FINAL REPORT

Low Emission Thermal Processing of Munitions Constituents

ESTCP Project WP18-5038

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14. ABSTRACT

This ESTCP project demonstrated a new more cost- and process-efficient method to thermally decontaminate material potentially presenting an explosive hazard (MPPEH) that reduces emissions of $PM_{2.5}$, total carbon, black carbon and CO_2 compared to a legacy thermal decontamination unit that requires large amounts of wood dunnage as a heat source. The new MPPEH processing propane-fueled unit was designed and built by engineers at NAWCWD China Lake. The reduction in emissions of harmful pollutants over the wood-fired method was quantified using an emission sampler, which was developed by the U.S. Environmental Protection Agency, and attached to an unmanned aerial system owned and operated by the University of Maryland.

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MPPEH, thermal processing, air pollutants, energetics

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Acronyms

BC	black carbon
CAA	Clean Air Act
CO	carbon monoxide
CO_2	carbon dioxide
CRTDA	Caffee Road Thermal Decontamination Area
CWAP	Comprehensive Work Approval Process
DDESB	Department of Defense Explosives Safety Board
DoD	Department of Defense
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
gpm	gallons per minute
MDAS	material documented as safe
MPPEH	material potentially presenting an explosive hazard
NAWCWD	Naval Air Warfare Center Weapons Division
NAWS	Naval Air Weapons Station
NOSSA	Naval Ordnance Safety and Security Activity
NSASP	Naval Support Activity South Potomac
NSWC	Naval Surface Warfare Center
ORD	Office of Research and Development
PAH	polycyclic aromatic hydrocarbon
PCDD	polychlorinated dibenzodioxins
PCDF	polychlorinated dibenzofurans
PEP	propellant, explosive, and pyrotechnic
$PM_{2.5}$	particulate matter with a diameter of 2.5 µm or less
PSI	pounds per square inch
RCRA	Resource Conservation and Recovery Act
SERDP	Strategic Environmental Research and Development Program
UAS	unmanned aerial system
UDRI	University of Dayton Research Institute
UMD	University of Maryland
UVPM	ultraviolet-absorbing particulate matter
VOC	volatile organic compound

Figures

Tables

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Abstract

Introduction and Objectives: This objective of this project was to demonstrate a new cost- and process-efficient method to thermally decontaminate material potentially presenting an explosive hazard (MPPEH) with lower emissions of air pollutants compared to a legacy wood-fired unit.

Technology Description: An MPPEH processing propane-fueled unit was designed and built by engineers at Naval Air Warfare Center Weapons Division (NAWCWD) China Lake. The burner design is modular to customize for different sizes and consists of up to four modules of closely spaced, parallel-aligned pipes for propane delivery.

Researchers at the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) used their in-house developed sampling equipment attached to an unmanned aerial system, which was owned and operated by pilots from the University of Maryland UAS Test Site, to sample emissions from the wood-fired and propane-fueled units. Researchers from EPA ORD and the University of Dayton Research Institute analyzed the emissions samples for CO, CO_2, $PM_{2.5}$, total carbon/organic carbon/elemental carbon (TC/OC/EC), black carbon (BC), and VOCs.

Performance and Cost Assessment: The successful functioning of the propane unit was first demonstrated by engineers at NAWCWD China Lake with a follow-on successful demonstration by Naval Surface Warfare Center (NSWC) Indian Head Division. Surrogate MPPEH materials were instrumented with thermocouples to demonstrate the effectiveness of the decontamination based on known temperatures for the thermal degradation of energetic materials. Attributes demonstrated for the propane unit included (1) met Department of Defense Explosives Safety Board standards for thermally processing MPPEH; (2) reductions in emissions of $PM_{2.5}$, TC, BC and benzene compared to the wood-fueled method; (3) reductions in overall costs compared to the wood-fueled method; and (4) achievement of time-temperature decontamination requirements in much less time than wood-fueled fires. Conservative estimates indicate that the burner will pay for itself in under four years, with better returns for more frequent use.

The emission samples were limited in numbers, and the testing conditions differed from normal operations. Additional samples would be required to establish reliable emissions factors. One finding that warrants further investigation is that the propane burner emitted surprisingly high emissions of methylene chloride and of other chlorinated VOCs not found from previous similar measurements. This is related to the fuel composition rather than the performance of the propane burner. These chlorinated VOC emissions may be a byproduct of the natural gas and crude oil refining where chlorides occur naturally or due to trace chemicals from fracking processes.

Implementation Issues: There are no known implementation issues with this technology. The system has been installed for use by NSWC Indian Head Division, and can be easily replicated to benefit any Department of Defense installation requiring the capability to thermally process MPPEH.

Publications: 2020 SERDP and ESTCP Symposium – poster presentation; January 4, 2021 UMD UAS Test Site newsletter

Executive Summary

Introduction:
The objective of this project was to demonstrate a new more cost- and process-efficient method to thermally decontaminate material potentially presenting an explosive hazard (MPPEH) that produces lower emissions of air pollutants compared to a legacy wood-fired unit.

MPPEH is produced at almost all Department of Defense (DoD) installations, to include DoD installations that train with, manufacture, demilitarize, conduct research, develop, test, or evaluate munitions. These munitions activities produce MPPEH that requires disposition in the form of reuse, disposal or recycling. Examples of such MPPEH include decommissioned production equipment, scrap metal, expended casings, containers, packaging, etc. Before MPPEH can be transported over public roads or released to the public sector for disposal or recycling it must be assessed and certified as material documented as safe (MDAS) (DoDI 4140.62, 2017). The most common method for assessing and documenting materials as MDAS is by a dual 100% visual inspection for explosive hazards. However 100% visual inspection is not possible for many materials, such as materials with voids, cracks, rivets, weld overlaps, or for contaminants that don't leave a visible trace, such as nitroglycerin.

When a 100% visual inspection is not possible to assess and document MPPEH as MDAS, an alternative method can be approved by the Department of Defense Explosives Safety Board (DDESB) (DoDI 4140.62, 2017). The most common type of DDESB-approved alternative method is thermal processing, sometimes referred to as safety flashing. Most energetic residues thermally decompose below 650 °F (Hewitt, 2001; Harris, 1976, Urbanski, 1990). Therefore, the DDESB requirement for most MPPEH thermal processing units is 650 °F. 1,050 °F is used as a target temperature for materials contaminated with explosives that have an elevated thermal decomposition temperature (e.g., boron potassium nitrate and magnesium Teflon Viton). These temperature thresholds have been set by the DDESB as prescriptive for total decomposition.

At present, large amounts of wood dunnage are sometimes used as a heat source to thermally degrade energetic residues. Burning large amounts of wood to create sufficient temperatures to decompose energetic residues results in long duration fires at suboptimal temperatures, potentially resulting in excessive emissions of particulates, volatile organic compounds (VOCs), carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs), and other harmful air pollutants that can readily exceed quantities authorized by an installation's air permit, thus prohibiting the use of this method for safe certification of these materials. Unable to be processed, the decommissioned equipment remains stored without possible further disposition and presents safety and environmental risks. This project investigates the use and transfer of a propane-fueled, low-emission, right-sized turnkey fire environment to replace wood dunnage-fueled MPPEH decontamination.

Objectives:
The objectives of this work were to: 1) develop and demonstrate a propane-fueled unit capable of meeting DDESB requirements for thermally decontaminating MPPEH so that energetic residues do not pose environmental or explosive hazards; 2) demonstrate a reduction in emissions over the legacy wood-burning method resulting from the use of a cleaner fuel and the ability to stop

the burn on demand; and 3) quantify the cost savings of this unit compared to the legacy wood-fueled fired burner unit. The overarching goal is to provide the DoD with a cost effective and low emission process to thermally process MPPEH to MDAS.

The initial user will benefit, most immediately, from the ability to begin processing their growing inventory of large MPPEH that cannot be visually inspected as safe. Shorter operator-controlled propane-fueled fires will dramatically reduce processing time compared to wood-fired burns, and since the propane fuel burns cleaner than wood for critical pollutants, harmful emissions are expected to be reduced. In addition to helping installations meet their environmental and hazard risk reduction goals and reducing the emissions impact of MPPEH processing, the clean-burning fire is also expected to be less expensive to operate than wood-fueled alternatives.

Technology Description:
The system consists of a large fuel tank or delivery truck that supplies liquid fuel, a pipeline that transports the liquid fuel to the burner and finally the burner. In this study the pipeline is over 300 feet of 3 inch diameter 300 PSI rated flanged pipe.

The pipeline separates the burner from the propane tank by at least 200 feet, a distance that prevents the tank from excessive heating by the large fire (see figure 1).

Figure 1. Photograph taken at NAWC China Lake of a portion of the pipeline with the propane tank in the background.

The pipeline is connected by up to four modules of pipe arrays for propane delivery with capped ends. Each module (~20x21 feet) has an on/off valve that allows the operator to turn on or off select burners and therefore to choose the appropriate-size fire for a given task. Using a fiber tube laser, holes (0.040 inch diameter) are formed in the active section of the pipes to create a spatially uniform bank of tiny fuel nozzles. Fuel flow rate is proportional to the square root of the density of the fluid and the upstream pressure. Past propane-fueled fires have suffered to some degree from pressure drop and an associated loss in firepower. The smaller nozzles used in this burner limit fuel flow rates to approximately 10-20 gallons per minute (gpm) per module over a wide range of flow pressures and fuel densities, which is much lower than similarly designed fast cook off propane burners. Therefore, pressure drop will be less severe for flashing burners compared to fast cook off burners. Thermal feedback from the fire vaporizes propane in the burner pipe network (figure 2). The steadiness and power of the fire are governed by fuel delivery rate.

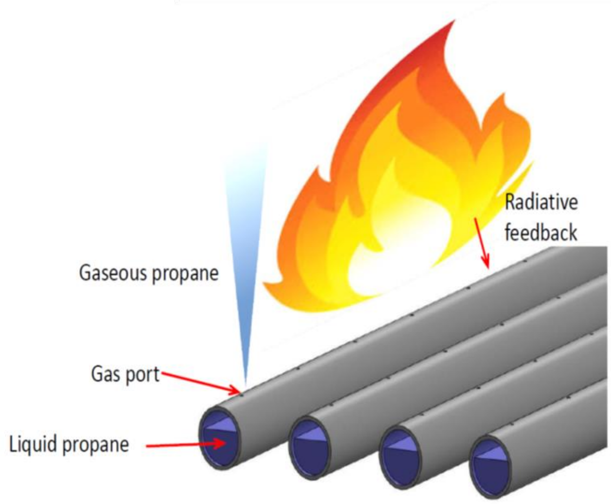


Figure 2. Schematic from Hubble and Washburn (2016) illustrating radiative feedback.

Burner modules are shown in figure 3. The burner module is a series of 41 21-foot-long, 2-inch-diameter pipes that are spaced 6 inches apart. Each pipe has 41 0.040-inch diameter nozzles also 6 inches apart. The pipes are connected at one end by a series of tee nipples and unions. Fuel is delivered to the burner module in a direction perpendicular to the burner pipes. The perpendicular direction of fuel delivery facilitates a more equal distribution of fuel among the burner pipes. Since steel weakens at high temperatures, the burner pipes must be protected from the weight of the MPPEH being flashed. An early iteration of the burner used railroad track to support the weight of MPPEH. A newer iteration used an I-beam support system to both support the weigh to MPPEH and to limit the warping of pipes at high temperatures.

As depicted in figure 3, fuel enters the burner in the bottom right corner. The top of schematic in figure 3 depicts the original design, which used steel railroad track to support MPPEH from a prevent damage to the burner. The bottom picture depicts the final burner design, which uses steel I-beams and square stock to support the MPPEH and prevent pipe warping.

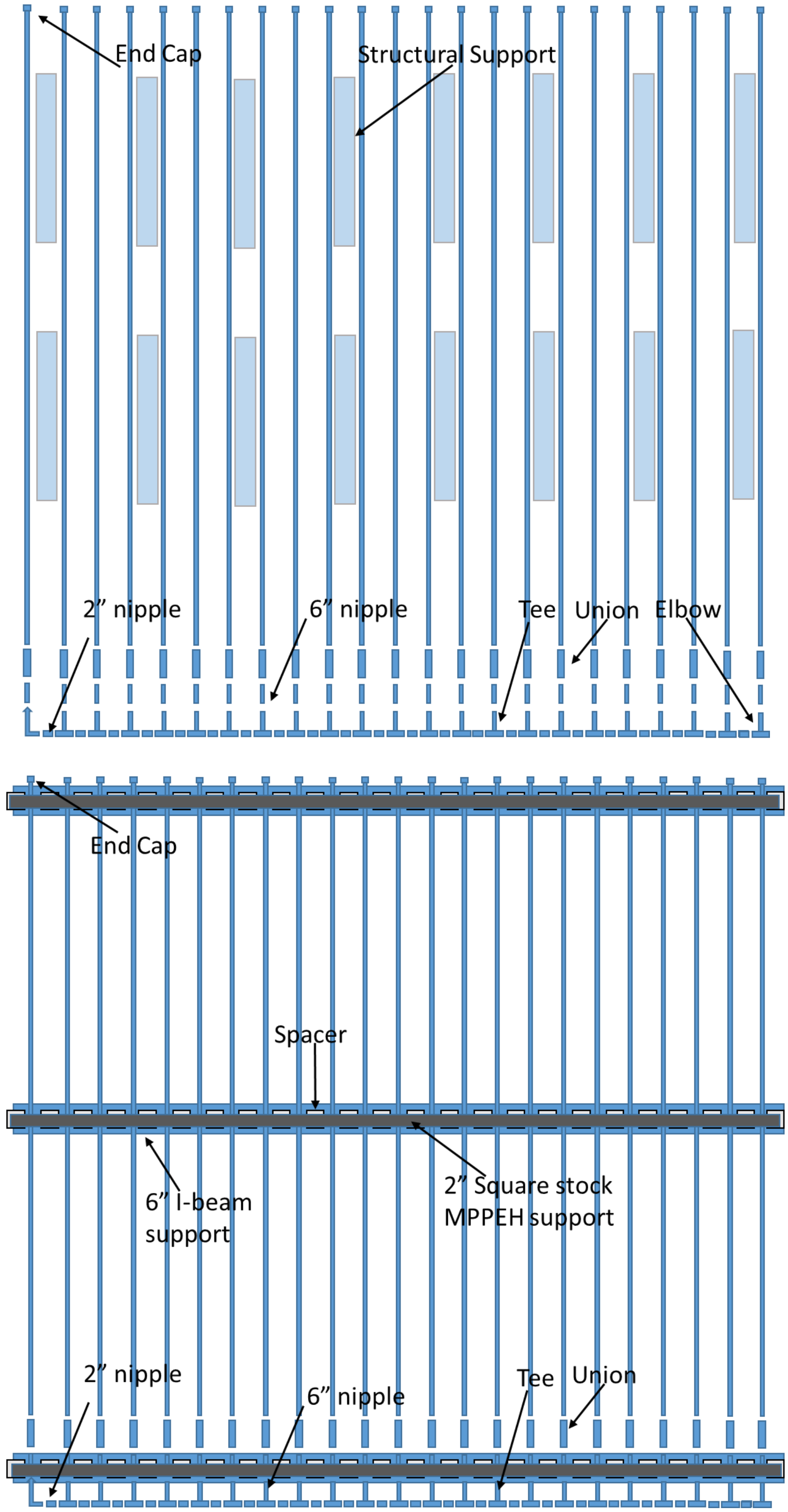


Figure 3. Diagram of burner (not to scale).

Figures 4 and 5 show the burner during a large-scale test and representative thermal data from that test, respectively. During this test, fuel was supplied from a fuel delivery truck rather than from a stationary tank, allowing the operator to carefully control fuel flow rates.

Figure 4. Photograph taken at Naval Air Weapons Station China Lake of large scale flashing of a sea container as a surrogate for MPPEH.

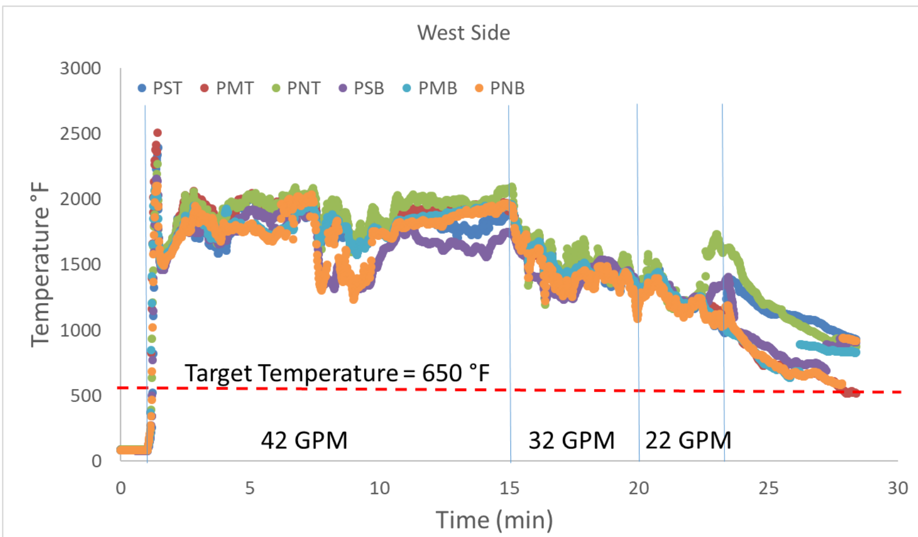


Figure 5. Thermocouple data from the fire shown in figure 4.

Temperatures depicted in Figure 5 were measured with thermocouples placed inside of the west side of the sea container. Note that the required temperature (650 °F) was achieved very quickly. Fuel flowrate was adjusted from the fuel delivery truck's pump.

Performance Assessment:

Met DDESB Standards for Thermally Processing MPPEH to MDAS

The propane burner easily surpassed DDESB's criteria for thermal processing. The duration of the thermal treatment depends on the thickness and material properties of the MPPEH being flashed. Unsteady state heat transfer through a material is a function of its thermal diffusivity, a physical property based on its thermal conductivity, heat capacity, and density. The thermal diffusivity of metals is high compared to other materials, and thus, theoretical required times-at-temperature are low (1 minute for 1 inch and 11 minutes for 4 inch thick metals) (Eastern Research Group, 2012). Since the burner quickly surpasses required temperature levels, the duration of the burn is only slightly longer than required by predetermined metrics based on the MPPEH materials and thickness. In practice, many installations will likely seek a longer dwell time, ~10-15 minutes, as a margin of safety to promote decontamination. The dwell time can be easily controlled with the propane unit, whereas the wood unit continued to burn and smolder for several hours after required dwell times were exceeded.

Generated Fewer Emissions of benzene, PM $_{2.5}$, TC and BC than Wood-Fueled Fires

The U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) collected and analyzed emission samples from the propane unit and the legacy wood-fired unit. ORD used their in-house-developed, light-weight, battery-powered, and remotely controlled sampling equipment called the "Kolibri" to measure CO_2, CO, $PM_{2.5}$ (particulate matter of mass median diameter 2.5 µm or less), black carbon (BC), total carbon/organic carbon/elemental carbon (TC/OC/EC), and volatile organic compounds (VOCs) from the plumes of the two fuel sources. The Kolibri package was attached to the body of an unmanned aerial system (UAS) owned and operated by University of Maryland (UMD) UAS Test Site. UMD's UAS operator maneuvered the sampling equipment into the plume with guidance from the Kolibri's operator who monitored real-time temperature and CO_2 levels.

Two propane burns and one pallet pile burn were conducted. One $PM_{2.5}$ and one TC/OC/EC batch sample was collected for each burn. A single, composite sample for VOCs was collected from the two propane burns in order to ensure collection of sufficient sample to obtain detectable levels. The first propane burn ignited the adjacent pallet pile within a few minutes of the propane ignition. As a result, the $PM_{2.5}$ and OC/EC/TC batch samples collected from the first propane burn were excluded from the results.

Additional samples would be required to establish reliable emissions factors from these two types of decontamination units. For the sampling event, the pallet pile was placed too close to the propane burner. This resulted in ignition of the pallet pile within a few minutes after starting to sample the propane burner emissions. Additionally, the pallet pile may have been smaller and configured differently than normal operational burns. These testing artifacts, plus the limited sample numbers, limit the confidence in the results reported below.

The propane burner had a lower modified combustion efficiency (MCE, CO_2/(CO2 + CO)) than the burning pallet piles, 0.975 compared to 0.992. Due to the wood's lower energy value the CO_2 emission factor in g CO_2/kWh fuel from the wood pallet pile burn was almost two times higher than from the propane burner. The CO emission factor was two times higher from the propane burner than the wood pallet pile burn. It's not clear from the limited tests whether this was an operational issue of the burner related to the air/fuel ratio.

The $PM_{2.5}$ and BC emission factors on an energy basis were, respectively, approximately 14 and 26 times less for the propane burner than the pallet pile burn. The propane $PM_{2.5}$ emission factor on a fuel mass basis was in the same range as previous, similar measurements. The benzene emission factor from the wood pallet burn was three times higher than the propane burner. However, the propane burner emitted surprisingly high emissions of methylene chloride and other chlorinated VOCs not found from previous similar measurements. This is certainly related to the fuel composition rather than the performance of the propane burner. These chlorinated VOC emissions may be a byproduct of the natural gas and crude oil refining where chlorides occur naturally or due to trace chemicals from fracking processes.

Additional details on the emissions sampling results can be found in Aurell and Gullett (2021).

Cost Savings:
We estimated future uses of the propane system will cut labor costs in half, and fuel costs will be approximately 10%, for the propane system compared to the legacy wood-fired system. Overall savings will depend on the frequency of use and local costs of fuel. Current costs of wood-fueled flashing and the labor to operate them vary from site to site, depending on the frequency of burning and the cost of wood fuel. At installations that burn regularly and can source free wood fuel, labor is the largest expense. For installations that must purchase wood fuel and perform burns infrequently, fuel is likely to be their greatest expense.

For installations that burn regularly and can source free wood fuel, we estimate annual savings of $12,480 to $18,720 for return on the investment of a one-burner unit of 1.2 to 1.9 years (Table 1).

Table E-1. Savings and return estimates for a single burner system assuming high labor rates and free wood dunnage

Comparison of annual costs for the legacy system versus one-burner propane system costs for an installation with frequent burns and free wood		
	wood	propane
system cost	$ 0	$ 23,122
labor costs ($110/hr, 26 burns/year, 24 hours labor/burn for wood or 12 hours labor/burn for propane)	$ 68,640	$ 34,320
labor savings/year		$ 34,320
annual fuel consumption in gallons (26 burns/year, 12 minutes/burn/20 gpm)		6240 gallons

low fuel costs ($2.5/gallon)	$ 0	$ 15,600
high fuel costs ($3.5/gallon)	$ 0	$ 21,840
savings with low fuel costs		$ 18,720
savings with high fuel costs		$ 12,480
years to payback with low fuel costs		1.2
years to payback with high fuel costs		1.9

For installations that burn infrequently and must purchase wood fuel, we estimate annual savings of $18,565 to $28,127 for return on the investment of a more expensive four-burner unit of 2.3 to 3.6 years (Table 2). The site that received the burner and hosted the demonstration, falls into this category.

Table E-2. Savings and return estimates for a four burner system assuming low labor rates and the purchase of wood dunnage

Comparison of legacy versus propane-burner annual costs		
	Current	Propane
System Cost	0	$65,960
Annual Fuel Consumption[1]	2,168 pallets	890 gallons
Fuel Costs (Low Estimates)[2]	$21,680	$2,225
Fuel Cost (High Estimates)[2]	$30,352	$3,115
Low estimate of fuel savings (assumes low wood and high propane costs)[2]		$18,565
High estimate of fuel savings (assumes high wood and low propane costs)[2]		$28,127
Years to payback – low estimate[2]		2.3
Years to payback – high estimate[2]		3.6
[1] CRTDA expected fuel of demand is 2168 pallets annually, equivalent to energy in 890 gallons of propane		
[2] Cost of pallets estimated to be $10 or $14, cost of propane estimated to be $2.5 or $3.5 per gallon.		

Because this technology will replace an existing process it is not expected that there will be added costs for permissions, audits, reporting, or compliance related to converting from wood to a propane fueled burner. The new process will generate less waste since it will not produce ash; however, solid waste is not factored in the cost savings above. Maintenance and replacement of heat-damaged steel parts that make up the burner are not estimated.

Implementation Issues:
The propane burner has been installed on Naval Support Facility Indian Head for use at the Naval Surface Warfare Center (NSWC) Indian Head Division Caffee Road Thermal Decontamination Area (CRTDA). Since the legacy wood-burning unit at the CRTDA is DDESB-approved as a method to thermally decontaminate MPPEH, a change in the fuel type is not expected to present any obstacles for continued DDESB approval (K.F. Warner, DDESB, personal communication, 21 December 2020). The modular propane unit can be replicated and installed at any DoD installation requiring MPPEH thermal processing with local safety and environmental approvals.

The most significant implementation issues were caused by the high temperatures damaging metal components of the burner. The first iteration of this burner used machined brass nozzles inserted in threaded holes in the burner pipes. The resulting burner functioned as expected during startup, however after approximately 10 minutes into the fire test, the brass nozzles began to fail and were ejected from the burner. This was due to the fact that the brass nozzles approached their melting point (~1700 °F), causing thread failure.

Although steel melts at a much higher temperature (~2500 °F) it begins to weaken around 800 °F. As shown in data in figure 5, the fire environment quickly exceeds temperatures beyond the weakening of steel. After the fires, the steel burner pipes were noticeably warped. The warping of steel pipes has been encountered in fast cook off burners as well. In order to mitigate pipe warping, a later version of the burner was set on a steel I-beam support with steel bars on top of the pipes holding them in place as depicted in figure 3. The I-beam support was successful at limiting pipe bending during the test.

During an extended burn in which the fuel was supplied directly from the pump of a propane truck, several 2 in steel endcaps on the burner, which were rated to 150 PSI failed. Similar to the failure of the brass threaded nozzles, this was most likely caused by the hardware exceeding its temperature-pressure limitations. To mitigate the failing of endcaps the burner installed at CRTDA was fitted with more robust steel endcaps rated at 300 PSI.

Chapter 1 INTRODUCTION

1.1 Background

Material potentially presenting an explosive hazard (MPPEH) is produced at almost all DoD installations, to include DoD installations that train with, manufacture, demilitarize, conduct research, develop, test, or evaluate munitions. These munitions activities produce MPPEH that requires disposition in the form of reuse, disposal or recycling. Examples of such MPPEH include decommissioned energetics production equipment, range scrap metal, munitions components, expended casings, containers, packaging, etc. For safety reasons, MPPEH cannot be transported over public roads or released to the public sector for disposal or recycling until it is assessed and certified as material documented as safe (MDAS) (DoDI 4140.62, 2017). The most common method for assessing and documenting materials as MDAS is by a dual 100% visual inspection for explosive hazards. However a 100% visual inspection is not possible for many materials. For example, the below types of materials cannot be visually inspected for potential explosive hazards:

- All surfaces may not be visible due to the presence of holes, seams, rivets, or cracks;
- Porous materials may be penetrated by contaminants and physical removal or cleaning cannot decontaminate the material;
- Nonporous materials over 1/8-inch thick are assumed to contain cracks which could contain enough contaminant to present and explosive hazard;
- Thick, cast metals over 1-inch thick have manufacturing voids which cause cracks in the weakened area and hazardous amounts of contaminants could migrate through the cracks into the voids;
- Regardless of the thickness, items containing overlapping welds may harbor hazardous contaminants in the area between the welds and only heat processes can decontaminate overlapping welds; and
- Contaminants such as nitroglycerin do not leave a visible trace.

When a 100% visual inspection is not possible to assess and document MPPEH as MDAS, an alternative method can be approved by the Department of Defense Explosives Safety Board (DDESB) (DoDI 4140.62, 2017). The most common type of DDESB-approved alternative method is thermal processing, sometimes referred to as safety flashing. Thermal decomposition of energetics varies with energetic composition, levels of confinement, temperature ramp up rate, etc. However, most energetic residues thermally decompose well below 650 °F (Hewitt, 2001; Harris, 1976, Urbanski, 1990). To provide a conservative safety measure, the DDESB requirement for most MPPEH thermal processing units is 650 °F to ensure total decomposition. 1,050 °F is used as a target temperature for materials contaminated with explosives that have an elevated thermal decomposition temperature (e.g., boron potassium nitrate, or BKNO3, and magnesium Teflon Viton, or MTV). These temperature thresholds are conservative measures to ensure total decomposition

One alternative means to process MPPEH is through a closed furnace (example: hot gas decontamination at Hawthorne Army Depot). Closed furnace technologies generate fewer emissions but are costly to build and therefore generally limited to small units (and small volumes) or facilities with dedicated large scale MPPEH processing, such as Hawthorne, which may process several thousand tons of MPPEH annually (McFassel, personal communication).

This project focuses on demonstrating an affordable MPPEH thermal processing method that produces less aerial pollutants than a current wood-fueled system. While the goal of this project is to replace wood-dunnage fueled MPPEH safety flashing of non-combustible non-ash forming materials, it is conceivable that it can be adapted to treat combustible ash-producing waste by making the burner easily moveable. With a burner movable, ash generated during a combustible burn can be removed from an underlying liner or pan.

Currently, the high emissions associated with using wood to thermally decontaminate MPPEH may limit the amount of material that can be processed because a single burn can exceed annual emissions limitations for an installation. At sites with emissions limitations, MPPEH can accumulate, presenting a growing environmental and safety risk. Beyond cleaner emissions, installations requiring MPPEH thermal decontamination can benefit financially from fires that are shorter in duration and do not require the delivery and placement of a large amount of wood fuel. The quicker processing of MPPEH translates to a labor savings. Setup and monitoring times will be significantly reduced and cleanup of propane burns requires much less labor when compared to ash-producing wood-fueled thermal decontamination. It is estimated that the intense turnkey type of fire from propane operations will require less than 15% of the energy consumed by current wood-fired burning methods. At installations where wood fuel is purchased, propane is less costly per unit energy than wood dunnage. The result is that the proposed system will use less of a more cost effective fuel. In a case study for Naval Surface Warfare Center (NSWC) Indian Head Division, it is estimated that the proposed system will save approximately $20-30K per year in fuel costs alone. Furthermore, by safely and readily decontaminating MPPEH, the risk of soil and groundwater contamination from residue on the MPPEH is reduced. Therefore, the proposed system will cut potential legacy costs associated with soil and groundwater remediation.

1.2 Objective of demonstration

The overarching goal of this project was to provide the DoD with a cost effective and low emission process to thermally process MPPEH to MDAS. Specific objectives of this work are to: 1) develop and demonstrate a propane-fueled unit capable of meeting DDESB requirements for thermally decontaminating MPPEH so that energetic residues do not pose environmental or explosive hazards; 2) demonstrate a reduction in aerial emissions over the legacy wood-burning method resulting from the use of a cleaner fuel and the ability to stop the burn on demand; and 3) quantify the cost savings of this unit compared to the legacy wood-fueled fired burner unit.

The initial user will benefit, most immediately, from the ability to begin processing their growing inventory of large MPPEH waste items. By decontaminating this MPPEH, the users will be performing their duty to make safe materials that pose environmental and explosive risks. At present, large amounts of wooden dunnage are often used as a heat source. Long durations at suboptimal temperatures from wood dunnage burning are believed to result in excessive emissions of particulates, volatile organic compounds (VOCs), carbon monoxide (CO) and other harmful air pollutants. Short operator-controlled propane-fueled fires will dramatically reduce the time of burning and since the propane fuel is expected to burn cleaner than wood, emissions could be drastically reduced.

1.3 Regulatory drivers

The potential for MPPEH to present an explosive hazard is the single characteristic that distinguishes it from other DOD material to be reused, excessed, recycled or otherwise disposed (NAVSEA OP 5, 2020). For safety reasons, MPPEH may not be transported over public roads or released from DoD control unless its explosive safety status has been assessed and documented. In order for MPPEH to be assessed as safe (i.e., MDAS), 100% of its surface area must be visually inspected for the presence of energetics, or it may be processed using DDESB-approved technical methods. Inaccessible surfaces and safety risks to personnel prohibit visual inspection of some types of MPPEH. The most common alternative to visual inspection is to use heat to thermally decontaminate energetic residues.

MPPEH processing is not regulated as a Resource Conservation and Recovery Act (RCRA) hazardous waste treatment process. Only materials that are contaminated with insufficient energetics to support combustion or cause detonation are processed in MPPEH thermal decontamination units. These items do not meet the RCRA definition of reactivity.

MPPEH processing units may be regulated under the Clean Air Act (CAA). CAA requirements are installation specific since CAA requirements vary by state and according to installation permits. The excessive emissions from even a single wood-fueled MPPEH decontamination event can exceed quantities authorized by an installation's CAA permit, thus prohibiting the use of this method for safe certification of these materials. As a result, local emissions restrictions may limit MPPEH processing, resulting in stockpiling of MPPEH.

Chapter 2 DEMONSTRATION TECHNOLOGY

2.1 Technology description

This technology is based on a similar technology for conducting fast cookoff tests (Hubble et al., 2015; Washburn et al., 2018). The system demonstrated for this project consists of a large fuel tank or delivery truck that supplies liquid fuel, a pipeline that transports the liquid fuel to the burner and finally the burner. In this study, the pipeline is over 300 feet of 3 inch diameter 300 PSI rated flanged steel pipe. The purpose of the pipeline is to deliver fuel to the burner without experiencing excessive pressure drop and also to separate the burner from the propane tank by at least 200 foot, a distance that prevents the tank from excessive radiant heating from the large fire (see figure 2-1). The pipeline is painted and rests on risers to prevent corrosion. Along the pipeline there is at least one on/off valve that allows for emergency shutoff.

Figure 2-1. Photograph taken at NAWS China Lake of a portion of the pipeline with the propane tank in the background.

The burner consists of up to four modules of closely spaced, parallel-aligned pipes for propane delivery with capped ends. Each module (~20x21 feet) has an on/off valve that allows the operator to turn select burners on or off, and therefore to choose the appropriate size fire for a given task. A fiber tube laser was used to form holes (0.040 inch diameter) in the active section of the pipes to create a spatially uniform bank of tiny fuel nozzles. Thermal feedback from the fire evaporates the propane, which is in the liquid phase in the pipe network (figure 2-2).

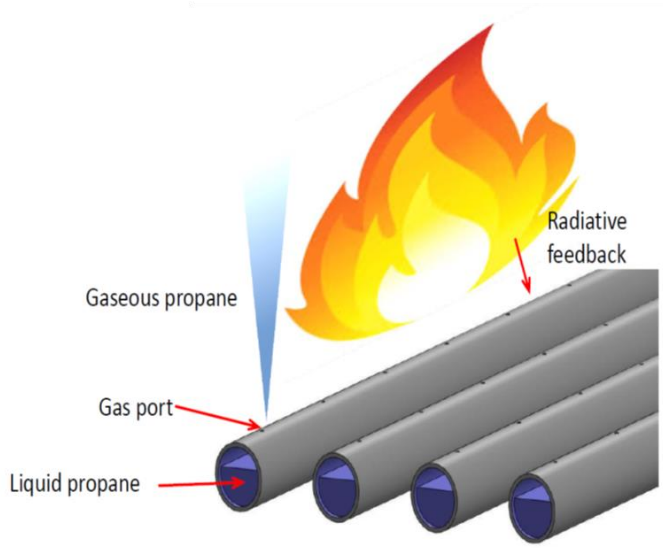


Figure 2-2. Schematic from Hubble and Washburn (2016) illustrating radiative feedback.

The steadiness and power of the fire are governed by fuel delivery rate. The nozzle holes are small and the flow through them is expected to be critical over most of the duration of the fire. The fuel flow rate is proportional to the square root of the density of the fluid and the upstream pressure. Over most of the duration of the fire, heat flux to the burner pipes is expected to be relatively constant, a consequence of radiant heat transfer from large fires. With a stable heat flux and fuel flow rate, the density of the fuel in burner should also reach a steady state. It follows that the primary variable determining fluid flow rate in this burner is the tank pressure. For a large tank delivering low flow rates of fuel, the burner should provide a stable flame. The smaller nozzles used in this burner limit fuel flow rates to approximately 10-20 gpm per module over a wide range of flow pressures and fuel densities, which is much lower than for the similarly designed fast cookoff propane burner (Hubble et al., 2015; Washburn et al., 2018). Therefore, pressure drop will be less severe for flashing burners compared to fast cook off burners.

Schematics of the burner modules are shown in figure 2-3. The burner module is a series of forty-one 21-foot long, 2-inch diameter pipes that are spaced 6 inches apart. Each pipe has 41 0.040-inch diameter nozzles also 6 inches apart. The pipes are connected at one end by a series of tee nipples and unions. Fuel is delivered to the burner module in a direction perpendicular to the burner pipes. The perpendicular direction of fuel delivery is important because if facilitates a more equal distribution of fuel among the burner pipes.

The burner consists of an array of tiny nozzles spaced 6 inches apart. In the diagram depicted in figure 2-3, fuel enters the burner in the bottom right corner. The top depicts the original design, which used railroad track to support MPPEH from a prevent damage to the burner. The bottom picture depicts the final burner design, which uses steel I-beams and square stock to support the MPPEH and prevent pipe warping. As discussed in section 5, multiple modules can be used to make up a burner that offers the operator the option to size a fire based on need.

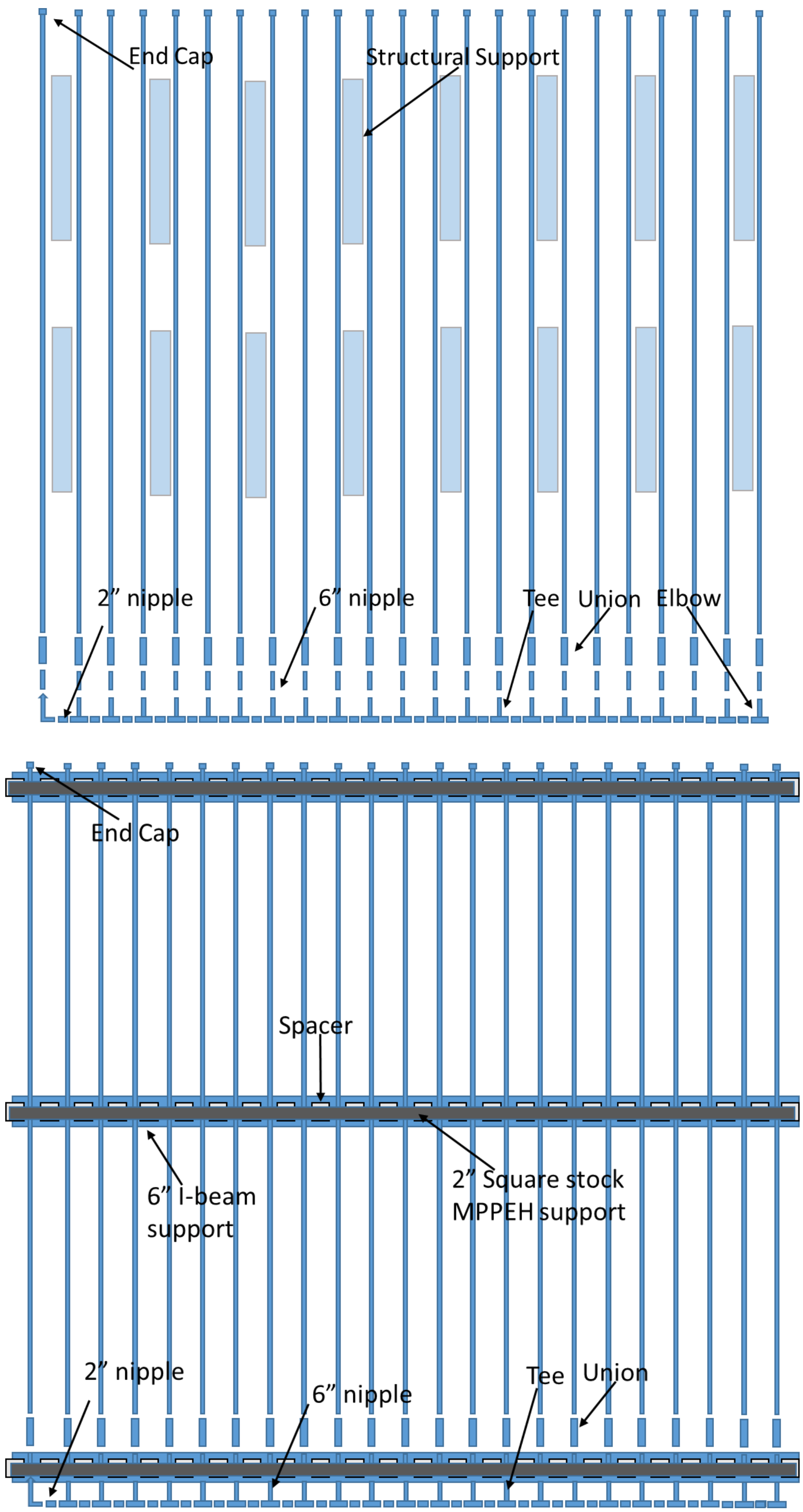


Figure 2-3. Diagram of a burner module (not to scale)

Since steel weakens at high temperatures, the burner pipes must be protected from the weight of the MPPEH being flashed. An early iteration of the burner used steel railroad track to support the weight of MPPEH. A newer iteration used an I-beam support system (figure 2-4) to both support the weigh to MPPEH and to limit the warping of pipes at high temperatures. Burner pipes are sandwiched between a massive I-beam on the bottom and a steel bar on top. In a permanent installation, the I-beam could be burried a few inches deep in the soil. Most of the I-beam under the soil line will remain at low temperatures compared to the flame and therefore maintain its strength and shape.

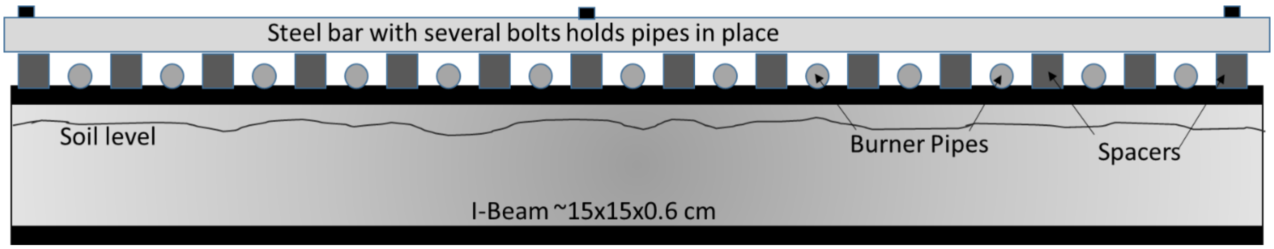


Figure 2-4. Schematic of the I-beam support

Below are photographs of a single nozzle in a 2-inch burner pipe (figure 2-5), the propane burner (figure 2-6) and the final demonstration fire test at Naval Air Weapons Station China Lake (figure 2-7).

Figure 2-5. Photograph of a single nozzle in a 2 inch burner pipe

Figure 2-6. The propane burner on an I-beam supporting a large-scale MPPEH surrogate.

Figure 2-7. Photograph taken at NAWS China Lake of the large-scale flashing of a sea container as a surrogate for MPPEH.

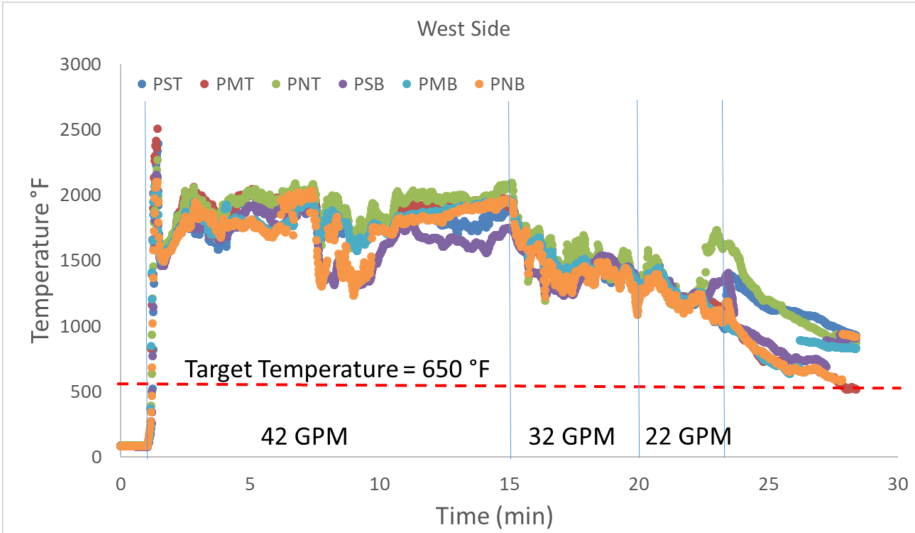


Figure 2-8. Thermocouple data

Representative temperature data from thermocouples placed on the west side of the container is shown in figure 2-8. Note that the required temperature (650 °F) is achieved very quickly. Fuel flowrate was adjusted from the fuel delivery truck's pump.

The first iteration of the burner tested an estimated lower limit of fuel flow rate. This was essentially a test to see how small the burner nozzles could be made. It was determined that at moderate tank pressures a bank of 0.024 inch nozzles would provide approximately the same firepower as a wood fueled-fire (on a power per area basis). Machining these tiny holes directly in the steel pipes was simply not feasible. 0.024 inch brass nozzles with 1/8 inch threads designed for commercial propane tools were purchased and the burner pipes were drilled and tapped to accommodate these machined nozzles. The operation of the first burner was not stable. The very small orifices restricted fuel flow to very low levels and the velocity of fuel jetting out of the nozzles was very high. The combination of low flow rate and high velocity resulted in a burner that did not become fully engulfed with flames. The addition of a skirt, which extended approximately one foot above the burner prevented excessive shear between air and fuel and helped to stabilize the flame. In addition, placing an item (bluff body) to be flashed (sheet metal in early tests) helped to stabilize the flame by creating a recirculation zone. Although the skirt and bluff body helped to stabilize the flame to some degree, the results were not satisfactory. The nozzles needed to be larger to deliver more fuel at lower velocities in order to enhance stability.

The 0.024 inch diameter nozzles were bored out to 0.040 inch to provide approximately 10-20 gpm of liquid propane per burner over a wide range of pressures, as predicted by critical flow theory. After boring out the holes, the burner operated with a stable flame. However, the high temperatures caused the brass nozzles to fail. The failure of the brass nozzles created a need for an inexpensive approach to forming tiny nozzles directly in the steel burner pipes. A fiber tube laser was identified as the best currently available tool that can perform this task in an automated and inexpensive manner.

In both fast cook off propane burners as well as early tests of this burner, steel components of the burner that are exposed to extreme heat became warped after the fire. The team was approached by the owners of a fast cook off propane burner to develop a solution to mitigate pipe warping. The solution that we arrived at was the I-beam support shown in figures 2-3, 2-4, and 2-6. Although the I-beam support is intended to be buried in a permanent installation, it was determined that burying the support for the test was too time intensive for a single test. If burying the I-beam support is not feasible, lava rock or other insulating materials can be used to protect the propane burner.

During the final test at Naval Air Weapons Station (NAWS) China Lake, it was demonstrated that "tankless" flashing—delivering liquid propane directly from a delivery truck rather than from a passive tank—could produce a stable and controllable fire. The I-beam support mitigated warping of the pipes, however it was decided that the final installation would benefit from thermally protecting the I-beams by burying them and from more bolts holding the MPPEH-supporting steel bars firmly on the spacers. After long periods of time several of the original steel 150 PSI endcaps failed during the large scale test.

The final changes, which were made to the burner installed at NSWC Indian Head Division's Caffee Road Thermal Decontamination Area (CRTDA), were to install sturdier burner pipe endcaps rated for 300 PSI and to bury the I-beam support under red lava rock so that the support would resist heating and maintain its strength and shape in order to mitigate warping.

The initial expected application of this technology is that it can be used to decontaminate the large-scale noncombustible MPPEH that continues to stockpile at CRTDA because the emissions from the current wood-fired flashing process prevent use. This technology can be easily transferred to any installation with a requirement to thermally process noncombustible MPPEH. Installations that require thermal processing of combustible MPPEH will need to remove ash from an underlying liner or pan after flashing. Although the propane itself will not produce ash, combustible materials can produce ash. With some modification, it may be possible to make the entire burner and I-beam support both durable and light enough that the process can be adopted by small-scale processors of combustible MPPEH.

2.2 Technology development

This technology is based on a similar technology for studying fast cookoff (Hubble et al., 2015; Washburn et al., 2018). In this work, which has since gained acceptance as a fast cook off standard, it was shown that clean, low-cost propane could meet the strict temperature and heat flux requirements demanded of fast cook off testing while producing significantly fewer emissions (Aurell et al., 2017). Prior to the acceptance of this propane burner as a fast cookoff standard, excessive amounts of jet fuel were used in fast cook off testing. The recently approved propane burner is capable of operating while delivering only the amount of fuel needed for the operation. It leaves behind much less fuel waste and the cost of propane fuel is lower than that of the jet fuel that it replaces, and therefore offers both cost and emissions savings.

In principle, this technology should work in much the same way; however, this proposed system is much larger. Compared to the fast cookoff burner, the MPPEH burner does not need to meet strict temperature ramp and heat flux uniformity criteria, as long as it can heat its target to the required temperatures for the required dwell time.

2.3 Advantages and limitation of the technology

The environmental advantage of this technology is that it uses less energy than wood-fueled fires and burns a cleaner fuel over a shorter duration; the combination of these factors means that this technology will release far fewer emissions. Financial benefits will come from the fact that: 1) the burner uses less fuel than a wood-fueled fire; 2) propane is less costly than wood fuel in case the wood must be purchased; and 3) the shorter setup, burn time and simple cleanup requires less labor.

One limitation of this burner is that a long fuel supply line from the burner to the tank may hold a significant amount of fuel. Excess capacity in the pipeline results in a time lag between ceasing fuel flow and burn off of residual fuel. One possible way to overcome this limitation is to cease fuel supply slightly before the required time-temperature dwell in such a way that the decontamination requirements are met while as the fire loses power slowly as the fuel in the supply line is exhausted. Another way to mitigate excessive pipeline capacity is to use a smaller diameter pipeline, provided there is confidence that pressure drop in the pipeline will not be excessive or to use “tankless” drive-up delivery since the pump can easily overcome pressure drop of smaller pipelines.

Another limitation is related to the durability of steel exposed to extreme temperatures. The I-beam support mitigated warping during testing but over many thermal cycles it is possible that cumulative damage to the burner could result in high maintenance costs. All steel components of the burner that are exposed to extreme temperatures (burner pipes and endcaps) will degrade over time and it is not clear how long their useful life is. One solution to mitigate thermal damage to the burner is to use more durable materials. For example a propane-fueled fast cook off burner in a recent report may benefit from the use of stainless steel to mitigate thermal damage to the burner. The tradeoff between using steel compared to more costly but durable materials should be examined.

Chapter 3 PERFORMANCE OBJECTIVES

The overarching goal of this project was met, which was to provide the DoD with a cost effective and low emission process to thermally process MPPEH to MDAS. Specific objectives and success criteria are provided in Table 3-1.

Table 3-1. Performance Objectives

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
1. Meet DDESB standards for thermally processing MPPEH	Thermocouple readings from testing	Surpass 650 °F for several minutes	Met
2. Reduce aerial emissions	Airborne emissions testing of wood and propane fueled fires during demonstration at IH CRTDA	<1/20 emissions for most species	Mostly met (results provided in Aurell and Gullett, 2021)
3. Reduce costs	Compare labor and fuel expenditures during demonstrations.	Less fuel and labor costs compared to wood-fueled fires	Met
Qualitative Performance Objectives			
4. Demonstrate "tankless" fuel delivery	Show that the burner can meet objectives using fuel from delivery truck	Demonstration at China Lake	Met
5. Demonstrate quick processing	Measure time from ignition to achieving time-temperature dwell	Thermocouple reading reach required level in one to two min.	Met

Objective 1. Meet DDESB standards for thermally processing MPPEH. The time and temperature criteria is the most important part of this project. Not meeting this criteria would mean that the technology is not suitable for processing MPPEH. This metric was assessed by flashing a very large MPPEH surrogate, a 40-ft L x 8-ft W x 8.5-ft H shipping container that was instrumented with thermocouples. From the recorded thermocouple data, this criterion was a success, easily surpassing the required 650 °F temperature within minutes and sustaining sufficient temperatures to meet required dwell times to process MPPEH as safe.

Objective 2. Reduce emissions. One impetus for this proposal was due to the fact that wood fueled flashing has been effectively disallowed at Indian Head's CRTDA because of excessive emissions. In order to implement this technology there, it must be demonstrated that propane fires produce far fewer emissions. This criterion was substantively met, with some surprising results, and caveats about the test conditions.

Additional samples would be required to establish reliable emissions factors from these two types of decontamination units. For the sampling event, the pallet pile was placed too close to the propane burner. This resulted in ignition of the pallet pile within a few minutes after starting to sample the propane burner emissions. Additionally, the pallet pile may have been smaller and configured differently than normal operational burns. These testing artifacts, plus the limited sample numbers, limit the confidence in the results reported below.

The propane burner emitted approximately 14, 26 and 2 times less $PM_{2.5}$, BC and CO_2 emissions, respectively, than from the pallet pile burn. The benzene emission factor from wood pallet burn was three times higher than the propane burner. The propane burner combusted the propane fuel less efficiently than the burning pallet piles as revealed by the lower MCE, 0.975 compared to 0.992. Due to the wood's lower energy value the CO_2 emission factor in g/kWh fuel from the pallets was almost two times higher than from the propane burner. The CO emission factor was two times higher from the propane burner than the wood pallet pile burn, possibly due to issues with the air/fuel ratio.

The propane burner emitted surprisingly high emissions of methylene chloride and of other chlorinated VOCs not found from previous similar measurements from NSWCDD's fast cook-off propane burner. This is certainly related to the fuel composition rather than the performance of the propane burner. These chlorinated VOC emissions may be due to the processing of natural gas and crude oil refining where chlorides occur naturally or is a result of organochlorinated fracking chemicals. Refer to Aurell and Gullett (2021) for additional details of the emissions results.

Objective 3. Reduce costs. Reducing costs is important for successful transition and adoption by DoD installations. We estimated that labor costs will be cut in half, and fuel costs will be approximately 10%, for the propane system compared to the legacy wood-fired system.

Objective 4. Demonstrate "tankless" fuel delivery. Purchasing and maintaining a propane tank comes with a cost to the installation. The ability for on-demand fuel delivery allows the operator to flash MPPEH without having to buy or rent and maintain a tank. In addition to cost savings, the operator can control fuel flow rate and firepower with precision by adjusting the flow rate from the truck's pump. This objective was demonstrated by fueling the final test at NAWS China Lake, which involved the flashing of the large sea container as a surrogate for large scale MPPEH.

Objective 5. Demonstrate quick processing. This objective is intended to show that propane-fueled flashing, with quick turn on and shut down can be performed in much less time than wood-fueled flashing. Because of this, propane-fueled flashing will be less labor intensive than wood-fueled flashing since the time required to setup and monitor the fire will be significantly reduced. Data from the final sea container flashing test at China Lake shows that the large MPPEH surrogate reaches the temperature criteria very quickly. Since temperature thresholds are reached quickly and shut down is also fast, processing takes approximately as long as the predetermined dwell time of the MPPEH article.

Chapter 4 SITE/PLATFORM DESCRIPTION

4.1 Test platforms/facilities

Design, scale up and testing of the propane burner took place at NAWS China Lake's Mini Deck site. This site is well suited for large-scale research development test and evaluation fire testing and has liberal emissions standards. The propane burner was transported to the NSWC Indian Head Division CRTDA in October 2019.

The CRTDA demonstration took place on October 14, 2020. CRDTA has the infrastructure and the demand for this technology. The propane burner is installed at the location labeled "New CRTDA Burn Pad" shown in figure 4-1.

Figure 4-1. View of the CRTDA

4.2 Present operations

Although there is a small number of contained MPPEH thermal processing units within DoD, their use is typically limited to either small materials or high throughput operations at dedicated MPPEH processing sites. Outside of these scenarios, open flashing is often the most cost effective, quickest, and safest processes for processing MPPEH into MDAS. This is the case with the large scale MPPEH CRTDA is tasked with processing. Open flashing is usually performed with wood fuel, which may be obtained free or at cost depending on the facility. Wood is placed under or around the MPPEH and ignited by electric heater. Because the wood fuel can only be set in place once, and the burning behavior of the wood fuel is slow and unpredictable, it is desirable to set in place an abundance of fuel. Failing to supply enough fuel can result in a failed decontamination and increased costs. Therefore, operators err on the side of excess fuel use, which results in long lasting fires with increased emissions (Figure 4-2). At some installations such as the NSWC Indian Head Division CRTDA, emissions permits have prevented the processing of MPPEH.

Traditional MPPEH flashing consists of the following steps: 1) fuel accumulation and placement; 2) MPPEH placement; 3) burning and monitoring; and 4) clean up. With this technology, step 1) will be eliminated, and steps 3) and 4) will be less labor intensive. Since less energy is consumed by using a cleaner fuel, a right-sized fire, and a fire of limited duration, fewer emissions are generated.

Figure 4-2. Photographs of a legacy MPPEH decontamination at CRTDA.

In the MPPEH flashing event depicted in Figure 4-2, hundreds of wood pallets were used as a fuel source. The duration of the burn is several hours as evidenced by the sun setting in the bottom row.

4.3 Site-related permits and regulations

There were no permits or regulations hampering the design, scale up and testing at NAWS China Lake. The team has had several teleconferences about permitting requirements for demonstration at CRTDA. Permitting for the Indian Head demonstration falls under two categories: 1) permission to install and operate the burner, and 2) permission to fly an unmanned aerial system (UAS) to interrogate the emissions plume during demonstration.

Indian Head uses a Comprehensive Work Approval Process (CWAP) to review projects on the base. This process requires that relevant subject matter experts approve the proposed work —the installation of the burner in this case. The CWAP for this testing was approved after review from infrastructure, environmental and safety experts at Indian Head in May 2018.

Conducting emissions testing at CRTDA required approval from the Naval Support Activity South Potomac (NSASP) Air Operations Office, and an additional CWAP approval. The CWAP approval to use a UAS to sample air emissions was approved in April of 2020, and an Air Operations approval was granted in October 2020.

Chapter 5 TEST DESIGN

5.1 Testing outline

The approach to this project was straightforward: use the lessons learned from the fast cookoff propane burner (Hubble et al., 2015; Washburn et al., 2018) to design an MPPEH thermal decontamination unit that is more fuel efficient; then build, test, and scale up the burner. The primary test, which was used to assess both fuel consumption and the ability of the burner to meet DDESB MPPEH thermal processing standards involved setting a large MPPEH surrogate that was instrumented with thermocouples in the fire.

Table 5-1. Gantt chart of major testing tasks prior to demonstration.

Task	Q4 2018	Q1 2019	Q2 2019	Q3 2019	Q4 2019
Modeling Nozzle Array Design					
Fuel Tank Installation					
Subscale Burner Optimization					
Modular Scale Up, Debugging					
Full Scale Thermal, Cost Analysis				*	

*Decision point for final system scaling and cost/benefit analysis.

5.2 Pre-demonstration testing

The overarching goals of pre-demonstration testing were to 1) develop a stable fire; 2) harden the burner to improve its longevity; and 3) demonstrate that the burner could meet the thermal requirements for MPPEH flashing. Pre-demonstration testing efforts included the testing of nozzle size, flame stability enhancement, electronic ignition, developing a support to mitigate warping, on-demand fuel delivery, and most importantly, a thermal characterization of MPPEH flashing. Early tests to establish stable burning simply involved igniting a fire on the burner and visually monitoring the fire for quick ignition and stable operation. Later tests included adding thermocouples to the fire and flashing surrogate MPPEH in order to gather data to support the technology's adoption as a suitable flashing method. The final pre-demonstration fire used the I-beam support described in section 2 and fuel was delivered to the pipeline directly from a fuel truck to demonstrate on-demand fuel delivery capability.

5.3 Design and layout of technology components

The system can be divided into four subsystems: a fuel tank, fuel supply line, burner arrays and accessory systems for stabilizing and igniting the fire. Burners should be located on ground that is relatively level; level ground and the I-beam support mitigate warping of the burner when heated. Burners should be located in areas that are five or more burner diameters away from combustible materials, such as buildings and trees (Shokri and Beyler, 1989). The ideal location to install a burner is likely on top of or adjacent to current burning sites. We expect that in most cases a propane delivery truck can supply the fuel at the time of burning, which means that the operator may not need to invest in installing a dedicated propane tank.

The fuel supply line for the burner in this study is 3 inch flanged steel pipe rated to 300 lb. Small burners can likely operate well with a 2 inch fuel supply line, depending on expected fuel backpressures and fuel flow rates. For the large burner in this demonstration a 3 inch fuel supply line was chosen because flow calculations suggested a 2 inch line would experience excessive pressure drop. Various accessories including flexible hoses and on/off valves are a part of the fuel supply line. These accessories are important to protect the integrity of the fuel supply line and give the operator a means to quickly turn off fuel flow.

Each burner module (described in detail in section 2.2) is a network of parallel 2 inch steel pipes spaced 6 inches apart center to center. An important aspect of this technology is that it consists of multiple burner modules that can be selectively turned on or off. Figure 5-1 shows a schematic of how four modules may be arranged to selectively turn on a quarter, half, or the full burner using two on/off valves.

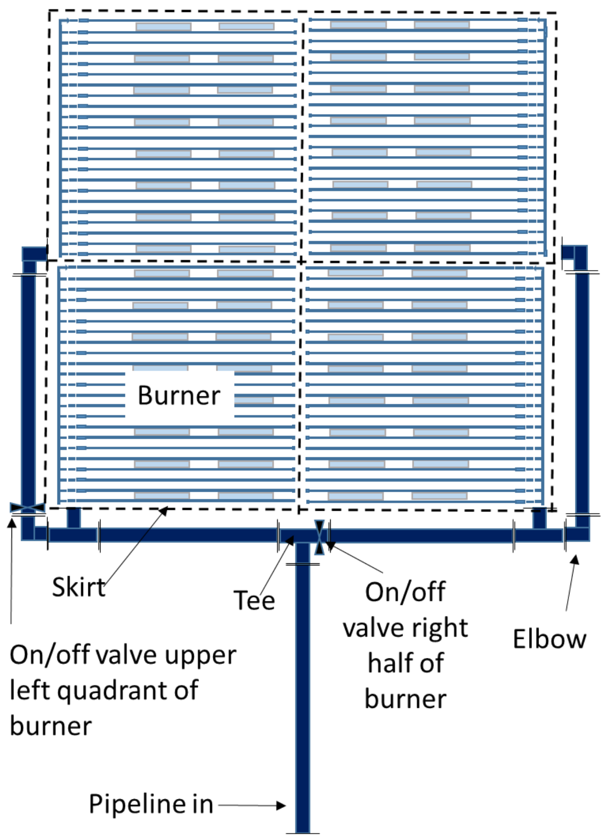


Figure 5-1. Schematic of modularity of the burner units

Intense heat from fires will cause the metal under stress to deform; therefore it is critical that the burner pipes are not used to support massive items. To support the weight of surrogate MPPEH during the fire, railroad track was initially used. Later we developed the I-beam support described in section 2.2. The I-beam support is intended to be either partially buried or otherwise insulated, such as with lava rock, as was done at CRTDA, so that the unexposed portion of the beams do not become very hot and are therefore able to maintain their strength and shape.

The burner also benefits from having a skirt around it to limit flow shear between the fuel, which is issued at a high velocity, and entrained air. The burner can be ignited using a cartridge heater or heat gun element. A convenient location for the igniter is near the corner or the operating module(s) a couple of inches above a bluff body that will generate a recirculation zone.

5.4 Field testing

Inspection prior to burning

Prior to testing, the fuel supply line, burner pipes and nozzles are visually inspected to ensure that they are in place and not broken. The reasons for the inspection are to prevent excessive flows of fuel from a missing nozzle or damaged pipe and to prevent the chance of flashback during ignition by eliminating any gaps larger than a flame quenching distance, approximately 2 mm. If any damage is identified, the damaged part must be replaced prior to burning.

Article Placement

A skilled and licensed equipment operator must use a forklift, boom or crane to carefully place the item being flashed on the burner. Care should be taken to place the heavy items on structural supports designed to bear weight rather than on the burner pipes because the weight of the item and high temperatures can cause unnecessary warping of the burner. Light items may be placed on the burner manually, however, most MPPEH processed by this burner is expected to be too heavy to move without lifting equipment.

Burning

1) With the fuel supply line still closed, if the burner has a skirt, the skirt will be placed around the perimeter of the burner(s) being used.
2) The electric heater will be placed near the corner of the operating module(s) a couple of inches above a bluff body that will generate a recirculation zone.
3) The heater will be powered up (plugged in) for at least thirty seconds, enough time so that the heater can become glowing hot.
4) The operator tasked with fuel supply will begin opening the pipeline, starting with the on/off valve furthest downstream from the fuel supply, followed by the on/off valve near the tank.
5) Once the valves are open, fuel supply will begin and the burner will soon become fully engulfed.
6) The main operator will give the signal to turn off fuel supply once the objective has been met. Pressure in the pipeline will drop over time as fuel remaining in the pipe burns. The fire will self-extinguish due to a lack of fuel supply. Power to the electric heater igniter will be shut off. The pipeline operator should close the on/off valve nearest the tank first and then close the on/off valve near the burner. The burner and MPPEH surrogate will remain hot.

NOTE: Emergency Shut Down: In case of an emergency, or in the event that any team member decides it is necessary to stop the burn due to safety concerns, fuel supply to the burner should be stopped by activating an emergency shut-down switch on the tank or closing the on/off valves, whichever is nearest.

NOTE: Under no conditions will the propane-fueled fire be extinguished. Doing so could result in unburnt propane being released, creating a potential hazard if ignited.

Cool Down
The burner and MPPEH will remain hot after the last flames disappear. Departments that require sign off, such as the Fire Department and Range Control should be notified that the burn has been completed. The burner and article should not be approached until temperature readings approach ambient.

Disposition
Once the burner and article reach temperatures that allow approach by personnel, the burner skirt may be removed, if present. A licensed heavy equipment operator can remove the article for reuse, recycling, or other disposition according to installation procedures.

5.5 Measurement and monitoring plan

Two burn demonstrations were conducted at Indian Head's CRTDA using similar MPPEH items. One burn used wood as a fuel source and the other burn used the propane burner. The wood-fueled fire burned until the fuel supply was exhausted while the propane burner was run until the necessary time-temperature criteria was met. The surrogate MPPEH items for these tests were metal waste containers, approximately 8x8x8 ft.

During the burn demonstration events, a UAS equipped with gas and particle monitors and samplers collected emissions from the wood and propane fires to compare emissions of pollutants. The UAS was owned and operated by the University of Maryland (UMD) UAS Test Site. The UMD UAS Test Site pilot flew an M600 hexacopter-style UAS equipped with the EPA-developed sampling package. The UAS was maneuvered in a hover pattern over the emissions plumes while carrying the sampling system called the "Kolibri."

Refer to Aurell and Gullett (2021) for details about the emissions sampling plan.

5.6 Laboratory material testing

The time and temperature requirements have been derived from a DDESB-approved process in use by NSWC Indian Head Division (Eastern Research Group, 2012). To successfully decontaminate energetic-contaminated materials, all portions of the treated material must reach a target temperature which is at or above the thermal decomposition temperature of the explosives contaminant (<650 °F for most chemistries). The required dwell time at this temperature depends on the type of material and thickness (see Chapter 6 for more discussion). For most metal materials, energetics will decompose within a minute, but the CRTDA builds in a margin of safety with a dwell time requirement of 10-15 minutes. Surface mounted thermocouples were used to verify these testing requirements (Table 5-3).

Table 5-2. Laboratory Testing Requirements

Engineering Requirement	Test	Acceptance Criteria	References
Meet thermal requirements for flashing	Test flash large MPPEH surrogate (sea container)	Thermocouple measurements ≥650 °F for ≥15 minutes	ERG 2012

Chapter 6 PERFORMANCE ASSESSMENT

Objective 1. Met DDESB standards for thermally processing MPPEH

As discussed in section 3, to meet the DDESB's criteria for thermal processing, thermal decontamination technology must heat an article to 650 °F or higher for a predetermined period of time, depending on the material and thickness. Unsteady state heat transfer through a material is a function of its thermal diffusivity, a physical property based on its thermal conductivity, heat capacity, and density. The thermal diffusivity of metals is high compared to other materials, and thus, theoretical required times-at-temperature are low (1 minute for 1 inch and 11 minutes for 4 inch thick metals) (Eastern Research Group, 2012). Most materials processed at CRTDA are steel and thin, typically 1/16 -1/8 inch thick. In practice however, CRTDA would likely seek a longer dwell time, ~10-15 minutes, as a margin of safety to promote decontamination. Thermal certification testing was carried out using a large sea container, which represents the approximate size and thickness of the largest items processed at CRTDA. The walls of the container were approximately 1/16 inch thick and structural portions were approximately ¼ inch thick. The sea container prior to testing is shown in figure 6-1. The photo was taken from the southeast corner of the burner.

Figure 6-1. Photograph of surrogate for MPPEH on the burner prior to testing at NAWS China Lake.

The sea container was instrumented with 18 K type thermocouples. Six thermocouples were placed on the west side of the container, six on the east side, two on the door on the south side and four thermocouples were located in the center of the container in a heat flux gauge. Figure 6-2 describes the placement of the thermocouples. Except for one thermocouple on the door, all thermocouples were placed inside the container. A ¼ inch thick cylindrical heat flux gauge, which contained four of the thermocouples, was placed near the center of container to simulate a thick and difficult to heat feature. The thin walls that are in direct contact with the flame will approach flame temperatures almost immediately, however items not in direct contact with the fire, in the center of a large container will heat more slowly.

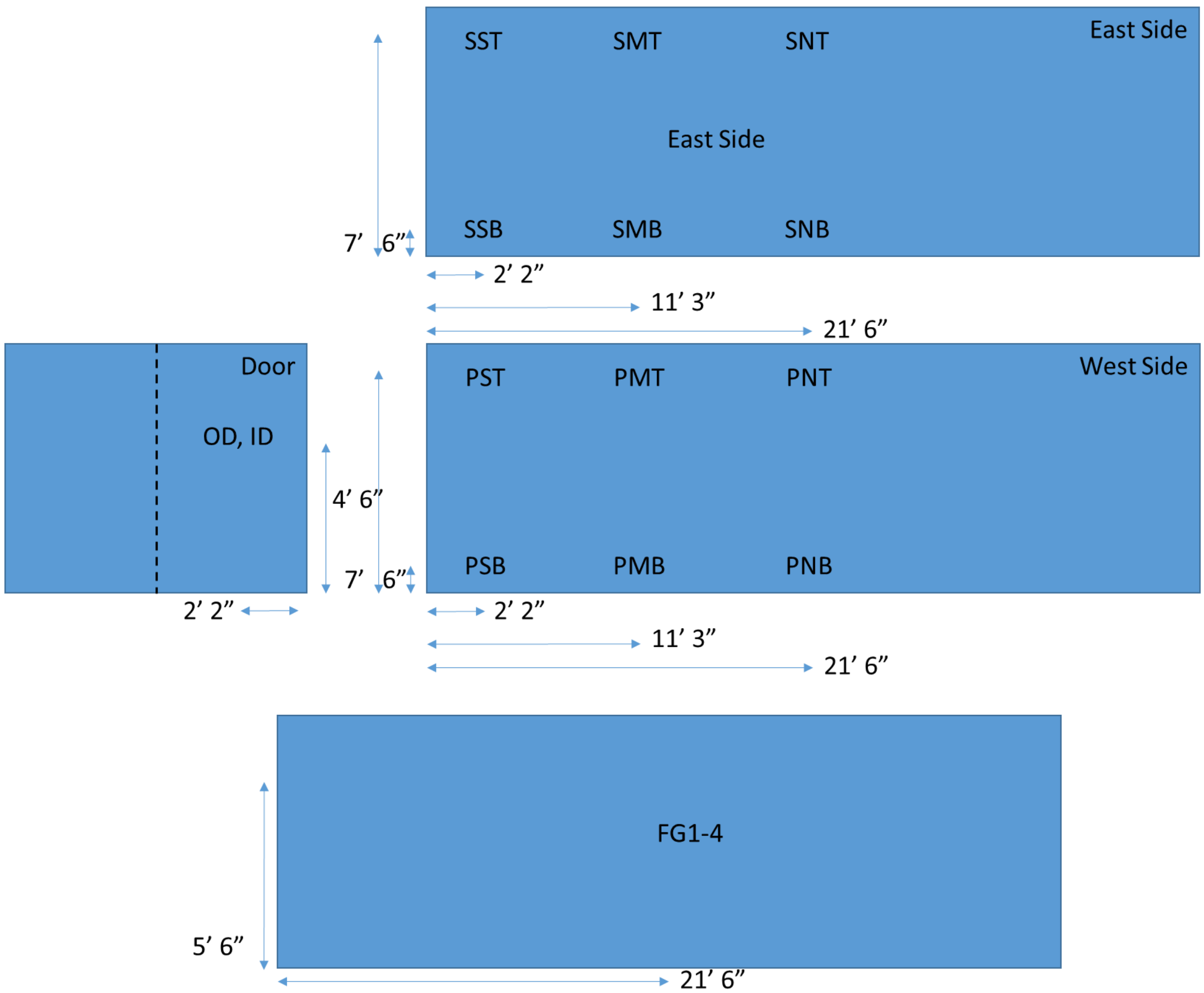
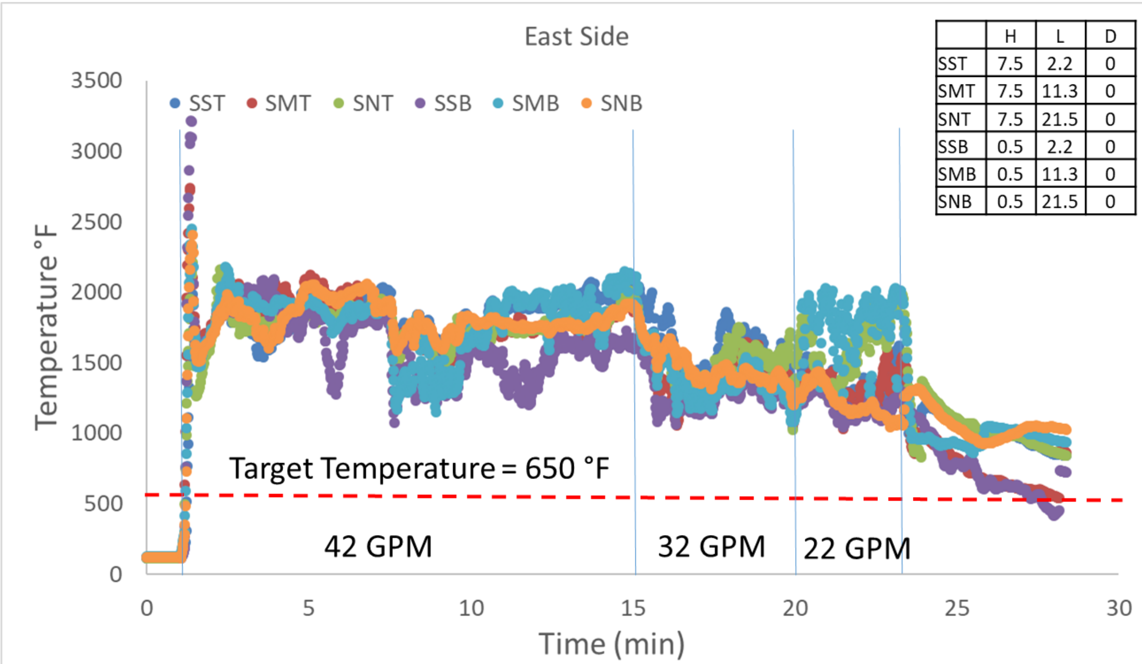
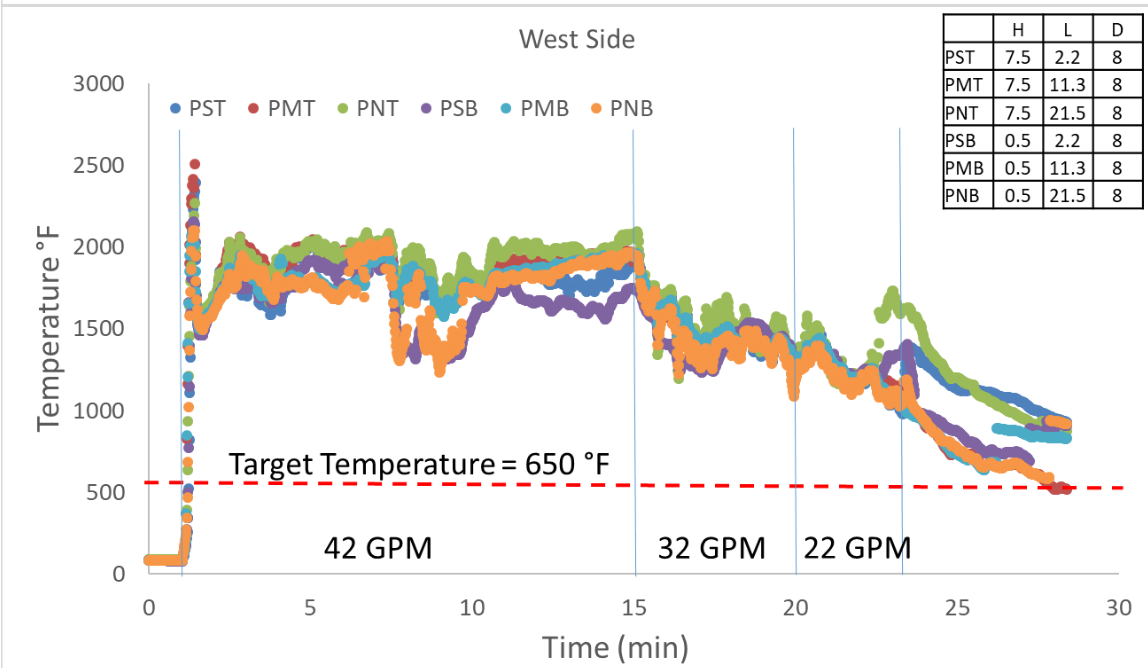


Figure 6-2. Diagram of thermocouple placement in and on the sea container.

Except for the thermocouple on the outside of the door (labeled “OD”) all thermocouples were tack welded to the inside of the container. The thick cylindrical heat flux gauge was placed at a height of 5 feet 6 inches, in the center of the container, 21 feet 6 inches from the south side (coinciding with the placement labels of PNT, PNB, SNT and SNB). Temperature data from all thermocouples are shown in figure 6-3.

Data depicted in the graphs of Figure 6-3 were collected during the final test at NAWS China Lake. The table in the inset of the charts describes the thermocouple locations, where H is the height, L is the length and D is the distance from the bottom southeast corner of the container. During this test, fuel flow rates were controlled from the pump of a fuel delivery truck. The thin walls of the container reach high temperatures almost immediately, whereas the thermally thick cylindrical heat flux gauge centered in the container away from intimate contact with flames required approximately 6 minutes to achieve decontamination temperature criteria.


East Side
H L D
SST 7.5 2.2 0
SMT 7.5 11.3 0
SNT 7.5 21.5 0
SSB 0.5 2.2 0
SMB 0.5 11.3 0
SNB 0.5 21.5 0
SST SMT SNT SSB SMB SNB
Temperature °F
3500
3000
2500
2000
1500
1000
500
0
Target Temperature = 650 °F
42 GPM
32 GPM
22 GPM
0
5
10
15
20
25
30
Time (min)


West Side
H L D
PST 7.5 2.2 8
PMT 7.5 11.3 8
PNT 7.5 21.5 8
PSB 0.5 2.2 8
PMB 0.5 11.3 8
PNB 0.5 21.5 8
PST PMT PNT PSB PMB PNB
Temperature °F
3000
2500
2000
1500
1000
500
0
Target Temperature = 650 °F
42 GPM
32 GPM
22 GPM
0
5
10
15
20
25
30
Time (min)

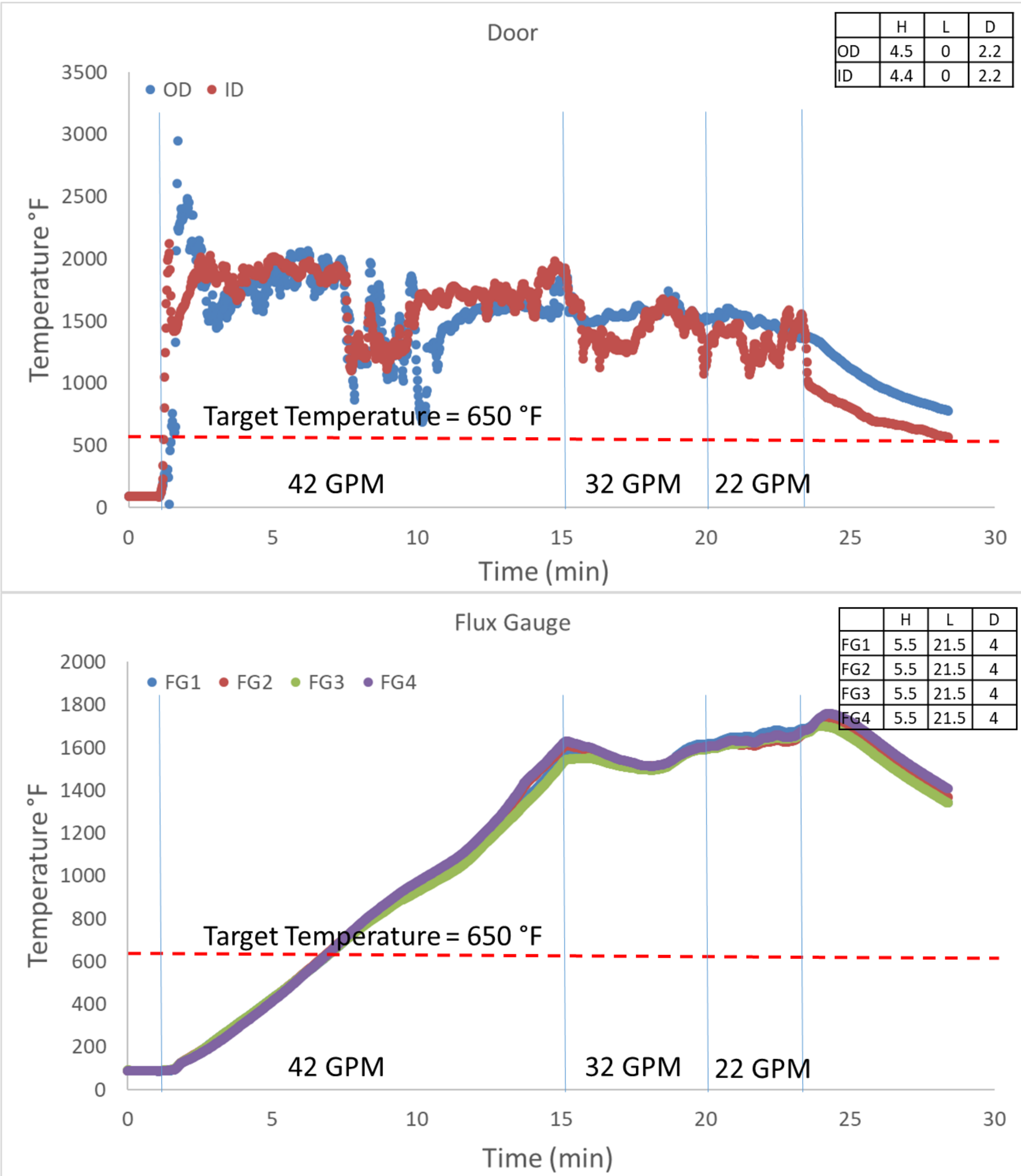


Figure 6-3. Thermocouple data.

Objective 2. Reduced emissions

Details on the emissions results are provided in a separate report by Aurell and Gullett (2021) and a short summary is provided here.

Additional samples would be required to establish reliable emissions factors from these two types of decontamination units. For the sampling event, the pallet pile was placed too close to the propane burner. This resulted in ignition of the pallet pile within a few minutes after starting to sample the propane burner emissions. Additionally, the pallet pile may have been smaller and configured differently than normal operational burns. These testing artifacts, plus the limited sample numbers, limit the confidence in the results reported below.

Two propane burns and one pallet pile burn were conducted. One $PM_{2.5}$ and one TC/OC/EC batch sample was collected for each burn. A single, composite sample for VOCs was collected from the two propane burns in order to ensure collection of sufficient sample to obtain detectable levels. The first propane burn ignited the adjacent pallet pile within a few minutes of the propane ignition. As a result, the $PM_{2.5}$ and OC/EC/TC batch samples collected from the first propane burn were excluded from the results.

The propane burner had a lower modified combustion efficiency (MCE, $CO_2/(CO_2 + CO)$) than the burning pallet piles, 0.975 compared to 0.992. Due to the wood's lower energy value the CO_2 emission factor in g CO_2/kWh fuel from the wood pallet pile burn was almost two times higher than from the propane burner. The CO emission factor was two times higher from the propane burner than the wood pallet pile burn.

The $PM_{2.5}$ and BC emission factors on an energy basis were, respectively, approximately 14 and 26 times less for the propane burner than the pallet pile burn. The propane $PM_{2.5}$ emission factor on a fuel mass basis was in the same range as previous, similar measurements. The benzene emission factor from the wood pallet burn was three times higher than the propane burner. It's not clear from the limited tests whether this was an operational issue of the burner related to the air/fuel ratio.

The propane burner emitted surprisingly high emissions of methylene chloride and of other chlorinated VOCs not found from previous similar measurements. This is certainly related to the fuel composition rather than the performance of the propane burner. These higher chlorinated VOC emissions may be a byproduct of the natural gas and crude oil refining where chlorides occur naturally or due to trace chemicals from fracking processes.

Objective 3. Reduced costs

We estimated that labor costs will be cut in half, and fuel costs will be approximately 10%, for the propane system compared to the legacy wood-fired system. Overall savings will depend on the frequency of use and local costs of fuel. Current costs of wood-fueled flashing and the labor to operate them vary from site to site, depending on the frequency of burning and the cost of wood fuel. At installations that burn regularly and can source free wood fuel, labor is the largest expense. For installations that must purchase wood fuel and perform burns infrequently, fuel is likely to be their greatest expense. Additional details about the costs are provided in Chapter 7.

Objective 4. Demonstrated "tankless" fuel delivery

During testing at China Lake, we showed that using a common bobtail propane delivery truck is an ideal means of delivering fuel to the propane burner. This approach to fuel delivery allows users of the propane burner to save money by not having to purchase or maintain fuel tanks. Furthermore, metered pumps on fuel delivery trucks provide a controllable and steady fuel flow rate. Figure 6-3 shows the temperature history of thermocouples during on-demand fuel delivery with fuel flow rates indicated along the time axis.

Objective 5. Demonstrated quick processing

Testing at China Lake as well as the demonstration at CRTDA demonstrated the time savings of the propane burner compared to wood-fueled fires. Once the propane burner is installed, there is no need to set up large amounts of wood fuel for the flashing. The instantaneous fire quickly heats up its surroundings, whereas wood-fueled fires have slow flame spread rates. Since heat up is instantaneous, the duration of the burn is essentially equal to the predetermined time-temperature governed by the materials and their thicknesses. Wood-fueled flashes are carried out over several hours. Finally, propane combustion produces no ash, which makes cleanup easier.

Chapter 7 COST ASSESSMENT

7.1 Cost model

The focus here is to estimate the cost of developing and running a clean controlled propane fueled burner for MPPEH decontamination. Although the quick removal of MPPEH has certain hazard and legacy environmental cost benefits, this will focus on the fuel and labor savings while accounting for the estimated cost of developing and installing the propane burner.

Since thermal MPPEH flashing demands vary from installation and over time, we will discuss three systems here: 1) a single burner 2) a double burner system 3) a four burner system. Systems with multiple burners are depicted in such a way that burners can be turned off if desired. Figure 7-1 depicts the main components of various system configurations.

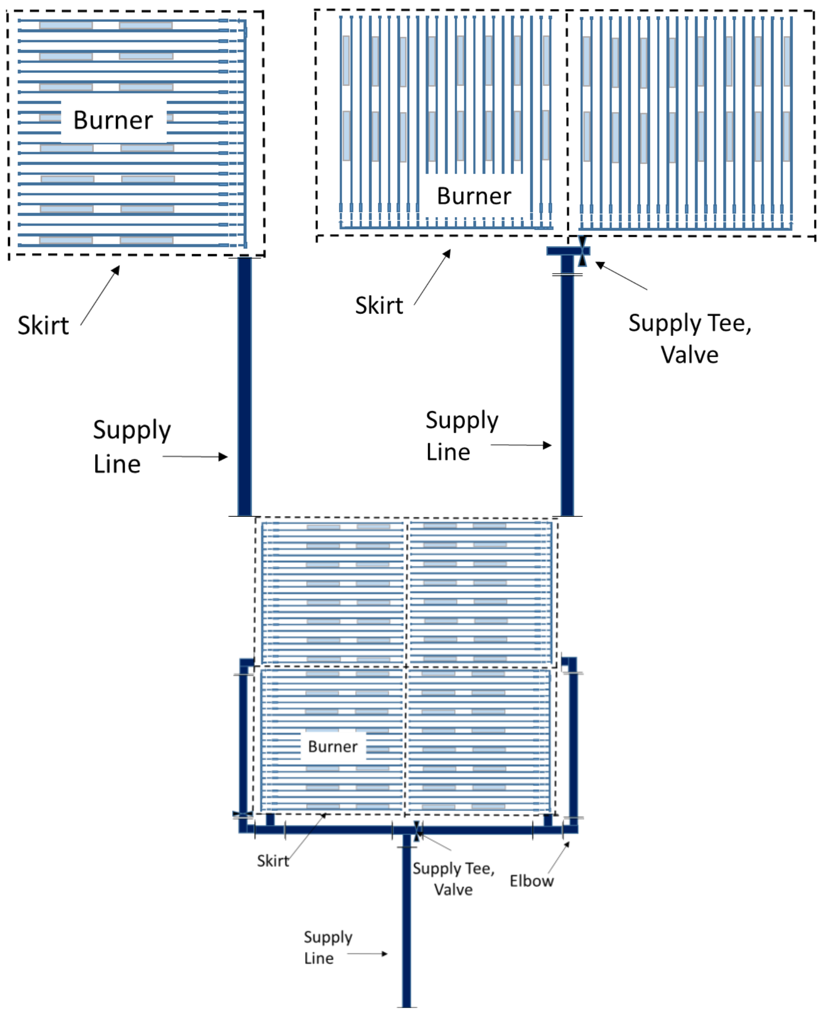


Figure 7-1. Depiction of a single, two burner, and four burner systems (not to scale).

Systems with multiple burners have inline valves allowing the operator to choose to operate select burners. Multi-burner systems will require more pipeline and pipeline components than single burner systems. During operation, the burner may be surrounded by a modular, removable skirt. Upstream of the supply line, which should total over 200 feet, there are multiple flex connectors as well as a shutoff valve near the fuel supply (not shown). Note that all the supply lines are assumed to be standard 21 foot lengths.

Equipment Costs: Perhaps the costliest portion of the system that may need to be purchased is a propane tank. Large, skidded refurbished propane tanks cost approximately $5/gallon of capacity. Depending on the site, and the size of the tank, it may be necessary to mount the tank on a concrete foundation, which would increase the price of the fuel supply system. For a system without a pump, it is desirable to have capacity far above the expected fuel required for a single burn because excess capacity in a partially filled tank results in a lower pressure drop for a given fuel flow rate and also because a given burn may require more fuel than expected. The promise of drive up delivery of fuel is probably the most affordable solution since it does not require a large initial investment or user maintenance. If burning is conducted only semi-regularly, then drive up delivery is likely to be the most cost effective solution by a wide margin. It should be noted that the nature of propane delivery is such that dispensing stations are refilled typically once or twice a week, so the occasional delivery of fuel for a fire should not incur significant delivery or labor expense. In other words, fuel delivered on demand to a live fire should not cost substantially more than fuel delivered to a tank. Ultimately the decision to purchase, lease, or pay for delivery will depend on the site and expected demand over a long period of time.

Piping Costs: There are two types of pipes on this demonstration system: 300 lb 3-inch flanged pipe that makes up the pipeline used to transport fuel from the tank to the burner and the smaller 2 inch threaded pipe that make up the burner. Both pipes are made of steel. Flanged 3-inch 300 PSI rated pipeline is approximately $600 per 21 foot section. Importantly, the prices of flanged pipe and fittings can vary significantly; large manufacturers can produce these products for much less than small shops can. Propane tanks should be at least 200 feet from the burner to ensure that the tank does not get heated by the flames. At a distance of 200 feet, it is estimated that the tank experiences a radiant heat flux much less than 1 kW/m^2 (Shokri and Beyler, 1989). The pipeline therefore will consist of at least ten 21-foot sections of flanged pipe. Importantly, small burners will benefit in terms of fuel efficiency and cost by using a smaller 2 inch flanged pipe.

The cost for the threaded burner pipe is approximately $70 for a 2-inch schedule 40 21-foot long section. The nozzles chosen for this work are very small, 0.040 inches. Nozzles are machined into the burner pipes every 6 inches and pipes are placed 6 inches apart. In this work, a burner is sized at 20x21 feet and there are 41 pipes, each with 41 holes for a total of 1681 holes per module. Because they are so small and numerous, it is not feasible to mechanically machine these holes into pipes due to cost and time. We have been able to identify only one type of tool that can produce such small holes in a reliable and automated—and therefore cost effective—manner: a large fiber tube laser. This machine is relatively specialized and we were only able to several shops that have one. The rate for machining is approximately $70 per pipe.

Pipe Fittings and Accessories: The pipes making up the burner are connected through a series of tees, nipples and unions. The ends of the burner pipes are closed off with end caps. The supply pipeline has flanged fittings including tees, elbows and flanged valves as well as flexible connectors and risers to protect the integrity of the pipeline.

Burner Accessories: Intense heat from fires will cause metal under stress to deform, therefore it is critical that the burner pipes from the effects of warping at high temperatures. A system of I-beams described in section 2-2 was used to both prevent warping and support the mass of MPPEH. Three supports, consisting of 6 inch steel I-beams and 2 inch square stock were evenly distributed lengthwise over the entire width of the burner.

The burner also benefits from having a skirt around it to limit flow shear between the fuel, which is issued at a high velocity and entrained air. While the burner can operate without a skirt, the presence of a skirt is believed to limit the leakage of unburnt fuel. For this burner, we used “landing mat” or “Marston Mat” which are sheets of corrugated steel approximately 10 feet long and 20 inches wide. Stakes driven into the ground support the skirt.

It is desirable to ignite the fire remotely and electronically. We used a 750 W cartridge heater (6 inch x ½ inch). This heater is capable of glowing red-hot and is durable. Cartridge heaters sell for approximately $45 and can likely be used several times.

It is desirable that the main fuel supply line has a pressure gauge and a valve to control upstream pressure. Pressure gauges cost approximately $60 and a high quality globe valve costs around $375.

Area and area improvements: It is assumed that the ideal location for a propane flasher is on top of current MPPEH processing sites and therefore area improvements are minimal. A burner the size of the one used in the demonstration should be 200 feet away from trees and buildings and the propane tank to ensure that the radiant flux reaching these areas does not cause thermal damage (Shokri and Beyler, 1989). The ground under the burner should be leveled so that the pipes do not warp to conform to the ground contours.

Fuel cost: Each 20 ft x21 ft burner module will consume approximately 10-20 gallons of propane per minute, depending of upstream pressure as well as the operator’s desired firepower. A typical dwell time for MPPEH decontamination is expected to be ~10-15 minutes. It is assumed that the total run time is 12 minutes since temperatures will quickly exceed the target temperature of 650 °F. The price for residential propane is approximately $2.50 per gallon (averaged using data from EIA.gov, depending on location, season).

Assembly Costs: Assembly costs are the one-time cost of assembling the burner. The process includes fitting all the burner pipes and fittings together, plumbing the burner to the fuel supply line and connecting the sections of the fuel supply line, placing the MPPEH structural support between the fuel lines, and setup of the burner skirt. It is estimated that a total of 20 labor-hours are needed to complete setup of the supply line, 16 labor-hours per burner and 4 labor-hours for the accessories per burner.

Setup and cleanup costs: The propane fueled burner will inherently save labor costs of setup and clean up, primarily because the fuel can be easily flowed from the tank rather than set in place manually or using lifting equipment as is the case in wood dunnage burning. In addition, there is no significant unburned materials remaining after the fire such as nails or ash or unburnt wood, which requires cleanup.

Maintenance/repair: We cannot accurately estimate the cost of maintenance and repair at this time. However, we expect that since this system has no moving parts and consists mostly of pipes that it should be durable over many cycles as long as care is taken to prevent resting the weight of MPPEH on the structural support at high temperatures.

Savings: The costs of wood-fueled MPPEH flashing will vary based on the decontamination demands and fuel supplies of particular installations. For example, Indian Head's CRTDA performs large infrequent burns using costly wood pallets. Other installations are able to source wood dunnage at no cost. Either type of installation would benefit from overall lower costs resulting from large reductions in labor costs by switching from wood to propane fuel. Importantly, these estimates of fuel and labor savings do not factor in the environmental and safety costs of not decontaminating MPPEH.

7.2 Cost analysis and comparison

The tables below outline the expected costs of single and multi-burner systems under multiple scenarios.

Provided in Table 7-1 are estimated tank costs, which may be too low for a tank that is required to be permanently installed. On-demand propane delivery may be the most cost-effective.

Table 7-1. Fuel consumption rates, tank sizes and estimated costs for tanks supplying three different systems.

	One Burner	Two Burners	Four Burners
Fuel Consumption (gal)[1]	240	480	960
Minimum Tank Size (gal)[2]	1,000	2,000	4,000
Estimated Tank Cost ($)[3]	**7,000**	**14,000**	**28,000**
[1] Assumes 20 gpm fuel flow rate per burner, 12 minute operation			
[2] Tank capacity is at least 4X the expected fuel consumption to account for possibility of higher fuel consumption rate, longer fire.			
[3] Assumes $5/gallon capacity and an additional 40% for install			

Estimates for fuel supply line components provided in Table 7-2 were obtained from a quote from the purchase made by the Naval Air Warfare Center Weapons Division (NAWCWD) China Lake Fire Science Laboratory. It is possible certain items can be obtained for lower prices than listed here by choosing high volume manufacturers.

Table 7-2. Fuel supply line components and cost estimates for three systems.

Supply Line 3 inch Sch 40 300# Flanged Steel	quantity	One Burner ($)	quantity	Two Burners ($)	quantity	Four Burners ($)
21 ft Pipe	10	6,000	10	6,000	14	8,400
Flanged Flex Connectors	1	1,050	1	1,050	1	1,050

Pipe Supports	20	1,000	20	1,000	28	1,400
Flanged Ball Valve	1	921	1	921	3	2,764
Flanged Tee	0	0	1	840	3	2,520
Flanged Elbow	0	0	0	0	4	1,780
Bolts, Gaskets	20	345	24	414	28	483
Total ($)		**9,316**		**10,225**		**18,397**

Prices provided in Table 7-3 were obtained from quotes from purchases made by the NAWCWD China Lake Fire Science Laboratory. It is possible that these items, can be obtained for lower prices than listed here.

Table 7-3. Pipe and accessories for the burner plumbing.

Burner Pipe	$	One Burner	Two Burners	Four Burners
21 ft, 2 inch Sch 40 Steel Pipe	70	41	82	164
Cost to Perforate	70	41	82	164
Subtotal $		5,740	11,480	22,960
Pipe Accessories				
End Caps	3.62	41	82	164
Nipples 6 inch	4.03	41	82	164
Tees	8.9	40	80	160
Elbows	6.18	2	4	8
Nipples 2 inch	2.47	39	78	156
Cross	32.63	1	2	4
Unions	15.08	41	82	164
3 inch to 2 inch reducer	47.78	1	2	4
Subtotal $		1,477	2,954	5,908
		7,217	**14,434**	**28,868**

Provided in tables 7-4 through 7-6 are estimates of burner accessories, labor costs for set-up, and grand totals of all materials and labor for the propane unit.

Table 7-4. Estimated cost for burner accessories

	$ / unit	quantity	One Burner ($)	quantity	Two Burners ($)	quantity	Four Burners ($)
Skirt (ft)[1]	5.5	84	462	123	676.5	164	902
Stakes[2]	2.25	20	45	50	112.5	60	135
Igniters	45	2	90	2	90	2	90
Structural Support (ft)[3]	664	3	1992	6	3984	12	7968
Total ($)			**2,589**		**4,863**		**9,095**

[1] Used landing mat, $1650/30 pieces (19 inch x10 foot)
[2] 3 ft long rebar, ½ inch thick
[3] 6x3.33x0.232 inch I-beam with 2x0.188 inch square stock $360 and $104 per 20 foot section, respectively. Assumes $200 in labor to weld support to I-beam. Three supports per burner module (see figures 2-3 through 2-5).

Table 7-5. Estimated labor costs for system setup

	One Burner		Two Burners		Four Burners	
	Labor (hours)	Cost ($)*	Labor (hours)	Cost ($)*	Labor (hours)	Cost ($)*
Fuel Supply Assembly	20	2,000	20	2,000	20	2,000
Initial Burner Assembly	16	1,600	32	3,200	64	6,400
Burner Accessories	4	400	8	800	12	1,200
Total	**40**	**4,000**	**60**	**6,000**	**96**	**9,600**

* Labor rates taken to be $100/hr.

Table 7-6. Sum of estimated costs for single, double and four burner systems

	One Burner System ($)	Two Burner System ($)	Four Burner System ($)
Supply Pipeline	9,316	10,225	18,397
Pipe and Accessories	7,217	14,434	28,868
Accessories	2,589	4,863	9,095
Labor	4,000	6,000	9,600
Tank	7,000	14,000	28,000
Total w/ Tank	**30,122**	**49,522**	**93,960**
Total w/o Tank	**23,122**	**35,522**	**65,960**

Since MPPEH processing is conducted infrequently at the CRTDA, the main cost benefit for NSWC Indian Head Division will be fuel savings. Provided in table 7-7 is an estimate of the expected savings for installations with similar MPPEH processing demands as the CRTDA. This estimate is for a four-burner system and assumes that the operator will not purchase a propane tank. This estimate does not take into account labor savings, which we estimate will only be about $1320 per year ($110/hour * 1 burn per year * 24 hours labor/burn for wood versus 12 hours labor/burn for propane).

Table 7-7. Savings and return estimates for a four burner system assuming low labor rates and purchased wood dunnage

Comparison of legacy versus propane-burner costs		
	Current	Propane
System Cost	0	$65,960
Annual Fuel Consumption[1]	2,168 pallets	890 gallons
Fuel Costs (Low Estimates)[2]	$21,680	$2,225
Fuel Cost (High Estimates)[2]	$30,352	$3,115
Low estimate of fuel savings (assumes low wood and high propane costs)[2]		$18,565
High estimate of fuel savings (assumes high wood and low propane costs)[2]		$28,127
Years to payback – low estimate[2]		2.3
Years to payback – high estimate[2]		3.6
[1] CRTDA expected fuel of demand is 2168 pallets annually, equivalent to energy in 890 gallons of propane (Quintiere, 2006).		
[2] Cost of pallets estimated to be $10 or $14, cost of propane estimated to be $2.5 or $3.5 per gallon.		

The net present value of the system analyzed in table 7-7 depends on fuel costs as well as the useful life of the system. At this time we cannot estimate the useful life of the system. Table 7-8 shows net present values of the system, for low and high estimates for fuel savings ($18,565 and $28,127 from table 7-7) over three different system lifetimes. The discount rate used in these calculations is 0%.

Table 7-8. Net present value of the system from table 7-7 over time

Net value of system for low usage installations that purchase wood dunnage		
	low estimate ($)	high estimate ($)
3 years	$ (10,265)	$ 18,421
5 years	$ 26,865	$ 74,675
10 years	$ 119,690	$ 215,310

The estimated costs provided in Table 7-9 are for an installation that has a free supply of wood fuel but high labor costs resulting from frequent burns. This estimate assumes that the operator will not purchase a propane tank. Estimates of labor savings are conservatively taken to be 50%. This estimate takes into account labor savings and adds in the costs of propane fuel.

Table 7-9. Savings and return estimates for a single burner system assuming high labor rates and free wood dunnage

Comparison of costs for the legacy system versus one-burner propane system costs for an installation with frequent burns and free wood		
	wood	propane
system cost	$ 0	$ 23,122
labor costs ($110/hr, 26 burns/year, 24 hours labor/burn	$ 68,640	$ 34,320
labor savings/year		$ 34,320
annual fuel consumption in gallons (26 burns/year, 12 minutes/burn/20 gpm)		6240 gallons
low fuel costs ($2.5/gallon)	$ 0	$ 15,600
high fuel costs ($3.5/gallon)	$ 0	$ 21,840
savings with low fuel costs		$ 18,720
savings with high fuel costs		$ 12,480
years to payback with low fuel costs		1.2
years to payback with high fuel costs		1.9

Table 7-10 provides the net present value of the system analyzed in 7-9 over 3, 5 and 10-year useful lifetimes assuming overall savings for low and high estimated fuel costs minus the cost of a single-burner system. The discount rate used in these calculations is 0%.

Table 7-10. Net present value of the system from table 7-9 over time

Net value of system for high usage installations that don't need to purchase wood dunnage		
	Low Estimate ($)	High Estimate ($)
3 years	14,318	33,038
5 years	39,278	70,478
10 years	101,678	164,078

While the operating costs of this system are much lower due to fuel and labor savings, a very important variable as shown in net present value calculations is the useful life of the system. At this time, there is not enough data to estimate the true life of the burner. It is expected that the propane tank (if present) and the pipeline will have very long useful lifetimes, well over 10 years. However, components that are in close contact with the fire including the burner pipes, endcaps and I-beam supports will have shorter lives, possibly much shorter. The occasional replacement of damaged burner components are an operating cost that cannot be determined at this time.

Chapter 8 IMPLEMENTATION ISSUES

The most important stakeholders are the operators of MPPEH processing sites who may be interested in adopting propane flashing either for environmental or financial benefit. Prior to using this technology, it is important that first it becomes accepted as a means of decontaminating MPPEH by DDESB for DoD-wide acceptance. DDESB has already approved the time-temperature criteria described in the Eastern Research Group report (2012) as an acceptable means of decontamination and this work demonstrated that it is capable of quickly surpassing those criteria. Any installation using a thermal method for decontaminating MPPEH should expect a DDESB requirement to use verify the time and temperature of each decontamination operation through the use of thermocouples or other measuring devices. At the local level, safety overseers will need to approve the process. Since it is expected that any properly operated propane flasher will significantly reduce emissions, occupy the same space as previous MPPEH processing operations, and save money in the long term, the major potential obstacle to adoption is propane storage near flashing operations. Although propane storage and usage is safe, there must be approval to install propane infrastructure or approve on-demand delivery.

Propane flashing is more cost effective and generally produces fewer emissions than wood-fueled flashing and there are not any serious safety concerns. However, using this method to thermally decontaminate MPPEH does not capture and treat the emissions. If there is an overall interest in reducing all air emissions related to military activity, there may be some reluctance to adopt any kind of open emissions, even if it proves to be better than current methods. Alternative closed loop MPPEH processing units that capture emissions may be preferable, but are sometimes prohibitively expensive. Transporting MPPEH to centralized locations to be thermally decontaminated is not feasible since MPPEH cannot be shipped over the roads for safety reasons (DoDI 4140.62, 2017).

The main technical issues with this project involve metal failure at very high temperatures. The pipeline and propane tank in this project are expected to have very long lifetimes with only small maintenance costs. However, certain burner parts become damaged after exposure to high temperatures. Specifically, burner pipes become warped and during the testing phase steel endcaps failed. In order to mitigate metal damage, we developed an I-beam support to limit warping of burner pipes and used sturdier steel endcaps on the burner. It is clear that these fixes will improve the longevity of the burner, however only through long term use can we determine true maintenance costs of the burner. The added cost of more durable burner materials, such as stainless steel, may have a positive impact on the long-term value of this burner by lowering replacement and maintenance costs.

The burner design is modular to customize for an installation's size requirements. For efficient heating and minimizing the escape of unburned fuel, it is ideal to have flames completely surround the item being flashed. A space of approximately two feet was demonstrated to be sufficient to support constant and continuous flames around the item being flashed. Therefore it is recommended that a burner be sized such that there is approximately two feet of space or more between the items being flashed and the edge of the burner.

There were several procurement difficulties during this project that can be improved upon. First, the procurement of a large propane tank was difficult and expensive. The tank used at China Lake during testing was excessively large and therefore expensive. Tank rental should probably only be used for short term operations, up to perhaps months in durations. Right-sizing the tank (see table 7-1) will help reduce the cost of purchasing or renting a tank. On-demand propane delivery is expected to be a better option of propane delivery in most cases. However, on-demand delivery may also encounter pushback. First, the delivery will take longer than a simple tank fill, and the driver and propane company would expect compensation for this delivery service. Second, it would have to be approved by safety overseers. Another issue relates to sourcing materials for the burner and pipeline. Flanged pipe and flanged fittings may be manufactured by hand and therefore can be costly. Large-scale manufacturers of flanged pipes can leverage automation to make low cost materials. The pipeline materials purchased prior to testing were found to be much more costly than those supplied by low-cost manufacturers. Buyers should be aware that very large cost savings can be achieved by identifying low-cost manufacturers of flanged pipe. Similarly, perforating the burner pipes in order to make an array of fuel nozzles is an expensive task to do manually. We think that the automated fiber tube laser is the ideal tool for this task. Although it was time consuming to identify a shop with this novel tool, the time and cost savings were well worth it. Consider for example that machining using this tool costs approximately $70 per pipe (41 holes). Even if a machinist could mechanically perforate the burner pipes as reliably as the fiber tube laser, the cost would likely be several times greater.

A single burner and excess pipes have been delivered to Indian Head's CRTDA. After gaining DDESB approval, CRTDA will have the flexibility to perform propane flashing of their stockpiled large-scale MPPEH waste. Since the legacy wood-burning unit at the CRTDA is DDESB-approved as a method to thermally decontaminate MPPEH, a change in the fuel type is not expected to present any obstacles for continued DDESB approval (K.F. Warner, DDESB, personal communication, 21 December 2020).

This burner may be adopted by any installation with a need for thermal MPPEH decontamination. It is most likely to be adopted by processors of non-combustible waste however, with some modifications it can likely be made amenable to processing combustible MPPEH if the burner can be moveable. Ultimately, the decision to adopt propane flashing requires an analysis of emissions reduction requirements, upfront costs (and long-term demand) and a comparison to alternative processing options.

Chapter 9 REFERENCES

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