only as a thermal destruction system. When including thermal energy recovery, the payback period shortens. MAGS has the potential to save over 210,000 liters of fuel per year. This is the equivalent capacity of 22 US Army M978A4 Heavy Expanded Mobility Tactical Truck (HEMTT) Fuel Servicing Tankers. When valued at the burdened rate of $2.63/L this offers savings of over $553,000 per year. The payback period on MAGS at the price purchased by the US Army at $315,000 is less than 1 year. For the purposes of the demonstration at the WTI event, the price point for the Navy was $301,199.

Table 3-9. Cost Savings of MAGS System versus Alternate Means using Closed Loop Heat Exchanger for Heat Recovery

(Based on testing for US Army)

Performance Data	Power	Energy	Max Capacity	.75 Duty Cycle	Fuel Used	Mass Ratio
	(kW)	(kWh/day)	(kg/day)	(kg/day)	(L/day)	(Waste:Fuel)
MAGS	28	672	1200	900	201	5.6
Alt. Incinerator				900	450	2.5
Costs		Labor	Fuel Low Cost $0.72/L		Fuel High Cost $2.63/L	
		(hrs.)	($/kg)	($/day)	($/kg)	($/day)

MAGS		3	$0.16	$144.86	$0.59	$529.15
Alt. Incinerator		8	$0.36	$324.00	$1.32	$1,183.50
Costs vs Alt		-5		$(179.14)		$(654.35)
Avoidances	**Power**	**Energy**	**Offset**		**Offset**	
	kW	**kWh**	**(L/day)**	**($/day)**	**(L/day)**	**($/day)**
MAGS Export	100	2,400				
Water heat @7.79 kWh/L equivalent			-304	$ (219.01)	-304	$(800.00)
Total w/ Energy Recovery			-103	$ (74.15)	-103	$(270.85)
Air Heating @ 4.54 kWh/L equivalent			-529	$ (380.62)	-529	$(1,390.31)
Total w/ Energy Recovery			-327	$ (235.75)	-327	$(861.16)
Yearly Costs		**Labor**	**Lowest Example**		**Highest Example**	
		(hrs.)	**(L/yr.)**	**($/yr.)**	**(L/yr.)**	**($/yr.)**
MAGS Only		-	-37,589	$(27,064.43)	-119,514	$(314,322.9)
Vs Alternative		-1825	-128,402	$(92,449.70)	-210,327	$(553,160.7)

The payback period for the WTI Event demonstration did not use the calculations shown in Table 3-7. This was due to the short duration of the testing during the WTI event, the use of the MAGS for less than 24 hours daily, and the lack of heat recovery during the demonstration. While a shorter payback period is likely due to the ability of the TRU Habitat to recover waste heat from the gasification process, it did not occur during this demonstration, and thus cannot be validated in this report.

The team analyzed the payback period for different operating scenarios in Section 7, including utilizing MAGS thermal energy to power M80 water heaters and air heaters.

3.8.2 WETT

WETT systems operating cost is dominated by electricity cost, operating at 3 kW for WETT-G and 10 kW for WETT-S and consumables cost. Consumables include spare parts, electrodes, and wiper blades for operation. The system works quietly and steadily in the background, requiring only very infrequent replacement of electrodes ($421 per set every 1-3 months) and wiper blades ($105 per blade every 1-3 months), a 30-minute task. Consumables costs must be included in the calculation, including:

- cost of electrodes and the frequency of replacement
- cost of wiper blades and the frequency of replacement
- cost of transportation of potable water against the cost of fuel to run the WETT systems for the period that the transported potable water would last in theatre, and
- cost of labor hours to perform maintenance on the systems.

Based on the numbers above, a future transition of a 10.6 year ROI was calculated. This is based on use for the system at future 8-week WTI events, twice yearly. The cost savings for treating blackwater was solely based on the cost saving of disposal of the quantity of water processed by the WETT-S. There was no cost savings based on the disposal of graywater as the graywater was pumped to the discharge pits. Savings for solid waste disposal were calculated in the same way.

Regarding man-hours and cost of labor to maintain the TRU Habitat, this was not possible to calculate as the demonstration of the system involved two technicians from Terragon, along with involvement from Sustained Turn and NAVFAC EXWC personnel, to install, operate, test and evaluate the systems at the WTI event. Assumptions can only be made based on the information provided by Terragon and their previous long-term operation of their technologies at their own facilities and other customer testimonials provided to us by Terragon. While these testimonials are not invalid, they were not corroborated by NAVFAC EXWC during the demonstration at the WTI event. The principal reason for not meeting this performance objective was a higher initial system cost since it is the first full version built, and sewage treatment issues during the demonstration.

3.9 Ease of Use

The ease of use of the TRU Habitat system was to be addressed by qualitative feedback from the end users. The assessment of ease of use should also include a comparison of operating the TRU Habitat for solid and liquid waste management as compared to conventional means (burn pits, field condition blackwater disposal, etc.). The standard of comparison for the TRU Habitat are highly varied, but ultimately the use of the technology compared to cruder conventional waste disposal means must be accurately conveyed to show the benefit of the TRU Habitat.

The project was originally scoped for multiple field demonstration, as explained in the original proposal, however the scope of the project was greatly reduced and therefore only one four-week long demonstration was carried out. Two thirds of this ESTCP project occurred during the COVID-19 pandemic, in which DoD and international travel bans greatly impacted planned demonstrations. Due to these circumstances, the team does not feel that the TRU Habitats' ease of use was fully demonstrated during the project. This performance objective can be properly assessed with an additional demonstration for a longer time period.

3.10 Suitability for Operating Environment

The TRU Habitat system was constructed to withstand elements experienced in the expeditionary field environment. The equipment must be able to handle a wide temperature range and multiple climate settings including high winds, snow, rain, dust, and more. To adequately test the ruggedness of the system, the team demonstrated the unit at a training site in Yuma, AZ. Temperatures ranged from 45°F during the night, to over 100°F during the day. The system was exposed to high winds, blown sand, and light rain (Figure 3-1). The TRU Habitat met the qualitative performance object and did not experience any operational issues due to the environment during testing.

Figure 3-1. Inside TRU Habitat during WTI Demonstration

4 SITES/PLATFORM DESCRIPTION

4.1 Test Platforms/Facilities

The demonstration of the TRU Habitat system was conducted at the Marine Corps Air Station (MCAS) Yuma, AZ AUX II site, approximately 8 miles southeast of MCAS Yuma. An expeditionary-style FOB is constructed here during the WTI event hosted by Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) (Figure 4-1). This two-month course is held twice a year, during the spring and fall, and brings together elements from each Marine Corps aviation specialty, and many ground combat and logistics entities. The FOB supports Aviation Ground Support and Aviation Command and Control units for the duration of the class, as well as providing temporary support to ground combat elements during the later stages of the course. The number of personnel (pax) living at the FOB averages 300 to 500, with excursions up to 800.

This test site was selected to demonstrate the operability of the TRU Habitat in an environment closely resembling FOBs where water and fuel (resources) are at a premium value for mission support, and the supply lines for these resources are constantly threatened by hostile activity while the mission is in operation. The AUX II FOB is a barren sand field immediately adjacent to the AUX II expeditionary runway. It is roughly level and devoid of vegetation. It is used only for the WTI course and sits vacant the remainder of the year. There are no utilities of any type.

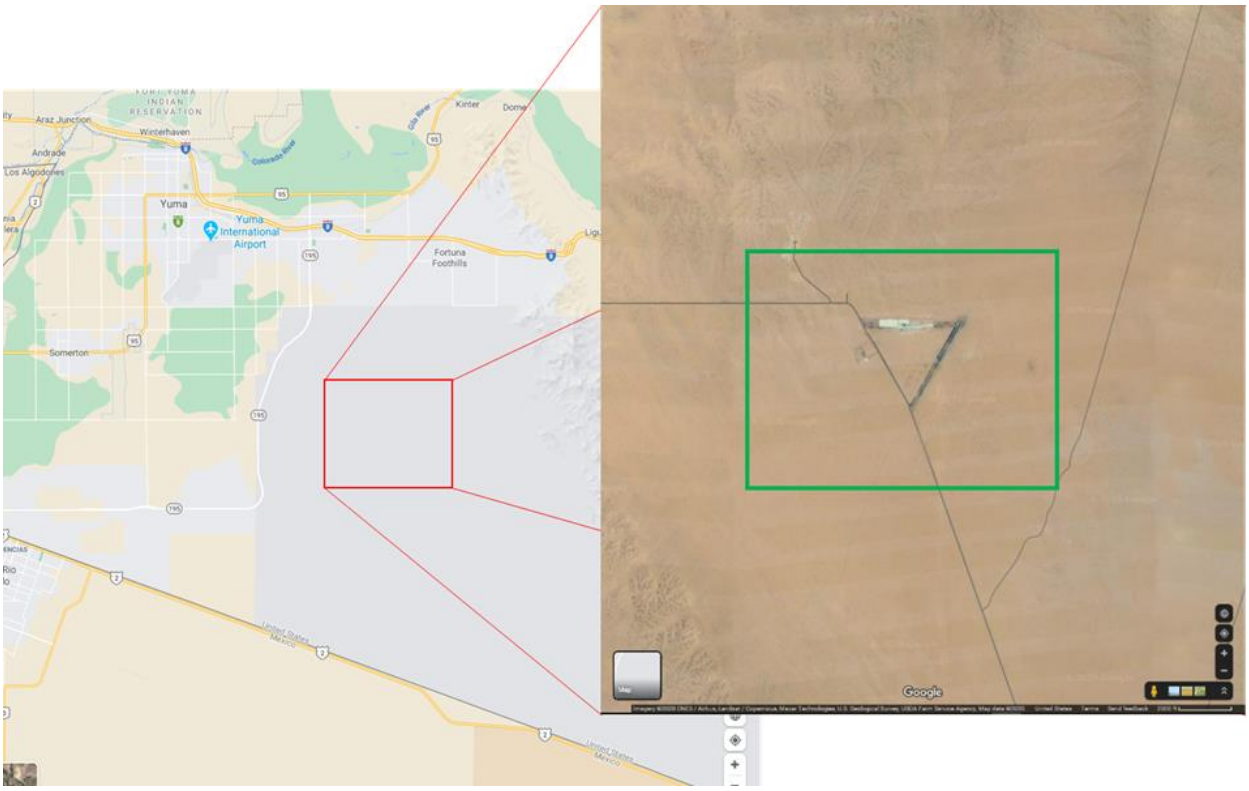

Figure 4-1. AUX II Site Layout at MCAS Yuma

This environment is an excellent demonstration site for this technology on many levels. The FOB exercise represents, as near as possible, the conditions that troops will meet in the field, including a harsh environment, a reasonable representative number of actively supported troops, and a

complete cadre of field support operations, including showers, latrine, laundry, dining, field medical, and aviation and ground equipment maintenance facilities. Together these facilities and their occupants use fresh water, produce graywater and blackwater, and have a solid waste stream representative of off-grid military operations. The fresh and wastewater streams, along with the solid waste streams, align with the TRU Habitat system requirements.

This site lacks local infrastructure to process wastewater and solid waste. Contract support from commercial vendors is required to remove waste from AUX II. The main stakeholders of this demonstration site (MCAS Yuma) have a vested interest in the performance of the TRU Habitat as it may reduce the amount of solid waste and liquid waste the base must contract for disposal as part of day-to-day operations.

Marine Wing Support Squadron (MWSS) 371 was tasked as the supporting logistics agency for this exercise. The utilities section took the lead on Camp Commandant functions, overseeing the planning and execution of the camp build up. A section of approximately 15 Marines were detailed to build out the camp services. These Marines bivouacked at the site, sleeping in ground tents and eating MREs for the first few days. MCAS Yuma Environmental designated a spot along the northern boundary of the AUX II for the graywater percolation (perk) pits. On day one of the buildup, MWSS began by digging two 3 meter wide by 5 meter long and 1 meter deep pits in the sand for the disposal of graywater. This formed the anchor for the utilities section's buildup of camp support infrastructure.

Support equipment on site on day one included one Rough Terrain Cargo Handler (RTCH, said "ratch") and one 10-ton forklift. The RTCH emplaced two Containerized Batch Laundry (CBL) system immediately adjacent to the west edge of the perk pits. The 10-ton forklift then emplaced the WETT- G and WETT-S on the west side of the CBLs. Finally, the forklift set the two Tricons of MAGS west of the WETT units. The total time for emplacement of four TRU containers was under 30 minutes. Over the remainder of the day, MWSS set the containers housing water utilities and showers on the east side of the perk pit with the forklift, while the RTCH was used to set a containerized deep freezer and the NAVFAC Containerized Living Unit (CLU) adjacent and west of TRU. Generators were distributed throughout the Camp and water bladders were set in place.

On day two, two EFKs were delivered and set up south of the deep freeze, including a scullery and large dining tents. Water and fuel deliveries began and connections to water supply and wastewater removal were made. By the end of day two, basic "house" services of food and electricity were in place. This allowed the TRU team to begin commissioning of the TRU Habitat subsystems.

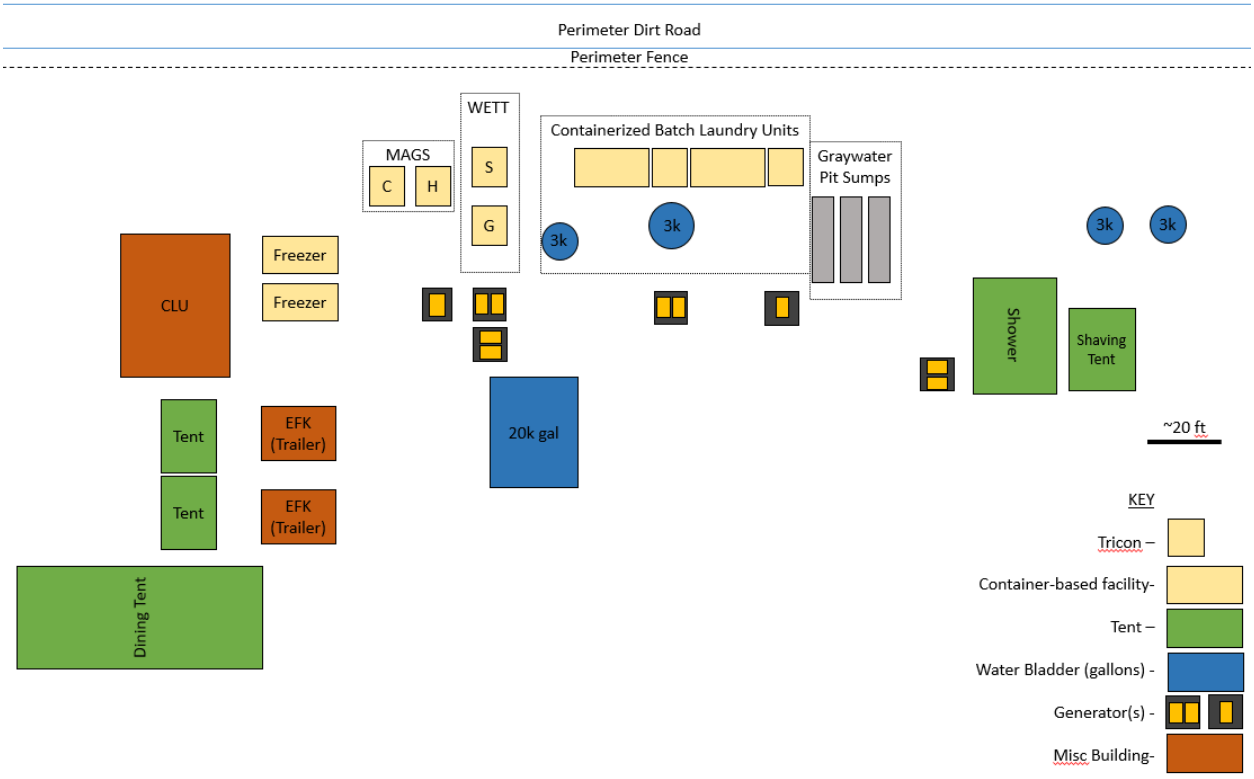

Figure 4-2. AUX II Facility Layout for WTI

4.2 Present Operations

By day three of the WTI startup, waste generation rates began to pick up with the addition of more food services Marines and as the camp welcomed Marines from the Aviation Command and Control Squadron for whom the camp was to serve.

2,700 gallon loads of potable water was trucked in from MCAS Yuma to AUX II. Once onsite it was transferred to waste storage bladders distributed around the utilities area. Fuel for generators were delivered daily, sourced from the fuel farm at MCAS Yuma (Figure 4-3).

Figure 4-3. WTI Fuel Delivery Truck and Filling Process

Waste streams were a byproduct of the daily operations. The bulk of the solid waste generated by the FOB was from the EFK and dining tent. Four meals per day were served, with hot meals for breakfast and dinner, and MRE's for lunch and mid-rations. The hot meals were made from box rations (Figure 4-4), Unitized Group Rations (UGRs), and were augmented by fresh and frozen foods.

Figure 4-4. Unitized Group Rations

These meals were served as "tray rats" on disposable cardboard trays with paper cups, plastic flatware, and paper napkins. Waste was collected at the exit of the dining tent in plastic garbage bags (Figure 4-5). MRE waste was collected similarly, consisting mainly of aluminum foil lined plastic and MRE heaters. Bulk food waste and cardboard packaging was delivered to MAGS straight from the EFK's and freezers immediately adjacent to the MAGS.

Figure 4-5. Solid Waste Collected for MAGS Influent

A scullery, the nautical term for dishwashing station, was the source of most of the blackwater (Figure 4-6). Pots and pans were washed, and wastewater was transferred via a sump pump to 275 gallon IBC containers.

Figure 4-6. Expeditionary Field Kitchen Scullery

The sump was also a collection point for liquid cooking waste and waste beverages such as coffee and reconstituted powdered sport drinks. These sport drinks introduced considerable acidity to the blackwater. Blackwater for WETT-S was soured from these containers (Figure 4-7).

Figure 4-7. Blackwater Storage Totes

Contract services, the same agency that serviced the porta-potties, emptied the BW containers daily. Graywater was generated by laundry, shower and shave stations. This graywater was pumped straight to the perk pits. The TRU team placed 275 gallon IBC totes between these utilities and the perk pits to collect water for treatment in WETT-G. Small pumps (Figure 4-8) were used to transfer the graywater to the IBC totes adjacent to the WETT-G.

Figure 4-8. Transfer Pumps Used to Move Liquids

The integration of TRU Habitat did not require any change in operation from MWSS-371. Wastewater was intercepted as it flowed to the perk pits. The use of ubiquitous 2" cam-lock fittings on TRU and on the Marine's equipment made connecting pumps easy. The ease of use of MAGS and its proximity to the EFK's and dining tents compared to the long walk to the commercial dumpsters made MAGS the preferred option of the Marines. Overall, the Marines were excited to see and use new technology to supplement their aging equipment.

The FOB has no bathrooms, and normal field operations will use either mobile portable toilets (porta-potty) or "Wag Bags." AUX-II uses contracted porta-potties for relief. These porta-potties were along the opposite (southern) edge of the FOB, approximately 250m from the utility section. This was deliberate for the prevention of foul odors bearing on the living spaces. The TRU Habitat team sourced a flush toilet trailer in an effort to collect human waste for blackwater. Unfortunately, the vendor dosed the blackwater holding tanks with chemicals that tainted the blackwater, rendering it unusable for the demonstration. The toilet trailer was deliberately placed adjacent to the showers by the TRU Habitat team to add incentive for Marines to use the toilet prior to showering. The intent to this human factors engineering is to keep the graywater gray, and the blackwater black.

4.3 Site-Related Permits and Regulations

Yuma Range Operations Department (Yuma Range) exercises administrative control over operations at AUX II. MAWTS-1 Aviation Ground Services Department exercises operational control of AUX II during the exercise, while MWSS-371 exercises tactical control of the site.

Air emissions from power generation are covered under the MCAS Yuma current operations agreements with the State of Arizona, and TRU Habitat creates no additional impact. Air emissions from MAGS is exempt from US EPA and the Arizona Department of Environmental Quality (ADEQ) incinerator regulations. MAGS is also exempt from ADEQ New Source Performance

Standards. ADEQ submitted a letter to NAVFAC EXWC on January 26, 2021 stating "that you will not need a permit or registration for the MAGS demonstration from March 8, 2021 to April 25, 2021 based on the information sent during your email correspondence with ADEQ from November 17, 2020 to January 20, 2021. This determination is based on the MAGS unit having a potential to emit all criteria pollutants below the permitting exemption thresholds, and the EPA's determination that this unit is not a solid waste incineration unit."

No additional permits are required for graywater. Graywater discharge into sumps and leach fields at AUX II is allowed under the Yuma Range regulations and is standard operating procedure for WTI events. Yuma Range and Environmental inspected the TRU Habitat set up during operations. The TRU demonstration had impact on WTI SOPs.

No additional permits were required for blackwater. Blackwater from EFK operations is collected in holding tanks and removed by contract services managed through Yuma Range. In an agreement with Yuma Environmental, TRU converted this blackwater to dischargeable water which was collected in holding tanks for sampling and disposal by contract services. Before allowing discharge, Yuma Environmental insisted upon holding the treated effluent as it underwent water quality testing. This water was eventually removed by contract services due to higher than expected influent concentrations of blackwater and extended water quality laboratory sampling time. Blackwater generated by human waste at the FOB is collected in portable toilets serviced by outside contract and covered under agreements managed through Yuma Range. The dedicated five stall portable restroom trailer with flush toilets was procured for the purposes of human waste collection for TRU, and all other effluent was collected by outside contracted services. Yuma Range has granted permissions for these operations as they are in keeping with SOP.

5 TEST DESIGN

5.1 Conceptual Experimental Design

The design of the components of the TRU Habitat were previously developed and tested in an experimental capacity during previous incarnations. The WETT-G and WETT-S, and MAGS systems are, individually, at a TRL level of 6 and 8, respectively. These components having the technical requirements mentioned in Section 2.1 were built for the purposes of this demonstration. The integration of the two technologies (WETT and MAGS) into the TRU Habitat solution and the demonstration of the integrated system was the main objective of the demonstration.

The systems were individually designed, tested for operational capability (processing of solid waste and testing of COD, BOD, turbidity, and pH of the representative liquid waste streams) and commissioned at the manufacturer's site. Upon completion, the systems were delivered to the test site and arranged to permit interconnection between the units.

Table 5-1. Laboratory Testing Performed Prior to Delivery

System	Test	Result	Date
WETT-G	COD	60-70% Removal	August 13, 2020
	BOD	>90% Removal	August 13, 2020
	Equipment confirms to P&ID	Pass	August 12, 2020
	Appearance	Pass	August 12, 2020
	Commissioning	Pass	August 12, 2020
WETT-S	COD	>90% Removal	August 30, 2020
	BOD	>90% Removal	August 30, 2020
	TSS	>90% Removal	August 30, 2020
	Fecal Coliforms	>99% Removal	August 30, 2020
	Total Residual Chlorine	<0.5 ppm	August 30, 2020
	Total Phosphorus	>99% Removal	August 30, 2020
	Total Nitrogen	>99% Removal	August 30, 2020
	Equipment confirms to P&ID	Pass	August 26, 2020
	Appearance	Pass	August 26, 2020
	Commissioning	Pass	August 26, 2020
MAGS	Waste Reduction	95% Reduction	December 13, 2019
	Cold Commissioning	Pass	December 13, 2019
	Hot Commissioning	Pass	December 13, 2019
	Operational Commissioning	Pass	December 13, 2019
	Factory Acceptance Test	Pass	December 13, 2019
	Decommissioning	Pass	December 13, 2019
	Equipment confirms to P&ID	Pass	November 12, 2019
	Appearance	Pass	November 12, 2019
	Commissioning	Pass	November 12, 2019

5.2 Pre-Demonstration Testing

The WETT-S, WETT-G, and MAGS were tested prior to delivery to EXWC. For the WETT systems, initial commissioning testing began using fresh water. Following successful completion of the first step, testing with a simulated wastewater was performed during which specific removal rates of contaminants was measured and documented. The WETT-S/G system reports and factory acceptance tests are included in Appendix D. Similarly, during commissioning of MAGS, all components and assembly were inspected to ensure conformity to piping and instrumentation diagrams, visual inspection to verify weld quality and damages is performed, followed by process commissioning using a simulated dry waste recipe to ensure proper operation, as per technical specifications. As a last step, all safety interlocks were verified and validated. The MAGS system report and factory acceptance tests are included in Appendix E.

5.3 Design and Layout of Technology Components

The TRU Habitat system consists of four Tricon containers; two Tricons for MAGS, one Tricon for WETT-G and one Tricon for WETT-S. The overall footprint of the equipment and staging area is 32’ by 34’ (1,088 SF). Figure 5-1 shows the dimensions of the TRU Habitat components and the approximate envelope needed for the system laydown. This layout area can be rearranged depending on field conditions, as demonstrated by the different layout used at WTI.

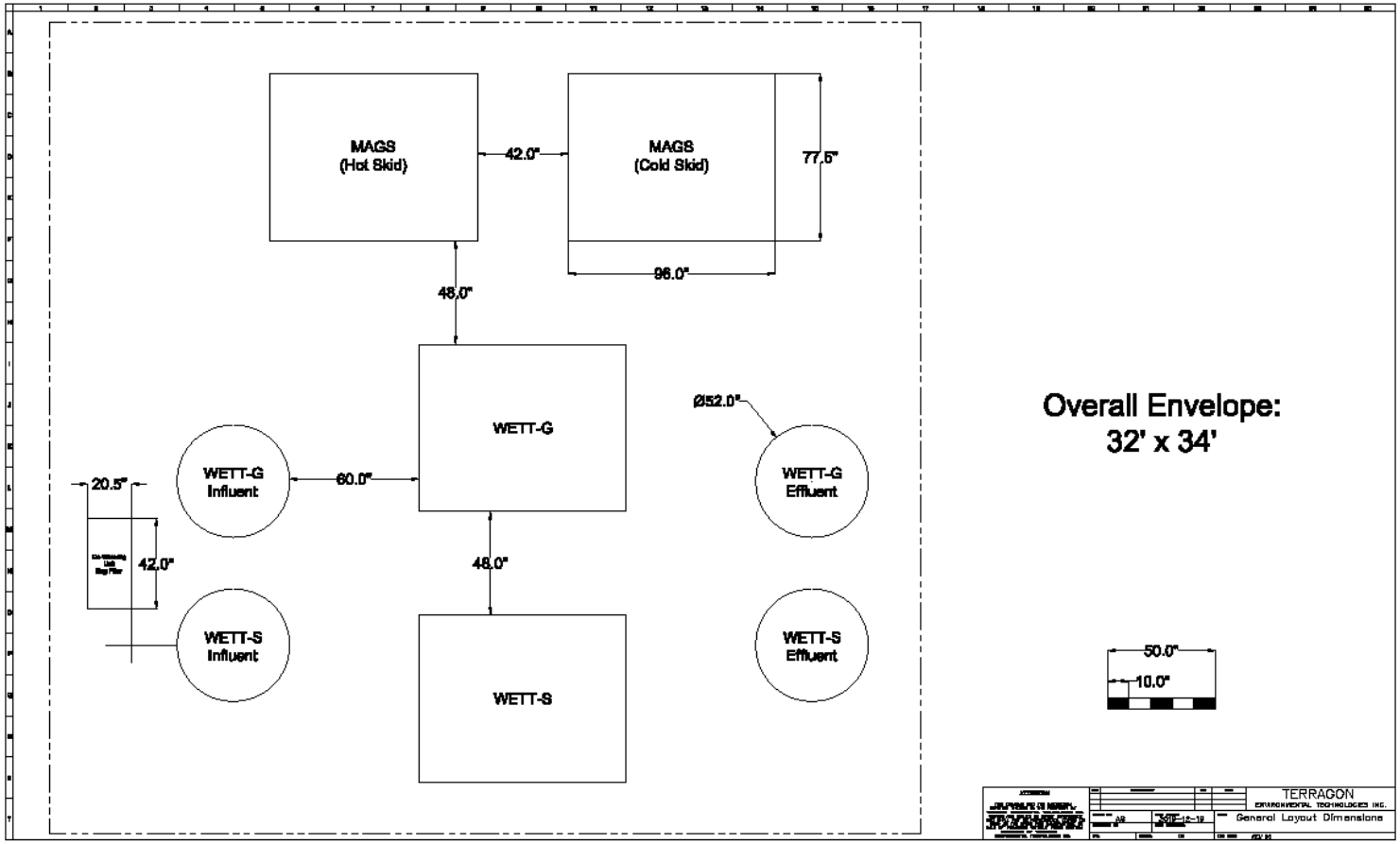

Figure 5-1. TRU Habitat Component Physical Dimensions

Figure 5-2 shows the TRU Habitat component flow streams, along with recycle/recirculation steams, surge and holding tanks. Figure 5-3 shows the actual layout of the TRU Habitat integrated into the Spring 2021 WTI exercise.

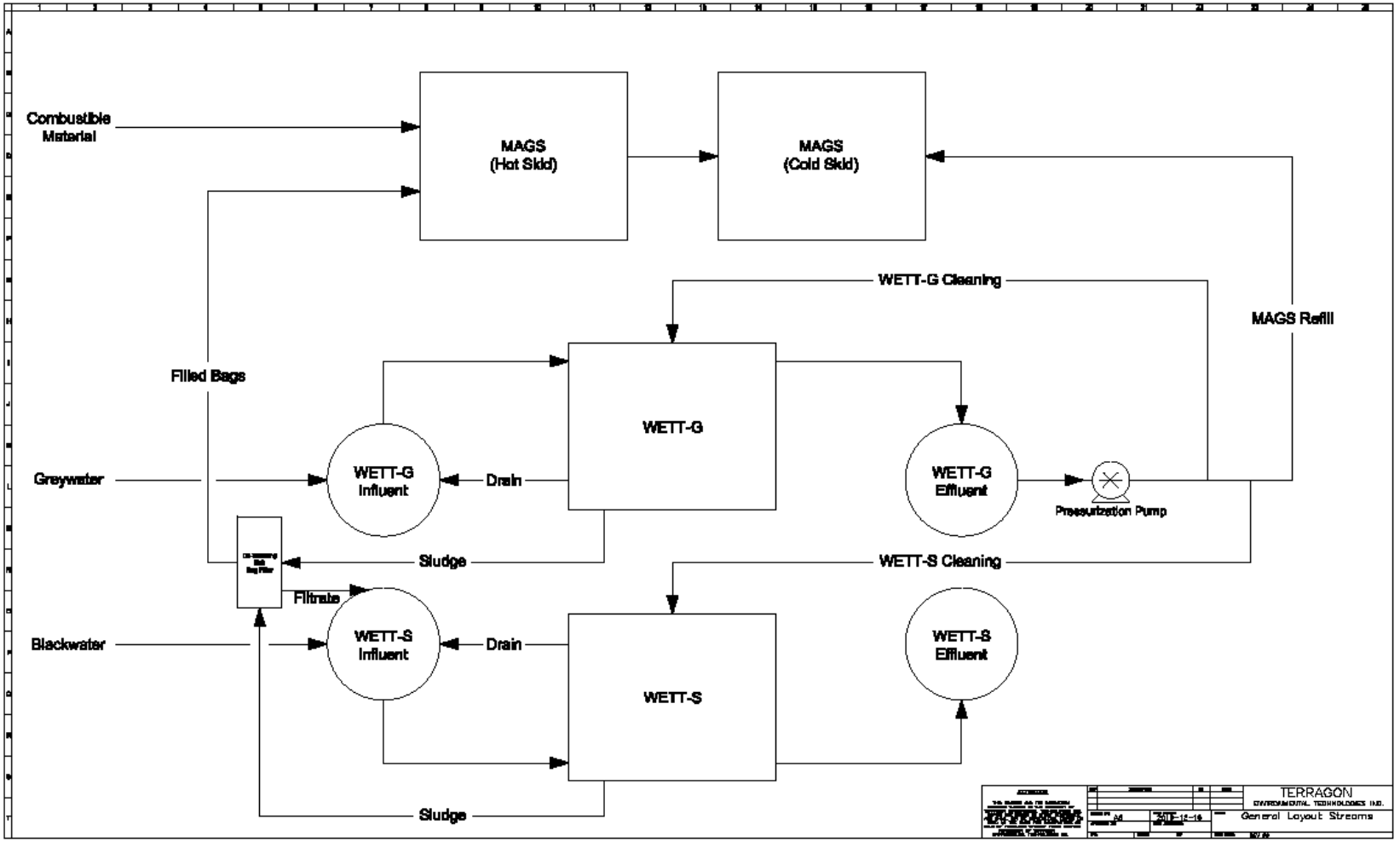

Figure 5-2. TRU Habitat Component Stream Diagram

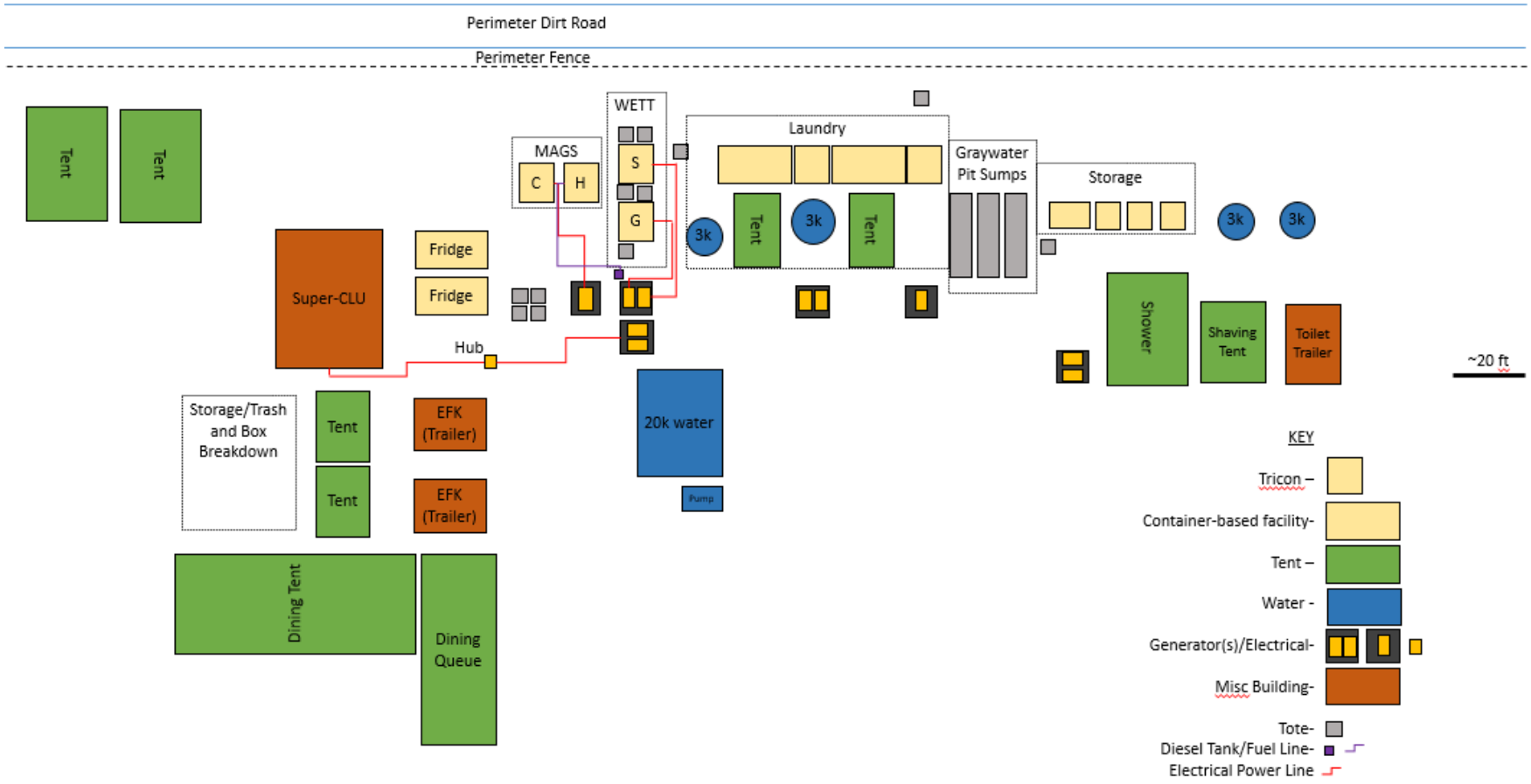

Figure 5-3. WTI Layout at MCAS Yuma AUX II Site

5.4 Field Testing

The testing methodology for the demonstration followed the proposed sampling given in the proposal. Baseline data on the waste streams, solid waste and water, from the demonstration site, as well as past WTI exercises, were obtained. This data served as a baseline for the performance of the treatment systems. Detailed test methods for each constituent are described in Section 5.5 - Measurement/Monitoring Plan. Field sampling was constricted during the four week demonstration period due to limited funding, environmental conditions, and on-site personnel availability.

Table 5-2. Sampling Plan Schedule by Week

Dates and Activities	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Week
- Equipment Delivery - TRU Team Arrives	2/28/2021	3/1/2021	3/2/2021	3/3/2021	3/4/2021	3/5/2021	3/6/2021 System Delivery & MWSS Arrives	0
- Set-up of TRU Habitat at WTI - Begin Processing Water/Solids	3/7/2021 System Layout	3/8/2021 System Connection & Power Layout	3/9/2021 Laboratory Set-up	3/10/2021 Toilet Trailer Arrives	3/11/2021	3/12/2021 MAGS Operational	3/13/2021	1
- Commission WETT systems	3/14/2021	3/15/2021	3/16/2021	3/17/2021	3/18/2021	3/19/2021 WETT-G Operational	3/20/2021	2
- Field and Lab Testing	3/21/2021	3/22/2021	3/23/2021 WETT-S Operational	3/24/2021	3/25/2021	3/26/2021	3/27/2021	3
- System Decommissioning and Transport	3/28/2021	3/29/2021	3/30/2021	3/31/2021	4/1/2021 Disconnect System	4/2/2021 Stage for Transport	4/3/2021	4

Legend	
	Field Test
	Field and Lab Tests
	MAGS Lab Samples

5.4.1 Week 1 (3/7/21 – 3/13/21)

Week 0, Day 1, 3/6 – TRU Habitat was delivered on site on March 6, 2021 and MWSS positioned equipment in place using a 10-ton forklift. Units were staged between the EFKs and laundry facilities on the North border of the exercise. The team opened and inspected each Tricon and did not observe any damage due to transportation. The existing layout based on observations from the Fall 2020 WTI exercise needed to be adjusted for the Spring 2021 WTI exercise, so the team diagrammed the new changes. The team also met with exercise support personnel (LT Price, MSgt Mason, and GySgt Robertson). The onsite Marines were very interested in the TRU Habitat and were inquisitive on how the system operates (Figure 5-4). The team briefed multiple Marines on the system capabilities and how it operates.

Figure 5-4. Marines Examining the TRU Habitat during Setup

Week 1, Day 2, 3/7 – Day 2's focus was laying out generators to power the units and to assess generator capabilities. Power was connected to both WETT units. A 15kW generator ran to WETT-S and presented possible issue with the generators rated at 27 amps for its 208v setting. The team assessed the power rating of the generator and determined the specifics of the generators wiring may be the limiting factor. The utilities chief mentioned a 30kW generator was available in reserve if the 15kW was not sufficient. The dedicated MAGS generator was awaiting procurement and delivery to the site.

Week 1, Day 3, 3/8 – Commissioning of MAGS and WETT units was initiated and the arrival of MAGS generator on March 9th was confirmed. The team updated the exercise layout of all the TRU Habitat inputs and outputs (Figure 5-3). The SuperCLU (Figure 5-5) was operational for an equipment laydown area and provided a workstation for water quality testing. The toilet trailer rental company was contacted to review the fresh water inlet connection and blackwater outlet collection. It was also determined that two more 275 gallon IBC totes were needed, as well as a maceration pump based on the distance from the toilet trailer to WETT-S.

Figure 5-5. SuperCLU Workstation and Mobile Testing Lab

Week 1, Day 4, 3/9 – This day was very windy with winds steady at 10-15mph and gust of 25+ mph. The system was tested in a dust/sand storm environment. Russ Emons briefed LtCol Barron on the system. LtCol Barron was excited to see the TRU Habitat's capabilities during the exercise and noted a use case for MAGS in Alaska to utilize waste heat to heat hangars. The MAGS generator arrived at 1200. The WETT-G pump and compressor were installed outside of the unit. The team positioned the laundry graywater tank and hosing. Secondary containment for generator and pumps was installed. The laboratory in SuperCLU was set up for daily analytical tests (Figure 5-6).

Figure 5-6. Field Lab Setup inside SuperCLU

The laundry water onion bladder was filled at 1330 via trucked in water. Analytical equipment and supplies were received from Terragon and the received equipment was loaded into the SuperCLU. The electrodes and wiper were installed on WETT-G (Figure 5-7).

Figure 5-7. Electrode and Wiper Blade for the WETT System

A 3,000 gallon laundry potable water bladder was filled. Potable water was trucked in on a large flatbed truck in three (3) 900 gallon SIXCONs. Water was then pumped from these containers into bladders and SIXCONs set across camp (Figure 5-8).

Figure 5-8. Marines Filling SIXCON from Supply Truck

Week 1, Day 5, 3/10 – A handheld scale for weighing bags of trash for MAGS was purchased. The WETT-S discharge was connected to an IBC tote tank collection point. Laundry was expected to be operational by Sunday March 7th, but MWSS needed to conduct operational tests first, which generated additional graywater for TRU Habitat commissioning. 20,000 gallon potable water bladder was filled along with a 5,000 gallon shower bladder. The water flush toilet trailer (Figure 5-9) arrived at 1200 and was operational by the afternoon.

Figure 5-9. Delivery of the Flush Toilet Trailer

This was the first week of WTI and the arrival of exercise personnel. The WTI students checked in and the ramp-up of the exercise was underway. Initial orientation for the host MWSS and camp residents took place during this first week, and therefore constituted the first week of system exposure for on-site personnel.

Week 1, Day 6, 3/11 – Rain showers occurred on and off during the day with no impact to the open TRU Habitat units. Shower commissioning filled a single IBC tote for WETT-G commissioning and fine tuning. The excess shower water was sent to the sump pits. Laundry commissioning water was collected and pumped to WETT-G for commissioning and fine tuning as well. WETT-G was commissioned with laundry water and clean water until it reached a fully operational status. The EFKs generated 1.5 totes of blackwater for processing in the WETT-S. MAGS commissioning and setup continued by preparing the gasification units to accept waste and verifying all electrical controls.

Week 1, Day 7, 3/12 – Solid waste in trash bags began piling up in front of the MAGS unit anticipating its start. MAGS was operational by the end of the day. Blackwater from the EFKs were pumped into the WETT-S holding tank awaiting treatment. The first MAGS char moisture content sample was taken on March 13th, the end of the first week of WTI, and sent to the contracted laboratory (Fresh Terra). No water quality sampling occurred this week. The EXWC team concluded their first week on site and traveled back to Port Hueneme, CA. Terragon and Sustained Turn remained on site for the full four week demonstration period and EXWC employees returned to the site for the last week on the demonstration. The data collection during the first week included the following:

- Volumes of fresh water coming into the exercise, number of vehicles, types of vehicles (make, model, and engine size), miles per gallon, vehicle mileage to and from the exercise site, and the labor hours for transfer of fresh water.
- Methods for fuel and water delivery to the site.
- Technical specification for generators supplying power to the TRU Habitat.
- Quantities/volumes/weights of solid refuse collected for MAGS processing
- Observation of disposal methods (contractor disposal, sewer disposal, transportation to the local wastewater processing facility).
- Collection of waste streams of graywater and blackwater being produced.

5.4.2 Week 2 (3/14/21 – 3/20/21)

During this week, the TRU Habitat was commissioned with waste streams produced on site, and began processing solid and liquid waste streams.

- MAGS processed mainly cardboard and food waste (40 lbs./day).
- WETT-G processed mixtures of shower and laundry wastewater.
- Fresh kitchen wastewater was found to have very low pH (varying between 2.7 and 4.5), due to discharge of sport drinks.
- The camp did not produce a lot of waste this week, due to low occupancy.
- The solid waste was mainly composed of military grade packaging material.
- The TRU Habitat system experienced harsh weather environments (heat, wind, sand, rain).

5.4.3 Week 3 (3/21/21 – 3/27/21)

Processing of solid and liquid waste streams continued this week. Training on water sampling and analysis was also conducted during this week, and several presentations and discussions were held with camp operators and Marines.

- MAGS treated various streams of mixed garbage including cardboard, food waste, plastic cups, and military food packaging.
- MAGS char removal was also performed during this week. WETT-G treated various streams of laundry water, shower water, and mixtures of the two streams. The treatment parameters were fine-tuned for best treatment performance. The treatment current varied between 25A and 35A, for all treated streams.
- The presence of sand in graywater was noticed. This sand would increase the solids content of the graywater, and would make the froth produced in the electrocoagulation unit harder to float during the separation process.
- The graywater was also found to have high hardness, due to presence of dissolved salts in the potable water supplied to the camp.
- Graywater water effluent was collected and further treated by the LWPS; unfortunately, the RO membrane of the LWPS system was fouled and damaged, so no effluent samples were collected and analyzed.
- Disinfection tests for treated graywater were conducted at 1-hour and 2-hour intervals, which provided the desired residual chlorine necessary for storage of treated graywater for further use.
- The pH of kitchen blackwater was adjusted by adding caustic soda. This activity was time consuming as precise amounts of caustic soda were required to be slowly mixed into the blackwater, in order for the pH to be in the working range for electrocoagulation (pH range = 6 to 9).
- The blackwater from the toilet trailer was found to be green, and in an advanced stage of degradation, due to the presence of odor control products. This stream was hard to process in WETT-S, and was specified to not be included when contracting the flush toilet trailer.
- Process water from MAGS was collected, mixed with the blackwater and treated in WETT-S.
- Char, graywater, and blackwater influent and treated effluent samples were collected and analyzed daily. Additional samples were sent to local laboratory for analysis.

5.4.4 Week 4 (3/28/21 – 4/3/21)

Week 4, Day 1, 3/28 - The NAVFAC EXWC team arrived onsite again in Week 4 to support Terragon and Sustained Turn during the final week of the TRU Habitat demonstration. The EXWC team did witness some of the operational challenges since the entire TRU system was operational. One issue was excess foam being produced by the electrocoagulation unit of the WETT-G during operation. The foam was getting pumped further into the system rather than being removed, causing the pump to cavitate; however, this was resolved by changing the low sensor levels in the load equalization tanks coming from the electrocoagulation unit. Issues with the WETT-S, such as high COD loading, low pH kitchen water (due to excess juice and coffee), and enzyme additives in the toilet trailer that prevented the effective treatment of the blackwater were more difficult to resolve. For the COD loading and pH issues, the team planned to begin diluting the incoming blackwater to bring the parameters down to what is more typically seen in sewer systems, where blackwater is diluted with mixtures of shower, laundry, or handwashing water. The toilet trailer needed to be pumped out by the contractor to remove the enzyme additive.

Week 4, Day 2, 3/29 - The focus of Week 4, Day 2 was to run the excess foam from the WETT-G through the WETT-S in order to pull more contaminates out and reduce the color of the effluent water. This was also the first day of testing the WETT-S treatment of diluted blackwater, starting with a 50-50 mixture of kitchen water and shower water. Additionally, the team worked to break down some of the cardboard boxes into pieces that are more manageable to load into MAGS. Terragon also walked through the use of their field testing equipment such that the EXWC team would be capable of helping perform the field tests, allowing Terragon and Sustained Turn to focus on operating the TRU Habitat. Terragon demonstrated replacement of the filter bags in the MAGS to the EXWC team. Replacement of the WETT unit's filters is a similar process. The EXWC team contacted the toilet trailer vendor to arrange a full cleaning of the trailer to remove the green enzyme as a last attempt to be able to treat the toilet trailer water with the WETT-S. Lab samples were dropped off to Fresh Terra.

Figure 5-10. MAGS Used Filter Bag after Removal

Week 4, Day 3, 3/30 - The toilet trailer was emptied by the contractor to remove all waste (Figure 5-11). Fresh water was flushed through the trailer to flush out as much of the green enzyme as possible. After flushing, the trailer's freshwater supply was refilled and the trailer was opened for all Marines onsite. EXWC continued with field testing and dropped off a batch of lab samples to Fresh Terra. This was also the final day of MAGS operation, allowing it to cool overnight for cleaning the next day.

Figure 5-11. Emptying of Toilet Trailer

Week 4, Day 4, 3/31 - Terragon demonstrated cleaning out the MAGS unit by removing the char buckets and cleaning any remaining char and soot from inside. MAGS was later disconnected, packed, and staged for return to NBVC Port Hueneme. The disconnection process also involved draining the water and removing the filters. The toilet trailer water effluent was treated in the WETT-S again. An insufficient volume of blackwater was collected after emptying the trailer the previous day, making it necessary to add fresh water from the toilet trailers internal storage tank to create enough volume to transport to and treat with the WETT-S. The resulting blackwater influent to the WETT-S was very diluted. Both influent and effluent water samples were collected for analysis. The final influent/effluent water and bio-char lab samples were dropped off to Fresh Terra for analysis.

Figure 5-12. MAGS Char Buckets

Week 4, Day 5, 4/1 - The focus of Week 4, Day 5 was to begin decommissioning of the WETT units. The final WETT-S sample of treated toilet trailer water was pulled and immediately field tested, then both the WETT-S and WETT-G were drained and cleaned by Terragon and disconnected from their electrical connections. The next step of the decommissioning process required removing the aluminum electrodes (Figure 5-13) from the base of the electrocoagulation units, which involves removing all the bolts from the base and lowering it with a hand-operated forklift. After removal of the used electrodes, the base was reattached and both WETT units were then packed and closed up. The units were later staged near the MAGS for return to NBVC Port Hueneme.

Figure 5-13. WETT-G Electrodes after the Demonstration

Week 4, Day 6, 4/2 - The final day of the demonstration primarily involved packing and breaking down the SuperCLU field testing setup. Any unprocessed water was left for removal by the WTI event's septic system contractor. The final e-coli field samples from the Week 4, Day 5 samples were counted and the SuperCLU was disconnected from power and folded up for later shipping back to NBVC Port Hueneme. The toilet trailer was also removed from the site by the contractor.

5.5 Measurement/Monitoring Plan

In order to be considered suitable for reuse as non-potable water, the requirements for the discharge of the TRU Habitat are to meet the ANSI 350 2018, TB MED 577 effluent standards for graywater, and the US EPA NPDES requirements. Table 5-3 lists the parameters that were tested for based on ANSI, TB MED, and NPDES standards.

Table 5-3. Water Quality Testing Parameters

Parameter	Standard	Rational for Test
Biochemical Oxygen Demand (BOD_5)*	ANSI 350	Measure of the oxygen consumed by bacteria from the decomposition of organic matter.
Chemical Oxygen Demand	ANSI 350	COD is a quicker field test that can be performed to estimate the BOD as opposed to the several-day BOD lab test.
e. *Coli* by MD/MTF	ANSI 350	Harmful microorganisms that can cause intestinal illness. Can be used to measure microbial quality of water.
Free Chlorine Residual	TB MED 577	Chlorine is an effective disinfectant for most pathogenic microorganisms.
pH	ANSI 350 TB MED 577	Can be irritating to skin and eyes if outside acceptable range. Heavy metals also tend to be more toxic at low pH.
Total Coliform by MD/MTF	ANSI 350 TB MED 577	Used to measure microbial quality of water, but total coliforms measures closely related, mostly harmless bacteria. Can be indicator of possible pollution and used to determine effectiveness of water disinfection.
Total Dissolved Solids	TB MED 577	Dissolved solids include organic matter in solution as well as inorganic salts/ions. Some ions (chlorides and sulfates) can affect water corrosivity.
Total Hardness Package	TB MED 577	Non-health related parameter related to dissolved multivalent ions such as calcium and magnesium.
Total Suspended Solids	ANSI 350	High suspended solids generally translate to higher concentrations of microorganisms and tend to interfere with disinfection process.
Turbidity	ANSI 350 TB MED 577	Microbial inactivation by chlorine (or equivalent disinfectant) is less effective in turbid waters. Higher-effluent turbidity levels are a useful indicator of system failure.
Total Phosphorous	ANSI 350	Excess nitrogen and phosphorous can cause algae growth, which results in decreased levels of oxygen in the water (known as eutrophication). High levels of algae growth can produce algal toxins which are harmful to animal and human health.
Total Nitrogen	ANSI 350	Excess nitrogen and phosphorous can cause eutrophication. Additionally, excess nitrates in drinking or ground water can cause health problems if consumed at high concentrations.

*For the purposes of this demonstration, COD was used to calculate BOD_5. Initial samples were collected and sent to an external laboratory for BOD_5 analysis. These values were used to calculate the COD/BOD_5 ratio.

The water quality and solid waste performance objectives that served as the basis for the field and lab data collection are outlined Table 3-4, Table 3-5, and Table 3-6. Table 5-4 and Table 5-5 are example data collection sheets that were used during the demonstration. The initial start-up of the individual systems, and their interconnection serve as a baseline set of measurements, establishing throughput of the components and subsequently the TRU Habitat. The following weeks involved the testing of the influent and effluent of each of the components. The testing regimen of the effluent wastewater streams and solid waste was organized in order to combine the ANSI 350 and TB MED 577 chemical and biological analyses. The requirements for discharge to US Waters and Streams is addressed by the NPDES standards (Arizona Pollutant Discharge Elimination System Permit No. AZG2016-001, Inventory No. 106376). In order to meet the discharge requirements of all three standards, Table 5-3 was developed to include all relevant and overlapping testing requirements.

Table 5-4. WTI Exercise Baseline Data

Week:	**Date:**	
Parameter	**Number**	**Units**
Fresh Feed Water		Gallons
Graywater		Gallons
Blackwater		Gallons
Trash Refuse Bag		Kilograms
Waste Truck Size		Engine CC
Waste Collection Frequency		Per Week
Fuel Use		Gallons/Day
Operation Collection		Hours
Operation Offload		Hours
Vehicle Mileage		Miles
Contract Cost		One Time

Table 5-5. TRU Habitat Influent/Effluent Data Collection Sheet

Week:		**Date:**	
System	**Parameter**	**Influent**	**Effluent**
WETT-G	Vol./Day		
	COD		
	Tot. Coli		
	TDS		
	Hardness		
	TP		
	TSS		
	Turb		
	e.Coli		
	Free Cl		
	pH		

	TN		
WETT-S	Vol./Day		
	e.Coli		
	Free Cl		
	pH		
	TN		
MAGS	Vol./Day		
	Tot. Solids		
Energy	MAGS kW/hrs.		
	WETT-G kW/hrs.		
	WETT-S kW/hrs.		

As this project was to demonstrate the TRU Habitat, which is the combined interoperation of the MAGS and WETT systems into a single functional system, testing was performed on both the influent and effluent of each of the component systems to demonstrate the capabilities of the whole system. Testing demonstrates interoperability and enables a quick analysis of where the system is operating at in respect to water treatment quality.

Field water quality data collection by on-site personnel was performed via sample collection in sample bottles and subsequent testing with field testing kits (Hach, Assy SL1000, and Mantech PeCOD® Analyzer). Samples were collected per the type of sample analysis. Laboratory samples were delivered to the certified lab (Fresh Terra) located in Yuma, AZ for analysis. Lab samples were pulled throughout the designated lab sampling day and refrigerated until being delivered at the end of the day. A list of the field and certified laboratory testing performed for each component is listed in Table 5-6, Table 5-7, Table 5-8, and Table 5-9. The list of specific laboratory tests that were performed is in Appendix C.

Table 5-6. Laboratory Testing for WETT-G Discharges

Chemical Testing	Abbreviation	Lab Test	Required by
Chemical Oxygen Demand (influent only)	COD	SM 5220D	ANSI 350
Total Dissolved Solids	TDS	SM 2540C	TB MED 577
Total Suspended Solids	TSS	SM 2540D	ANSI 350

Table 5-7. Laboratory Testing for MAGS Discharges

Chemical Testing	Abbreviation	Lab Test	Required by
Total Solids (moisture %)	Tot. Solids	SM 2540G	Proposal

Table 5-8. Field Testing for WETT-G Discharges

Chemical Testing	Abbreviation	Test Equipment	Required by

Chemical Oxygen Demand (Effluent Only)	COD	Mantech PeCOD	ANSI 350
e. Coli by MD/MTF	e. Coli	Hach Kit	BOTH
Free Chlorine Residual	Free Cl	Assy SL1000	BOTH
pH	pH	Assy SL1000	BOTH
Total Coliform by MD/MTF	Tot. Coli	Hach Kit	BOTH
Total Hardness Package	Hardness	Assy SL1000	TB MED 577
Total Phosphorus	TP	Assy SL1000	ANSI 350
Total Nitrogen Package	TN	Assy SL1000	ANSI 350
Turbidity	Turb	Assy SL1000	BOTH

Table 5-9. Field Testing for WETT-S Discharges

Chemical Testing	Abbreviation	Test Equipment	Required by
e. Coli by MD/MTF	e. Coli	Hach Kit	NPDES
Total Nitrogen Package	TN	Assy SL1000	NPDES
Free Chlorine Residual	Free Cl	Hach Kit	NPDES
pH	pH	Assy SL1000	NPDES

Laboratory analysis for the duration of the exercise was required for both graywater and blackwater streams, and moisture content testing of the MAGS char.

6 PERFORMANCE ASSESSMENT

Data collected during this project and demonstration shows how the TRU Habitat performs in a FOB environment. The performance objectives assess the system in regards to solid waste, liquid waste, water reuse, energy, and other metrics further described in the following subsections. Achieving these objectives combined with a reduction in the required logistics of transportation to and from the FOB exercise contribute to the TRU Habitat's value. The reduction of truck transport, reducing fuel use, and the reduction of labor hours for transporting the supply lines for the exercise are key results sought after in this technology demonstration.

6.1 Solid Waste Reduction

The reduction of solid waste generated by the exercise is compared to the typical amount of solid waste sent out for landfill disposal. The reduction percentage was calculated by comparing the mass of the solid waste influent stream to the char effluent stream produced by the TRU Habitat (Figure 6-1). Influent and effluent values were measured using a hand scale and logged by the demonstration team. In addition to weight, the team logged the composition of each influent waste bag from the field. During the WTI demonstration, a total of 3,125 lbs. of solid waste was treated by MAGS with the following composition:

- 58.5% Food waste
- 20.8% Assorted mess hall waste
- 9.8% Cardboard
- 1.4% Assorted office-type waste
- 6.4% MRE waste
- 1.7% Plastic
- 0.2% TRU Habitat filter bags

After treatment, the total weight of the remaining char was 178 lbs., resulting in a 94.3% reduction in the total weight of solid waste. This meets the performance objective of a >90% reduction. Additionally, the moisture content of the char was 0.74%.

Figure 6-1. MAGS Influent and Effluent Streams

6.2 Liquid Waste Reduction

The reduction of liquid waste produced is compared to the typical amount of liquid waste sent out for disposal through typical channels at the demonstration site. The team was unable to verify the exact sludge volume in the field, but Terragon provided past studies to verify sludge production. Individual waste streams (graywater and blackwater) were cataloged based on percentage mixes in the 275 gallon IBC containers and the gallons of sludge produced were calculated using a 5% sludge volume.

WETT-G

- 10,514 gallons of graywater treated
- The treated graywater was disposed of in the onsite sump pits
- 526 gallons of liquid sludge produced
- 10.5 gallons of solid sludge produced
- Treatment efficiency = 95%

WETT-S

- 3,355 gallons of kitchen blackwater treated
- 1,294 gallons of toilet trailer water treated
- 232 gallons of a liquid sludge produced
- 13.9 gallons of solid sludge produced
- Treatment efficiency = 95%

Combined, their liquid waste reduction totals 95%. In the TRU Habitat system as a whole, there is essentially no liquid waste stream produced since all waste is sent directly to MAGS for gasification. The liquid waste reduction performance objective was achieved.

6.3 Water Quality

The water quality of the effluent stream from the TRU Habitat was analyzed as mentioned previously, and documented against the NSF/ANSI 350, TB MED 577, and US EPA NPDES standards and maximum discharge limits, as shown in Section 5.5. The results of these tests were be given a pass or fail rating.

Table 6-1. WETT-G Graywater Treatment Results

Treated Effluent Characteristic	Performance Objective		Units	WTI Influent (Average)	WTI Effluent (Average)	WTI Effluent (Max)	Pass/ Fail
	Avg.	Max					
COD – Field Test	< 10	25	mg/L	158.2	88.9	138.5	Fail
COD – Lab	< 10	25	mg/L	305	105.5	120	Fail
BOD – Estimated from COD	< 10	25	mg/L	52.7	23.4	36.4	Fail
BOD – Lab	< 10	25	mg/L	84	24[a]	24	Pass
TSS – Lab	< 10	30	mg/L	101.3	21.7	40	Fail
Total Nitrogen	< 3	5	mg/L	0.73	1.39	1.8	Pass
Total Phosphates	< 1	4	mg/L	0.11	0.02	0.03	Pass
pH	6.0 – 9.0			7.45	7.33	7.09 - 7.74	Pass
Total Coliform	Absence		CFU/ 100mL	>1,500	1,300	>1,500	Fail
E. Coli	Absence		CFU/ 100mL	>1,500	1,300	>1,500	Fail
TDS – Lab	< 1500		mg/L	1,515	1,050	1,200	Pass
Turbidity	< 1		NTU	92.9	14.2	62	Fail
Hardness	< 500		mg/L	320	270	270	Pass
Free Chlorine Residual	0.2 – 2		mg/L	0.032	0.015	0.03	Fail

[a] Only one WETT-G effluent BOD sample was analyzed by the laboratory.

COD/BOD Results Discussion

COD field tests were performed for nearly all samples and the BOD values can be estimated from the COD data by using the conversion ratios established via lab testing to increase the amount of BOD data available. This was done as COD field tests are quick and simple to perform, but BOD tests require a much longer lab test. The conversion ratios established between COD and BOD during for this demonstration was 3.0 for the untreated graywater and 3.8 for the treated graywater.

Overall, WETT-G treatment failed to meet the COD and BOD performance objectives at the WTI demonstration. WETT-G treatments used applied current values between 25 and 63 Amps, with the best treatment results being obtained at current values between 25 and 35 Amps. For the

treatment tests COD removal per individual sample averaged 47.7% and BOD removal averaged 58.7%.

Turbidity and Total Suspended Solids Results Discussion

The WETT-G was able to remove a large portion of the turbidity and suspended particles, removing an average of 92.2% and 75% from individual samples respectively. Regardless of the high removal efficiency, the treated effluent fell short of both performance objectives as a result of high influent parameters.

Total Nitrates and Total Phosphates Results Discussion

Nitrates were mostly unaffected by the WETT-G treatment. Both the influent and effluent nitrates were within the performance objective range.

Phosphates were reduced by an average of 70% from individual samples, and both the influent and effluent phosphates were within the performance objective range.

pH Results Discussion

The pH of the WETT-G influent remained similar after treatment and was within the performance objective range for a Pass result.

E. Coli/Total Coliforms Results Discussion

Coliform testing for the graywater was performed at a dilution ratio of 1:5 for a total of 20mL of wastewater being added to the 100mL sample. The test limitation is that more than 300 colonies per dish is considered an invalid test, thus values in Table 6-1 that are greater than 1,500 CFU/100mL were uncountable due to high coliform counts. While the WETT-G did decrease the coliform counts from uncountable to countable, it was still far from meeting the performance objective.

Addition of a disinfection process and/or Lightweight Water Purification System (LWPS) may help with coliform removal in the treated graywater. During the WTI demonstration, the LWPS equipment available onsite was not functional and thus could not be demonstrated to treat the WETT-G effluent. A portable disinfection process was demonstrated which was successfully shown to reduce the total amount of coliforms as seen in the images below. Even with the large reduction in the overall coliforms, the disinfection treatment process did not meet the ‘absence’ performance objective in the 1-2 hour treatments performed.

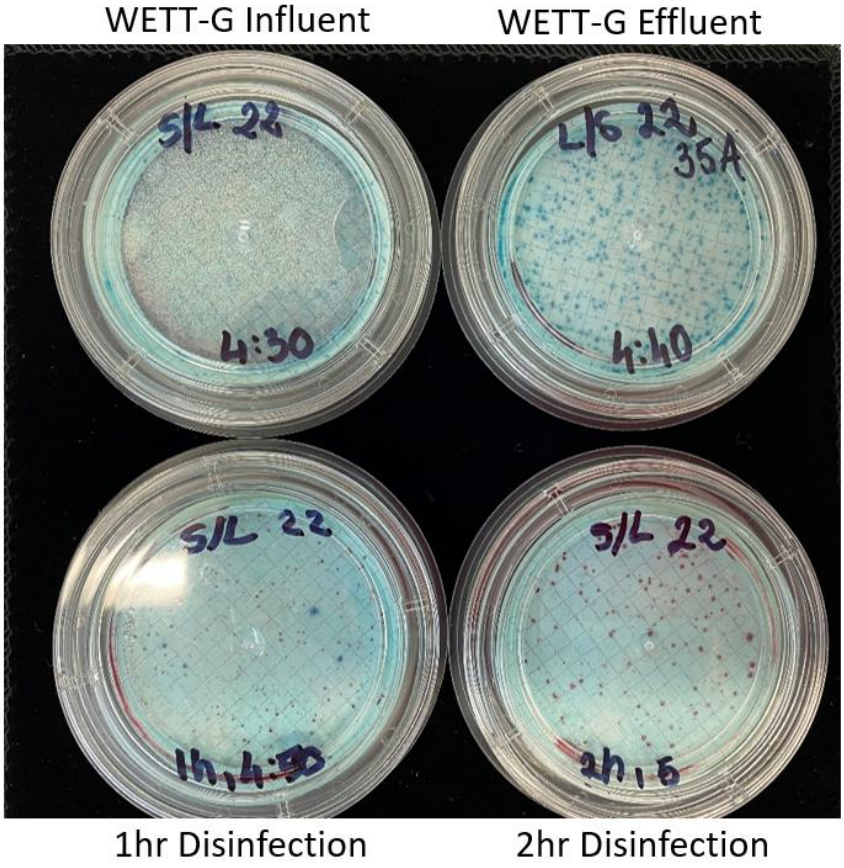

Figure 6-2. WETT-G Coliforms after Disinfections

(Blue colonies are e. coli and Red is all other coliforms)

Total Dissolved Solids and Hardness Results Discussion

TDS was reduced by an average of 22.6% from individual samples, but the influent TDS was never outside of the performance objective.

Hardness was reduced by an average of 13% from individual samples, but the influent was never outside of the performance objective.

Chlorine Residual Results Discussion

The TRU Habitat does not add chlorine into the treated effluent. Additionally, chlorine evaporates out of water over time, decreasing the chlorine residual and disinfection effectiveness. To meet the reuse standards, chlorine levels would need to be continually monitored and added into the treated effluent while it is being stored.

Table 6-2. WETT-S Blackwater Treatment Results

Treated Effluent Characteristic	Performance Objective		Units	WTI Influent (Average)	WTI Effluent (Average)	WTI Effluent (Max)	Pass/ Fail
	Avg.	Max					
Kitchen Blackwater							
e. Coli	Absence		CFU/ 100 mL	0	0	0	Pass
Total Coliform	Absence		CFU/ 100 mL	400	0	0	Pass
TSS - Lab	< 50	100	mg/L	1000	N/A	N/A	Fail
pH	N/A			5.30	7.01	6.63 – 7.44	N/A
COD – Field Test	N/A		mg/L	7,999	4,295.25	6,338	N/A
BOD – Estimated from COD	N/A		mg/L	4,078	2,190	3,231	N/A
Turbidity	N/A		NTU	1,158	259.9	410	N/A
Toilet Trailer Sewage*							
e. Coli	Absence		CFU/ 100mL	Uncountable	>15,000	>15,000	Fail
Total Coliform	Absence		CFU/ 100mL	Uncountable	51,250	51,250	Fail
TSS – Lab	< 50	100	mg/L	290	N/A	N/A	Fail
pH	N/A			7.48	7.55	7.55	N/A
COD – Field Test	N/A		mg/L	500	542	542	N/A
BOD – Estimated from COD	N/A		mg/L	255	276.3	276	N/A
Turbidity	N/A		NTU	68.6	3.57	3.57	N/A

*Note that the toilet trailer wastewater field tests are the treatment results using an influent mixture that was diluted with a 1:3 blackwater to treated graywater ratio. The lab sample was not diluted.

e. Coli/Total Coliform Discussion

Coliform testing for blackwater was limited. For the kitchen blackwater, the influent sample showed no e. coli, but did show a relatively small amount of total coliforms. The low coliform counts could be a result of the low pH of the kitchen wastewater due to presence of concentrated sports drink and coffee. After treatment with the WETT-S, no coliforms were identified in the effluent, demonstrating that the electro-oxidation process utilized by the WETT-S may provide adequate disinfection to meet the performance objective for coliforms; however, limited data means that this result is based on only a single influent and single effluent kitchen water sample and future work would be needed to fully validate this result. In the toilet trailer samples, the influent and effluent had to be heavily diluted to be countable. E. coli appeared at a 1:50 dilution ratio with 2mL of blackwater per 100mL sample, showing much more than the 300 colonies per plate for a valid test (thus >15,000 colonies per 100mL). Total coliforms were estimated using a dilution ratio of 1:500 with 0.2 mL of blackwater per 100mL sample. Overall the WETT-S did not meet the e. coli and total coliform performance objectives after treatment.

Total Suspended Solids Discussion

The WETT-S had several difficulties and issues during setup and operation when trying to treat the highly concentrated kitchen water and toilet trailer sewage. As a result, the team was unable to provide lab samples on the limited days that samples were sent to the lab for analysis. Thus there are no total suspended solids results for the treated blackwater effluent from the WETT-S. Additionally, the enzyme additive present in the toilet trailer water broke down many of the long molecules that the WETT-S relies on to effectively remove contaminates during the electrocoagulation process, limiting the separation and removal of solids during treatment. This will be considered a failure to meet the performance objective during this demonstration and future work could prioritize collecting more sufficient WETT-S data.

pH Discussion

pH was not a performance objective for the WETT-S but field test data was recorded. The field kitchen wastewater had very low pH, likely as a result of excess fruit juice and coffee. Caustic soda was added into the influent to raise the pH closer to neutral. The toilet trailer pH was relatively unchanged and remained about neutral.

COD/BOD Discussion

COD and BOD were not performance objectives for the WETT-S, but field test data was recorded. COD tests were performed for most of the samples and the BOD can be calculated using a conversion factor of about that was established from the influent blackwater lab COD and BOD test. The WETT-S reduced both COD and BOD in the kitchen wastewater by 25% after treatment, but the effluent still showed very high COD/BOD loading as a result of the high influent parameters. The toilet trailer sewage showed no change in COD/BOD as the green enzyme additive prevented effective treatment, even with dilution of the influent using treated graywater from the WETT-G.

Turbidity Discussion

Turbidity was not a performance objective for the WETT-S, but field data was able to be recorded. The WETT-S was able to reduce the turbidity in both the kitchen wastewater and the toilet trailer sewage. The kitchen water turbidity was reduced by 74% and the diluted toilet trailer water was reduced by 95%.

Table 3-2 and Table 3-3 reference different water quality criteria that needs to be met to reuse treated non-potable water. These use cases include laundry water, dust suppression, toilet flushing, vehicle washing, construction use, and firefighting. The following section describes which parameters the WETT system met, and which ones it did not meet. In order to be approved for reuse, all parameters must be met.

Laundry Wash Water:

- Pass: pH (6.5-8.5)
- Fail: Coliforms, Chlorine, BOD/COD, TSS, Turbidity

Dust Suppression

- Pass: pH (6.5-8.5), Total Nitrogen (10 mg/L mean), TSS (30 mg/L), Turbidity (15 NTU)
- Fail: Coliforms, Chlorine, BOD/COD (BOD was close to passing)

Toilet Flushing

- Pass: pH (6.5-8.5), Total Nitrogen (10 mg/L mean), TDS (1000 mg/L)
- Fail: Coliforms, Chlorine, BOD/COD, TSS, Turbidity

Vehicle Washing

- Pass: Total Nitrogen (10 mg/L mean)
- Fail: Coliforms, Turbidity

Industrial Use (construction)

- Pass: Total Nitrogen (10 mg/L mean)
- Fail: Coliforms (e. coli only required)

Firefighting

- Pass: Total Nitrogen (10 mg/L mean)
- Fail: Coliforms, BOD/COD, Turbidity
- Note: Chlorine requires different standard (disinfection not residual). Likely not met

6.4 Water Recovery

The amount of wastewater collected and processed was cataloged and reported. This included water captured from the blackwater and graywater streams, and water recovered from solid waste using the MAGS system. Treated effluent water quality data is cross referenced against the reuse criteria in Table 3-2 (ANSI 350) and Table 3-3 (TB MED 577). The amount of water recovered for reuse or safe discharge is calculated by comparing the TRU Habitat liquid influent streams and the amount of water treated for reuse and/or safe discharge. Due to pending sampling results and concentration issues with the WETT-S influent, no treated blackwater was approved for discharge for the WETT-S system.

WETT-G

- 10,514 gallons of graywater was treated
- No treated amount of effluent met reuse standards
- 0% recovery

WETT-S

- 3,355 gallons of kitchen blackwater was treated
- 1,294 gallons of toilet trailer water was treated
- No treated amount of effluent met reuse standards

- 0% recovery

No treated graywater or blackwater met reuse standards or was approved for reuse. This did not meet the performance objective of at least 60% treated water is available for reuse.

6.5 Thermal Energy Production

The thermal energy was removed by cooling fans on the MAGS during WTI, but could be captured and used for other applications such as shower and laundry water heating. The detailed graph (Figure 6-3) below shows the calculated thermal energy that was removed by the cooling fans and is displayed to demonstrate how the output fluctuates based on the type of waste loaded into MAGS. In general, a higher water content of input waste leads to lower thermal energy outputs and vice versa. This graph validates that a production output >100 kWh/h was achieved to meet the performance objective.

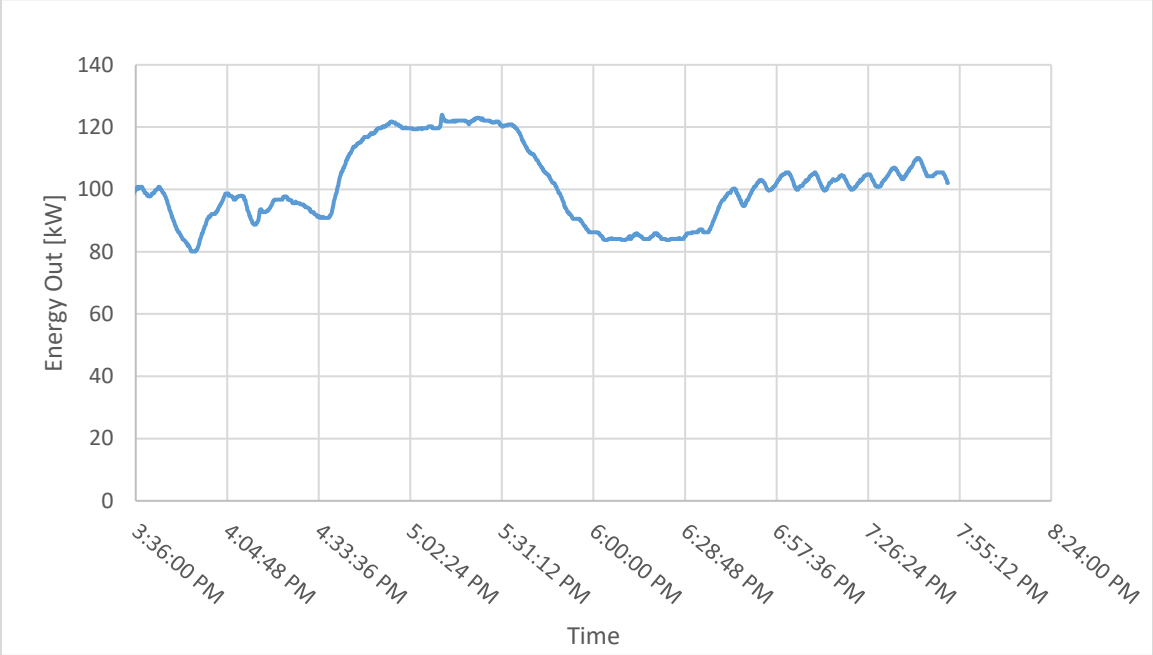

Figure 6-3. MAGS Thermal Energy Removal 3-28-2021

Table 6-3 displays the thermal energy output of MAGS on a daily basis during WTI. Operational time is when MAGS is processing solid waste and excludes start-up, heating, gas check, and cooling times. The daily power recovery varies based on the composition of solid waste treated during the day. In general, MAGS performs best with a semi-constant stream of input waste versus an idle scenario which requires supplemental heat (diesel fuel), or cooling then reheating the gasification chamber. If a constant stream is not available at camp, then the team recommends running MAGS every other day, or when a sufficient solid waste stream is available to be processed.

Table 6-3. MAGS Daily Thermal Energy Output Summary

Date	Start Time	End Time	Operational Time (hrs.)	Avg. Power Recovered (HP)	Avg. Power Recovered (kW)	Avg. Recovered (kWh)
12-Mar-21	10:33:15	21:00:15	10.45	19	14	148
13-Mar-21	12:00:30	18:17:10	6.28	63	47	295
14-Mar-21	14:24:20	16:56:45	2.54	87	65	165
15-Mar-21	13:27:55	18:32:45	5.08	78	58	296
17-Mar-21	14:04:50	18:32:45	4.47	78	58	260
18-Mar-21	14:04:50	19:12:10	5.12	85	63	325
19-Mar-21	12:33:30	15:00:20	2.45	88	66	161
20-Mar-21	12:35:05	20:16:25	7.69	136	101	780
21-Mar-21	13:21:40	20:16:25	6.91	107	80	552
22-Mar-21	13:51:10	20:16:25	6.42	102	76	488
24-Mar-21	12:50:40	20:16:25	7.43	89	66	493
25-Mar-21	14:16:15	19:35:50	5.33	87	65	346
28-Mar-21	13:53:50	19:51:35	5.96	126	94	560
29-Mar-21	13:29:25	20:16:25	6.78	130	97	658
30-Mar-21	13:37:20	19:42:20	6.08	131	98	594
Average			**5.93**	**93.73**	**69.90**	**407.91**

6.6 Energy Use

The total fuel consumption of the site for waste processing consisted of fuel used for transportation of raw materials (fresh water) to the site, and export of solid and liquid waste from the exercise/FOB. The energy cost of fuel for waste water and solid waste disposal from the demonstration site was calculated from the MWSS 371 data sheet from WTI. The amount of fuel saved by the system was compared to the amount of water processed and the fuel used to transport this via transport vehicles. Fuel usage for transportation of wastewater and solid waste was estimated by using a multiplication factor of 1.5 for blackwater and 0.5 for solid waste against the calculated cost for transporting fresh water to WTI for laundry and shower water.

The amount of solid waste processed by MAGS and liquid waste processed by the WETT system was calculated and then referenced against the energy consumption of each system. Power meters and data loggers were installed on each system to record the amount of power required to operate the system during the demonstration. MAGS uses supplemental fuel to maintain internal gasification chamber temperature when solid waste is not available for processing. This fuel value was incorporated into the total energy use of MAGS. MAGS generates thermal heat, which was calculated and would be subtracted from the overall energy use during the demonstration if it was utilized on site. Table 3-7 summarizes the energy use of each system during the WTI exercise. Without using the thermal heat from MAGS, and reusing the treated WETT effluent, the TRU Habitat consumes 196.2 kWh/m^3 of input waste. WTI uses approximately 16.9 kWh/m^3 to process

solid and liquid waste streams. If the TRU Habitat system reused its output streams onsite, it would actually produce energy (Table 3-8) due to the MAGS thermal energy output.

Based on data received from MWSS 371, the camp consumed 15,998 gallons of fuel and 134,800 gallons of water during the four weeks the TRU Habitat system was on-site. This resulted in a total of 269 gallons of fuel spent on the transit of 7 fuel resupply trips and 50 water resupply trips. If the camp reused WETT effluent water for non-potable uses, this would reduce the water delivered to camp by 15,163 gallons and reduce the number of water resupply trips by 6, with a fuel savings of 26.7 gallons. If the camp reused the waste heat produced by MAGS to heat shower water, this would reduce fuel consumption by 204.8 gallons. However, the TRU Habitat did not meet the performance objective goal of reducing baseline WTI fuel consumption by >50% when in operation. Although the system did not meet the performance objective, there are huge manpower and force protection benefits of reducing resupply trips into a FOB that the TRU Habitat is capable of providing. During the four-week demonstration, the TRU Habitat system would have reduced resupply trips by 10.5% if the effluent water was reused and been able to heat shower water if the MAGS thermal energy output was route to the M80 water heaters.

Figure 6-4. Fuel Resupply (Background) and Water Resupply (Foreground)

6.7 Transportability

The TRU Habitat component units were delivered in four 8’ x 8’ Tricon containers to Naval Base Ventura County, Port Hueneme. The WETT-S and WETT-G units each fit in a single respective Tricon, and the MAGS unit requires 2 Tricons. These units were transported by flatbed truck to the WTI event without difficulty and were staged by the Marines on site. The 10 ton forklift (Figure 6-5) on-site did not have difficulty transporting and maneuvering the Tricons, including aligning and positioning the MAGS units that required close proximity to each other and proper alignment for the required hose connections between the two halves of the system. Maneuvering larger 20’ containers in the desert environment was required during the exercise for various pieces of ground support equipment. These larger containers challenged the Marines, considering the sandy conditions of the training event, but the smaller 8’ x 8’ shipping containers were much easier to

move and position. This environment, as well as other terrains such as jungle or snow, lends itself to the lighter, more maneuverable 8' Tricons wherever possible. The modularity of the TRU Habitat works well in this respect and met the transportability performance objective.

Figure 6-5. Marines Positioning TRU Habitat Tricons at WTI

6.8 Payback Period

The payback period for this system (detailed in Section 7) was calculated from the potential cost savings from the contracted disposal of the solid and wastewater streams from the WTI event. Based on these cost of the system and the costs of the waste disposal costs, a payback period of 112 years was calculated for the 4-week testing at the Spring 2021 WTI. However, the payback period of future implementation will involve the combined savings of wastewater and solid waste stream reduction, air heating fuel savings, and fresh water resupply fuel costs for direct costs, as well as force protection and logistical benefits, offsetting the systems initial capital investment and transportation of the complete system. These additional cost savings offer a 10.6 year payback period for running the TRU Habitat system at WTI's two annual events. The third ROI scenario is for continuous use for 8 hours per day, 7 days per week, and 48 weeks per year. This scenario also involves processing blackwater for non-potable reuse, using the MAGS thermal energy output to power air heaters, and has a payback period of 1.36 years. The payback period performance objective for a payback of <12 months was not met for the three scenarios.

6.9 Ease of Use

As mentioned in Section 3.9, the project was originally scoped for multiple field demonstration, however the scope of the project was greatly reduced and therefore only one four-week long demonstration was carried out. Two thirds of this ESTCP project occurred during the COVID-19 pandemic, in which DoD and international travel bans greatly impacted planned demonstrations. Due to these circumstances, the team does not feel that the TRU Habitats' ease of use was fully demonstrated during the project. This performance objective can be properly assessed with an additional demonstration for a longer time period.

7 COST ASSESSMENT

7.1 Cost Model

The cost model of this system and demonstration compares the benefits of the TRU Habitat directly to the costs that would have been incurred had the waste processed through the system been disposed of by conventional means. This implies all solid waste processed through the MAGS would have been treated as conventional waste and disposed of by delivery to the local landfill. It also implies that all wastewater, graywater and blackwater, would normally be disposed of via pump truck and, in the field, tanker truck transport and open pit burning. The TRU Habitat is comprised of COTS units (MAGS, WETT-G, and WETT-S), all available from Terragon Environmental for procurement. The price of these units can be broken down individually, but the overall cost of the complete system is provided in Table 7-1.

The initial capital investment for the TRU Habitat was $659,692.

Table 7-1. Total Costs Incurred for Demonstration of TRU Habitat

Direct Environmental Activity Process Costs		
Start-Up		**Source**
Activity	$0 for demonstration	
Equipment Purchase	$659,692	NAVFAC EXWC Contracting
Design Drawings, FAT Testing, Commissioning	$29,741	NAVFAC EXWC Contracting
Site Specific Drawings	$4,265	NAVFAC EXWC Contracting
Installation	$27,760	NAVFAC EXWC Contracting
Training of Operators	$0 for demonstration	
Operation & Maintenance		**Source**
Activity	$0 for demonstration	
Labor to Operate Equipment	15min/MAGS load, 15min WETT load cycle	WTI Demonstration observation
Labor to Manage Hazardous Waste	$0 for demonstration	
Utilities	$2,392	Power Meter Data
Management and Treatment of By-products	$0 for demonstration	
Hazardous Waste Disposal Fees	$0 for demonstration	
Process Chemicals and Nutrients	$4,500	NAVFAC EXWC Purchasing for Demo
Consumables and Supplies	$36,202	NAVFAC EXWC Contracting
Equipment Maintenance	$0 for demonstration	
Training of Operators	$0 for demonstration	

Indirect Environmental		
Activity Costs		**Source**
Activity	$0 for demonstration	
Compliance audits	$0 for demonstration	
Document maintenance	$0 for demonstration	
Environmental Management Plan development and maintenance	$0 for demonstration	
Reporting requirements	$0 for demonstration	
Test and analyze waste streams	$2,150	Fresh Terra Laboratory
Waste transportation (on and off site)	$103,000	2021 WTI Contract for Servicing of Water Bladders and Kitchen Containers
ESOH training	$0 for demonstration	

7.2 Cost Analysis and Comparison

7.2.1 Solid Waste Reduction

During the demonstration, the MAGS processed 3,125.8 lbs. of waste, including food waste, solid waste, and filters from the TRU Habitat. The overall reduction of waste was calculated to be 94.3% by weight. The disposable bio char totaled 178.26 lbs., with only 0.74% moisture content. This quantity can be directly translated into a reduction of the amount of waste transported, loaded into containers, and cost of disposal for the onsite trash generated at WTI.

The alternatives to the MAGS process of gasification are landfilling, incineration, and physical removal. Landfilling waste in the theatre of operations is not a viable option, and can be a costly one in established locations. Incinerations is an alternative method of disposal, but the process of constructing a full scale (not portable) incinerator is a great capital cost. MAGS provides the benefits of an incinerator, without the infrastructure and capital cost, and avoids open pit burning.

7.2.2 Liquid Waste Reduction

The amount of graywater processed by the WETT-G was 10,514 gallons. This water, while typically released into settling ponds for disposal, was instead processed by the WETT-G with the intent of reuse for other non-potable purposes (Table 3-1 3.4). The amount of blackwater processed by the WETT-S was 4,649 gallons. At WTI, blackwater has no treatment options and would require removal by a contracted waste disposal company. This wastewater, in established and forward bases, would be pumped to and from waste reservoirs then trucked to waste processing locations at the expense of labor, fuel, contracting costs, and logistical risk to supply channels for water transportation. Considering the reuse of the graywater and blackwater as, gallon per gallon, quantities of freshwater no longer needed via supply, constitutes a financial payback. This cost is difficult to quantify, based on the various locations where the TRU Habitat might be deployed. The quantity more easily calculated is the cost of fuel to transport fresh water to and blackwater away from a given location. The cost of fuel can be estimated, as per Table 3-9, and the fuel cost savings per tanker truck calculated from that.

7.2.3 Water Quality

During normal WTI training events, the graywater from showers, laundry, and handwashing stations is pumped into earthen pits for disposal, which was acceptable for the training event in Yuma, AZ. In other locations, this graywater may not be fit for discharge and require contracted removal. The blackwater from kitchen facilities and latrine units is normally pumped out into holding tanks (for kitchen facilities) and directly from latrine units. This waste water is then disposed of by contracted services. The cost for this contract during the Spring 2021 WTI event was $232,623 per government contract N6247321F4381 (USASpending.gov). This contract covered multiple WTI locations including AUX II in Yuma, AZ. Per conversations with the contracting officer representatives on these contracts, the WTI event held at AUX II had a wastewater disposal cost of $27,144 for the Spring 2022 event.

During the demonstration, all graywater treated by the system was tested and then pumped into the same earthen pits as the excess graywater streams. No additional cost was incurred.

The blackwater stream from the kitchen facilities was treated by the system and stored in holding tanks, then pumped out by the same contracting services the training event was using for chemical toilet pump-out services. No additional cost was incurred.

The additional cost incurred by the rental of the portable toilet trailer was $6,585. This cost was necessary due to the nature of the chemical additives to the wastewater of the on-site chemical toilets. This cost was added on to the demonstration to show how the WETT-S handles highly concentrated human sewage water. It is not a necessary cost for implementing the TRU Habitat system, and is excluded from the overall system cost.

Laboratory testing for the wastewater samples was $2,250 for the duration of the exercise. This cost would likely be competitively bid in a long term contract for the service life of the TRU Habitat as installed in a location where commercial laboratory services are available. For the four week demonstration, the testing required from a professional laboratory, extrapolated to a full year, comes to $29,250. With a reasonable accommodation of 10% increase for unforeseen fees and additional costs, a yearly cost of $32,175 is likely the minimum costs for laboratory services required to ensure the water quality testing for this system could be expected. However, for full implementation of the TRU Habitat, this level of testing is not considered necessary (unless required by regulators at the location), and is excluded from the payback period of the system.

7.2.4 Water Recovery

The amount of wastewater processed during the demonstration was 15,163 gallons. This constitutes 10,514 gallons from the WETT-G unit, 4,649 gallons from the WETT-S unit. MAGS and the dewatering unit produce a small amount of water, which is processed in the WETT-S. This amount of water is negligible and not included in the total gallons treated. It should be noted that the amount of water processed during the demonstration was less than the amount of full production capability of the TRU Habitat.

The quantity of water treated constitutes a reduction in water shipment to the facility. For the WTI event, the cost of fresh water resupply was calculated based on the amount of water recorded for laundry and hygiene (showers). This cost came to $3,159 in fuel costs for the 2021 WTI. The

payback for the TRU Habitat was calculated based on 2023 fuel costs and came to $4,065 per event.

For an established facility, the transportation of fresh potable water does not have the hazards present in field or theatre environments. The reuse and recycling of wastewater has an operation security benefit (human life and convoy safety) that, while obvious, was not appropriate for this demonstration.

7.2.5 Thermal Energy Production

The thermal energy produced by the MAGS unit was not utilized for energy recovery, although the data was captured and calculated during this demonstration, as shown previously in Figure 6-3. When captured, thermal energy can be used to heat water or air in established or forward operating situations. Thermal energy capture can be used with heat exchangers to heat air in hangar, tents, or living spaces, and to heat water for various use cases, including laundry, shower, hygiene, and dining facilities.

A contributor to the payback of the TRU Habitat is the capture of the waste heat energy from the MAGS exhaust. This waste heat was analyzed by the Air Force Institute of Technology (AFIT) as part of a master's degree study, and compares the heating requirements for shower water, heated by a high efficiency diesel powered water heater (Polar BEAR 130K field space heater), using the MAGS rejected heat in place of burning diesel fuel. There are savings in fuel costs by heating water using the MAGS system's integrated water to water heat exchanger. This was not observed at WTI due to logistical integration issues preventing the hook-up and use of the heat exchanger. The thermal output from the MAGS was assumed to be able to raise water from 20 C to 50 C, making it available to transfer waste heat to the cold incoming shower water. Excess residual heat from fans could also be used for space heating in field tents. Using these examples, the payback of these energy capture methods will significantly and positively affect the payback period of future implementations of the TRU Habitat. At the WTI demonstration, no heat capture was performed.

7.2.6 Energy Use

The cost of energy use of the demonstration, for the purposes of baselining and performing a cost comparison, was not calculable for the disposal of solid waste, via trucking away trash dumpsters, nor for disposal of waste water, by pumping and trucking away via pump truck. These values were incorporated into the solid and liquid waste disposal contracts for the WTI event.

7.2.7 Transportability

The TRU Habitat subsystem component units were delivered in four 8' x 8' Tricons to Naval Base Ventura County, Port Hueneme. These units were transported from Port Hueneme to Yuma by flatbed truck to the WTI event for $1,250.

7.2.8 Payback Period

Table 7-2 shows the total fixed cost for the TRU Habitat, acceptance testing, commissioning, installation, and training. The capital cost of the TRU Habitat and one set of spare parts/consumables is $695,894.

Table 7-2. TRU Habitat Demonstration Costs

Unit	Cost (USD)
MAGS	$301,199
WETT-G	$161,944
WETT-S	$196,549
Dewatering Unit and Consumables	$36,202
Acceptance testing, drawings, and commissioning	$29,741
Site specific drawings	$4,265
Installation	$27,760
Training	$8,500
Total	$766,160

The recurring costs for the WTI demonstration are presented in Table 7-3 below. These costs reflect a single WTI event to conduct this ESTCP demonstration and validation project for this system. The costs are not necessary to operate and run the TRU Habitat during normal operation.

Table 7-3. WTI Demonstration Recurring TRU Demonstration Costs

Annual Expenses	Cost (USD)
Toilet Trailer	$6,855
Laboratory supplies and consumables	$6,576
Laboratory testing	$2,250
Total	$15,681

The payback **for the Spring 2021 WTI event**, with initial and recurring laboratory analysis costs, rented flush toilet trailer cost, and a specified percentage of the event's waste processed by the TRU Habitat, is shown in Table 7-4 below. However, this payback period will change in a real operating environment versus this four week ESTCP project demonstration. The solid waste cost savings of the MAGS and WETT systems was calculated based on an estimate of the contracted cost of waste pickup/disposal and the assumed percentage of waste that cannot be processed by MAGS (metals, glass, and large wood pieces). The 60% process efficiency of the kitchen waste water is based on the observed WTI kitchen waste water having high concentrations of oil and grease, and a much lower pH than anticipated.

Table 7-4. Spring 2021 WTI Four-Week Demonstration Payback Period

Payback Period	**Cost (USD)**
Cost for WTI Demonstration	$766,160
Exercise Recurring costs	$15,681
Cost savings	**Cost (USD)**
Solid waste (80% MAGS processed, 4 week demo only)	$13,407
Kitchen Water (60% WETT processed 4 week demo only)	$8,143
Blackwater (0% WETT processed 4 week demo only)	$0
Freshwater fuel (60% reduction)	$948
Total Saving per WTI event	$22,498
Payback Period	112.4 years

The arguments for the cost savings are based on the extrapolation of the assumed percentage of the waste treated by the TRU Habitat, versus the quantity of waste treated at the WTI event. These assumptions include:

- No treatment of toilet trailer wastewater, which was not possible during the WTI event due to the incompatibility of the chemical treatment in the on-site chemical toilets.
- An 80% reduction in contracted solid waste removal, as the vast amount of solid waste from the camp was able to be processed by MAGS. Solid waste treatable by the MAGS unit would be reduced by the demonstrated 94%.
- A 60% reduction in kitchen wastewater, resulting in 60% reduction in contracted removal of blackwater away from the WTI event.
- A 60% reduction in fuel for fresh water would be a direct result of using WETT treated graywater for laundry, vehicle washing, dust suppression, or hand washing station (non-potable) reuse (using 2023 commercial cost of fuel).

Cost benefits not realized during the WTI Event include:

- Cost of fuel for transportation of wastewater from FOB base to remote location (incorporated in WTI contract cost)
- Cost of disposal of graywater that is not permissible to discharge to ground (no cost at WTI but possible at other demonstration sites)
- Risk of hostile environment convoy transportation when not in CONUS
- Cost of water and fuel for transportation of water for non-potable usage (dust suppression, vehicle washing).

The demonstration of the TRU Habitat at the Spring 2021 WTI exercise gave the system a chance to demonstrate its capabilities in a near-operational environment. With the assumptions discussed above, the payback period of the demonstrated system was calculated in Table 7-4 to be 112 years when used at the Yuma WTI event.

Transition of the TRU Habitat to future WTI events, the calculated ROI in Table 7-5 was 10.6 years. WTI runs twice annually for two eight-week periods in the Spring and Fall.

Table 7-5. Payback Period for Two WTI Events per Year

Payback Period	**Cost (USD)**
Cost for TRU Habitat (System only)	$766,160
Recurring Consumables Cost (Excluding lab analysis)	$16,344
Annual Fuel Costs	$9,439
Cost Savings	**Cost (USD)**
Solid Waste (80% MAGS processed)	$53,627
Kitchen Water (60% WETT processed)	$32,573
Blackwater (0% WETT processed)	$0
Freshwater Fuel (60% reduction)	$4,878
MAGS Heat Energy Recovery	$6,762
Total Annual Savings	$97,840
Payback Period	10.6 years

For any future transition of the TRU Habitat to alternative installation, FOB, or exercises, Table 7-6 shows a revised payback period of 1.36 years. This payback involves an environment where the operation of the TRU Habitat would be 8 hours per day, 7 days a week. Operation of the system would encompass 48 weeks, approximating six eight-week WTI event periods. An additional consideration is the treatment of non-kitchen blackwater, which the cost value is based on the contract cost for latrine waste removal during the Spring 2022 WTI event. This contract cost, divided over the three installations covered by the WTI event, and scaled to approximately 50% treatability of the actual waste stream, came to a yearly cost savings of $307,822, and is included in the Total Annual Savings in Table 7-6.

Table 7-6. Payback Period for 48-Week Operation

Payback Period	**Cost (USD)**
Cost for TRU Habitat (System only)	$766,160
Recurring Consumables Cost (Excluding lab analysis)	$21,609
Annual Fuel Costs	$28,317
Cost Savings	**Cost (USD)**
Solid Waste (80% MAGS processed)	$160,882
Kitchen Water (60% WETT processed)	$97,718
Blackwater (50% WETT processed)	$307,822
Freshwater Fuel (60% reduction)	$14,635
MAGS Heat Energy Recovery	$32,905
Total Annual Savings	$613,962
Payback Period	1.36 years

This value is close to meeting the proposed <1 year payback period offered in the technology description. The assumptions made for this last scenario were not the exact conditions found at the Spring 2021 WTI event at AUX II. These conditions could be achieved after slight improvements and implementation of the lessons learned from the demonstration period. The proposed payback period was not met for a host of reasons explained previously, and the performance of this system, and its economic viability, would be better demonstrated with further testing and refinement, both at field demonstrations like the WTI Event, and in more established locations within the DoD.

One major influence on the payback period of this system was the short duration during which the TRU Habitat was used. Using the assumed contract costs, fuel usage, consumable use and initial capital cost, the calculated payback period changed from 112 years to a more reasonable 10.6 years, assuming two WTI events held per year. Included in the recurring costs are the additional fuel costs inherent with running the MAGS and WETT systems as well as the capture of the MAGS waste heat for water heating as part of the TRU Habitat.

Extrapolated over the course of 48 weeks versus two 8-10 week events, and assuming use of the system for 8 hours per day, 7 days per week, the short calculation comes to a payback period of 1.36 years. However, these assumed costs are likely much different. Contracting disposal costs would likely be cheaper over a longer time period, and fuel costs would likely vary considerably. Consumable costs associated with the components of the TRU Habitat (WETT and MAGS systems) are shown in Table 7-7 and Table 7-8, respectively.

Table 7-7. WETT System Consumables Cost Information

Part Name	Terragon P/N	Units	Unit Cost	Total Cost
EC Cartridge O-Ring	TER_HIT_ECORING_LARGE	2	$ 4.59	$9.18
EC Cartridge Springs	TER_ACX_ECSPRINGS_LARGE	12	$18.07	$216.86
1/2" Solenoid Valve	PVAL-412-04PIP03-S2	1	$652.52	$652.52
3/4" Solenoid Valve	PVAL-412-06PIP04-S2	1	$652.52	$652.52
1/2" Motorized Ball Valve	PVAL-112-04PIP02-S2	1	$404.46	$404.46
1" Motorized Ball Valve	PVAL-112-08PIP02-S2	1	$539.28	$539.28
P400 Repair Kit	TER_MCM_2620-1103.REP	1	$118.01	$118.01
Pressure Transmitter	PURC-200-0300008-AA	1	$585.34	$585.34
Pressure Transmitter	PURC-200-0300022-AA	1	$136.03	$136.03
Pressure Transmitter	PURC-200-0300020-AA	1	$136.03	$136.03
Temperature Transmitter	PURC-200-0300026-AA	1	$99.62	$99.62
Flow Switch	PURC-200-03000007-AA	1	$206.11	$206.11
Interface Level Sensor	PURC-200-0700001-AA	1	$531.00	$531.00
Ventilation Blower	TER_FIS_VENTFAN	1	$78.01	$78.01
EC Motor Retaining Rings	TER_MCM_91590A133	1	$15.98	$15.98
Metal Miter Gear	TER_MCM_3560N16	1	$209.39	$209.39
Vibrating Level Switch	TER_BUR_00563555	1	$314.52	$314.52
			Total (USD)	$4,904.87

Table 7-8. MAGS System Consumables Information

Part Name	Terragon P/N	Units	Unit Cost	Total Cost
Char Bucket	TER_CAR_08W95N	6	$10.38	$62.28
Char Bucket Lid	TER_CAR_08W29L	6	$9.90	$59.40
V8 Electrodes	PURC-900-0001009-AA	2	$40.98	$81.96
Diesel Filter Cartridge RF-1	PURC-900-0000021-AA-(01)	1	$5.11	$5.11
Process Water Discharge Filter	PURC-900-0000020-AA	4	$567.00	$2,268.00
Compressed Air Particulate Filter	PURC-200-1200011-AA-(01)	1	$10.73	$10.73
Process Air Replacement Filter	PURC-900-0001020-AA-(01)	2	$19.25	$38.50
Polyester Felt Filter Bag	TER_FLP_PE5P12S	100	$7.04	$704.00
Sanitary Clamp PTFE Gasket	TER_MCM_43315K29	2	$34.63	$69.26
Sanitary Clamp Gasket	PTUB-921-16S0000-P9	2	$4.32	$8.64
Sanitary Gasket, Silicon, 3" Tube	C40S - 3" Tube OD	5	$6.29	$31.44
Filter Housing O-Ring	TER_MCM_9452K396	2	$12.10	$24.20
Pipe Flange Silicone Gasket - 1"	PURC-340-0101001-AA	2	$3.34	$6.67
Charbox O-Ring	TER_CHAR_ORING	2	$20.97	$41.95
Inflatable Silicon Door Seal	PURC-900-0000137-AA	2	$225.00	$450.00
Inflatable Silicon Gate Seal	DR247_M0800-02GG3-C1-00	6	$243.00	$1,458.00
18-8 Stainless Steel Hex Screws	TER_MCM_92210A198	1	$14.11	$14.11
Spray Nozzle	PURC-900-0000055	6	$12.07	$72.43
Oxygen Sensor	PURC-200-1300001-AA	1	$557.28	$557.28
pH Probe	PURC-200-0200004-AA	1	$201.35	$201.35
pH Probe Holder	TER_BUK_00561476	1	$492.18	$492.18
ASCO Subminiature Solenoid Valves	TER_ASC_SC8356A002V-24VDC	2	$56.02	$112.04
K Type Thermocouple, M12	PURC-200-1100002-AA	6	$82.50	$495.00
Gould 2HP Replacement Impeller	TER_LIQ_2K1202	2	$283.19	$566.38
Gould Pump Rebuild Kit	TER_LIQ_RPKNPE-1ST1E5D4	2	$116.65	$233.31
Spray Nozzle	TER_MCM_3282K416	6	$112.28	$673.66
Sliding Gate Support	TER_GATE_SUPPORT	1	$540.00	$540.00
6 - 60 SCFM Rotameter 1" FNPT	TER_MCM_ROT60	1	$199.04	$199.04
4 - 40 SCFM Rotameter 1" FNPT	TER_MCM_ROT40	1	$199.04	$199.04
Durablanket 2300 (Sq. Ft. Price)	TER_FIB_218230	50	$2.30	$115.00
			Total (USD)	$9,790.96

8 IMPLEMENTATION ISSUES

The TRU Habitat performance objectives highlight how this system performs in the field. Not all of the performance objectives were met, showing room for improvement and implementation of lessons learned. However, the team demonstrated that the TRU Habitat is a valuable asset for FOB solid and liquid waste treatment. The system is most applicable for generator run remote operations that need to limit resupplies, conserve water, and cannot readily dispose of generated waste. DoD applications include USMC and US Army camps, as well as remote humanitarian assistance. Ultimate acceptable of this system lies at the program level, such as the US Army Force Sustainment Systems (FSS), Product Manager LTC Daniel J. O'Neill. This system also has potential to be integrated in the Army's Force Provider Expeditionary kit due to its containerization and waste treatment capabilities. The NAVFAC EXWC Expeditionary Program Office (ExPO) expressed interest in using this system based on existing customer needs. The project team has briefed the ExPO Expeditionary Basing branch lead on the TRU system.

The USMC responsibilities are split between procurement and requirements. The Marines' Expeditionary Energy Office within Capabilities Development and Integration (CD&I) is responsible for requirements related to this program. Procurement responsibility lies within Marine Corps Systems Command, Program Manager Engineer Systems (PMES). Two teams within PMES share responsibility for the overlapping capabilities of TRU Habitat: Family of Expeditionary Water Systems group is responsible for water and the Power Team for the waste-to-energy capability. Together the Requirements and Procurement responsible officers judge the suitability and acceptability of the system for adoption.

8.1 Performance Objectives

Section 3 and 6 both highlight the demonstration's performance objectives. Certain performance objectives were not met, but can be achieved with additional steps that would not impact the technologies transition potential.

8.1.1 Water Quality

Section 6.3 describes each of the parameters analyzed for the WETT-G and WETT-S in depth. Overall, the team faced a reduced time period and budget that greatly affected the amount of water quality sampling performed on the system. On-site time was limited to half the demonstration period for the EXWC team, leaving Terragon personnel on site with the main objective of running the TRU habitat versus conducting water quality sampling. Terragon flew their Vice President of Engineering to the demonstration to fine tune the WETT-S/WETT-G and conduct sampling to mitigate this issue.

The influent and effluent water for the WETT systems was not consistent in nature and field conditions impacted results. Kitchen staff emptied large amounts of concentrated single waste streams (ex. coffee, sports drinks/powders, grease, etc.) which filled the influent tanks for WETT-S. This inundated the WETT-S and can be mitigated with mixing these highly concentrated streams with dishwashing water, or graywater sources. The high winds added sand particles into the effluent samples during transit to the field laboratory, leading to higher TSS and turbidity levels.

The wastewater totes would often sit in direct sunlight for days at a time for varying causes such as waiting to collect enough wastewater to run a batch through the system, waiting for other waste streams to finish processing, or due to fine tuning and operating challenges as seen in the WETT-S. This would cause the water to become septic and start breaking down, reducing the treatment efficiency of the WETT-S/WETT-G. To mitigate this, graywater streams were combined to decrease collection time, and blackwater streams could be diluted with graywater to aid with treatment and increase processing speed. Avoiding the disposal of large amounts of grease in the kitchen wastewater would further help WETT-S processing time and treatment efficiency.

To fully mitigate these impacts, the team recommends dedicating a single staff member to perform water quality analysis during the demonstration which would increase data accuracy and the number of analyses performed. In addition, using larger collection totes and incorporating graywater into highly concentrated blackwater streams would improve the performance of WETT-S.

8.1.2 Water Recovery

The main reason this performance objective was not met was due to the chemical additive in the rented toilet trailer. The team specifically requested a toilet trailer rental without any chemical additives and a clean tank. WETT-S was not able to process any sewage water from the toilet trailer, which reduced the TRU Habitats overall water recovery. Also, the water quality impacts noted above led to graywater effluent that did not meet the reuse standards. To mitigate these loses, the team recommends treating sewage from an establish restroom facility or a flush toilet trailer that does not include chemicals (Figure 8-1).

Figure 8-1. Green Chemical Additive Found in Toilet Trailer Holding Tank

8.1.3 Energy Use

The principal reason the TRU Habitat demonstration did not meet the energy use performance objective was due to lack of output reuse. MAGS thermal output heat can supply power to M80 water heaters for heating the showers, or to supply heated air to tents. This capability was not demonstrated during the 4-week period, but data from MAGS show how energy it is capable of producing. If the treated WETT effluent met water quality standards for reuse, then this water could be used on site and offset the amount of fresh water supplied to the location. Implementing the methods identified in Section 8.1.1 would lead to an increase of reusable water. For future use cases, these outputs can be used on site to save fuel and fresh water, and meet the energy use performance objective.

8.1.4 Payback Period

The team calculated payback periods for multiple scenarios including the actual 4-week WTI demonstration, annual WTI exercises, and year-round operation. The best payback period for the system was calculated at 1.36 years. This makes the following assumptions: similar capital cost of the unit EXWC procured, similar waste disposal contracts from previous WTI events, reduced cost of these contracts based on the predicted waste reduction from the event (estimated percentage reduction), an assumed cost for consumable materials based on the manufacturer's estimates, and a recurring 8 week-long event expanded to continuous year-round use.

The worst-case scenario for payback on this system was 112 years, assuming: similar capital costs for the system, the assumed reduction in waste from the WTI event as mentioned above, and a 4-week long use of the system for waste reduction. The worst of these scenarios does not make full use of the system (blackwater removal/reduction) or full use of waste heat recovery (hot water and hot air generation), while the best case does. These additional cost savings shorten the payback period to within the proposed timeframe. The more the system is run, the lower the use of fuel for waste disposal and transportation. Additionally, the less fuel used for heating of water, or air, as the environment demands. Less use of contracted labor and increased expertise by military personnel represents one more avenue of cost savings. Finally, reduced use of burn pits for solid waste disposal and reduced fuel and water convoy transportation is a savings of health and life of service members in the field.

8.1.5 Ease of Use

The original RDT&E effort was scope for multiple demonstrations. Due to exercise changes at 29 Palms and COVID-19 travel restrictions, the team was limited to a 4-week demonstration at WTI in Yuma, AZ. This period was not sufficient to fully evaluate the ease of use for the system. System commissioning took longer than anticipated, so on-site Marines were not trained how to operate the system on their own. The team used the short demonstration period to ensure the whole TRU Habitat system was up and running and perform analytical sampling.

8.2 Implementation Impacts

Currently there are no known environmental or worker safety regulations that would impact implementing the TRU Habitat. Prior to demonstration, ADEQ deemed the unit was acceptable to

operate without a permit due to its low emissions from MAGS. Emissions are expected to meet future regulations as well, and the unit is a safe alternative to open burn pits. For the WETT portion of TRU, the process does not involve harsh chemicals or produce highly concentrated waste streams that require additional handling requirements. The units work together to produce clean char from solid waste, and clean non-potable water from the WETT-G and WETT-S units.

8.3 Design and Proprietary Information

The TRU Habitat was designed and built for this ESTCP project. The four Tricons were custom made to operate in a DoD setting. The demonstration unit is located at NAVFAC EXWC in Port Hueneme, CA and is currently available for use. Future units can be procured through Terragon. These units can be custom tailored for different operating climates (ex. incorporation of insulation for arctic environments) and modular in nature to accommodate larger operations. Terragon has protected the intellectual property of both MAGS and WETT, through two international patents for each technology. All patents are assigned to Terragon's wholly owned subsidiary, Proterrgo Inc. The two patents for MAGS describe the auto gasification process and also a unique control strategy that enables MAGS to optimize fuel efficiency while maintaining extremely low environmental emissions. WETT is protected by two patents describing the innovative process, with special emphasis on the unique design of the EC reactor.

8.4 Transition

The original demonstration location was set for MCAGCC 29 Palms, but changed to MCAS Yuma during the project life. NAVFAC EXWC has continued conversations and briefs to 29 Palms to keep them informed on the project. 29 Palms still remains as a potential end-user for this product due to their remote training exercises. NAVFAC EXWC has also engaged internally with the Expeditionary Programs Office, specifically the Expeditionary Basing Engineering Branch Manager as they are looking into graywater and blackwater treatment options.

An Acquisition Guidance document is included with this report in Appendix F. This document serves as a fact sheet, demonstration summary, and procurement guide for the TRU Habitat. Interested agencies and offices can utilize this document to learn more about the project and technology, as well as to guide their procurement of the system for use.

9 REFERENCES

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10 APPENDICES

Appendix A: Points of Contact

Point of Contact			Role in Project
James Pilkington	NAVFAC EXWC 1000 23rd Avenue Port Hueneme, CA 93043	805-982-1335 James.Pilkington@navy.mil	PI
Gene Griffin	NAVFAC EXWC 1000 23rd Avenue Port Hueneme, CA 93043	805-982-2267 Gene.griffin@navy.mil	Co-PI
Hunter Klein	NAVFAC EXWC 1000 23rd Avenue Port Hueneme, CA 93043	805-982-4839 hunter.w.klein@navy.mil	Project Engineer
Russ Emons	Sustained Turn Corporation	858-863-6667 Russ.emons@sustainedturn.com	Contractor
Theodora Alexakis	Terragon Corporation	Theodora.alexakis@terragon.net	Contractor
Ramona Pristavita	Terragon Corporation	Ramona.pristavita@terragon.net	Contractor
LtCol Paul Barron	MAWTS-1	928-269-7300 paul.r.barron@usmc.mil	AUX II Support
GySgt Dallas Mason	MWSS-371	910-376-5686 dallas.mason@usmc.mil	AUX II Support
William Barr	Arizona Department of Environmental Quality	602-771-0149 barr.william@azdeq.gov	Regulator

Appendix B: Health and Safety Plan

1. INTRODUCTION

This plan has been prepared to ensure the safety of workers during the Weapons and Tactics Instructors (WTI) course in Yuma, Arizona in conjunction with Marine Corps Air Station (MCAS) Yuma. The event will take place for eight (8) weeks from March 23, 2021, and will involve two personnel from Naval Facilities Engineering and Expeditionary Warfare Center (EXWC) and one contractor from Sustained Turn Corporation, Inc. The team consists of Gene Griffin (Project Lead), Hunter Klein (Project Engineer), and Russ Emons (Sustained Turn Corporation). This plan provides an overview of the project, describes roles and responsibilities, and identifies potential hazards and steps to minimize them.

2. HEALTH AND SAFETY POLICY

Worker safety is of paramount importance. Every effort will be taken while on site to ensure a safe work environment. The purpose of this plan is to identify and eliminate potential health and safety risk, including engineering and administrative controls and use of appropriate Personnel Protective Equipment (PPE). This plan was written to be consistent with OPNAVINST 5100.23G, Navy Safety and Occupational Health (SOH) Program Manual.

3. SITE LOCATION

The assessments will take place at the Marine Corps Air Station Yuma Auxiliary Airfield II (Aux II) during the Weapons and Tactics Instructors (WTI) course hosted by Marine Aviation Weapons and Tactics Squadron - One, in Yuma, AZ.

4. PROJECT DESCRIPTION

During the demonstration, the project team will be operating and monitoring the Total Resource Utilization (TRU) Habitat. This system will be processing solid and liquid waste from the WTI event. Solid waste will be comprised of trash, refuse, and other materials which would normally be collected in waste bins or dumpsters and transported to a municipal waste facility. Liquid waste will be graywater and blackwater streams coming from the training event. Graywater will come from laundry facilities, showers, and handwashing stations. Blackwater will come from dining facilities and from latrine wastewater. Treated graywater and shower blackwater will be discharged in the same manner as the event would typically discharge waste water during normal operations. Solid waste byproducts (char) will be disposed of with other typical solid waste for the event. Latrine water will be collected from a mobile latrine trailer, which will be provided by EXWC for the purposes of this demonstration. Solid waste and water sampling will occur at specific predetermined times throughout the event and these samples will be tested both on-site and sent to a local laboratory for analysis. During the demonstration, the team will operate the TRU Habitat, recording performance measurements, and address issues/troubleshoot the system. At the conclusion of the WTI event, the system will be purged, shut down, closed, sealed, and shipped back to NAVFAC EXWC.

5. RESPONSIBILITY AND LINES OF AUTHORITY

EXWC is executing the assessment and is responsible for safety at the work site. The individual workers will be responsible for ensuring they follow all safety protocols and have the appropriate PPE supplied or accessible to them. The on-site safety manager will be responsible for checking that all personnel are following proper safety procedures and wearing appropriate PPE while at the work site. The safety manager will handle all on-site safety meetings. The project manager will be responsible for any mishap reporting.

6. SAFETY MEETINGS

The safety manager will conduct safety plan review meetings at the beginning of each day to address the following and answer any questions or concerns from team members:

- Recognition of safety issues
- Prevention of unsafe conditions
- Notification of onsite emergencies

The meeting will also cover site specific hazards, the use of PPE, and any other issues. Any subsequent safety issues that are brought to the knowledge of the safety manager will be addressed prior to the start of the work day or as necessary.

7. HAZARD ANALYSIS

The following hazard analysis is based on the tasks that personnel will perform and site conditions that might be encountered. Specific tasks will be the following:

- Handling/lifting of refuse and loading into MAGS unit
- Discharging waste char from MAGS unit
- Connection of waste water influent/effluent wastewater lines
- Handling of wastewater samples
- Working near/around elevated temperature air/water lines
- Collecting data from various component systems (MAGS/WETT) with ground water and power lines

Potential hazards include handling of waste products (solids waste bags, trash receptacles and bins, bags), connection and disconnection of wastewater lines, collection of influent and effluent waste water samples, collection of waste char from MAGS unit, and working around elevated heat exchanger units with water and air connections. Potential hazards at the site might include tripping hazards, fall hazards, exposure to weather conditions (sun, rain), potential biological hazards (wildlife, insects, etc.), and exposure to elevated noise levels (operating equipment, adjacent machinery, etc.) This section provides details on the site-specific conditions that will be encountered at the WTI training event and provides details on the elimination or minimization of hazards to personal safety.

Each hazard is ranked by a Risk Assessment Code (RAC). The RAC is a quantitative number that represents the potential health effects based on the subjective measurements of the mishap probability and hazard severity. The RAC is a number (1-5) representing the risk posed by each hazard and is used to determine abatement priorities. The RAC numbers represent the following:

1. Critical
2. Serious
3. Moderate
4. Minor
5. Negligible

7.1. Hazardous Material / Hazardous Waste / Medical Waste (RAC 3)

Hazardous Materials (HM) are expected to be encountered in the form of waste collected from the TRU Habitat for sampling.

- One source will be blackwater from field dining facilities (DFACs) and latrines. HM will be handled with appropriate PPE, including rubber gloves, coveralls, masks, goggles, and appropriate footwear. Good laboratory procedures will be followed for the collection of samples, elimination of spills, and clean-up of incidental mishaps.
- Graywater sampling is not generally considered hazardous material, but appropriate PPE will also be worn in the same fashion as during blackwater sampling.
- Handling of char from the discharge of the MAGS unit is not considered hazardous, but may be at elevated temperatures and must be treated as harmful if at high temperatures. This waste will then not be handled until it has cooled to close to ambient temperatures. It will then be discarded with other typical solid waste generated by the training event.

If other hazardous material is encountered during the demonstration, a determination will be made as to the potential hazard to worker safety and the environment. If the material poses a greater risk to worker safety or to the environment, work will cease and the personnel will leave the area. Work will continue once appropriate remedial action is taken by environmental office personnel.

7.2. Exposure (RAC 4)

Work outside will expose EXWC personnel to various conditions found in nature including heat, cold and precipitation. Heat and sunshine is expected at the WTI event during the demonstration. Personnel are responsible for their personal clothing being appropriate for the prevailing weather conditions, including hats, sunscreen, and long sleeve shirts and pants. Cold weather during evening hours will also necessitate appropriate cooler weather clothing.

7.3. Sharp Objects (RAC 5)

There is a medium to low degree of probability that sharp edges will be encountered during the demonstration. To protect the body from this hazard, personnel will be aware and cautious of surroundings in interior and exterior spaces, and look for protruding objects on the ground, walls

and ceiling. Before work begins, the team will locate the first aid kit and contact information for medical emergency personnel.

7.4. Flying Objects (RAC 5)

While the TRU Habitat will be operating during demonstration, surrounding operations of the WTI event will be ongoing. However, due to the non-elevated nature of the system, the potential for objects to fall from overhead is unlikely.

7.5. Trip / Fall (RAC 4)

The working surface will generally be dirt and soil, which can create a tripping hazard when uneven. However, this is unlikely. The main working area will be dry and outdoors, but with water hoses and power cables on the ground. This could potentially lead to a trip or fall, so care and self-awareness should be maintained at all time when walking around the demonstration site. This is especially true when collecting or handling waste samples, as this is a cause for distraction and could lead to trip of a fall. The weather will be assessed for precipitation, however, this is unlikely to occur. Personnel will wear work boots with good tread to mitigate trip or slip hazards.

7.6. Heavy Lifting (RAC 4)

Employees will be expected to be able to lift solid waste (trash/refuse bags or containers) to load the MAGS system. It is not expected that personnel will be required to lift weights over 50 lbs. All employees should be trained in the proper ergonomics of lifting, holding the object close to the body, bending at the knees, and lifting with the legs. Heavier objects should be moved with the help of a co-worker or a lifting aid device.

7.7. Motor Vehicle Traffic (RAC 4)

All personnel will be required to wear a high visibility traffic vest, if required, and should be cognizant of the equipment in their vicinity. When in an area in which heavy equipment is being operated, maintain clear line of sight with the operator and establish communication through hand signals.

7.8. Biological (RAC 4)

Potential biological hazards at the demonstration site will include desert wildlife in the form of insects, arachnids, reptiles and wild mammals. Within the perimeter of the exercise, most if not all large animal life will be negligible. Mosquito threat is negligible due to the hot arid environment. Workers shall not deliberately kill any mammal or reptile that does not pose an immediate danger.

7.9. Noise (RAC 4)

Noise levels in the work area are not expected to reach or exceed 84 decibel (dBa) sound level. However, due to the proximately to generators and operational systems, proper hearing

protection shall be worn in close proximity to any generators of motorized equipment, and any other areas in which the noise exceeds limits or if deemed appropriate by the safety manager.

7.10. Explosives, Munitions, and Unexploded Ordnance (UXO) (RAC 5)

It is highly unlikely that personnel might encounter energetic material, due to the nature of operations on training event. However, if this occurs, the material is to be left untouched, and all personnel will be notified for evacuation of the area. Security will be immediately notified.

7.11. Dust or Inhalation Hazard (RAC 4)

Dusty conditions may be encountered in the work area, as the discharge of the solid waste unit (MAGS) will be operated. Nuisance dust may be generated while releasing the solids from the discharge side of the unit, and also if any cleaning of the system is required. Dust masks will be worn during these events.

7.12. Electrical Hazard (RAC 5)

All electrical connections to the TRU Habitat system and any generators will be handled by qualified training event personnel. Terragon or Sustained Turn personnel will also be allowed to operate any electrical systems of the TRU Habitat system itself. Any changes or connections to on-site generators will be coordinated with training event personnel. All electrical information will be obtained from gauges on the individual system components, and from the gauges on the on-site generators.

8. PERSONAL PROTECTIVE EQUIPMENT

Workers will have access to or will be provided with PPE and wear when necessary, at a minimum, the following while working:

- Rubber gloves
- Goggles
- Aprons
- Dust masks
- Steel toed boots
- Hearing protection
- Hard hats

The following is on-site safety equipment that will be provided or be accessible:

- First Aid Kit

9. POINTS OF CONTACT

Project Points of Contact (POC) include the following:

ADT&E Department Head	LtCol Paul R Barron	928-269-7300
WTI Event CWO In-charge	CWO2 Adam James	adam.james@usmc.mil

Branch Head	Mark Patterson	(805) 982-1530
Division Head	Thomas Webb	(805) 982-2574

10. EMERGENCY RESPONSE PLANNING AND CONTINGENCY OPERATIONS

For severe injury or incapacitation that requires immediate medical attention, call 911 (base clinic) for emergency response.

11. ACCIDENT REPORTING

Initial reporting of an accident will be to the safety manager on site. Appropriate notification of MCAS Yuma safety manager and EXWC personnel (supervisor / safety manager) will be made by the project manager with no delays. Any appropriate follow-up will be the responsibility of the EXWC personnel and their immediate supervisor.

Appendix C: ANSI and TB MED Testing Criteria

Table C-10-1. Excerpt from TB MED 577 Regarding Graywater Quality – Laundry and Shower Recycling

Constituent	Acceptable Range or Maximum Allowable Limit	Unit
pH	5 – 9	-
Turbidity	1	NTU
Hardness	500	mg/L
TDS	1500	mg/L
Coliforms	Absent	Detection
FAC Chlorine Residual	1	mg/L after 30 min

Table C-10-2. Excerpt from ANSI 350-2018 Effluent Criteria

Measurement	Class R (Residential Output)		Class C (Commercial Output)		Units of Measure
	Test Average	Single Sample Max	Test Average	Single Sample Max	
$CBOD_5$	10	25	10	25	(mg/L)
TSS	10	30	10	30	(mg/L)
Turbidity	5	10	2	5	(NTU)
E. Coli[1]	14	240	2.2	200	(MPN/100mL)
pH	6.0 – 9.0	N/A	6.0 – 9.0	N/A	(SU)
Storage Vessel Disinfection	≥0.5 – ≤2.5	N/A	≥0.5 – ≤2.5	N/A	(mg/l)[2]
Color	MR	N/A	MR	N/A	
Odor	Non-Offensive	N/A	Non-Offensive	N/A	
Oily Film and Foam	ND	ND	ND	ND	
Energy Consumption	MR	N/A	MR	N/A	

N/A: Not Applicable
ND: Non-Detectable
MR: Measured and Reported Only

1 Calculated as geometric mean
2 See sections 8.6.2.6 or 8.6.3.6 in ANSI 350-2018

Table C-10-3. ANSI 350-2018 Influent Water (Base Water Supply)

Parameter	Required Range	Units
Hardness	100 – 220	mg/l
Alkalinity	> 40	mg/l as CaCO3

Table 10-4. ANSI 350-2018 Influent Water (Bathing Source Water)

Parameter	Required Range	Individual Sample Max	Units
TSS	50 – 100	—	mg/l
BOD_5	100 – 200	—	mg/l
Temperature	25 – 35	—	°C
pH	6.0 – 8.5	—	
Turbidity	30 – 70	—	NTU
Total Phosphorus – P	1.0 – 4.0	—	mg/l
Total Kjeldahl Nitrogen – N	3.0 – 5.0	—	mg/l
COD	200 – 400	—	mg/l
Total Coliforms (30 day geometric mean)	10^3 – 10^7	10^9	cfu/100ml
E. coli (30 day geometric mean)	10^2 – 10^6	10^7	cfu/100ml

Table C-10-5. ANSI 350-2018 Influent Water (Laundry Source Water)

Parameter	Required Range	Individual Sample Max	Units
TSS	50 – 100	—	mg/l
BOD_5	220 – 370	—	mg/l
temperature	25 – 35	—	°C
pH	6.0 – 8.5	—	
Turbidity	50 – 90	—	NTU
Total Phosphorus - P	< 2	—	mg/l
Total Kjeldahl Nitrogen - N	4.0 – 6.0	—	mg/l
COD	300 – 500	—	mg/l
Total Coliforms (30 day geometric mean)	10^3 – 10^7	10^9	cfu/100ml
E. coli (30 day geometric mean)	10^2 – 10^6	10^7	cfu/100ml

Table C-10-6. ANSI 350-2018 Influent Water (Bathing and Laundry Source Water Combined)

Parameter	Required Range	Individual Sample Max	Units
TSS	50 – 160	—	mg/l
BOD5	130 – 210	—	mg/l
Temperature	25 – 35	—	°C
pH	6.0 – 8.5	—	
Turbidity	30 – 100	—	NTU
Total Phosphorus - P	1.0 – 3.0	—	mg/l
Total Kjeldahl Nitrogen - N	3.0 – 5.0	—	mg/l

COD	250 – 400	—	mg/l
Total Coliforms (30 day geometric mean)	10^3 – 10^7	10^9	cfu/100ml
E. coli (30 day geometric mean)	10^2 – 10^6	10^7	cfu/100ml

Appendix D: WETT System Test Results

Form # 1029

TERRAGON
Technologies de l'environnement inc.
Environmental Technologies Inc.

CERTIFICATE OF CONFORMITY

Certificate number: CC00011

Product type: WETT-G 6.5

Product serial number: WETT-G6.5-0011

Manufacturer: *Terragon Environmental Technologies Inc.*
651 Rue Bridge, Montréal, QC, Canada, H3K 2C8

This certificate attests that the above product met Terragon quality insurance standards and treatment performance under the following conditions according to Terragon Conformity Test instructions for a specific product.

System main components:

- ☐ Lamella Plate Separator (LPS)
- ☒ Electro Coagulation (EC)
- ☒ Bead Filter (BF)
- ☐ Electro Oxidation (EO)
- ☒ Other, specify: Granulated Activated Carbon

Type of wastewater:

- ☐ Oily water
- ☐ Blackwater
- ☒ Greywater
- ☐ Blackwater and Greywater
- ☐ Other, specify:

Operating conditions:

Nominal hydraulic loading: 5 L/min Conductivity: 0.2 - 15 mS/cm

EC unit current: 5 - 100 A EC unit voltage: 10 - 100 V

EO unit current: A EO unit voltage: V

Temperature: 5 - 55 °C pH: 6 -8

Treatment efficiency:

Parameter	Influent	Effluent	Removal %
☒ COD	ppm	ppm	60-70%
☐ BOD	ppm	ppm	
☒ TSS	ppm	ppm	>90%
☐ Oil and Grease	ppm	ppm	
☐ Fecal Coliforms	cfu/100ml	cfu/100ml	
☐ Total Residual Chlorine	ppm	ppm	
☐ Total Phosphorus	ppm	ppm	
☐ Total Nitrogen	ppm	ppm	
☐ Other, specify:	ppm	ppm	

Signature:	
Authorized person and title: Director of Product Development	Date: August 13th, 2020

Factory Acceptance Test

WETT Serial Number	WETT-G 6.5-0011
Test Location	Montreal, Canada
Date	August 12, 2020
Start Time	9:00
End Time	14:00
Stakeholders present	Terragon

☐ WETT has been accepted – no non-conformity has been identified

☑ WETT has been accepted – with comments

Factory Acceptance Test has been completed:

	Terragon Representative	Client Representative
Name	Alex Sokaris	
Signature		
Date	August 12, 2020	

Scope of Factory Acceptance Test

The following Factory Acceptance Test Plan identifies the test and inspection activities to be undertaken in order to demonstrate the functionality of the newly commissioned WETT unit before delivery to client.

Time	Item
8:00 – 8:30	Equipment start-up
8:30 – 9:00	Equipment mechanical inspection
9:00 – 11:00	WETT operation: treatment of specific wastewater
11:00 – 12:00	Wrap up meeting – discussion of any outstanding issues

Test Procedure

Wastewater type: *specific to the WETT system tested*

Wastewater will be prepared according to specific recipe. The unit will be fed with specific wastewater for 3 hours. The machine will demonstrate its ability to adequately treat the wastewater being fed.

Item	Description	Conforms? (Y/N)
1	Equipment conforms to P&ID: *Check all components and assembly is complete as per the drawings.*	✓
	Comments:	
2	Appearance: *Visual inspection of weld quality, correct materials, and damage.*	✓
	Comments:	
3	Commissioning: *System has been fully commissioned in-house as per the Process Commissioning Checklist.*	✓
	Comments: See Process Commissioning Checklist for comments	

Form # 1029

TERRAGON
Technologies de l'environnement inc.
Environmental Technologies Inc.

CERTIFICATE OF CONFORMITY

Certificate number: CC00012

Product type: WETT-S 5.5

Product serial number: WETT-S5.5-0012

Manufacturer: *Terragon Environmental Technologies Inc.*
651 Rue Bridge, Montréal, QC, Canada, H3K 2C8

This certificate attests that the above product met Terragon quality insurance standards and treatment performance under the following conditions according to Terragon Conformity Test instructions for a specific product.

System main components:

- ☒ Lamella Plate Separator (LPS)
- ☒ Electro Coagulation (EC)
- ☐ Bead Filter (BF)
- ☒ Electro Oxidation (EO)
- ☐ Other, specify:

Type of wastewater:

- ☐ Oily water
- ☐ Blackwater
- ☐ Greywater
- ☒ Blackwater and Greywater
- ☐ Other, specify:

Operating conditions:

Nominal hydraulic loading: 5 L/min
Conductivity: 0.2 - 15 mS/cm
EC unit current: 5 - 150 A
EC unit voltage: 10 - 100 V
EO unit current: 5 - 30 A
EO unit voltage: 10 – 100 V
Temperature: 5 - 55 ºC
pH: 6 -8

Treatment efficiency:

Parameter	Influent	Effluent	Removal %
☒ COD	ppm	ppm	>90%
☒ BOD	ppm	ppm	>90%
☒ TSS	ppm	ppm	>90%
☐ Oil and Grease	ppm	ppm	
☒ Fecal Coliforms	cfu/100ml	cfu/100ml	>99%
☒ Total Residual Chlorine	ppm	ppm	<0.5
☒ Total Phosphorus	ppm	ppm	>90%
☒ Total Nitrogen	ppm	ppm	>90%
☐ Other, specify:	ppm	ppm	

Signature:	
Authorized person and title: Director of Product Development	Date: August 30th, 2020

Factory Acceptance Test

WETT Serial Number WETT-S 55-0012
Test Location Montreal, Canada
Date
Start Time 9:00
End Time 14:00
Stakeholders present Terragon

☒ WETT has been accepted – no non-conformity has been identified

☐ WETT has been accepted – with comments

Factory Acceptance Test has been completed:

	Terragon Representative	Client Representative
Name	Alex Sokaris	
Signature		
Date	08/26/2020	

Scope of Factory Acceptance Test

The following Factory Acceptance Test Plan identifies the test and inspection activities to be undertaken in order to demonstrate the functionality of the newly commissioned WETT unit before delivery to client.

Time	Item
8:00 – 8:30	Equipment start-up
8:30 – 9:00	Equipment mechanical inspection
9:00 – 11:00	WETT operation: treatment of specific wastewater
11:00 – 12:00	Wrap up meeting – discussion of any outstanding issues

Test Procedure

Wastewater type: *specific to the WETT system tested*

Wastewater will be prepared according to specific recipe. The unit will be fed with specific wastewater for 3 hours. The machine will demonstrate its ability to adequately treat the wastewater being fed.

Item	Description	Conforms? (Y/N)
1	Equipment conforms to P&ID: *Check all components and assembly is complete as per the drawings.*	Y
	Comments: Conforms to Rev 05 P&ID	
2	Appearance: *Visual inspection of weld quality, correct materials, and damage.*	Y
	Comments: N/A	
3	Commissioning: *System has been fully commissioned in-house as per the Process Commissioning Checklist.*	Y
	Comments: N/A	

Appendix E: MAGS System Test Results

A result of the air and water quality tests from the output of the MAGS system was provided by ConsulAir in a report dated December 2014. A summary of this report contains the following air emissions results:

- CO average discharge: 34mg/Rm3*
- Particulate Matter: 0,80mg/Rm3 using PM-ME method and 0.60mg/Rm3 using PM-HCL method
- HCL: <0.62mg/Rm3 HF: <0.028mg/Rm3
- Dioxin and furan: 0.0010ng/Rm3
- Mercury: 0.58µg/Rm3 using PM-ME method

*Cubic meter of air at the reference conditions of twenty-five (25) degrees Celsius and 101.325 kPa" (https://www.qp.alberta.ca/documents/codes/ENERGY.PDF)

TERRAGON
Technologies de l'environnement inc.
Environmental Technologies Inc.

CERTIFICATE OF CONFORMITY

Certificate number: 8.30-2019

Product type: MAGS V8

Product serial number: V8.00030

Manufacturer: *Terragon Environmental Technologies Inc.*
651 Rue Bridge, Montréal, QC, Canada, H3K 2C8

This certificate attests that the above MAGS product met Terragon quality assurance standards under the conditions and requirements presented in the *MAGS Assembly & Inspection Protocol, MAGS Electrical Assembly & Inspection Protocol* and the *MAGS V8 Commissioning Protocol, Decommissioning and packaging procedure*. This certificate also attests to the fact that the above MAGS product was tested for waste treatment capacity as delineated below:

Type of waste:

☑ Solid waste, specify: MARPOL, simulated dry waste

☑ Sludge waste, specify: used engine oil

☐ Other, specify: N/A

Operating conditions:

Solid waste loading: 1 week of treating, 60 bags

Sludge waste loading: 1 day of treatment

Treatment efficiency:

Parameter	Initial waste	Final waste	Reduction %
☐ Waste reduction	300 kg	15 kg	95

Energy recovery: ☐ N/A

Parameter	Value
☐ Energy recovery type	
☐ Energy recovery amount	

13/12/19

Stephan Lavigne, Ing. Date:

MAGS 8.30 Commissioning Report

Refer to commissioning checklist.

Process Commissioning

Cold Commissioning

Water flows were adjusted, no leaks were identified. Seal pressure was set to 27 psi to seal the chamber.

Side wall of gasifier bends when system enters or exits vacuum state. The system maintains structural integrity at all times. The sound created from the slight bending of the wall is noticeable.

Hot Commissioning

Diesel pressure was set to 100 psi. Safety interlocks were validated.

Combustion chamber heat-up validated. Gasifier heat up adequate.

Sludge injection and treatment was tested. Variable frequency drive adjusted to output 15 L/h. Compressed air feed was adjusted to 2 cfm.

Operational Commissioning

System treated 60 bags over several days. Emissions were measured, averaging below 30 ppm CO.

Factory Acceptance Test

System treated bags for a day, encountering no issues. Filter 1 was changed as part of normal operation.

Decommissioning

System was cleaned and drained. System was then purged with glycol to protect against freezing during shipment.

13/12/2019

Factory Acceptance Test

MAGS Serial Number	8.30
Test Location	Montreal, Canada
Date	11/12/2019
Start Time	9:00
End Time	14:00
Stakeholders present	Terragon

☑ MAGS has been accepted – no non-conformity has been identified

☐ MAGS has been accepted – with comments

Factory Acceptance Test has been completed:

	Terragon Representative	Client Representative
Name	Nicolas Njoo	N/A
Signature		N/A
Date	11/12/2019	N/A

Scope of Factory Acceptance Test

The following Factory Acceptance Test Plan identifies the test and inspection activities to be undertaken for the MAGS in order to demonstrate the functionality of the newly commissioned MAGS unit before delivery to client.

Time	Item
8:00 – 9:00	Equipment start-up and heating period
9:00 – 9:30	Equipment tour and inspection during heating period
9:30 – 12:00	MAGS operation: waste loading period and measurement of emissions
12:00 – 13:00	Break for lunch
13:00 – 14:00	Wrap up meeting – discussion of any outstanding issues

Test Procedure

Waste type: *Dry waste (paper, cardboard and plastic)*

Dry waste bags will be prepared. The unit will be loaded with bags continuously for a duration of up to 2.5 hours. The machine will demonstrate its ability to adequately handle the material stream being fed. Emissions will be tested for this material stream.

Item	Description	Conforms? (Y/N)
1	Equipment conforms to P&ID: *Check all components and assembly is complete as per the drawings.*	Y
	Comments:	
2	Appearance: *Visual inspection of weld quality, correct materials, and damage.*	Y
	Comments:	
3	Commissioning: *System has been fully commissioned in-house as per the Process Commissioning Checklist. Emissions measured during operation.*	Y
	Comments:	

Consul air MC

Échantillonnage de l'air
Conformité environnementale

CARACTÉRISATION DES ÉMISSIONS ATMOSPHÉRIQUES

SYSTEME DE GAZEIFICATION DE DECHETS (MAGS)

TERRAGON
Technologies de l'environnement inc.
Environmental Technologies Inc.

TERRAGON, LOCALISÉ À MONTRÉAL, QUÉBEC

A L'ATTENTION DE MADAME KAROLINA APLAND, M.ENV.

NOTRE RÉFÉRENCE : 3351

MESURE DE DECEMBRE 2014

REPORT SUMMARY
TRANSLATION

Rapport de caractérisation

QUÉBEC :
2022, Lavoisier, local 125, Québec (Québec) G1N 4L5
Téléphone : 418.650.5960
Télécopieur : 418.704.2221
Sans frais : 1.866.6969.AIR (247)

REPENTIGNY :
600, rue Leclerc, Repentigny (Québec) J6A 2E5
Téléphone : 450.654.8000
Télécopieur : 450.654.6730

SITE INTERNET : www.consul-air.com

TABLE 7-10 CONCENTRATION AND EMISSION OF METALS

TESTING SCHEDULE	
Date	03/12/14
Start time	12:52
End time	14:54
PARTICULATE MATTER	
Particulate matter (mg/m^{3}R)	0,80
Particulate matter (kg/g) (emissions)	0,00018
Particulate matter (g/s) (emissions)	0,000051
PARTICULATE METAL EMISSIONS (µg/Rm^3)	
Cadmium (Cd)	0,16
Mercury (Hg)	<0,017
Lead (Pb)	10,7
PARTICULATE METAL EMISSIONS (mg/h)	
Cadmium (Cd)	0,036
Mercury (Hg)	<0,0040
Lead (Pb)	2,4
TOTAL DETECTED	2,5
TOTAL	<2,5
GASEOUS METAL EMISSIONS (µg/Rm^3)	
Cadmium (Cd)	<0,017
Mercury (Hg)	0,58
Lead (Pb)	<0,17
TOTAL DETECTED	0,58
TOTAL	<0,77
GASEOUS METAL EMISSIONS (mg/h)	
Cadmium (Cd)	<0,0040
Mercury (Hg)	0,13
Lead (Pb)	<0,040
TOTAL DETECTED	0,13
TOTAL	<0,18
TOTAL METAL EMISSIONS (µg/Rm^3)	
Cadmium (Cd)	0,16
Mercury (Hg)	0,58
Lead (Pb)	3,7
TOTAL DETECTED	4,42
TOTAL	4,42
TOTAL METAL EMISSIONS (mg/h)	
Cadmium (Cd)	0,036
Mercury (Hg)	0,13
Lead (Pb)	0,84
TOTAL DETECTED	1,01
TOTAL	1,01
PARTICULATE METAL EMISSIONS VERSUS PARTICLES (%)	
Cadmium (Cd)	0,02%
Mercury (Hg)	0,002%
Lead (Pb)	1,3%

R : Reference Condition of 101.3 kPa and 25°C, dry basis

**Translated page 22 of "Rapport de caractérisation des émissions atmosphériques"*

TABLE 7-11 GASEOUS EMISSIONS AND CONCENTRATIONS – TEST 1

TESTING SCHEDULE	
Date	03/12/14
Start time	09:33
End time	12:33
OXYGEN (O_2)	
O_2 (mg/m^3R)	140 906
O_2 (%) dry – average	**10,8**
O_2 (%) dry – minimum	**4,4**
O_2 (%) dry – maximum	**16,1**
O_2 (kg/h)	31,3
O_2 (g/s)	8,7
CARBON DIOXIDE (CO_2)	
CO_2 (mg/m^3R)	139 177
CO_2 (%) dry – average	**7,73**
CO_2 (%) dry – minimum	**4,00**
CO_2 (%) dry – maximum	**13,05**
CO_2 (kg/h)	30,9
CO_2 (g/s)	8,6
CARBON MONOXIDE (CO)	
CO (mg/m^3R)	38
CO (ppm) dry – average	**34**
CO (ppm) dry – minimum	**2**
CO (ppm) dry – maximum	**1050**
CO (kg/h)	0,009
CO (g/s)	0,002
SULFUR DIOXIDE (SO_2)	
SO_2 (mg/m^3R)	<2,6
SO_2 (ppm) dry – average	**<1,0**
SO_2 (ppm) dry – minimum	**<1,0**
SO_2 (ppm) dry – maximum	**<1,0**
SO_2 (kg/h)	<0,00058
SO_2 (g/s)	<0,00016
NITROUS OXIDE as NO_2 EQUIVALENT	
NO_2 (mg/m^3R)	139
NO_2 (ppm) dry – average	74
NO_2 (ppm) dry – minimum	23
NO_2 (ppm) dry – maximum	207
NO_2 (kg/h)	0,031
NO_2 (g/s)	0,0086
TOTAL HYDROCARBON EMISSIONS (THC)	
THC C_3H_8 Equivalent (ppm wet) – average	**0,3**
THC C_3H_8 Equivalent (ppm wet) – minimum	**<0,1**
THC C_3H_8 Equivalent (ppm wet) – maximum	**1,8**
THC C_3H_8 Equivalent (ppm wet) at 7%O_2	0,4
THC C_3H_8 Equivalent (ppm dry) at 7%O_2	**0,4**
THC C_3H_8 Equivalent (ppm) dry	**0,3**
THC(mg/m^3R) dry	0,6
THC(kg/h)	0,00013
THC(g/s)	0,000035

R : Reference Condition of 101.3 kPa and 25°C, dry basis

**Translated page 23 of "Rapport de caractérisation des émissions atmosphériques"*

TABLE 7-12 GASEOUS EMISSIONS AND CONCENTRATIONS – TEST 2

TESTING SCHEDULE	
Date	03/12/14
Start time	12:52
End time	14:54
OXYGEN (O_2)	
O_2 (mg/m^3R)	139 216
O_2 (%) dry – average	**10,6**
O_2 (%) dry – minimum	**2,5**
O_2 (%) dry – maximum	**17,7**
O_2 (kg/h)	31,9
O_2 (g/s)	8,9
CARBON DIOXIDE (CO_2)	
CO_2 (mg/m^3R)	140 710
CO_2 (%) dry – average	**7,82**
CO_2 (%) dry – minimum	**3,74**
CO_2 (%) dry – maximum	**11,43**
CO_2 (kg/h)	32,2
CO_2 (g/s)	9,0
CARBON MONOXIDE (CO)	
CO (mg/m^3R)	28
CO (ppm) dry – average	**24**
CO (ppm) dry – minimum	**2**
CO (ppm) dry – maximum	**144**
CO (kg/h)	0,0064
CO (g/s)	0,0018
SULFUR DIOXIDE (SO_2)	
SO_2 (mg/m^3R)	<2,6
SO_2 (ppm) dry – average	**<1,0**
SO_2 (ppm) dry – minimum	**<1,0**
SO_2 (ppm) dry – maximum	**<1,0**
SO_2 (kg/h)	<0,00060
SO_2 (g/s)	<0,00017
NITROUS OXIDE as NO_2 EQUIVALENT	
NO_2 (mg/m^3R)	116
NO_2 (ppm) dry – average	62
NO_2 (ppm) dry – minimum	21
NO_2 (ppm) dry – maximum	158
NO_2 (kg/h)	0,027
NO_2 (g/s)	0,0074
TOTAL HYDROCARBON EMISSIONS (THC)	
THC C_3H_8 Equivalent (ppm wet) – average	**0,6**
THC C_3H_8 Equivalent (ppm wet) – minimum	**<0,1**
THC C_3H_8 Equivalent (ppm wet) – maximum	**2,5**
THC C_3H_8 Equivalent (ppm wet) at 7%O_2	0,8
THC C_3H_8 Equivalent (ppm dry) at 7%O_2	**0,8**
THC C_3H_8 Equivalent (ppm) dry	**0,6**
THC(mg/m^3R) dry	1,1
THC(kg/h)	0,00025
THC(g/s)	0,000069

R : Reference Condition of 101.3 kPa and 25°C, dry basis

**Translated page 24 of "Rapport de caractérisation des émissions atmosphériques"*

TABLE 7-13 GASEOUS EMISSIONS AND CONCENTRATIONS – TEST 3

TESTING SCHEDULE	
Date	03/12/14
Start time	15:22
End time	16:44
OXYGEN (O_2)	
O_2 (mg/m^3R)	139 955
O_2 (%) dry – average	**10,7**
O_2 (%) dry – minimum	**3,0**
O_2 (%) dry – maximum	**16,5**
O_2 (kg/h)	32,8
O_2 (g/s)	9,1
CARBON DIOXIDE (CO_2)	
CO_2 (mg/m^3R)	142 217
CO_2 (%) dry – average	**7,90**
CO_2 (%) dry – minimum	**5,07**
CO_2 (%) dry – maximum	**11,36**
CO_2 (kg/h)	33,3
CO_2 (g/s)	9,3
CARBON MONOXIDE (CO)	
CO (mg/m^3R)	36
CO (ppm) dry – average	**32**
CO (ppm) dry – minimum	**3**
CO (ppm) dry – maximum	**358**
CO (kg/h)	0,0085
CO (g/s)	0,0024
SULFUR DIOXIDE (SO_2)	
SO_2 (mg/m^3R)	<2,6
SO_2 (ppm) dry – average	**<1,0**
SO_2 (ppm) dry – minimum	**<1,0**
SO_2 (ppm) dry – maximum	**<1,0**
SO_2 (kg/h)	<0,00061
SO_2 (g/s)	<0,00017
NITROUS OXIDE as NO_2 EQUIVALENT	
NO_2 (mg/m^3R)	82
NO_2 (ppm) dry – average	**43,7**
NO_2 (ppm) dry – minimum	**25,0**
NO_2 (ppm) dry – maximum	**63,0**
NO_2 (kg/h)	0,02
NO_2 (g/s)	0,01
TOTAL HYDROCARBON EMISSIONS (THC)	
THC C_3H_8 Equivalent (ppm wet) – average	**<0,1**
THC C_3H_8 Equivalent (ppm wet) – minimum	**<0,1**
THC C_3H_8 Equivalent (ppm wet) – maximum	**0,3**
THC C_3H_8 Equivalent (ppm wet) at 7%O_2	<0,14
THC C_3H_8 Equivalent (ppm dry) at 7%O_2	**<0,14**
THC C_3H_8 Equivalent (ppm) dry	**<0,1**
THC(mg/m^3R) dry	<0,2
THC(kg/h)	<0,000043
THC(g/s)	<0,000012

R : Reference Condition of 101.3 kPa and 25°C, dry basis

**Translated page 25 of "Rapport de caractérisation des émissions atmosphériques"*

GAS

The average concentrations of CO measured for the three samples are 38, 28 and 36 mg/Rm^3 respectively for an average of 34 mg/Rm^3. This respects the norm of 57 mg/Rm^3 prescribed by article 103 of the RAA.

PARTICULATE MATTER

The concentration of particulate matter measured at the outlet of the scrubber using the PM-ME sampling train is 0,80 mg/Rm^3. Corrected to 11% oxygen, the concentration is 0,77 mg/Rm^3.

The concentration of particulate matter measured at the outlet of the scrubber using the PM-HCl sampling train is 0,60 mg/Rm^3. Corrected to 11% oxygen, the concentration is 0,58 mg/Rm^3.

These results respect the 20 mg/Rm^3 criteria from article 104 of the RAA.

ACIDS

The concentration of hydrochloric acid (HCl) measured at the outlet of the scrubber is <0,62 mg/Rm^3. Corrected to 11% oxygen, the concentration is <0,60 mg/Rm^3. These results respect the criteria of 50 mg/Rm^3 from article 104 of the RAA.

The measured concentration of hydrofluoric acid (HF) is <0,028 mg/Rm^3.

PCDD/DF

The dioxin and furan concentration corrected according to TEF (toxicity equivalence factor) is 0,0010 ng/Rm^3.

This respects the criteria of 0,080 ng/Rm^3 from article 104 of the RAA. These concentrations are corrected to 11% oxygen.

MERCURY

The concentration of mercury measured at the outlet of the scrubber for the PM-ME sampling train is 0,58 µg/Rm^3. Corrected to 11% oxygen, the concentration is 0,56 µg/Rm^3 which respects the norm of 20 µg/Rm^3 prescribed by particle 105 of the RAA.

CONCLUSION

According to the combined sampling methods and procedures using a rigorous quality control, the concentration results and/or emission rates presented in this report are valid and representative of normal sampling process conditions.

**Translated page 26 of "Rapport de caractérisation des émissions atmosphériques"*

Naval Facilities Engineering Systems Command

EXWC Engineering and Expeditionary Warfare Center

Acquisition Guidelines to Procure the Total Resource Utilization (TRU) Habitat Environmental Waste Management System

DEVELOPED BY

NAVAL FACILITIES ENGINEERING AND EXPEDITIONARY WARFARE CENTER

September 2022

F.1 Overview

This is an acquisition guideline step by step instruction to the procurement of the Total Resource Utilization (TRU) Habitat environmental waste management system. This document will go through the steps a Navy activity would need to address prior and during the procurement process, with links to various forms required for the procurement. Other Department of Defense (DoD) services may follow similar steps, but each will differ based on their respective service specific processes.

F.2 Activity Need and TRU Habitat Benefits

To begin, the activity needs to present the actual need and overall requirements for waste management/disposal and the intended benefit that the activity hopes to gain with the procurement of this system. For example:

- Activity X has a need to dispose of 1,000+ lbs. of solids waste material per week at a remote site.
- Removal of this waste has been problematic, with transportation of the waste from the remote site being the only solution that removes the waste while complying with health and safety regulations involving dumping of solid waste into earthen landfills. No incineration is available and burn pits pose a significant health and safety risk, and are therefore discouraged.
- Removal of 3,000 gallons of gray and blackwater from the site has also been problematic, with transportation of the liquid waste from the remote site being the only options of disposal, for the same reasons as described above for solid waste disposal. Disposal of graywater is possible via earthen leach ponds, but this may affect the fresh water wells in the immediate area. Blackwater must be either transported from the site or burned in diesel honey pots, which is discouraged.
- The activity as has force protection requirements to limit contractor site access. Reusing water and reducing solid waste is a priority.

Treatment of solid waste streams can result in the following benefits:

- Reduced solid waste transported away from the activity, heat capture for heating water (laundry and shower), heat capture for heating air (cold weather environmental heating), reduced hazardous emissions from smoke/particulates from open pit burning/incineration practices.

Treatment of waste water streams can result in the reuse of the effluent water for activities presently using potable water for activities including:

- For treated graywater: laundry, hand washing, vehicle washing, toilet flushing, dust suppression, irrigation, and shower (during contingency operations).
- For treated blackwater: latrine flushing, dust suppression, general irrigation (purple pipe).

These needs will drive the requirement for a system that will be able to handle the activity's requirements. The next step will be to conduct a solicitation for a system that will meet these needs.

F.3 Solicitation

Solicitation for a system that will meet the needs of the activity is the next step for the procurement of the system. EXWC acquired the TRU Habitat system by using the below path, which is the suggested path for the procurement of these systems. The TRU Habitat system has the following capabilities:

Solid Waste:

- Treatment (gasification) of solid waste up to 110 lbs./hour of mixed solid waste
- Solid waste reduction of 94% by mass
- Clean air emission exhaust that do not exceed 80°F at stack
- Initial diesel startup fuel requirement
- Self-sustaining gasification operation for an 8 hour minimum operating period per day
- Thermal energy production for hot water heat exchanger and air heating (100 kW output)

Liquid Waste:

- Electrical power (diesel generator) <2 kW per unit
- Treatment of 7.2 m^3/day (1,900 gpd)
- Effluent reject waste water stream of <10% of the influent water
- Up to 60% of the water used on base can be sent through the waste water system for treatment
- Effluent graywater can meet the NSF/ANSI 350 and TB MED 577 standards for recycling/reuse
- Effluent graywater can meet the local EPA NPDES discharge permit requirements

All component units of the solid and wastewater treatment system must be modular and containerized into a total of four (4) TRICONS, not exceeding 10,000 lbs. each.

F.4 Operations and Maintenance

Operation and training materials must be obtained for the specific systems. In this case, the Micro Auto-Gasification System (MAGS) and Wastewater Electrochemical Treatment Technology (WETT) systems have operations and maintenance manual, provided to EXWC. These manuals for the MAGS unit are linked in the followings files:

MAGS 8.0 - Operator's Manual	Double Click
MAGS 8.0 - Maintainer's Manual	Double Click
MAGS 8.0 - User's Manual	Double Click

The manuals for the WETT units are linked in the following files:

WETT-G Operator Manual	Double Click
WETT-S Operator Manual	Double Click

Specific training on the use and operation of the TRU Habitat system should be arranged and procured directly from the vendor.

F.5 Procurement

For the procurement of this system, different DoD component commands will have their own specific methods of soliciting for a bid, as it is unlikely that this system will be available through the more common procurement avenues in the DoD (GSA Advantage, DoD FedMall, etc.). The anticipated total cost of the TRU Habitat is estimated at $770,000.

For the demonstration of the system with NAVFAC EXWC, the TRU Habitat was selected via a Broad Agency Announcement (BAA) for a system that would address the Navy's need for a solid and liquid waste treatment system. This system had a set of specifications to meet and was selected based on the contractors bid.

For the purchase of the system itself, the BAA abstracts for the project conducted by NAVFAC EXWC can be found in the following links:

BAA Abstract Form - Terragon	Double Click

BAA Abstract Form - Sustained Turn Corp

For the Navy, NAVSUP is a potential avenue for the procurement of this system and its operations and maintenance components.

F.6 Performance

The system will operate in a field environment with diesel fuel and generator power provided by the local activity. Operation of the MAGS component will require a supply of diesel fuel for startup and for periods of low solid waste input. All systems will need to be connected to a generator for power. These systems are not energy intensive, so the size of the generator needed is <50 HP (observed at 13kW).

F.7 Regulations and Approvals

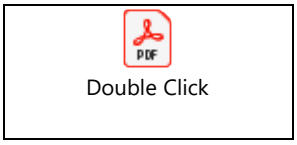
The use of the TRU Habitat in any environment may need approval from the local environmental governing body (i.e. EPA, Air Quality Board, etc.) and the appropriate government authority to install and operate in that area. Permitting is the chief concern as well as the subsequent environmental impact the system might have on the surrounding flora and fauna.

The site approval process, including explosive, small arms and airfield requirements, is given here:

Site Approval Process 11010.45(3)

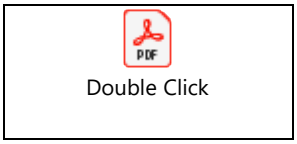
The NAVFAC Request for Project Site Approval is here:

NAVFAC 11010_31, Part I Request for Project Site Approval



The request for an Environmental Impact Review is given here:

Request for Environmental Impact Review



For air quality permitting, the Arizona Department of Environmental Quality (ADEQ) was contacted with the intension of gaining an approval to operate. The request was coupled by a document showing the output to the MAGS unit as compared to the Permit Exemption threshold values provided by ADEQ. That document provided to ADEQ is given here:

MAGS ADEQ Threshold Emissions Requirements

The approval of the MAGS for exemption from requiring an air permit during the Spring 2021 WTI event is given here:

ADEQ Site Approval for Spring 2021 WTI Demonstration

For the prospective discharge of water to ground versus collection and reuse, there are permitting issues that must be addressed. For the state of Arizona, the ADEQ Water Quality Division has a document that spells out the requirements for discharging water to earth or ephemeral waters.

An example of this permit is given here:

Arizona Pollutant Discharge Elimination System Permit

F.8 Additional Support

NAVFAC EXWC has successfully procured and demonstration this system and is available to assist with any additional questions you may have. Additionally they have a unit onsite in Port Hueneme, California that is available for interested parties to inspect and operation (with prior training). For more information on the system, please contact James Pilkington at james.t.pilkington.civ@us.navy.mil or (805) 982-1335.

Appendix G: Lessons Learned

During the project, the team identified multiple areas to improve the TRU Habitat system. These areas are documented throughout the report, but summarized in this Appendix. The demonstration at the Spring 2021 WTI proved to be a great test bed for this technology, and with more time on site, the team believes that more of the project performance objectives would be met. The following sections describes the lessons learned in detail.

G.1 Accurate Information on Waste Streams

Knowledge of the actual waste stream conditions and concentrations at the site will increase the performance of the TRU Habitat system, specifically the WETT units. At WTI, the team encountered highly concentrated waste streams of sports drinks, coffee, oil and grease, and other kitchen waste. Also, the kitchen staff did not utilize their oil water separator in the EFK. With knowledge of these conditions, the team would have mixed the highly concentrated blackwater with graywater from the shower or laundry facilities. By reducing the concentrations, the WETT-S would be able to treat the influent water down to acceptable reuse levels. For further demonstration efforts, it is recommended that the initial site visit include baseline sampling of all liquid waste streams that would enter the TRU Habitat.

G.2 Dedicated Water Quality Sampling Personnel

During WTI, Terragon had to fly out an additional person to conduct water quality sampling as their two other employees were occupied with commissioning the systems. Having a dedicated sampling person would increase data accuracy and influent stream descriptions. The team did not have capacity to conduct daily samples on all influent streams, effluent streams, and on each waste source. This information is key to the project success because it allows analysis of high concentrations and the ability to fine tune the WETT systems to increase their removal efficiencies. The team did have a dedicated lab setup inside a containerized living unit, but still experience difficulties gather and processing multiple samples per day. For future demonstrations, the teams recommends creating a larger sampling contract with a local accredited laboratory and having one staff member solely dedicated to water quality sampling.

G.3 Demonstration Duration

A longer demonstration period is required to account for field delays. The team planned for contingencies, but still fell short due to different situations that were out of our control. COVID-19 restricted travel to conduct the field demonstration, and international restrictions did not permit Terragon employees from returning to Canada without a work waiver. Additionally, there were other unexpected field conditions such as, sourcing a generator, procuring a new fuel tank to find it had a leak, MCAS Yuma fuel truck breaking down mid-route, and other logistical delays due to the remote site location. With additional funding, the team should have ran the TRU Habitat for the full eight week demonstration with a full staff. Multiple WTI demonstrations would also be beneficial to confirm results and implement previous lessons learned.

G.4 Utilizing MAGS Thermal Heat

The team did not route any thermal output heat from MAGS during the Spring 2021 WTI demonstration. The demonstration plan did not include this aspect, it only included measuring the output values. This waste heat could have been used in a heat exchanger to heat shower water on site. In colder climates, it can be used to heat interior spaces such as hangars or tents. Thermal heat reuse provides a positive impact on the systems ROI and provides a necessary resource to the site. Additional demonstration should include using the thermal heat from MAGS to assess its use cases at the demonstration location.