Technical Report
TR-NAVFAC-EXWC-EV-1502
November 2014

ALTERNATIVE METAL HOT CUTTING OPERATIONS FOR OPACITY

Prepared by:
Edwin Chiang P.E.
Kathleen Paulson P.E.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **NOV 2014**	2. REPORT TYPE **Technical Report**	3. DATES COVERED **16-12-2013 to 17-12-2013**

4. TITLE AND SUBTITLE **Alternative Metal Hot Cutting Operations For Opacity**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Edwin Chiang; Kathleen Paulson**	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NAVFAC Engineering and Expeditionary Warfare Center,1000 23rd Avenue,Port Hueneme,CA,93043**	8. PERFORMING ORGANIZATION REPORT NUMBER **TR-NAVFAC-EXWC-EV-1502**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **Chief Of Naval Operations, Energy and Environmental Readiness Division (N45), 2000 Navy Pentagon Room 2E258, Washington, DC, 20350-1200**	10. SPONSOR/MONITOR'S ACRONYM(S) **NESDI** 11. SPONSOR/MONITOR'S REPORT NUMBER(S) **NESDI #480**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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15. SUBJECT TERMS

Shipbreaking; Opacity

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**48**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

REPORT DOCUMENTATION PAGE				FORM APPROVED OMB NO. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
30-10-2014

2. REPORT TYPE
Technical Report

3. DATES COVERED *(From – To)*
16 to 17 December 2013

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Chiang, Edwin P.E.
Paulson, Kathleen P.E.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NAVFAC Engineering and Expeditionary Warfare Center (EXWC)
1000 23rd Avenue
Port Hueneme, CA 93043-4301

8. PERFORMING ORGANIZATION REPORT NUMBER
TR-NAVFAC-EXWC-EV-1502

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Chief Of Naval Operations
Energy and Environmental Readiness Division (N45)
2000 Navy Pentagon
Room 2E258

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					Edwin Chiang
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
U	U	U	SAR	48	(805) 982-5284

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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Navy Environmental Sustainability Development to Integration Program

ALTERNATIVE METAL HOT CUTTING OPERATIONS FOR OPACITY

NESDI Project Number 480

Edwin Chiang P.E.
Kathleen Paulson P.E.

NAVFAC EXWC

FINAL REPORT

NESDI Program

Final Report

Alternative Metal Hot Cutting Operations For Opacity

Project # 480

November 2014

Submitted By:		
	Edwin Chiang, Principal Investigator *NAVFAC Engineering and Expeditionary Warfare Center, EV11*	Date
Reviewed By:	Name *Internal Reviewer(optional)*	Date:
Reviewed By:	Name *TDWG Member*	Date
Reviewed By:	Name *TDWG Member (optional)*	Date
Approved By:	Name NESDI Program Manager	Date:

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ACRONYMS AND ABBREVIATIONS

AUL	Authorized Use List
CFH	Cubic Feet Per Hour
COTS	Commercially Off The Shelf
EPA	Environmental Protection Agency
EWI	Edison Welding Institute
GHG	Green House Gases
GSA	General Service Administration
HAZ	Heat Affected Zone
HS	High Strength
HY	High Yield
IDR	Initiation Decision Report
IPM	Inches Per Minute
MAPP	Methylacetylene-propadiene
mils	Paint thickness measurement- 1/1000 inch
MRR	Material Removal Rate
NAVFAC EXWC	Naval Facilities Engineering and Expeditionary Warfare Center
NCMS	National Center for Manufacturing Sciences
NESDI	Navy Environmental Sustainability Development to Integration
NOV	Notice of Violation
OFC	Oxy-fuel Cutting
OCCU	Opacity Control Containment Units
PM	Particulate Matter
PSCAA	Puget Sound Clean Air Agency
PSNS & IMF&IMF	Puget Sound Naval Shipyard & Intermediate Maintenance Facility
SCF	Standard Cubic Feet
Std dev	Standard Deviation

ACKNOWLEDGEMENTS

MagneGas™ Corporation was a partner in this demonstration and supplied the alternative fuel used in the demonstration. More importantly, they provided a significant amount of research and development work gratis. Thank you for your hard work in developing a product that can be demonstrated while complying with Navy safety regulations.

Special thanks to Lenny Blocher, Tony Corso, Tim Lunsford, and Ken Hoy for your diligent work and for providing the material and resources to conduct this demonstration. Without your help, this demonstration would not have happened.

EXECUTIVE SUMMARY

Puget Sound Naval Shipyard (PSNS & IMF) is the only location authorized to cut, dismantle, and recycle U.S. nuclear ships and submarines. The primary metal cutting technology is oxy-fuel torching. The shipyard must comply with the Puget Sound Clean Air Agency's 20% opacity rule or face a Notice of Violation. When shipyard personnel are cutting ships or submarines, they must not generate emissions greater than 20% opacity for more than 3 minutes in any 1-hour period. During ship cutting operations, the 20% opacity limit can be easily exceeded, depending on the condition and type of vessel being cut (e.g. painted, rusted, submarine piece with rubber). To continue ship cutting operations while complying with the air permit, the shipyard is cutting underneath a tent and, in some situations, is halting operations. Ship cutting underneath tents is not a long-term solution for safety concerns under windy climates and constantly moving the tent slows down production.

In March 2012, NAVFAC EXWC released an Initial Decision Report (IDR) with a recommendation on hot-cutting technology that may reduce the amount of opacity emitted to less than 20%. The hot-cutting technology recommended in the IDR was selected for a demonstration and validation by the NESDI Program. The demonstration took place at PSNS & IMF in December 2013. The purpose of the testing was to determine whether the alternative fuel would prevent the 20% opacity exceedance during ship cutting while maintaining production standards. The testing consisted of 32 test cuts, each approximately six feet in length. Sixteen cuts were performed using the alternative fuel and 16 cuts were performed using propane. Opacity, cutting speed, kerf width and fuel efficiency data were recorded for both the alternative fuel and propane. Test cuts were on 9/32" steel surface ship sections with additional demonstration cuts performed on thicker surface ship sections and 2" high yield strength steel submarine pressure hull as the pieces became available. The results from the demonstration are shown in the table below:

December 2013 Demonstration Results.

Parameter	Alternative Fuel	Propane
Average Opacity (%)	1.82%±2.73	2.00%±2.83
Cutting speed (inches/minute)	24.5 inches/minute±4.1	30.8 inches/minute±4.0
Kerf Width (inches)	0.191 inches±0.019	0.193 inches±0.042
Fuel Efficiency (inch/ft^3 gas)	33.9 inches/ft^3±7.8	175.8 inches/ft^3±23.9
Ease of Use	Easy	Easy
Cost	26% more than propane	Baseline

From the demonstration, it was determined that the alternative fuel did not significantly produce less opacity compared to propane. Propane was also superior in cutting speed and fuel efficiency. Edison Welding Institute also evaluated the performance of the gas and determined that it cut much faster than propane. However, the test conditions were different from the conditions at the demonstration. Under the right conditions, the alternative fuel will cut faster. Based on the Navy's results, the alternative fuel will not be included in the toolbox of different approaches to recycle ships to comply with the opacity limits.

1.0 INTRODUCTION

1.1 BACKGROUND

Puget Sound Naval Shipyard and Intermediate Maintenance Facility (PSNS & IMF) is the U.S. Navy's designated site for breaking and recycling nuclear powered submarines and nuclear powered surface ships. The main air pollution generator during this mission is the oxy-fuel metal cutting, a hot combustion process that forms visible particulate matter (PM) emissions. Since the beginning of its program in 1990, PSNS & IMF grew dependent on oxy-fuel gas cutting (OFC) for the advantages in its fast cutting rate and the overall availability in both infrastructure and supply. However, despite these advantages, the use of OFC torches are currently restricted to cutting clean steel or to use within enclosed areas, since the process is also responsible for fugitive PM emissions and opacity. In November 2008, the site received a written warning for exceeding the state's 20% opacity limit. To ensure it does not repeat similar violations in the future and receive a Notice of Violation (NOV), PSNS & IMF is actively seeking to identify (or create) and demonstrate alternative cutting technologies to integrate into their cutting protocol.

Currently, there is no known single technology that meets all of the performance and usability capabilities of OFC without generating opacity. The ultimate solution is likely to be a "toolbox" of many technologies. The site's first addition to the toolbox was to utilize large fabric tents (connected to large ventilation systems) to enclose areas of submarines in the dry dock to prevent the release of smoke thereby preventing opacity violations. Their secondary effort was the search for new technologies and the funds to acquire and demonstrate their use. In 2009, PSNS & IMF submitted a NESDI need as a part of its approach to a systematic acquisition of new metal cutting tools. The site's goal was to identify tools at various stages of development (prototype to commercially-off-the shelf [COTS]) with similar performance specifications (i.e., lineal cutting speed), but lower in opacity, to that of OFCs such as propane.

In best practice, new technologies should be demonstrated in order to determine future acquisition. Its availability and capability for seamless integration with the site's protocol must be evaluated in order to ensure no interruption in mission readiness. Demonstration and validation is the topic of this project. This project seeks solution by modification of the existing OFC technology with the potential to improve the supply infrastructure and increase environmental stewardship in supplement to compliance with the Puget Sound Clean Air Agency's (PSCAA) 20% opacity rule.

1.2 REGULATORY DRIVERS

The need to comply with PSCAA's 20% opacity rule generated this NESDI need. PSNS & IMF has already received a warning for exceeding the 20% opacity rule, and the shipyard needs to explore new technology and practices to ensure compliance with the opacity requirements.

1.3 OBJECTIVE OF THE PROJECT

The purpose of NESDI Project No. 480 was to demonstrate and validate the potential benefits expected from the addition of the alternative hot-cutting fuel to the protocol at PSNS & IMF as fuel gas for the OFC torches other than propane. (Throughout this document, the hot-cutting being demonstrated is identified as the alternative fuel.) The objectives included comparing an alternative fuel with propane gas cutting performance and opacity. The following was evaluated:

- Opacity of the alternative fuel compared to propane
- Operational performance (e.g. cutting speed, kerf volume, fuel efficiency) compared to propane
- The employees' rating in its ease-of-use is similar to that of any other OFC torch
- No significantly negative impact on the current operational (i.e., personnel safety) and maintenance economics (i.e. requirements for infrastructure change)

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

The second generation of the alternative fuel is mostly hydrogen and nitrogen with minimal amount of methane and acetylene. The first generation was not permitted, by PSNS & IMF Safety C/106, to be demonstrated on-site due to the levels of carbon monoxide in the gas. The company developed, at no-cost to the Government, the second generation of the alternative fuel with no levels of carbon monoxide. The alternative fuel can be used in OFC torches as a drop-in replacement of conventional fuel gases, namely methylacetylene-propadiene (MAPP) and propane. The alternative fuel is created via plasma gasification, where the liquid industrial waste (e.g. ethylene glycol, a popular anti-freeze substance) flows through an electric arc. The electric arc breaks down the liquid waste and forms the alternative fuel and plasma. The waste diversion aspect yields the product appropriately as a “green” alternative for use in OFC torches. This demonstration only compares the end product with currently used cutting fuel and does not evaluate the industrial waste recycling process. Other potential products for the generated alternative green fuel include fuel for vehicles and stoves, as shown in Figure 1, Schematic for the Gas Production Process. The Edison Welding Institute (EWI) laboratory testing showed the alternative fuel emits less green house gases (GHG) than propane, and it has the potential to enhance compliance with air pollution and clean water requirements when used in combustion processes. To specifically investigate its visible PM emissions in metal cutting, in 2011, the first generation of the alternative fuel was tested in a laboratory setting by the National Center for Manufacturing Sciences (NCMS) and EWI following the recommendation by NESDI in the Initial Decision Report (IDR). (The IDR was an initial NESDI project on ship recycling prior to this project). Since then, other industries have also begun using the first generation alternative fuel, not necessarily for opacity mitigation, or as a greener alternative (in recognition of production lifecycle), but as an available supply to fuel OFC torches.

On December 8, 2012, the company sponsored an Industry Day at a local salvage yard in Tacoma, WA attended by representatives from the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC), PSNS & IMF and NCMS (Figure 2). The alternative fuel performance for both speed and opacity emissions visually appeared better than those for propane.

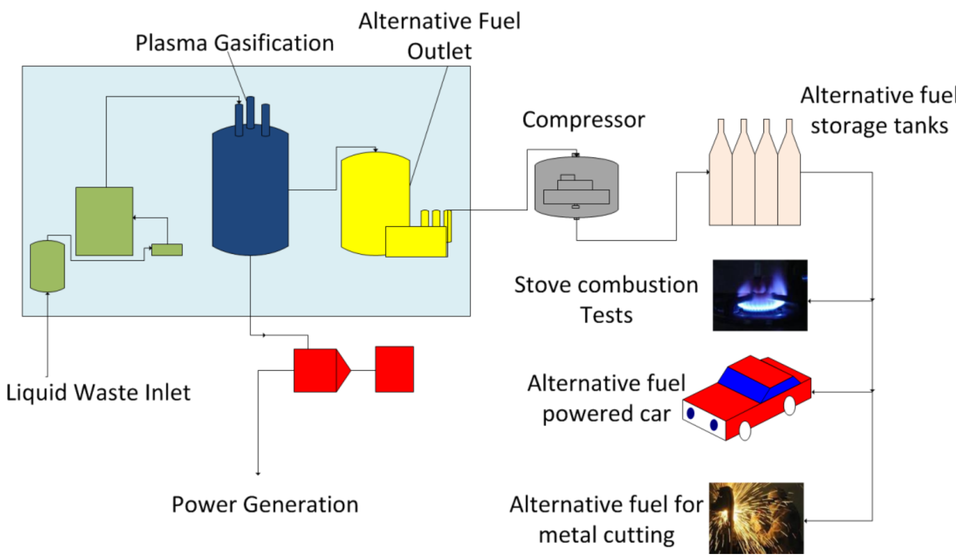


Figure 1: Schematic of the Gas Production Process.

Figure 2: Demonstration of the Alternative Fuel during Industry Day, Tacoma, WA.

2.2 TECHNOLOGY DEVELOPMENT

Prior to this project, a separate study (IDR also funded by NESDI) investigated various types of technologies that could be used for shipbreaking. From the study, two technologies were selected that were deemed useable by the Navy to dismantle ships and meet the 20% opacity limit. One technology was hot-cutting while the other was a cold-cutting type technology. Details concerning the study can be found in the IDR. The hot-cutting technology selected in the IDR is the same technology identified for demonstration in this project.

During the project, the first generation alternative fuel was not approved for the demonstration by the host base safety personnel due to carbon monoxide as a component of the gas. The project was halted indefinitely while the company developed a new gas that did not contain carbon monoxide. During that time, the company used its own funding (i.e. not NESDI funding) to modify the fuel production process. After 8 months, the company developed a new gas, the second generation alternative fuel, which had no carbon monoxide. The base safety approved of the gas and the project was restarted.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 Advantages

To the best of the team's knowledge, PSNS & IMF is the first and only ship recycling facility that has been affected by a regulatory opacity limit. Currently, the alternative technology in-place, Opacity Control Containment Units (OCCU), (i.e. portable, fabric tents with large ventilation systems) were designed to capture and filter the smoke produced from thermal cutting operations during submarine recycling only. The tents prevent the opacity limit from being exceeded during submarine hot-cutting. Despite these benefits, the alternative technology has its limitations too (See Section 2.3.2).

The current cutting technology is oxy-fuel torch cutting with propane as the fuel. The advantage of this fuel is that it cuts fast (12 inches per minute), is cheap, and the [Shop 26] mechanics know how to use it.

The alternative technology identified for this project was the alternative fuel gas for hot-cutting. From this project, the proposed benefits to the Navy are:

1) ***Sustainability***. Availability of the alternative fuel will increase the cutting options and contribute to the prevention of work stoppage in the event of untimely depletion of propane.
2) ***Environmental compliance***. If the field tests reveal greater efficiency, performance, or lower opacity (in comparison to propane), the site may be able to lower its opacity by increasing the use of the alternative fuel and decreasing the use of propane. The volume of cutting transitioned from hot cutting to cold cutting will mean a decrease in overall opacity at PSNS & IMF.
3) ***Potential opportunity to contribute to waste management***. PSNS & IMF may be able to contract for continuous supply of the alternative fuel. Local production of the alternative fuel may also turn out to be an option, with the additional benefit to recycle disposable antifreeze, oily bilge water, and other appropriate industrial spent chemical – at best, this may result in reduced capital and O&M and infrastructure costs.

As air quality regulations become stricter, any large-scale metal cutting facility or installation (e.g. demilitarizing aircrafts, tanks) may become potential customers for alternative torch gases.

2.3.2 Limitations

Although the OCCUs have proven to be effective, they do have drawbacks. During windy conditions, they cannot be moved without the risk of being blown over, which is a safety hazard. In addition, setting up and moving the OCCUs to cut each section of submarine can be a time consuming and tedious process. More importantly, the OCCUs are limited for submarine cutting only and not for aircraft carrier cutting because the tents are not large enough to cover an aircraft carrier. A larger OCCU that could cover the aircraft carrier is not feasible due to portability, movement, storage concerns and high costs.

The primary limitation of propane is the opacity that is generated when propane is used to cut submarines and ships. The 20% opacity can easily be exceeded, and when the opacity limit is exceeded for more than 3 minutes in 1-hour, the work must stop. This issue of opacity is the driver for this NESDI need. Therefore, an alternative cutting technology is being sought to replace propane or limit propane usage to cuts that do not exceed the 20% opacity. Major costs to be considered for using propane include NOVs and work stoppage i.e. dollar value of productivity lost due to opacity exceedance.

Upon conducting the demonstration, several performance limitations were realized that were not known prior to the demonstration. The alternative fuel cuts slower than propane and the opacity generation was on-par with that of propane. More details on the performance assessment of the fuel are in Section 6. Other than performance limitations, there may be a supply limitation as well. Currently, the second generation of the alternative fuel is created from virgin methanol instead of the original virgin ethylene glycol. The reason for this switch was because the original fuel included carbon monoxide in its composition, a molecule that the host base disapproved. Whether the supply of the alternative fuel is continuous in the long-run is uncertain.

3.0 PERFORMANCE OBJECTIVES

Satisfying the 20% opacity limit is only one of the performance criteria. The ship cutting personnel must also meet the demand of the workload. Average cutting speed of oxy-fuel cutting torches is about 12 inches per min at PSNS & IMF, which is the site's working standard. Propane has proven its ability to meet this rate since its acquisition by the site in 2011, and the alternative fuel must meet the standard as well. Performance will be assessed by using both the calculated operational performance values and the employees' technical feedback on usability. A successful demonstration will reveal no negative impact on the site's ability to meet the Navy's mission readiness. However, the actual recommendation will depend on both the performance and (if applicable), the site's ability to fund any necessary upgrade to the current infrastructure (i.e. new regulators). In addition to evaluating the fuel performance, an assessment of the company's ability to supply a consistent quantity and quality of fuel gas to support the programs need is necessary prior to long-term procurement.

The objectives listed in Table 1 will be used to compare the performance between propane and the alternative fuel.

Table 1: Performance Measurement Basis for the Alternative Fuel vs. Propane.

Performance Objective	Data Requirements	Success Criteria
QUANTITATIVE		
Cutting Speed	Stop watch time to cut X inches per run	Cutting speed of alternative fuel > Cutting speed of propane
Kerf Volume	Cut length, kerf width, thickness	Kerf volume of alternative fuel > Kerf volume of propane
Energy usage	All raw energy values should be in cu ft of fuel usage, but efficiency will be yielded in units of cu ft (gas) per lineal inch cut and cu ft (gas) per cu inch cut.	Consumption alternative fuel plus oxygen < Consumption of propane plus oxygen
Opacity	Average opacity per run	• Average alternative fuel opacity < 20% • Average alternative fuel opacity < propane opacity
QUALITATIVE		
Ease of use, adaptability	Note any differences between the use of two gases, for example: • Any need for new equipment to accompany use of alternative fuel? • Difference in fuel consumption? • Difference in cut initiation i.e. how fast the hull plate comes up to cutting temp • Differences in how well the torch pierces a plate for hull cutting. • Difference in material compatibility.	Workforce team generally agrees alternative fuel is easy to use compared to propane
Cost	Note any differences in gas cost, understanding that the cost may come down when bulk purchases are made. How many lineal feet will a bottle of the alternative fuel cut when compared to propane Note differences in *true cost* in particular any additional labor costs	Economic impact upon replacement with alternative fuel is negligible to PSNS & IMF's interests

4.0 FACILITY/SITE DESCRIPTION

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The demonstration site is at PSNS & IMF located in Bremerton, WA. The site was focused on ship construction during World War I, and then the focus was on both U.S. and allied ship repairs during World War II. Since the end of World War II, the site took on the role of modernizing carriers, including converting conventional flight decks to angled decks. In the 1950s, the site's primary role changed again to focus on building a new class of guided missile frigates and support ships. Then, in the mid-1960s, it began the routine overhaul and refueling of Navy nuclear submarines.

The current recycling program started in 1990. The site performs the U.S. Navy's function to design, build, operate and recycle nuclear powered vessels. The site has always recycle ships and submarines with consideration for possible environmental impacts. However, its goals for mission readiness coupled with the stricter enforcement of environmental compliance by the regulators resulted in a warning in 2008 for exceeding PSCAA's 20% opacity limit during metal cutting operations. Instead of seeking exemption, the site addressed the problem by seeking assistance from government and private engineering centers to identify and acquire appropriate technologies that may help to meet both performance and compliance goals.

4.2 SITE FEATURES

PSNS & IMF has indoor facilities and dry dock areas designated for metal cutting. Much of the submarine recycling is performed under OCCUs. The size of the OCCUs is just large enough to enclose sections of the submarines. In the future, hull sectioning on the larger ships is expected to be performed outside OCCUs. The preference is to maximize cold-cutting on any part of the ships that cannot be enclosed until the pieces are small enough to be moved to either the indoor facility or enclosed areas.

5.0 TEST DESIGN

Due to the composition reformulation requirement of the initial alternative gas and a corresponding schedule delay, the original test plan was significantly modified. In addition, the original testing period was reduced from 6 months to 1 week. The criteria used in this demonstration to measure performance are opacity, cutting speed, kerf volume, and fuel efficiency. Table 2 summarizes the data and calculations required for comparing the performance of the alternative fuel to the performance of propane. All data was analyzed for average, error analysis, or standard deviation.

Table 2: Overview of Data for Comparative Analysis.

Parameter	Material	Raw Data	Total # of Runs	Calculation, Statistical Form
Opacity	Surface Ship	EPA Method 9A Test (%)	16 cuts of 72" (nominal) cuts per gas with a total cut of (about) 96 linear feet per gas	No derived value, but the tester must be certified
Cutting Speed,	Surface Ship	Cutting length (inches); duration of cut (min:sec)		Speed = Length/duration
Kerf Volume (steel volume)	Surface Ship	Kerf width (inches), cut length (inches) and depth (inches)		Kerf Volume = width x depth x length
Material Removal Rate	Surface Ship	Steel Volume; Duration of cut		MRR = Volume/duration
Heat Affected Zone (pre-heat)	Surface Ship	Width of burnt paint (inches) x cut length (inches)		HAZ = width x length
Heat Affected Zone (torch side)	Surface Ship	Width of burnt paint (inches) x cut length (inches)		HAZ = width x length
Heat Affected Zone (back side)	Surface Ship	Width of burnt paint (inches) x cut length (inches)		HAZ = width x length
Pre-heat Period	Surface Ship	Pre-heat time (sec) before cutting begins		

5.1 CONCEPTUAL TEST DESIGN

During testing, PSNS & IMF ship cutters alternated the use of the alternative fuel and propane. The purpose was to allow the workers to compare the performance of the two fuels side-by-side. Each run consisted of cutting straight for 72 inches. The operational cutting speed should be the highest at which the personnel can operate comfortably. A total of 16 runs were conducted per material per fuel, and the total linear foot to be cut per material per fuel was 96 feet. During each run, the following parameters were recorded: opacity, non-stop cutting time, kerf volume, and fuel consumption.

Although there may be an optimal torch, tip, and mechanic combination, this test did not include finding the best configuration due to a compressed demonstration schedule. For both the alternative fuel and propane, workers used the Harris 62-5E “Low Flow” torch with torch tip #4. The testing was conducted on 9/32” ordinary strength steel bulkhead section from the ex-CGN-9 and, if possible, 2” high yield strength steel (HY80) submarine pressure hull. Submarine sections have asbestos mastic on the interior surfaces and rubber residue on the exterior that needed to be removed prior to hot cutting. During typical operations, the asbestos is removed but the rubber is not, and a tent captures the emissions that are released. Personnel at PSNS & IMF state that rubber residue on the submarine sections is the source of the emissions, and most likely the alternative fuel will not alleviate the emissions problem. To conduct an unbiased test on the submarine sections, the sections would have to be cleaned of the rubber residue, which is a very painstaking and time consuming task. If the man-power is available as well as time, then the alternative fuel and propane would be used to cut the submarine sections. Also because of limited time, the cleanliness of the metal sections (i.e. painted, clean or rust) would not be controlled. However, it would be good scientific practice to note the information.

Opacity determination is the primary focus of this demonstration and readings will be taken during each step of the demonstration. Opacity will be taken every 15 seconds using EPA Method 9A according to PSNS & IMF policy. The opacity and other emissions data such as emission color, background color, ambient temperature, relative humidity, etc. will be recorded on The Visible Emission Observation worksheet shown in Appendix B. The average opacity produced by alternative fuel and propane will be compared to determine the best emission performance.

Another objective of this test is to compare the operational performance of the alternative fuel to the operational performance of propane (e.g. cutting speed, kerf volume produced and fuel efficiency). The operational parameters were calculated per run and an average value was determined per parameter per fuel. Therefore, the parameters per fuel can be compared directly. The time and opacity data was collected during each run; however, distance measurements and calculations to determine the values will be done post-testing. The worksheet in Appendix B was used to collect the opacity data for each of the 32 cuts. The worksheet in Appendix C was used for collecting the real time data during the test, and the worksheet in Appendix D was used for collecting post-test data. Lastly, the schematic of the cutting plan is shown in Appendix E.

5.2 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The functional layout for the equipment used during this testing is depicted below in Figure 3.

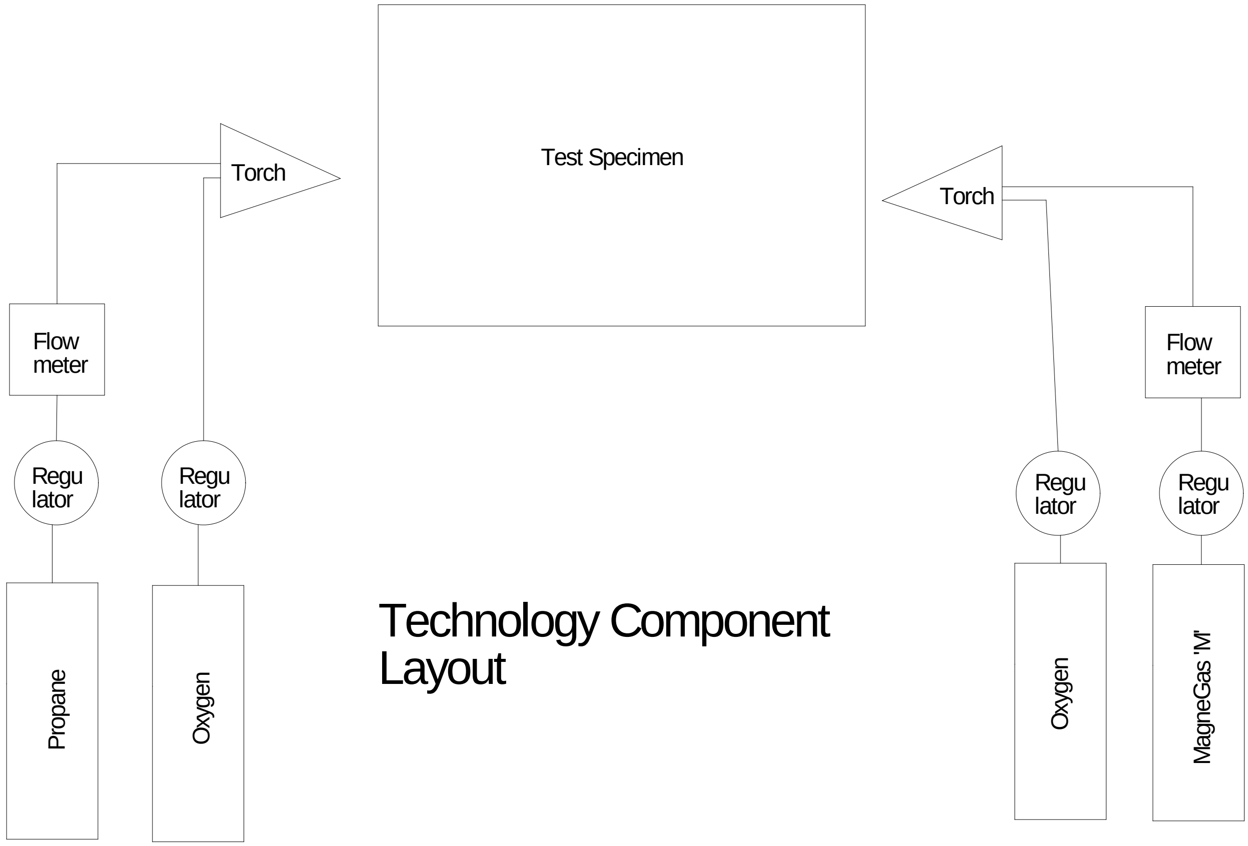


Figure 3: Equipment Layout of the Test Site.

The propane cylinder is the PSNS & IMF standard cylinder. The propane pressure is regulated with the standard PSNS & IMF propane regulator.

The oxygen is provided from a hard piped manifold, and the oxygen regulators are the standard PSNS & IMF models.

The alternative fuel cylinder is a 210 standard cubic feet (scf). The composition of the gas is hydrogen (55 – 65%), nitrogen (30 – 35%), acetylene (3 – 5%), methane (2 – 4%), trace gases (.5 – 1%), and water vapor (1000 – 2000 ppm).

The gas pressure is controlled with a hydrogen regulator, and propane and the alternative fuel flow are measured with identical flow meters. The alternative gas flow meter is calibrated for the gas formation H_2=62.5%, N_2=32.5%, CH_4=3%, C_2H_2=2%. The specification sheet for the flow meter is located in Appendix F. Up to 30 different process gas mixtures can be precisely measured.

The torches are low flow models equipped with Harris #4 tips. This torch was recommended for further testing by EWI. The Harris #4 tips have an orifice size of 0.0935 inches which is slightly larger than the size of Victor #5 (0.089 inches) tips in use for PSNS & IMF recycling operations.

The test specimen was a 9/32" thick bulkhead section from the ex-CGN-9. Paint thickness varied from 7 – 8 mils (1/1000 inch) on the front side and was 6 mils on the backside (See Figure 4).

Figure 4: Test Specimen. Photograph by Kevin Tosh.

5.3 OPERATIONAL TESTING

The testing was conducted 16 –17 December 2013. The following visiting groups were present at the kick-off meeting: alternative fuel representatives (Jack Armstrong and John McElroy), NCMS (Dana Ellis), NESDI (Kathleen Paulson and Edwin Chiang). PSNS & IMF groups included C/350 (Tony Corso, James Kershaw, Mark Sage, and Tim Lunsford), C/106 (Ann Walsh, Joe Goosey, and Danny Schroedle), Shop 26 (Leigh Thompson and Chris MacNealy), and the C/350 Process Improvement Consultant (Nick Whittleton). Production personnel included Randy Schmittler (thermal cutter) and Ed Griffin, Eddie Lopez, and Grant Boere as fire-watchers.

The testing was performed on the B980-0-01 Thermal Cutting Slab. The personnel listed above were present to observe the production personnel perform the testing (See Figure 5).

Figure 5: Thermal Cutting of Test Specimen. Photograph by Kevin Tosh.

For further demonstration purposes, the following samples were cut using the alternative fuel and propane: The submarine section (see Figure 6) of 2" HY 80 (alternative fuel cuts #33, #35, Propane #34, #36) had SHT residue on bottom side and paint on the torch side.

Figure 6: Submarine Section. Photograph by Danny Schroedle.

The large deck section (see Figure 7) was from the ex-CGN-9; the piece was upside down (non-skid on the bottom and paint on the torch side). The paint thicknesses of this deck piece varied greatly (7 – 22 mils) on the webs, but this piece does not represent a controlled sample.

Figure 7: Ex-CGN-9 Deck Section. Photograph by Danny Schroedel.

Cuts #33 - #46 should only be used for demonstration purposes (See Figure 7). The description of each cut (from #33 – 46) is listed below in Table 3.

Table 3: Cut Number with Description.

Cut Number	Description
33, 35/34, 36 (Alternative fuel/Propane)	Submarine section 2" HY 80 with SHT residue on bottom side and paint on the torch side
37/38 (Alternative fuel/Propane)	5/8" HS ship section
39/40 (Alternative fuel/Propane)	9/16" thick bulkhead, paint on torch side, bare on backside
41/42 (Alternative fuel/Propane)	9/16" thick bulkhead, bare on torch side, paint on backside (opposite from previous two cuts)
43	This cut was shut down due to excessive smoke
45/44, 46 (Alternative fuel/Propane)	5/8" HS ship section

6.0 PERFORMANCE ASSESSMENT

The testing consisted of 32 test cuts, each approximately 6 feet in length. Sixteen cuts were performed using the alternative fuel and 16 cuts were performed using propane. The length of the alternative fuel cuts averaged 70.3 inches and the length of propane cuts averaged 69.8 inches.

The opacity was measured and recorded at 15 second intervals during each cut. The cuts using the alternative fuel required 47.19 minutes to perform while the propane cuts required 36.97 minutes. The alternative fuel generated opacity that averaged 1.82% and the standard deviation (std dev) was 2.73. The propane opacity average was 2.00% (std dev 2.83). These two averages are within 1/10 of a standard deviation, which represent no discernible difference in opacity especially since the EPA Method 9A observations are recorded to the nearest 5%.

The cutting speed was calculated (cut length divided by cut duration) for each cut. The cutting speed using the alternative fuel averaged 24.5 inches per minute (IPM) (std dev 4.1). Propane cutting speed averaged 30.8 IPM (std dev 4.0). Propane cuts significantly faster.

The kerf width was measured at multiple (4 or more) locations along the length of each cut, with the estimated average kerf width recorded. Wider kerf widths are desired to facilitate easier removal of ship sections. The alternative fuel kerf width averaged 0.191 inches (std dev 0.019). Propane kerf width averaged 0.193 inches (std dev 0.042). These two averages are statistically indistinguishable.

The fuel efficiency was calculated (cut length divided by fuel used) for each cut. The fuel usage was calculated by multiplying the fuel flow (liters per minute) rate by the cut duration. The fuel efficiency is displayed as linear inches cut per cubic foot of fuel. The alternative fuel efficiency averaged 33.9 inches per cubic foot (std dev 7.8). Propane efficiency averaged 175.8 inches per cubic foot of propane (std dev 23.9). Propane clearly cuts more efficiently than the alternative fuel.

The ease of use was evaluated by asking the mechanic the difficulty of using the alternative fuel. Propane is considered easy to use by the mechanics. The mechanic mentioned that using the alternative fuel is easy, but he needed some time to practice using the gas to optimize the gas to oxygen ratio and to adjust to the “behavior” of the gas. The ease of use of the alternative fuel is considered as easy as propane to use, given time for adjustment.

The results from the demonstration are also compiled into Table 4. The explanation for how the cost is calculated is delineated in Section 7.0.

Table 4: Results from the December 2013 Demonstration.

Parameter	Alternative Fuel	Propane
Average Opacity (%)	1.82%±2.73	2.00%±2.83
Cutting speed (inches/minute)	24.5 inches/minute±4.1	30.8 inches/minute±4.0
Kerf Width (inches)	0.191 inches±0.019	0.193 inches±0.042
Fuel Efficiency (inch/ft^3 gas)	33.9 inches/ft^3±7.8	175.8 inches/ft^3±23.9
Ease of Use	Easy	Easy
Cost	26% more than propane	Baseline

The company of the alternative fuel also requested a third party to evaluate their products with respect to cutting speed and gas consumption only i.e. no opacity testing. The third party laboratory selected to complete this testing was EWI, the laboratory that was also used to test the original alternative fuel manufactured by this company. The testing and the final report were both conducted and written in 2014. The testing differed from the demonstration because different torches, tip sizes and testing protocol were used. Changing the torches or tips used may either improve or worsen the cutting performance of the gas. In the demonstration, the Harris 62-5AEL Low Flow torch equipped with Harris 6290NFF-#4 (0.0935 inch) tip was used, and in the EWI study Harris Model 98-6F torch was used with varying tip sizes depending on whether one inch uncoated or two inch uncoated was being cut. See Table 5.

Table 5: EWI Study: Gas/Tip Combination.

GAS	THICKNESS (INCH)	TIP TYPE	TIP SIZE	ORIFICE DIAMETER (INCH)
Propane	1	Harris 6290-2NX	#2	0.0656
Alternative Gas	1	Harris 6290-2NXP, ATTC NXM-2	#2	0.0644 0.0637
Propane	2	Harris 6290-3NX	#3	0.0794
Alternative Gas	2	Harris 6290-3NXP, ATTC NXM-3	#3	0.0787 0.0773

The results from the test are shown in Table 6. Quantitative conclusions cannot be ascertained about the performance of the alternative gas because of the variation in the test protocol i.e. different torch, tips, steel thicknesses, personnel were used compared to the Navy demonstration. The cutting speed of the alternative fuel in the EWI test was slightly slower than the cutting speed during the Navy test, and the fuel consumption was better in the EWI test compared to the Navy demonstration. Comparing the performance of the alternative fuel and propane in the EWI test, the alternative fuel cut faster but consumed more fuel. Propane probably performed poorer on the EWI than the Navy demonstration because the steel thickness was much greater. However, it is expected that the alternative fuel should have performed better during the Navy demonstration because the test specimen was much thinner. As mentioned earlier, several factors may contribute to the differences. The qualitative conclusions that can be deduced are that torch/tip combination and personnel can influence cutting speed, and that the alternative fuel can cut faster than propane under the right conditions.

Table 6: Performance results from EWI study.

FUEL	THICKNESS (INCH)	CUTTING SPEED (INCHES/MINUTE)	EFFICIENCY (INCH/FT^3)
Propane	1	15.0	94.5
Propane	2	16.0	107.5
Alternative Fuel	1	18.0	42.1
Alternative Fuel	2	12.5	36.3

7.0 COST ASSESSMENT

7.1 COST MODEL

This project has both capital investments and intangible benefits. Therefore, a Technology Integration and Cost Analysis (TICA) was generated from the NESDI website (See Figure 8). The cost elements for propane include capital equipment, labor and material. The same cost elements apply for the alternative fuel except with the additional cost of purchasing or constructing additional storage lockers for tanks containing the gas. Because the composition of the alternative fuel is 65% hydrogen, safety personal at PSNS & IMF classify the gas as a hydrogen fuel. Therefore, extra precautions for storage and handling must be taken. See Sections 7.1.1 and 7.1.2 for cost elements information for propane and the alternative fuel respectively. More details on the cost elements are provided later in this section. From the TICA, it is shown that the return on investment (ROI) is negative. Although the ROI may be negative, the alternative technology may still be a good option if the use of it meets the opacity limits and the intangible benefits are worth pursuing.

Two intangible benefits associated with this alternative technology include better community relations and the potential reduction of hazardous waste on-site (See Figure 9). The alternative fuel concept in general is a “green” fuel i.e. the production process converts liquid hazardous waste into a fuel and the effluent is clean water. By using this gas, the Navy is supporting renewable energy for its shipbreaking operations. In addition, if PSNS & IMF acquires this technology, it can potentially turn its liquid hazardous waste into the gas. Then the base would not need to pay for the transport and tipping fee for its hazardous waste and the base would have a continuous supply of the gas. The technology purportedly can process sewage, sludge, agricultural waste, leachates, oil based liquids and industrial waste liquids. The vendor is still researching the optimal types of oil-based liquids and industrial waste liquids its technology can handle. More research needs to be conducted to ensure that the end product is useable and safe. For example, the gas must perform better than propane and it must not contain carbon monoxide. This cost model, however, does not include the cost for acquiring the appropriate permitting under the Resource Conservation and Recovery Act (RCRA) and the National Environmental Policy Act (NEPA). Costs include the permit costs, labor costs for preparing and renewing the permits and any other miscellaneous costs associated with these permits. RCRA and NEPA may need to be satisfied if the waste-to-energy technology is implemented on-site. However, if the base only procures the alternative fuel, then these permits are not needed.

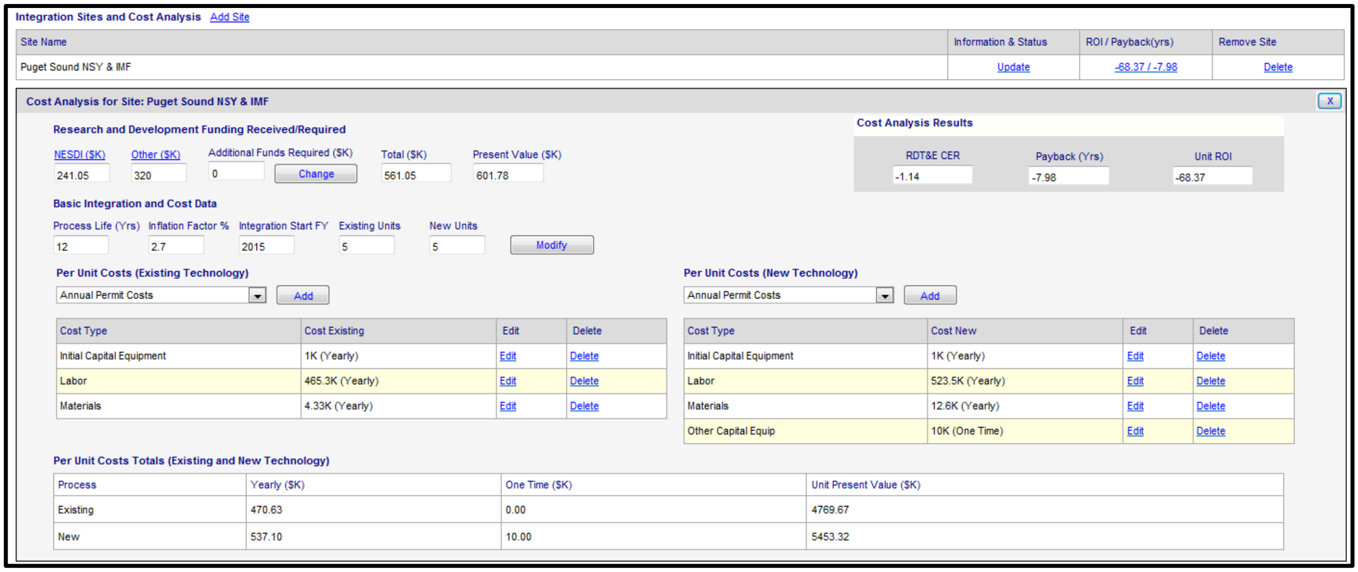


Figure 8: TICA Screenshot.

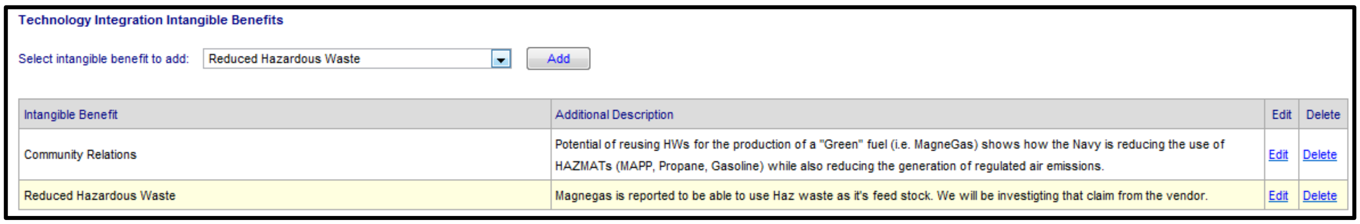


Figure 9: Intangible Benefits.

7.1.1 Cost Elements Propane

- Labor: The current labor rate is $52.75/hour and applies to those involved in thermal cutting and fire watching. For this analysis, the labor is included as the dollar value per shift. In each shift, there are on average 4.5 people working at 8 hours a day. It is assumed that only one shift occurs per day. The labor expense can be scaled up or down by increasing or decreasing the number of shifts expected to accomplish a task.

- Equipment: Each piece of equipment such as torch, regulator, respirator etc. has a shelf life before it must be replaced. For this analysis, the dollar value of the equipment per shift was calculated. The sum of the price of the equipment divided by its associated shelf life produces the dollar value of the equipment per shift. The equipment cost can be scaled up or down by increasing or decreasing the number of shifts expected to accomplish a task.

- Material: Similar to the equipment cost element, there is required material for proper shipbreaking operation. Material include propane gas, oxygen gas, torch tip, welding jackets, welding hoods, etc. Each material has a specific shelf life, and the material cost is normalized to the cost of the material per day or shift. For this analysis, the dollar value of the material per shift was calculated. The sum of the price of the material divided by its associated shelf life produces the dollar value of the material per shift. The material cost can be scaled up or down by increasing or decreasing the number of shifts expected to accomplish a task.

7.1.2 Cost Elements Alternative Fuel

- Labor: The current labor rate is $52.75/hour. This rate applies to those involved in thermal cutting and fire watching. For this analysis, the labor is included as the dollar value per shift. In each shift, there are on average 4.5 people working at 8 hours a day. It is assumed that only one shift occurs per day. The labor expense can be scaled up or down by increasing or decreasing the number of shifts expected to accomplish a task.

- Equipment: Because the alternative fuel can be used with the existing equipment, the cost of the equipment is the same as the cost of the equipment if propane were used. (Instead of a propane regulator, a hydrogen regulator is used, which is the same price as the propane regulator.) Each piece of equipment such as torch, regulator, respirator etc. has a shelf life before it must be replaced. For this analysis, the dollar value of the equipment per shift was calculated. The sum of the price of the equipment divided by its associated shelf life produces the dollar value of the equipment per shift. The equipment cost can be scaled up or down by increasing or decreasing the number of shifts expected to accomplish a task.

  An additional “equipment” cost associated with the alternative fuel and not with propane is the need for separate and additional inflammable storage lockers for the gas tanks. Because the gas is considered to be a hydrogen fuel, extra safety precautions must be taken. The storage unit either must be constructed or procured to be with the safety standards for hydrogen fuel. This cost element is necessary for implementing the technology because base safety would not approve the order of the gas without the safety precautions already in place. The additional storage lockers are one-time purchases. The minimum number of lockers would be purchased, or the proper storage would be constructed.

- Material: Similar to the equipment cost element, there is required material for proper shipbreaking operation. Special material is not required to use the alternative fuel. Material include propane gas, oxygen gas, torch tip, welding jackets, welding hoods, etc. Each material has a specific shelf life, and the material cost is normalized to the cost of the material per day or shift. For this analysis, the dollar value of the material per shift was calculated. The sum of the price of the material divided by its associated shelf life produces the dollar value of the material per shift. The material cost can be scaled up or down by increasing or decreasing the number of shifts expected to accomplish a task.

7.2 COST DRIVERS

As previously mentioned, the alternative fuel production process generates useable fuel from used liquid industrial wastes. For the demonstration, the alternative fuel was produced and delivered from its corporate office in Tarpon Springs, FL. The gas was produced with virgin material and not from used liquid industrial wastes. Currently, no GSA contract is setup to readily procure the gas. Most likely, the gas would come from Tarpon Springs, FL, in which shipping would be a significant factor. There have been discussions that another private vendor in Washington State would produce the gas from the gas’ production equipment. If this is the case, the shipping cost for the gas would significantly be reduced.

There is the option that the base produces the alternative fuel on-site at PSNS & IMF which would require acquisition of the liquid waste processing technology (either as a capital investment or through a lease). If so, the base could possibly avoid industrial liquid waste disposal and tipping fees as well as produce fuel that can be used to demolish ships. The cost savings from the tipping fees and the production of the alternative fuel may be a very attractive option. Also, by owning the production equipment, the supply of the gas would be certain. However, processing liquid waste on-site is expected to require NEPA review and consideration of liquid waste permitting requirements. Acquiring any permit(s) may significantly add more costs to use the waste-to-energy technology on-site. Costs include permit costs, labor and any other miscellaneous costs associated with permitting. Further investigation on specific permitting requirements is needed if the base is contemplating about purchasing or leasing the equipment.

Lastly, before the gas can be procured, the gas would first need to be approved by the process shop, PSNS & IMF safety, and industrial hygienists for shipboard use (the gas was only approved for non-shipboard application). In addition, separate nonflammable storage of the gas either must be constructed or purchased. The gas must be stored apart from other gases due the hydrogen composition. The additional storage is mandatory and enforced by base safety. Although the capital investment is one-time only, it is a significant cost driver.

7.3 COST ANALYSIS AND COMPARISON

This cost analysis and comparison compared the cost of using the alternative fuel versus propane to recycle two 688 Class submarines. Typically, either one aircraft carrier or two submarines are recycled at a time. From this comparison, it was determined which technology is more cost effective from a production standpoint. Although the calculation is based upon recycling submarines, similar production rates can be assumed for recycling aircraft carriers. To accurately compare the current process to other cutting processes, the process time is established as 8-hours per shift. The average cutting rate is calculated for both propane and the alternative fuel. The process requires one mechanic and 3.5 fire watches. Costs for all equipment, PPE, and expendables are prorated for one shift based upon useful life estimates.

7.3.1 Assumptions for Propane Use

The following assumptions apply to this propane cost analysis:

7.3.1.1 Cutting location

The cutting location is a 688 Class submarine undergoing recycling in dry dock #3. The typical cut defined in Figure 10 is representative of the cutting process, but it does not identify submarine design criteria. Cutting accomplished at other facilities or upon other ship platforms may be different.

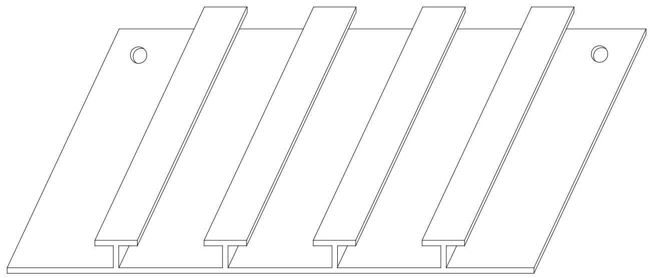


Figure 10: Sketch of Hull Section for Cutting.

7.3.1.2 Allowances

1. Allowances for unavoidable delay
   a. Allowances for miscellaneous work such as repair of equipment, removing obstructions, and renewing broken tools is not included in the standard time.
   b. Allowances for interferences not under the control of the worker, which stops progress on the job is not included in the standard time.
   c. Stand-by, which occurs when the worker is forced to wait for other personnel, is not included in the standard time. This includes delays caused by material handling. It is assumed that material handling systems would be similar for any cutting operation and would therefore not be a factor in an economic analysis.
   d. Rework is not included in the standard time.
   e. Authorized policy allowances for unavoidable delays, such as clean up at the end of shift, donning and doffing special clothing, and showers, are applied individually within the standard time.
2. Personal time.
   This is the time used by the mechanic for personal reasons such as hand washing, restroom breaks, drinking water, etc. Personal time of 14% for shipboard work is applied.

7.3.2 Cost Analysis of Using Propane to Cut Two Submarines

The following methodology was used to determine the cost of using propane to recycle two submarines. Labor, equipment and material costs were analyzed and the dollar value of using propane per shift was calculated. Next, the number of shifts required was calculated based on the cutting rate of propane. The product of the cost of per shift and the number of shifts produced a dollar figure for recycling two submarines using propane.

Cost data for material and equipment was obtained from the Central Tool Room. Useful life estimates were made by a Welding Planner and Estimator (P&E) who has working knowledge of this equipment and material. One year of useful life is equivalent to 250 work days of one shift per day.

7.3.2.1 LABOR COSTS

The production labor rate is $52.75/hour (https://homeportnw.PSNS & IMF.navy.mil/dept/600/620/Funds%20ControlReimbursable/Shop_Rates.pdf).

7.3.2.2 EQUIPMENT COSTS

Equipment costs are shown in Table 7.

Table 7: Propane Equipment Costs*.

EQUIPMENT DESCRIPTION	ITEM COST	DAYS OF USEFUL LIFE	COST PER SHIFT
Oxygen regulator	$232	1,250	$0.19
Propane regulator	$232	1,250	$0.19
Cutting torch	$453	1,250	$0.36
Propane and oxygen hoses	$148*	500	$0.30
Water hose & spray nozzle	$56*	500	$0.11
Black box	$1088*	1,250	$0.87
4 Black box hoses	$780*	500	$1.56
2 Full face respirator	$310*	750	$0.42
			Total: $3.22

* 1993 prices adjusted by inflation index of 1.612%

7.3.2.3 MATERIAL COSTS

Material costs are shown in Table 8. Per the General Services Administration (GSA) catalogue, propane gas is $3.09 per gallon and oxygen is $0.54 per gallon. The quantity of propane and oxygen consumed during one shift of thermal cutting operations is based upon the Total Thermal Cutting Man-hours (Table 8) and the average flow rates from the 2012 Victor- Cutting, Heating, and Welding Guide. The propane flow rate is 25 cubic feet per hour (cfh) and the oxygen flow rate is 345 cfh. The actual thermal cutting operation requires 4 hours of shift time.

Table 8: Propane Material Cost.

MATERIAL DESCRIPTION	ITEM COST	DAYS OF USEFUL LIFE	COST PER SHIFT
Propane gas	$0.0863 per ft^3	25 cfh * 4 hrs	$8.63
Oxygen gas	$0.0047 per ft^3	345 cfh * 4 hrs	$6.49
Torch tip	$17	250	$0.07
Air fed welding hood	$637	750	$0.85
4.5 pairs of coveralls	$50 ea	250	$0.90
Welding leather jacket	$56	1000	$0.06
Welding leather coveralls	$108 ea	1000	$0.11
Welding hood	$68	1250	$0.05
4.5 pairs of Leather gloves	$14	125	$0.50
			Total: $17.66

7.3.2.4 STEPS OF THERMAL CUTTING OPERATION

The man-hours associated with the thermal cutting and non-cutting tasks in a typical shift are estimated in Table 9.

Table 9: Steps of Propane Thermal Cutting Operation.

#	FUNCTION	MAN-HOURS
1.	Get job assignment and change clothes	0.5
2.	Hook-up regulators, hoses, breathing air, and black box	0.2
3.	Don leathers	0.3
4.	Perform morning thermal cutting operation	2.0*
5.	Morning personal time	0.56
6.	Turn-off gases, disconnect hoses, remove leathers, cool down watch (before lunch).	0.6
7.	Connect hoses/turn-on gas bottles after lunch	0.13
8.	Perform afternoon thermal cutting operation	2.0*
9.	Afternoon personal time	0.56
10.	Turn-off gas bottles, disconnect regulators, disconnect gas hoses, stow equipment, clean-up work area, cool down watch.	0.65
11.	Shower time	0.5
	TOTAL THERMAL CUTTING MAN-HOURS*	4.0
	TOTAL NON-CUTTING MAN-HOURS	4.0

7.3.2.5 CUTTING RATES

Timed studies were performed in 1993 by PSNS & IMF Code 248.34 to determine the cutting rates for HY 80 steel. In 1993 the thermal cutting process in use was high volume and the preheating gas was MAPP. Currently, the process uses smaller cutting tips and propane gas, which replaced MAPP gas. Therefore, the current cutting process is slower than the 20 IPM determined in the previous study. The specified cutting rate from the Victor Handbook for 2" thick steel is 12 IPM. PSNS & IMF uses #5 tips and the assumed cutting rate is interpolated at 16 IPM. The cutting rates shown in Table 10 are representative of the current process.

Table 10: Propane Cutting Rates.

	PREHEAT	TIME
1.	Preheat 2-inch HY80 pressure hull to start a cut at the edge	5 sec to preheat
2.	Preheat and thermal cut through 2-inch HY80 pressure hull away from an edge	20 sec to cut through
	THERMAL CUT	
1.	Thermal cut 2-inch HY80 pressure hull	44 sec/foot
2.	Thermal cut HY80 pressure hull frame including pressure hull	86 sec/frame

7.3.2.6 COST PER SHIFT SUMMARY

The cost per shift summary for propane is shown in Table 11.

Table 11: Cost Per Shift.

A.	LABOR COST PER SHIFT (4.5 workers x 8 hours x $52.75)	$1,899.00
B.	EQUIPMENT COST PER SHIFT	$3.22
C.	MATERIAL COST PER SHIFT	$17.66
		Total: $1,920.00

7.3.2.7 COST OF CUTTING

One 688 Class submarine requires approximately 10,500 linear feet of hull cutting. Therefore, two 688 Class submarines require approximately 21,000 linear feet of hull cutting. From Section E, the rate 16 IPM is assumed for this calculation. Assuming a total cut time of 4 hours per shift (i.e. 240 minutes), a total of 320 linear feet of cutting is accomplished per shift:

16 IPM x 240 minutes = 3,840 inches cut per shift = 320 feet cut per shift

Based on this rate, the number of shifts required to cut 21,000 linear feet (2 submarines) is:

21,000 feet / 320 feet per shift = 66 shifts

From Table 11 the cost per shift is $1,920, and the cost to break two submarines is calculated to be:

$1,920/shift x 66 shifts = $126,720

7.3.3 Cost Analysis for Using Alternative Fuel to Cut Two Submarines

Similar to the cost analysis conducted for propane, a cost analysis for using the alternative fuel was performed. The following analysis was used to determine the cost of using the fuel to recycle two submarines. Labor, equipment and material costs were analyzed and the dollar value per shift was calculated. Next, the number of shifts required was calculated based on the cutting rate of the gas. The product of the cost of per shift and the number of shifts produced a dollar figure for recycling two submarines using the alternative fuel.

Cost data for material and equipment was obtained from the Central Tool Room. Useful life estimates were made by a Welding Planner and Estimator (P&E) with working knowledge of this equipment and material. One year of useful life is equivalent to 250 work days of one shift per day.

7.3.3.1 LABOR COSTS.

The production labor rate is $52.75/hour (https://homeportnw.PSNS & IMF.navy.mil/dept/600/620/Funds%20ControlReimbursable/Shop_Rates.pdf).

7.3.3.2 EQUIPMENT COSTS

Alternative Fuel Equipment costs are shown in Table 12.

Table 12: Alternative Fuel Equipment Costs*.

EQUIPMENT DESCRIPTION	ITEM COST	DAYS OF USEFUL LIFE	COST PER SHIFT
Oxygen regulator	$232.00	1,250	$0.19
Hydrogen regulator	$232.00	1,250	$0.19
Cutting torch	$453.00	1,250	$0.36
Fuel and oxygen hoses	$148.00*	500	$0.30
Water hose & spray nozzle	$56.00*	500	$0.11
Black box	$1088.00*	1,250	$0.87
4 Black box hoses	$780.00*	500	$1.56
2 Full face respirator	$310.00*	750	$0.42
			Total: $3.22

* 1993 prices adjusted by inflation index of 1.612%

7.3.3.3 MATERIAL COSTS

Material costs are shown in Table 13. Per the corporate office and GSA catalogue, the alternative fuel costs $0.08 per cubic foot and oxygen costs $0.54 per gallon respectively. The volume of the alternative fuel and oxygen consumed during one shift of thermal cutting operations is based upon the Total Thermal Cutting Man-hours (Table 9; same as propane) and the cutting rates, based on the comparison testing in December 2013. The demonstration showed that the fuel flowrate was 4.3 times more than that of propane but oxygen flowrate was consumed 0.73 times compared to the oxygen flowrate when used with propane. Therefore the alternative fuel flowrate is 25 cfh x 4.3 = 107 cfh. The flowrate of oxygen flow is 345 cfh x 0.73 = 252 cfh.

Table 13: Alternative Fuel Material Costs.

MATERIAL DESCRIPTION	ITEM COST	DAYS OF USEFUL LIFE	COST PER SHIFT
Alternative fuel	$0.08 per cf	107 cfh * 4 hrs	$34.24
Oxygen gas	$0.0047 per cf	252 cfh * 4 hrs	$4.73
Torch tip	$17	250	$0.07
Air fed welding hood	$637	750	$0.85
4.5 pairs of coveralls	$50 ea	250	$0.90
Welding leather jacket	$56	1000	$0.06
Welding leather coveralls	$108 ea	1000	$0.11
Welding hood	$68	1250	$0.05
4.5 pairs of Leather gloves	$14	125	$0.50
			Total: $41.51

7.3.3.4 STEPS OF THERMAL CUTTING OPERATION

The work breakdown of a typical thermal cutting operation using the alternative fuel is the same as propane. See Section 7.3.2D for details on the man-hours involved for thermal cutting and non-cutting tasks.

7.3.3.5 CUTTING RATES

In December 2013, a demonstration was conducted that compared the performance of the alternative fuel to that of propane. From the demonstration, it was determined that cutting rate using the alternative fuel is 80% of propane, and the gas takes 1.5 times longer than propane to preheat the material. For the purpose of calculating cost, the cut rate using the alternative fuel is 12.8 IPM (80% of 16 IPM). Even though using the alternative fuel takes 1.5 times longer to preheat, the duration is negligible compared to the cutting rate. The cutting rates for preheating and thermal cutting were calculated proportional to the cutting rate of propane. The rates are shown in Table 14 below:

Table 14: Cutting Rates Using the Alternative Fuel.

	PREHEAT	TIME
1.	Preheat 2-inch HY80 pressure hull to start a cut at the edge	7.5 sec to preheat
2.	Preheat and thermal cut through 2-inch HY80 pressure hull away from an edge	30 sec to cut through
	THERMAL CUT	**TIME**
1.	Thermal cut 2-inch HY80 pressure hull	55 sec/foot
2.	Thermal cut HY80 pressure hull frame including pressure hull	108 sec/frame

7.3.3.5 COST PER SHIFT SUMMARY.

The cost breakout for using the alternative fuel per shift is shown in the table below.

Table 15: Alternative Fuel Cost Per Shift Summary

A.	LABOR COST PER SHIFT (4.5 workers x 8 hours x $52.75)	$1,899.00
B.	EQUIPMENT COST PER SHIFT	$3.22
C.	MATERIAL COST PER SHIFT	$41.51
		Total: $1,944.00

7.3.3.6 COST OF CUTTING WITH THE ALTERNATIVE FUEL

One 688 Class submarine requires approximately 10,500 linear feet of hull cutting. Therefore, two 688 Class submarines require approximately 21,000 linear feet of hull cutting. From Section E, the rate 12.8 IPM is assumed for the cutting rate using the alternative fuel.

Assuming a total cut time of 4 hours per shift (i.e. 240 minutes), a total of 256 linear feet of cutting is accomplished per shift:

12.8 IPM x 240 minutes = 3,072 inches cut per shift = 256 feet cut per shift

Based on this rate, the number of shifts required to cut 21,000 linear feet (2 submarines), is:

21,000 feet / 256 feet per shift = 82 shifts

From Table 15, the cost per shift is $1,944, and the cost to break two submarines is calculated to be:
$1,944/shift x 82 shifts = $159,408

7.3.4 Cost Comparison between Propane and the Alternative Fuel

Propane costs $126,720 to break down two 688 Class submarines while the alternative fuel costs $159,408. Using the alternative fuel costs 26% (about $33,000) more for cutting, primarily because it cuts slower and therefore more labor hours are needed. The cost analysis incudes labor and capital costs e.g. material and equipment. However, it excludes other potential benefits such as hazardous waste recycling, which may make using this alternative gas more cost effective. For breaking larger vessels such as aircraft carriers, the cost difference between using the alternative fuel and propane will be amplified. The main reason is because breaking aircraft carriers will require much more labor hours than breaking submarines. Therefore, the cutting speed is a critical parameter with regards to keeping costs down.

8.0 CONCLUSIONS, RECOMMENDATIONS, AND IMPLEMENTATION ISSUES

The use of the alternative fuel does not require special permits; however, safety, industrial hygiene (regarding personal exposure), environmental (regarding leaks and spills) and hazardous material regulations must be satisfied. The gas must be stored separately from other gases and in their own nonflammable lockers. In addition, the fuel cannot be in proximity to the propane gases. To comply with the hazardous material regulations, the gas must be listed on the base's Authorized Use List (AUL). Currently, the gas is listed on the AUL, but additional nonflammable lockers need to be purchased.

Before the demonstration, PSNS & IMF' industrial hygienists had reservations against using the original alternative fuel because carbon monoxide was a component of the gas (about 30%). Because they were against demonstrating the gas, the original gas could not be used. Instead, the vendor developed a different gas, the second generation of the fuel, which does not have carbon monoxide as part of its composition. As a result, the industrial hygienists approved the new gas, and the demonstration proceeded. The demonstration helped PSNS & IMF decide whether to include the alternative fuel in its toolbox when they recycle submarines and ships. To be considered for procurement, the gas had to at least not produce 20% opacity during cutting and be more economical than the current technology. While the alternative gas may meet the opacity requirement, it was not considered economical based on the other performance criteria. From the demonstration results, PSNS & IMF is not inclined to further pursue the use of this specific green fuel.

Following the demonstration, the Edison Welding Institute (EWI) was contacted by the alternative fuel company to conduct an evaluation comparing the cutting performance of both propane and the alternative fuel. The results cannot be directly compared to the demonstration results because the test protocols differed significantly. However, qualitative conclusions can be inferred: tip/torch combination may influence the cutting speed; the mechanic may not have been accustomed to using the gas; and under right conditions the alternative fuel may cut faster than propane. The primary reason to switch fuel is to reduce opacity, not to increase production. The alternative fuel neither proved nor disproved that it could perform better than propane in breaking ships without violating the 20% opacity limit.

The alternative gas that was demonstrated is a new commercial product and can be procured. For the long-term, the vendor must be on a GSA contract, so the base can make regular purchases. Currently the vendor does not have a GSA contract and getting the vendor onto a GSA contract may be a long process. Another topic of concern for implementation is the continuous supply of this alternative gas such as whether the supply would be available in the long-term. Because only one vendor currently produces this specific gas, the supply is always questionable. The base has the option to purchase or lease the alternative fuel production equipment and use it on-site; however, the performance, gas safety and economic feasibility would have to be evaluated.

Currently, no follow-on evaluation of this specific gas is warranted. After the completion of the demonstration, a few unused bottles remained. PSNS & IMF was deciding whether to use the remaining bottles for further in-house testing. The testing was based on having the mechanics be accustomed to the gas and different pressure settings so the cutting rate may be maximized. However, on 18-April 2014, the shipyard decided against further testing of the gas, and the remaining unused cylinders were returned to the vendor.

9.0 REFERENCES

Edison Welding Institute. 2014. *Evaluation of Oxygen-Fuel Cutting Gases*.

Appendix A: Points of Contact

List all the important points of contact (POC) involved in the demonstration, such as co-investigators, sponsors, industry partners, and regulators. The list should include the following information: (1) full name; (2) Organization; (3) telephone number, (4) e-mail address; and (5) the role of the individual in the project.

Use the tabular format below:

Name	Organization	Phone	E-mail	Role in Project
Edwin Chiang	NAVFAC EXWC/ EV11	(805) 982-5284	edwin.chiang@navy.mil	Project Manager
Leonard Blocher	PSNS & IMF/380	(360) 476-9140	leonard.blocher@navy.mil	Industrial Engineer
Nick Whittleton	PSNS & IMF/350	(360) 476-1408	nick.whittleton.ctr@navy.mil	
Grant Bosshardt	PSNS & IMF/1213	(360) 476-2453	grant.bosshardt@navy.mil	Business Manager
Teresa Brooks	PSNS & IMF/1213	(360) 476-7709	teresa.a.brooks@navy.mil	
Dana Ellis	NCMS	(360) 782-1370	danae@ncms.org	Project Manager

Appendix B: Visible Emission Observation Worksheet

Ringlemann Opacity Method 9 Worksheet (Source: PSNS & IMF Code106, received from NCMS June 12, 2012)

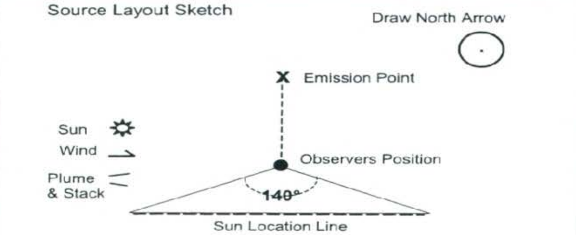
VISIBLE EMISSION OBSERVATION

Ref: NAVSHIPYDPUGETINST 5090.10

SOURCE NAME		OBSERVATION DATE	START TIME	STOP TIME
PHONE	SOURCE ID NUMBER			
PROCESS EQUIPMENT	OPERATING MODE			
CONTROL EQUIPMENT	OPERATING MODE			
DESCRIBE EMISSION POINT START	STOP			
HEIGHT ABOVE GROUND LEVEL START STOP	HEIGHT RELATIVE TO OBSERVER START STOP			
DISTANCE FROM OBSERVER START STOP	DIRECTION FROM OBSERVER START STOP			
DESCRIBE EMISSIONS START	STOP			
EMISSION COLOR START STOP	PLUME TYPE: CONTINUOUS ☐ FUGITIVE ☐ INTERMITTENT ☐			
WATER DROPLETS PRESENT NO ☐ YES ☐	IF WATER DROPLET PLUME: ATTACHED ☐ DETACHED ☐			
POINT IN THE PLUME AT WHICH OPACITY WAS DETERMINED START	STOP			
DESCRIBE BACKGROUND START	STOP			
BACKGROUND COLOR START STOP	SKY CONDITIONS START STOP			
WIND SPEED START STOP	WIND DIRECTION START STOP			
AMBIENT TEMPERATURE START STOP	RELATIVE HUMIDITY PERCENT			

SEC / MIN	0	15	30	45	COMMENTS
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					

Source Layout Sketch



AVERAGE OPACITY FOR HIGHEST PERIOD :	NUMBER OF READINGS ABOVE % WERE :
RANGE OF OPACITY READINGS MINIMUM:	MAXIMUM:
OBSERVER'S NAME (print)	BADGE
OBSERVER'S SIGNATURE	DATE
ORGANIZATION CODE	CERTIFICATION #

COMMENTS

PSNS 5090/192 (5-02) (Front)

VISIBLE EMISSION OBSERVATION GUIDELINES

This form is designed to be used in conjunction with EPA Method 9, "Visual Determination of the Opacity of Emissions from Stationary Sources." Any deviations, unusual conditions, circumstances, difficulties, etc., not dealt with elsewhere on the form should be fully noted in the section provided for comments. Following are brief descriptions of the type of information that needs to be entered on the form; for a more detailed discussion of each part of the form, refer to the "User's Guide to the Visible Emission Observation" form.

* **Source Name** – Puget Sound Naval Shipyard, Naval Station Bremerton, ship name, or contractor name.

Phone – if ship or contractor.

Source ID Number – use Code 106.3 Air (e.g., database).

* **Process Equipment, Operating Mode** – brief description of process equipment (include ID no.) and operating rate, % capacity utilization, and/or mode (e.g., charging, tapping).

* **Control Equipment, Operating Mode** – specify control device type(s) and % utilization, control efficiency.

* **Describe Emission Point** – stack or emission point location, geometry, diameter, color; for identification purposes.

* **Height Above Ground Level** – stack or emission point height, from files or engineering drawings.

* **Height Relative to Observer** – indicate vertical position of observation point relative to stack top.

* **Distance From Observer** – distance to stack ± 10%; to determine, use rangefinder or map.

* **Direction From Observer** – direction to stack; use compass or map; be accurate to eight points of compass.

* **Describe Emissions** – include plume behavior and other physical characteristics (e.g., looping, lacy, condensing, fumigating, secondary particle formation, distance plume visible, etc.).

* **Emission Color** – gray, brown, white, red, black, etc.

Plume Type:
Continuous – opacity cycle > 6 minutes
Fugitive – no specifically designed outlet
Intermittent – opacity cycle < 6 minutes

** **Water Droplets Present** – determine by observation or use wet sling psychrometer; water droplet plumes are very white, opaque, and billowy in appearance, and usually dissipate rapidly.

** **If Water Droplet Plume:**
Attached – forms prior to exiting stack
Detached – forms after exiting stack

** **Point in the Plume at Which Opacity was Determined** – describe physical location in plume where readings were made (e.g., 4 inches above stack exit or 10 feet after dissipation of water plume).

* **Describe Background** – object plume is read against, include atmospheric conditions (e.g., hazy).

* **Background Color** – blue, white, new leaf green, etc.

* **Sky Conditions** – indicate cloud cover by percentage or by description (e.g., clear, scattered, broken, overcast, and color of clouds).

* **Wind Speed** – estimate or use Intranet weather.

* **Wind Direction** – direction wind is from; use compass; be accurate to eight points.

* **Ambient Temperature** – in °F or °C.

** **Relative Humidity** – use Intranet weather.

* **Source Layout Sketch** – include wind direction, associated stacks, roads, and other landmarks to fully identify location of emission point and observer position.

Draw North Arrow – point line of sight in direction of emission point, place compass beside circle, and draw in arrow parallel to compass needle.

Sun Location Line – point line of sight in direction of emission point, place pen upright on sun location line, and mark location of sun when pen's shadow crosses the observers position.

** **Comments** – factual implications, deviations, altercations, and/or problems not addressed elsewhere.

* **Observation Date** – date observations conducted.

* **Start Time, Stop Time** – beginning and end times of observation period (e.g., 1635 or 4:35 pm).

* **Data Set** – percent opacity to nearest 5%; enter from left to right starting in left column.

* **Average Opacity for Highest Period** – average of highest 24 consecutive opacity readings.

Number of Readings Above (Frequency Count) – count of total number of readings above a designated opacity.

* **Range of Opacity Readings:**
Minimum – lowest reading
Maximum – highest reading

* **Observer's Name, Badge** – print full name and Shipyard 6-digit badge number.

Observer's Signature, Date – sign and date after performing final calculations.

* **Organization, Certification Number** – observer's code and certification number.

* Required by Reference Method 9; other items suggested.

** Required by Method 9 only when particular factor could affect the reading.

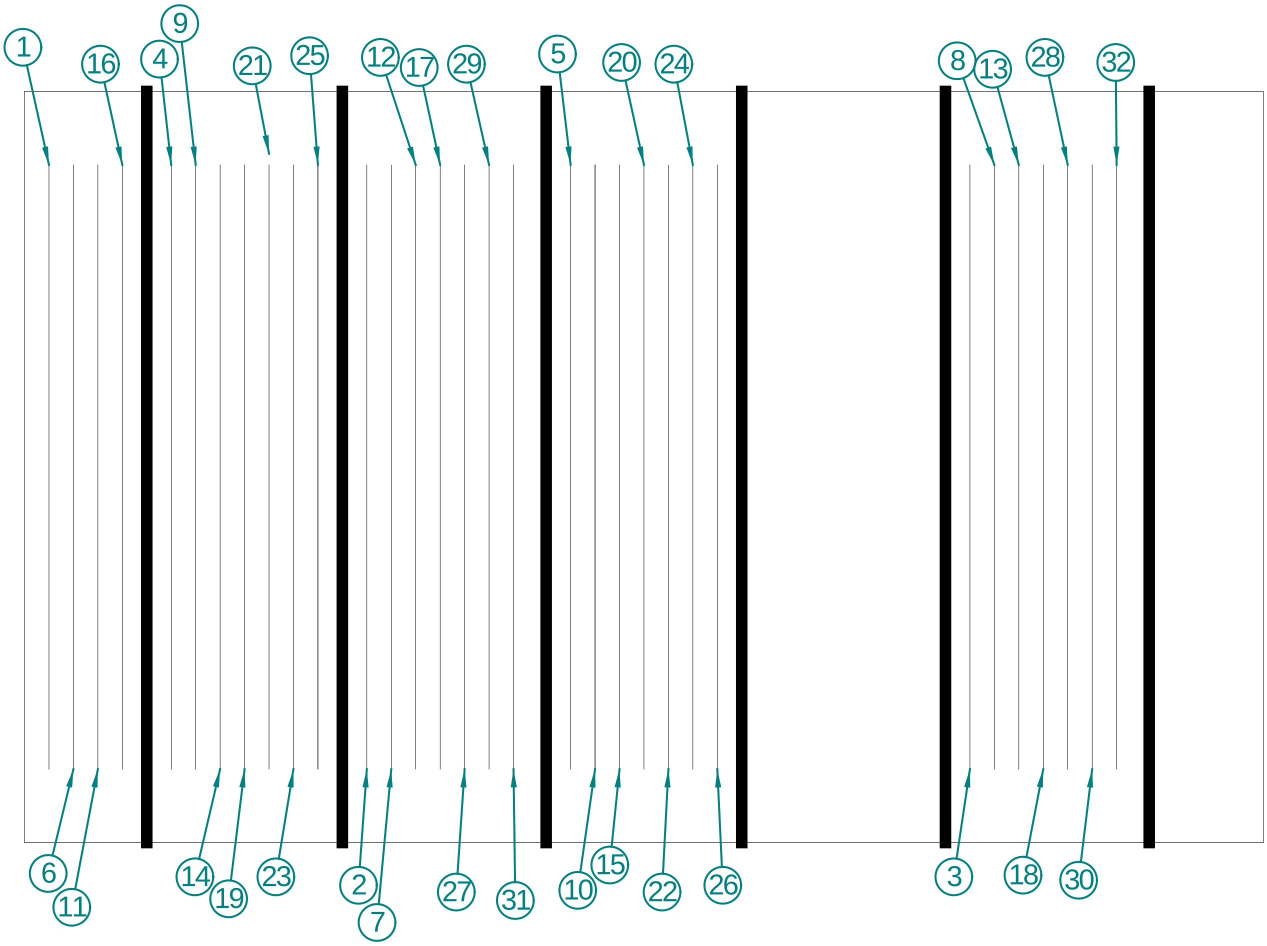
Appendix C: Sample Worksheet for Real Time Field Data Recording

Run#	Propane or Alternative Fuel	Oxygen Pressure	Gas Pressure	Gas Flow rate	Pre-heat Time	Cut Time (min:sec)	Notes
1	P						
2	AF						
3	AF						
4	P						
5	P						
6	AF						
7	AF						
8	P						
9	P						
10	AF						
11	AF						
12	P						
13	P						
14	AF						
15	AF						
16	P						
17	P						
18	AF						
19	AF						
20	P						
21	P						
22	AF						
23	AF						
24	P						
25	P						
26	AF						
27	AF						
28	P						
29	P						
30	AF						
31	AF						
32	P						

Appendix D: Sample Worksheet for Post Test Field Data Recording

Run #	Propane or Alternative Fuel	HAZ (pre-heat) Front	HAZ (pre-heat) Back	HAZ (front)	HAZ (back)	Kerf Width	Kerf Depth	Kerf Length	Paint Thkns (front)	Paint Thkns (back)	Notes
1	P										
2	AF										
3	AF										
4	P										
5	P										
6	AF										
7	AF										
8	P										
9	P										
10	AF										
11	AF										
12	P										
13	P										
14	AF										
15	AF										
16	P										
17	P										
18	AF										
19	AF										
20	P										
21	P										
22	AF										
23	AF										
24	P										
25	P										
26	AF										
27	AF										
28	P										
29	P										
30	AF										
31	AF										
32	P										

Appendix E: Sketch of Bulkhead Sections with Cut Lines



Appendix F: Alicat Technical Data Sheet

Technical Data for Alicat M-Series Mass Flow Meters

0 – 0.5 sccm Full Scale through 0 – 3000 slpm Full Scale

ALICAT SCIENTIFIC
Tel: 888-290-6060
www.alicat.com/m

Standard Specifications (Contact Alicat for available options.)

Performance	M-Series Mass Flow Meter
Accuracy at calibration conditions after tare	± (0.8% of Reading + 0.2% of Full Scale)
High Accuracy at calibration conditions after tare	± (0.4% of Reading + 0.2% of Full Scale) High Accuracy option not available for units ranged under 5 sccm or over 500 slpm.
Accuracy for Bidirectional Meters at calibration conditions after tare	± (0.8% of reading + 0.2% of total span from positive full scale to negative full scale)
Repeatability	± 0.2% Full Scale
Zero Shift and Span Shift	0.02% Full Scale / ºCelsius / Atm
Operating Range / Turndown Ratio	0.5% to 100% Full Scale / 200:1 Turndown
Maximum Measurable Flow Rate	128% Full Scale
Typical Response Time	10 ms (Adjustable)
Warm-up Time	< 1 Second

Operating Conditions	M-Series Mass Flow Meter
Mass Reference Conditions (STP)	25ºC & 14.696 psia (standard — others available on request)
Operating Temperature	−10 to +50 ºCelsius
Humidity Range (Non–Condensing)	0 to 100%
Maximum Pressure	145 psig
Mounting Attitude Sensitivity	None
Ingress Protection	IP40
Wetted Materials	303 & 302 Stainless Steel, Viton®, Silicone RTV (Rubber), Glass Reinforced Nylon, Aluminum If your application demands a different material, please contact Alicat.

Communications / Power	M-Series Mass Flow Meter
Monochrome LCD or Color TFT Display with integrated touchpad	Simultaneously displays Mass Flow, Volumetric Flow, Pressure and Temperature
Digital Output Signal[1] Options	RS-232 Serial / RS-485 Serial / PROFIBUS[3]
Analog Output Signal[2] Options	0-5 Vdc / 1-5 Vdc / 0-10 Vdc / 4-20 mA
Optional Secondary Analog Output Signal[2]	0-5 Vdc / 1-5 Vdc / 0-10 Vdc / 4-20 mA
Electrical Connection Options	8 Pin Mini-DIN / 9-pin D-sub (DB9) / 15-pin D-sub (DB15) / 6 pin locking
Supply Voltage	7 to 30 Vdc (15-30 Vdc for 4-20 mA outputs)
Supply Current	0.040 Amp (+ output current on 4-20 mA)

1. The **Digital Output Signal** communicates Mass Flow, Volumetric Flow, Pressure and Temperature
2. The **Analog Output Signal** and **Optional Secondary Analog Output Signal** communicate your choice of Mass Flow, Volumetric Flow, Pressure or Temperature
3. If selecting **PROFIBUS**, no analog signal is available. PROFIBUS units do not have the display. See PROFIBUS specifications for PROFIBUS supply voltages and currents. (***www.alicat.com/profibus***)

Features	M-Series Mass Flow Meter
30 Gas Select™ 30 On-Board User Selectable Gas Calibrations	**Programmed Gases:** Acetylene, Air, Argon, Butane, Carbon Dioxide, Carbon Monoxide, Ethane, Ethylene (Ethene), Helium, Hydrogen, Iso-Butane, Krypton, Methane, Neon, Nitrogen, Nitrous Oxide, Oxygen, Propane, Sulfur Hexafluoride, Xenon, A-25, A-75, A1025, C-2, C-8, C-10, C-25, C-75, P-5, Star29 If your application calls for a gas not on this list, please let us know. We can also calibrate to a wide variety of complex gas mixtures involving up to eight gas constituents. **Alicat's MS-Series meters are also compatible with these aggressive gases:** Ammonia, Chlorine Gas, Hydrogen Sulfide, Nitric Oxide, Nitrogen Triflouride, Propylene, Sulfur Dioxide, Nitrogen Dioxide to 0.5% in an inert carrier, Refrigerant gases (***www.alicat.com/ms***)

Range Specific Specifications

Full Scale Flow Mass Meter	Pressure Drop at FS Flow (psid) venting to atmosphere[1]	Mechanical Dimensions	Process Connections[2]
0.5 sccm to 1 sccm	1.0	3.9"H x 2.4"W x 1.1"D	M-5 (10-32) Female Thread (Shipped with M-5 (10-32) Male Buna-N O-ring face seal to 1/8" Female NPT fittings.)
2 sccm to 50 sccm	1.0		
100 sccm to 20 slpm	1.0	4.1"H x 2.4"W x 1.1"D	1/8" NPT Female
50 slpm	2.0	4.4"H x 4.0"W x 1.6"D	1/4" NPT Female
100 slpm	2.5		
250 slpm	2.1	5.0"H x 4.0"W x 1.6"D	1/2" NPT Female
500 slpm	4.0	5.0"H x 4.0"W x 1.6"D	3/4" NPT Female (A 1-1/4" NPT Female optional process connection is available for 2000 slpm meters.)
1000 slpm	6.0		
1500 slpm	9.0		
2000 slpm	5.0	5.3"H x 5.2"W x 2.9"D	
3000 slpm	7.1	5.3"H x 5.2"W x 2.9"D	1-1/4" NPT Female

1. Lower Pressure Drops Available, please see our **WHISPER-Series** mass flow controllers at ***www.alicat.com/whisper***.
2. Compatible with Beswick®, Swagelok® tube, Parker®, face seal, push connect and compression adapter fittings. VCR and SAE connections upon request.