ESTCP
Cost and Performance Report

(EW-201250)

Increasing Efficiency by Maximizing Electrical Output

September 2016

This document has been cleared for public release; Distribution Statement A

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
27-07-2016

2. REPORT TYPE
Cost and Performance Report

3. DATES COVERED *(From - To)*
04/01/2012 - 07/01/2016

4. TITLE AND SUBTITLE
Increasing Efficiency by Maximizing Electrical Output

5a. CONTRACT NUMBER
W912HQ-12-C-0048

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Ted Eveleth, COO, Ener-G-Rotors, Inc.
Scott Gold, Senior Engineer, Ener-GRotors, Inc.

5d. PROJECT NUMBER
EW-201250

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ener-G-Rotors, Inc. 17 Fern
Avenue, Rotterdam, NY 12306

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Environmental Security Technology Certification Program Program Office
4800 Mark Center Drive
Suite 17D03
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT

This demonstration project evaluated the performance, economic models and efficiency implications of using Ener-G-Rotors' flagship product, the ORCA. This project generated data from a real-world environment and gave important feedback on capital and installation cost for the unit, and performance in terms of electricity generation that determine operating costs.

15. SUBJECT TERMS
Building life cycle cost, Organic Rankine Cycle, ORCA, energy efficiency.

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Ted Eveleth
					19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	UU	UL	51	518-372-2608 x103

Page Intentionally Left Blank

Page Intentionally Left Blank

Page Intentionally Left Blank

COST & PERFORMANCE REPORT

Project: EW-201250

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

ACRONYMS AND ABBREVIATIONS

AC	Alternation Current
AIRR	Adjusted Internal Rate of Return
BLCC	Building Life Cycle Cost
BTU	British Thermal Unit
DA tank	De-aeration tank
DoD	Department of Defense
°F	Fahrenheit
hp	Horsepower
kW	kilowatt
kWh	kilowatt hour
NY	New York
MW	Megawatt
MM	Million
ORC	Organic Rankine Cycle
RPM	Rotations per Minute
V	Volts
W	Watt

Page Intentionally Left Blank

ACKNOWLEDGEMENTS

Ener-G-Rotors, Inc.

Michael Newell, CEO
Edward Eveleth, CFO
Scott Gold, Senior Engineer

Ft. Drum Army Base

Stephen Rowley

Page Intentionally Left Blank

EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

Our objective was to demonstrate the economic conversion of low temperature heat into electricity. For this project, we repurposed heat from a boiler stack from a helicopter hangar on United States Army Ft. Drum base and used data from a related installation at a biomass facility at the same location. Extracting value from stack heat in this manner is consistent with the Army's Net Zero installation strategy of "repurposing" waste energy as well as compliant with existing Federal mandates to reduce the energy intensity of installations. Current practice allows a large percentage of the fuel burned to climate control facilities to escape into the atmosphere. Using data from this implementation and another implementation on the Ft. Drum base at a biomass facility, we were able to create a model to determine the economic implementation of a given potential installation.

TECHNOLOGY DESCRIPTION

This demonstration project evaluated the performance, economic model and efficiency implications of using Ener-G-Rotors' flagship product, the ORCA™ and ancillary systems needed to support the heating and cooling needs of the ORCA system. The ORCA basically contains an ORC with the necessary controls to interface to the grid. A condensing economizer was needed to convert the boiler stack gas into a usable heat source and an air cooler was necessary to provide a cold sink in the hangar. Different installations of an ORCA system will require different needs for ancillary systems, for example, a biomass facility where we installed a similar system did not need either an economizer or air cooler.

DEMONSTRATION RESULTS

Due to the unusual arrangement of the boiler systems at the hangar, reliable, consistent performance data could not be generated. However, installation costs were acquired for both installations and performance data was generated at the biomass site. The original plan was to have a 235°F heat source which would provide 6% efficiency. We only had about 215°F on the heat source, so the efficiency was lower than expected, at ~5%, although we were able to achieve the output goal of ~20 kilowatt (kW). On the cost side, the long term goal of <$2/Watt (W) capital cost for the ORCA system was achievable. Installation costs for the two sites varied dramatically for a variety of reasons discussed later, but were within the $0.60/W goal. Clearly, the installation costs and needs for ancillary systems (economizer and air cooler) will have a large impact on the economics of any installation. We did not have a long enough test to determine maintenance costs. The carbon savings are based on kW generated and a diminished testing schedule made achieving a carbon saving goal difficult and affected our ability to assess reliability.

Using all the data collected we were able to build a model that shows the Adjusted Internal Rate of Return for different configurations of systems at different sizes. Assuming a 7.5% AIRR is required, then a 50kW system using an economizer and air cooler or a 40kW system using one or the other ancillary systems, or a 30kW ORCA only system are all economical. As waste heat sources are evaluated, this simple model, and the lessons learned from the effort, will aid in deciding upon the economics of any future installation.

IMPLEMENTATION ISSUES

The most important lessons learned from the implementation were to properly characterize stack temperature and flow early to be able to accurately know the conditions that will be experienced after installation. This was the first experience Ener-G-Rotors had with an economizer and air cooler and a number of lessons were learned from installation and operation of those systems including: installing a drain-back system in case the economizer gets too hot when the ORCA system is not running, using the proper temperature probe for the air cooler, and dealing with the weight of the economizer itself. All these lessons are easily internalized and subsequent installations by Ener-G-Rotors have gone relatively smoothly.

1.0 INTRODUCTION

1.1 BACKGROUND

Generally, experts agree the easiest path to energy savings is to use what we have more efficiently. First, reduce use, then be more efficient, and only then find ways to generate more power. The second law of thermodynamics says that any conversion of fuel to work, particularly in the production of electricity, will be inefficient and result in the loss of heat. Getting more out of the existing fuel we burn by taking advantage of that heat is clearly then a priority. Sometimes, that heat can be reused as a thermal source in certain applications, but often there is no practical use for that heat and it is usually expelled into the atmosphere. This is the case for all types of combustion engines/generators that burn liquid fuel and exhaust heat into the atmosphere. This is energy in the form of heat that has already been paid for, and is allowed to go to waste.

> **"Fundamentally, we know that saving energy saves lives…"**
>
> *Army Gen. Martin E. Dempsey, Chairman of the Joint Chiefs of Staff*
>
> **"The next step is to utilize waste energy – that is, to 'repurpose' energy. Boiler stack exhaust, building exhausts or other thermal energy streams…."**
>
> *Katherine Hammack, Asst. Sec. of the Army for IEE*

Extracting value from that heat should be a top priority. Unfortunately, the current methods of converting that heat into electricity are limited. Generally, that conversion is only efficient at large sizes and when the heat source is at a high temperature, say above 500 Fahrenheit (°F). Ener-G-Rotors believes we have developed a device that changes the economic equation and makes converting low temperature and small heat flows into electricity a great investment.

This project demonstrated that technology. We used heat from both a boiler stack exhaust and leftover heat from electricity generation to create electricity using biomass. Essentially, the fuel was free and the only expense is the cost of the system and its installation. Performance data from this project enabled Ener-G-Rotors to forecast the performance and economic benefit for a variety of other applications.

The Department of Defense (DoD) is only using heat to electricity technology in a few limited areas, one being a geothermal flash plant at Naval Air Weapons Station China Lake. But, there are few other heat to electricity products on the market that are less than several Megawatts (MW). This is a result of the inefficiency of this type of conversion using existing technology.

There are 381 boilers on Army bases in North America that produce enough waste heat to power an ORCA.[2] Some of them are large enough that an estimated 450 units for 30 kilowatt (kW) ORCA™ could be installed. By replicating this effort at all those sites, there is a potential for 13.5 MW of capacity to generate carbon free electricity. We are not aware of any other technology that can provide these sorts of paybacks from turning waste heat into electricity. In addition, validating the TGE™ technology in the size range from 20kW to 60kW opens up numerous possibilities for alternative uses.

We believe the opportunity within the DoD becomes larger with more development on different sized heat to electricity systems and integration of our technology into other systems.

The real benefit of this project to the DoD is in demonstrating the basics of our technology and then developing devices of different sizes specifically for different applications. The goal for this project was to create a model to calculate the performance and economics for a number of different sized systems.

1.2 OBJECTIVE OF THE DEMONSTRATION

Validate: This demonstration project evaluated the performance, economic models and efficiency implications of using Ener-G-Rotors' flagship product, the ORCA. This project generated data from a real-world environment and gave important feedback on capital and installation cost for the unit, and performance in terms of electricity generation that determine operating costs.

The overarching objective was to assess the overall economic benefit of converting waste heat to electricity. There are two components to this assessment:

1) **Output** – how much electricity is generated (and carbon emissions saved)
2) **Cost –** how much did the system cost to buy, install, and operate

In order to make this assessment, the project plan originally called for installing a condensing economizer which turned boiler stack heat into hot water to supply an ORCA unit. We measured performance by monitoring the overall kilowatt hour (kWh) output and the percentage uptime of the system over the testing timeframe. We used the electrical production to determine the reduction in carbon footprint of the facility. We estimated costs for commercial volume units, tracked installation costs, and developed a metric for maintenance costs from actual performance. With these metrics, we were able to analyze the performance of the ORCA system and its performance when integrated with a condensing economizer.

Findings and Guidelines: The end result of this demonstration was a model that can be used to evaluate other sites and opportunities for the economic value of turning waste heat into electricity. This model forecasts the benefits from any installation without the need for further demonstration. This project both (1) allows us to roll out this solution to other installations, and (2) demonstrates a cost effective method to turn heat into electricity that could be put to use in other DoD applications including increasing the efficiency of portable generators, ships and vehicles while also reducing the carbon footprint of the DoD.

1.3 REGULATORY DRIVERS

For this project, we used heat from a boiler stack that is part of the heating system for the Chinook and Blackhawk Hangars at Ft Drum. Extracting value from stack heat in this manner is consistent with the Army's Net Zero installation strategy of "repurposing" waste energy [1] as well as compliant with existing Federal mandates to reduce the energy intensity of installations.

Spring 2011 edition of the U.S. Army Journal of Installation Management, the Honorable Katherine Hammack, Assistant Secretary of the Army for Installations, Energy and Environment targets extracting value from waste heat as part of the Army's Net Zero strategy. She stated the second step to achieving a net zero installation "is to utilize waste energy – that is, to 'repurpose' energy. Boiler stack exhaust, building exhausts or other thermal energy streams can all be utilized for a secondary purpose." Clearly, there is a broad need within DoD for a technology to economically extract value from waste heat.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

This project demonstrated the economics of waste heat to electricity conversion. The installation was composed of three major systems: a condensing economizer to extract heat from a boiler stack, an ORCA system from Ener-G-Rotors to turn that heat into electricity, and an air cooling system to provide the necessary cold component. The condensing economizer and air cooling system are standard and readily available from multiple vendors. The novel technology is the ORCA system.

The ORCA basically contains an Organic Rankine Cycle (ORC) with the necessary controls to interface to the grid. The ORC, largely in the form of steam engines, generates about 90% of all electric power used throughout the world, including virtually all biomass, coal, solar thermal and nuclear power plants. The ORC replaces the steam with an organic refrigerant and is usually used for lower temperature (<700°F) and smaller sized applications.

ORC – This “appliance” contains all of the hardware and controls necessary to convert low grade heat into electricity using an ORC. In that cycle, shown in Figure 1, the heat input to the system can be hot liquid or steam that passes through a hot heat exchanger. A portion of the input energy is transferred to the working fluid, an environmentally friendly, non-toxic, organic high molecular mass fluid. It is the energy of the working fluid vapor that drives an expander which in turn rotates a generator. The working fluid is then condensed into a liquid in a cold heat exchanger and pumped back to the hot heat exchanger where it is vaporized. All the components except the expander are commercially available. The expander is the heart of the system and the core of our technology.

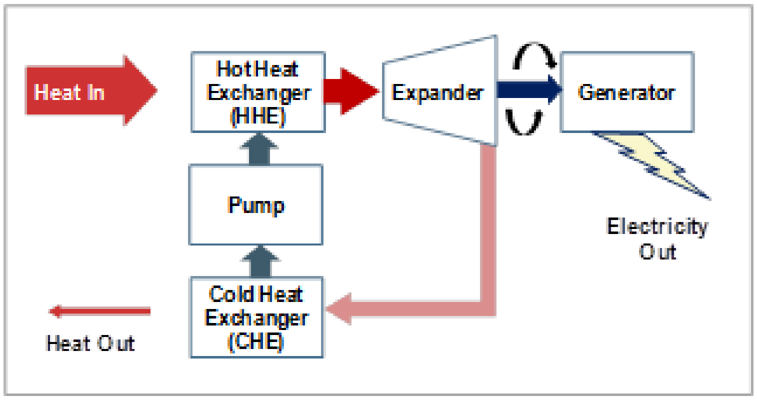


Figure 1. The ORC

TGE – Our TGE expander, shown in Figure 2, is a relatively simple positive displacement device. In essence, the mechanism is a modified generator running as an expander. The invention is to hold the inner and outer rotor each on two sets of pre-loaded roller element bearings controlling radial and axial tolerances. This innovative approach to the control of tolerances allows the working fluid to effectively extract the maximum amount of work from the expanding vapor while minimizing friction and gear wear. Mathias, et. al., [3] demonstrated 86% isentropic efficiency of the expander at Ohio State University with the very first TGE produced. We have reproduced those results in-house achieving that level of efficiency while producing 2kW-4kW. We expect better efficiency as the TGE grows in size, as is true of turbines and other types of expanders.

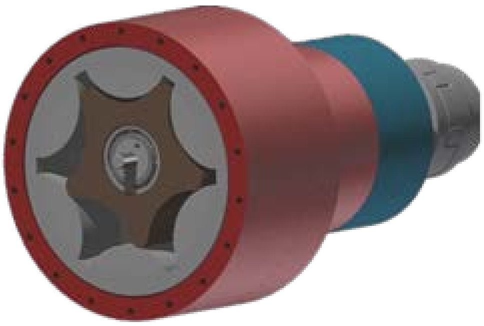


Figure 2. Schematic of the TGE Expander

Turbine Comparison – In general, turbine expanders that are less than 1MW in size struggle to achieve over 70% isentropic efficiency.[3-5] There are two reasons that turbines become inefficient at small sizes. First, the tip speed of the turbine blade is important and it needs to move quickly. Large turbine blades spin at 40,000 Rotations per Minute (rpm). To get the tip of short turbine blades to move at the same speed as large blades is very difficult without extreme rotational speeds.[6] Secondly, the surface area where leakage can occur gets larger in proportion to the volume in the expander at smaller sizes.[7] Imagine a pinwheel spinning in a tube. Air can leak around the tips of the pinwheel. A smaller tube and pinwheel means a larger relative area between the pinwheel and tube. More leakage means less efficiency or more cost to compensate. While it may be technically possible to achieve high efficiencies with small turbines, it has not proved commercially viable because of the costs. **Small turbine-based systems, defined as 50kW-100kW, cost between $3 and $4/kW, which makes them too expensive for the vast majority of applications**. [8]

In contrast, the TGE operates without a continuous flow through the expander, and with very tight tolerances around the chambers that minimize leakage. The TGE operates at either 1800 or 3600rpm, which is the speed of induction generators, making grid connection inexpensive and easy. The resulting efficiency of the TGE is superior to turbines at smaller sizes as shown in Figure 3. It should be noted that the first data point for turbines is taken from a demonstration of the PureCycle 250kW United Technologies turbine-based system. [4]

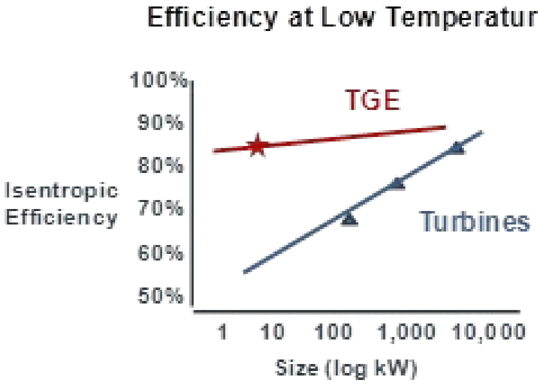


Figure 3. Comparing Expander Efficiency [3, 4, 5]

Expander efficiency is a force multiplier because it determines both the output of the system and the cost of the system. The majority of the cost of an ORC system is the heat exchangers.

More efficient conversion means smaller heat exchangers can be used dropping the cost of the overall system. That is why the TGE is so important and remarkable.

ORCA - The ORCA (shown in Figure 4) is a complete, modular, drop-in ORC system which can generate 25kW-60kW with 50kW as the target design point. The ORCA:

- will run using 190-240°F hot water or steam as a heat source
- uses an environmentally safe, non-flammable, off-the-shelf refrigerant
- uses an induction generator with a grid interface device to generate grid compatible 3 phase 480Volts (V) electricity

We expect to achieve breakthrough economics as well. Working in conjunction with the Center for Automation Technologies and Systems at Rensselaer Polytechnic Institute in Troy, New York (NY) and other external consultants, we have projected our long term manufacturing costs for the ORCA to be $40,000 or $0.8/kW. **The increased efficiency and reduced costs of the expander and system creates a new opportunity for small scale, low temperature heat to electricity conversion at manufacturing costs of lower than $1/watt.**

Development history: Ener-G-Rotors has successfully produced over twenty expanders, five ORCA systems and two 5kW prototype systems. The first TGE ever made would produce about 0.6kW. We scaled up the size to 5kW which was tested with input temperatures between 200°F and 270°F.

Figure 4. The ORCA Prototype

One particular expander, the TGE-5LB, shown in an ORC system in Figure 5, has operated for the last five years. The system was tested using three different working fluids and had over 2,000 hours of use at our facility. That system, shown in Figure 6, was tested at Harbec Plastics in Ontario NY. During the trial, that device produced 4.3kW Alternation Current (AC) that was delivered directly to the grid by bottom cycling on two 30kW Capstone micro turbines each running at 24kW, thereby increasing electrical output by 10%. The input hot water was only 220°F and left the system at 210°F because 210°F was the input temperature required for another process. This demonstration illustrates the potential to increase electrical output and/or reduce fuel consumption for combined heat and power systems.

Figure 5. TGE-5LB in 5kW ORC System

Figure 6. TGE-5LB at Harbec Plastics

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.2.1 Performance/Cost Advantages

The link between performance and cost of a heat to electricity system was discussed earlier. In short, efficiency of the expander, the main difference between ORC systems, directly relates to system cost because a more efficient expander can generate more power for the same heat input. Conceptually, this is shown in Figure 7 for turbines whose efficiency decreases with system size driving up costs. The cost in $/W for our system is substantially less than other competitive systems as shown in Figure 8. While installation at any particular site would be similar across competitive products, and maintenance may be comparable, the initial system cost is a significant portion of upfront investment and the difference between our cost and competitors' costs can be dramatic.

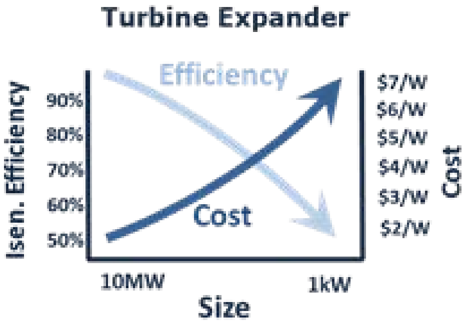


Figure 7. Turbine Expander Efficiency Cost Tradeoff

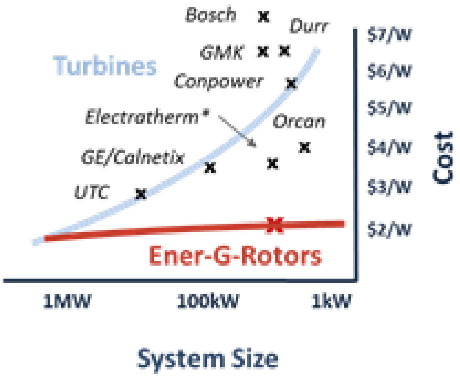


Figure 8. Competitive Comparison

2.2.2 Performance Limitations

There are performance limitations inherent to an ORC system, but there are not any performance limitations specific to our system. All the components of an ORC system can be purchased from commercial vendors except the expander. We expect our expander to be durable and require no more attention and maintenance than other ORC expanders.

There are some performance limitations of the ORC that will need to be recognized before any ORC systems can be used economically. The biggest issue with ORC systems is the need for a cold side. Electricity is generated by a differential between the waste heat and a cold source. The larger the differential, the more efficient is the ORC. The cold source can often be the atmosphere, a flow of water from a river, pond, or other source. Not having an easily available cold source will drive up the costs of some installations.

2.2.3 Cost Limitations

We expect to be able to manufacture ORCA systems in a controlled environment and have stable costs and prices once we get to volume manufacturing. Installation expense at any particular site is the biggest variable that will need to be considered on a site by site basis for widespread application. While the requirements of our system are not demanding, i.e. we have 4 hoses and a wire that connect to the outside world, the ease with which those input and outputs can be connected into an existing facility is completely dependent upon the facility. Mostly, the issue is having a space for the ORCA to fit that is close to the resources needed, namely the hot and cold sources.

Installation and maintenance costs for each of the components, ORCA, economizer, and air cooler, should be the same as later applications.

Page Intentionally Left Blank

3.0 PERFORMANCE OBJECTIVES

Table 1. Summary of Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Result
Performance				
Output	Net electricity produced - projected kWh produced annually assuming 85% uptime	Electrical output in kWh produced during test period on daily basis	> 80% of anticipated system efficiency; >20kW average annual	80% of anticipated system efficiency given conditions; ~20kW average annualized
System Efficiency	% of Carnot and actual System thermal efficiency	Electrical Output and energy content of the temperature sources (hot and cold) broken down by monthly average	>40% of Carnot; >6% system efficiency	~20% of Carnot and ~5% system efficiency
Cost				
System	Actual build cost; projected unit price	ORCA bill of materials; manufacturing cost study	Long term capital costs in <$2/W;	Long term costs expected at $2/W
Installation	Actual installation cost; projected installation costs	Installation report and bill of materials; installation cost study	Long term installation costs <$0.60/W	Installation costs of device consistent with $0.60/W
Maintenance	Actual maintenance costs; projected maintenance costs	Actual maintenance expenditures; maintenance cost study	Long term maintenance costs <$0.50 per hour of operation	Undetermined
Carbon benefit	Carbon savings of non-fossil fuel based electrical generation	Electrical output; standard CO2 emission from average electricity generation activity using fossil fuels	>100 tons of carbon emissions avoided annually	Achievable carbon reduction on par with output
High reliability	Up-time as percentage of test duration	Hourly operating performance	> 85% uptime when heat and cold flows in operational range	Notional results
Other Qualitative System Objectives				
Non-disruptive	No interruptions of normal operations outside of the ORCA	Feedback from on-site personnel	No impact on boiler operation from use of the ORCA	Achieved

Page Intentionally Left Blank

4.0 FACILITY/SITE DESCRIPTION

4.1 FACILITY/SITE LOCATION

4.1.1 Facility Criteria

The first criteria for a facility for this project was a source of heat large enough to generate at least 30kW of electricity. We estimated that a 350 horsepower (hp) boiler should exhaust sufficient heat from a single exhaust to allow for 1.2 Million (MM) British Thermal Units (BTUs)/hour to be removed from the stack via a condensing economizer. Boilers larger than 350hp would also suffice. At some point, boilers become large enough that they are likely to have economizers and reuse the heat for thermal purposes. In those cases, some of the sites we reviewed were still likely candidates because we could use heat from the De-Aeration tank, where oxygen is removed from the water by heating it before it becomes steam. We reviewed a list of 381 boilers at various Army bases that would be large enough for a demonstration.

Our preference was for boiler a system that generate steam and/or hot water year round for both heating and cooling purposes because that year round use would increase our utilization rate. Those system are often larger and built for campuses rather than single buildings.

Another consideration was a convenient space to put the ORCA unit and availability of a cold source.

4.1.2 Geographic Criteria

The source of heat was not sufficient alone, because of the need for a cold sink. Because of the application, boilers are mainly installed in a cold temperature climates and are only operational when the outside air is sufficiently cold. This means the facility criteria and geographic criteria were likely to match in terms of acceptability.

Larger installations reviewed had cooling ponds or sources of cold water that would have served our needs. But, cold outside air temperatures are sufficient to be used for cooling with the installation of an air cooling system.

4.1.3 Facility Representativeness

We ended up performing two installations at Ft. Drum Army Base in Ft. Drum, NY. Initially, we chose a helicopter hangar building that (Figures 9 and 10) met our criteria since each of the five 28A-16 RTS Series Smith cast iron boilers (Figure 11) is 122hp and they all share a single exhaust meaning only three boilers need to be operating for use to reach our maximum output.

Figure 9. Building P-19710 at Ft. Drum

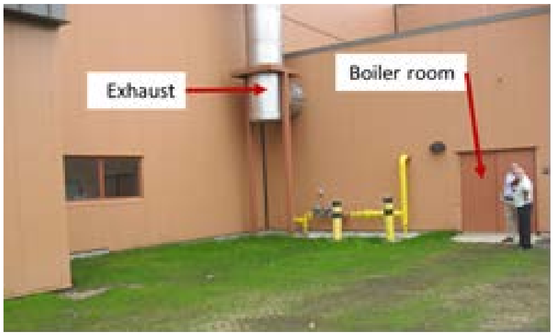


Figure 10. Close of Installation Area

Figure 11. The Smith Boilers

Also, the variable nature of the heat flow will allow us to assess the system under different operating conditions, something that would not have been possible at a larger facility. In addition, the lack of a cold source required an air cooling system which allowed us to demonstrate that technology as well. The main drawback was that utilization is low since the boiler will only operate continuously during the colder months of the year, i.e. September through May.

Additionally, during our initial work at Ft. Drum, we were introduced to the company who managed a biomass generator on site at the base. That facility had originally been a co-gen facility for the base, but the infrastructure for central heating did not work well. As a result, that facility is now operated by RE Energy burning biomass to make electricity which is mainly sold to the base, but also on the grid. This location was and ideal implementation of the ORCA system alone with the potential for high utilization.

Figure 12. RE Energy Facility on Ft. Drum

4.2 FACILITY/SITE CONDITIONS

4.2.1 Environmental Permits

There were no necessary environmental permits. Our system does not create any exhaust and is designed to not change the exhaust stream coming from the boilers. The only permits we needed related to installing a concrete slab to support our system.

4.2.2 Interconnect Agreements

We did not need an interconnect agreement with National Grid, who is the utility supplying Ft. Drum. Given the complexity of the Ft. Drum electrical grid, the fact that we would not be pushing electricity outside of that grid, and the fact that we would most likely be producing less than 25kW, National Grid told us that no interconnect was necessary. Similarly, the biomass installation was within a grid that already had an interconnect agreement regarding putting out electricity and we were just included in that existing agreement.

Page Intentionally Left Blank

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

This demonstration project took waste heat energy and repurpose it into electricity. The question we answered with this demonstration is as follows: Can waste heat be repurposed and used in an efficient method to make the costs of implementing such a system economical?

The investigator can change one major item, and that is the amount of heat energy lost to the atmosphere through the stack. This heat is converted into electricity by the ORCA system, thereby reducing the amount of heat exiting either the top of a stack or discarded into the environment. The amount of heat removed is controllable by the parameters the ORCA system runs, namely pump speed in the heating and cooling loops, refrigerant pump speed, and number of fans operating in the air-cooler.

During the investigation test, a number of items are variable over a long period of time, but over a short period (i.e. a few hours) should be constant enough to provide good before and after data. The five boilers on-site delivered output heat to the stack. The amount of heat exhausted to the stack is variable based on either the number of boilers running and the heat load required from each boiler or the waste heat flow from burning biomass. A final variable that affects the investigation is the ambient temperature experienced by the air cooling unit or the cooling water supplied. Changes in ambient temperature affect the amount of cooling the air unit can perform, which then affects the power capability and efficiency of the ORCA system.

The ORCA system decreased the electricity usage proportional to the amount of heat that it extracts. Ancillary to this reduction in external electricity usage was a corresponding reduction in carbon emissions that are avoided from traditional electricity generation methods. Corresponding total energy costs are reduced proportional to the amount of electrical power delivered by the ORCA unit.

Variable costs for running the ORCA system are the two pumps for the water glycol loops and the number of fans operating in the air-cooler. The pumps and fans will be adjusted to provide the most efficient ORCA system performance.

We hypothesized that the ORCA will fulfill the following metrics:

- Can produce an average of >20kW over an annual operating period
- Long term capital costs are < $2/W
- Long term installation costs are <$0.60 /W
- Long term maintenance costs are <$0.50 per hour of operation

To test this hypothesis, we installed an ORCA system alone at one site and with a condensing economizer and air cooling unit. We monitored the power produced by the ORCA system. We also took stack temperature readings before and after the ORCA system is running for a change in heat exited to atmosphere.

5.2 BASELINE CHARACTERIZATION

Baseline characterization is essentially no system installed to convert heat to electricity. The baseline is using the amount of electricity from the grid that equals the amount of electricity produced by the system.

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

A schematic of the planned installation at the hangar is as shown in figure 13

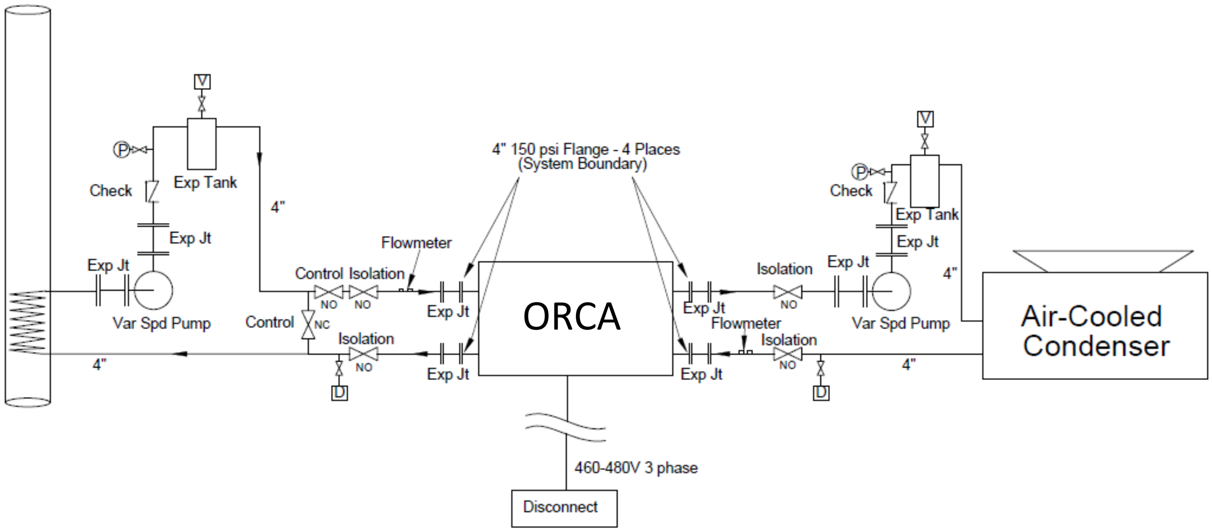


Figure 13. Installation Schematic

The major components are:

- ORCA: The ORCA (shown in Figure 4) is a complete, modular, drop-in ORC system which can generate 25kW-60kW.
- Condensing Stack Economizer: An off-shelf purchased component that is installed within the stack and transfers the heat energy from the flue gas into a closed-loop glycol/water feed for the ORCA system.
- Air Cooler: An off-shelf purchased component that uses ambient cold air to passively cool warm water.

For the RE Energy installation, the installation only covered the ORCA system.

5.4 OPERATIONAL TESTING

The ORCA system has self-contained measurement devices and data collection capability. Relevant temperatures, pressures, and electrical output parameters are monitored and recorded. The ORCA provides real-time output of all this data as well as capturing data periodically for local or remote download and analysis. Once powered on, the ORCA is constantly collecting this data. Therefore, no additional measurements need to be taken to record data from the ORCA system.

The only measurements that needed to be taken manually were the stack temperature, and the facility energy consumption.

5.5 SAMPLING PROTOCOL

The ORCA monitors and collects over 20 measurements twice a second. The key parameters for determining the investigation's success are:

- Heat Loop inlet and outlet temperatures, also flow rate
- Cold Loop inlet and outlet temperatures, also flow rate
- Power Output

This data is stored within the machine and can be downloaded remotely at any time for backup and analysis purposes. During the initial stages of the investigation, it will be downloaded at least twice a day. Up to 3 weeks of data can be stored on the machine before old data will be overwritten with new data.

All of the ORCA on-board measurement devices are either factory calibrated by the manufacturer or by Ener-G-Rotors factory test after assembly. Once the ORCA is located on-site, checks of temperature sensors and pressure gages are done while the system is under vacuum. This ensures all sensors read the same value relative to each other and no off-calibration has occurred.

For analysis of the ORCA data, measurements are collected and averaged over time. Typically, a minimum of 60 data points (30 seconds) are used.

5.6 SAMPLING RESULTS

The operations for each installation were very different. The hangar turned out to be an imperfect location because of the unusual boiler configuration and initial boiler control protocol, but provided valuable information about installation costs and efforts. The biomass installation provided better performance data, but was almost a best case installation.

We will review performance data from each site first followed by cost data.

5.6.1 Performance Results

For the hangar and its limited heat available from the stack there was limited run time. This precluded any steady state running that allows for more reliable efficiency results. The ORCA system draws more power and generates slightly less than optimal power prior to steady state. With the limited available heat power (181 kW), the ORCA generated 9.0 kW gross of electricity. The limited heat was the result of two issues. First, we had expected that when 2 or 3 boilers were running, it would be the equivalent of a 350HP boiler and produce meaningful data. However, with five separate boilers, the exhaust stack was sized for 5 boilers running (even though the hangar did not have the gas supply to run all 5 at the same time). That meant that with two boilers running, they were exhausting into a stack 2.5 times larger than necessary. This diluted the heat output from those two boilers making heat capture more difficult.

Secondly, the operating protocol was for boilers to cycle on every 15 minutes as can be seen in Figure 14. With all boilers cycling on every 15 minutes a continuous heat flow was impossible, while also being incredibly inefficient for the overall heating need. Even after a change that left a single boiler running at all times, the flow was still not close to continuous. Efforts to correct the protocol were made, but did not create a good operating environment.

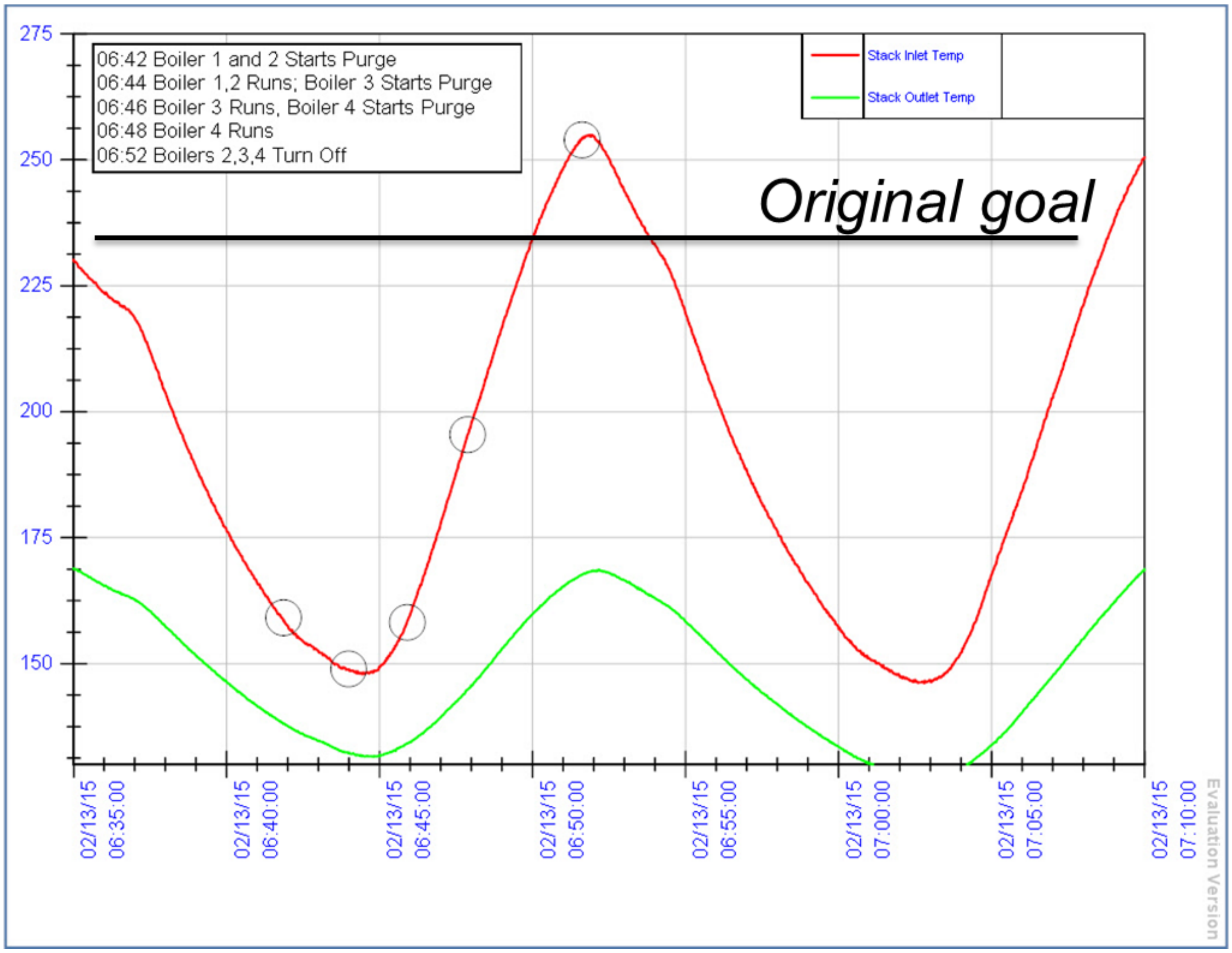


Figure 14. Heat Flows and Run Cycle of Boilers

The ORCA system power usage at this level was 1.85 kW for a net result of 7.12 kW. The air cooler is estimated to use only 40% (181 / 453 kW) of its available cooling capacity for a constant power usage of 3.49 hp or 2.62 kW. This results in a 4.49 kW net energy production by the ORCA.

Regarding air cooling at the Ft. Drum unit, it should be noted that because of the short run-time, the air cooler did not operate at the same time as the ORCA. There is a delay before the heat reaches and turns on the air cooler at the predefined levels. The energy consumption is an estimate of the ratio of heat dissipation required vs. the total available heat dissipation against the total power consumption capable.

Parasitic losses from the other systems were measured. For example, the economizer needed a pump to circulate a water/glycol mix through the stack and back to the ORCA. That pump used about 2.25kW to perform that work. In an overall system design, that parasitic load needs to be considered. In addition, the parasitic load of the air cooler was estimated at 4.85kW. That number may be higher depending upon the outside temperature and cooling conditions, but experimental testing was not feasible.

The biomass installation was very different. Constant heat flows were available in a range similar to those anticipated at the hangar. Figure 15 below illustrates 1,000 hours of run data over a similar period. On average that unit ran between 55% and 60% isentropic efficiency, steady 5% system efficiency, and produced between 16.5 kW and 22.8 kW.

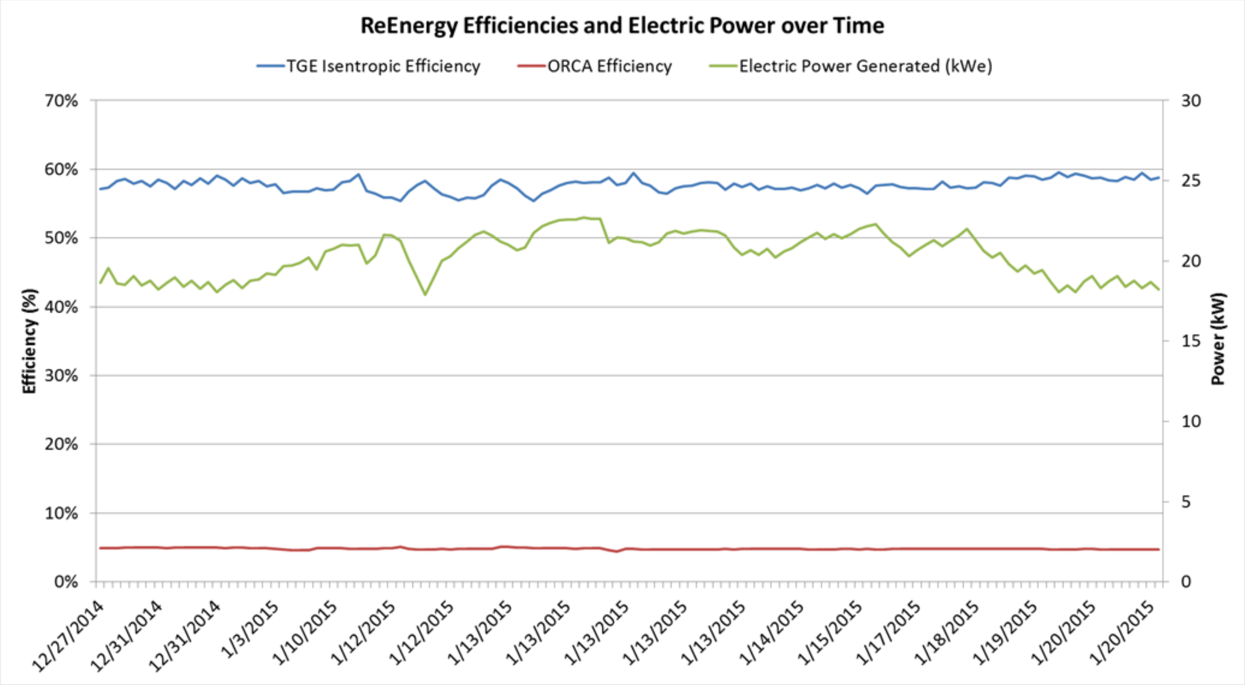


Figure 15. RE Energy Efficiencies and Electrical Power over Time

As shown in Figures 16 and 17, the incoming hot temperatures were between 212°F – 218°F and the amount of energy consumed was mostly stable between 1.0 – 1.3MM BTU/hr. About 0.9–1.2MM BTU/hr were rejected into the cold stream which was fairly stable between 31°F and 37°F.

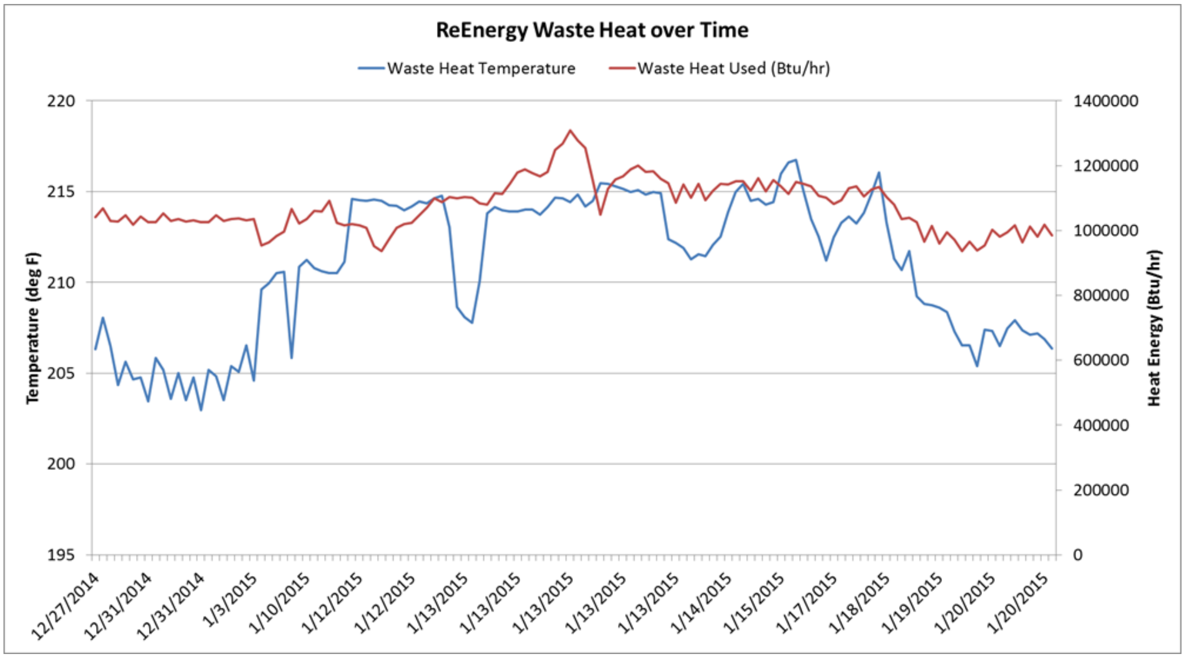


Figure 16. RE Energy Heat Fluctuations

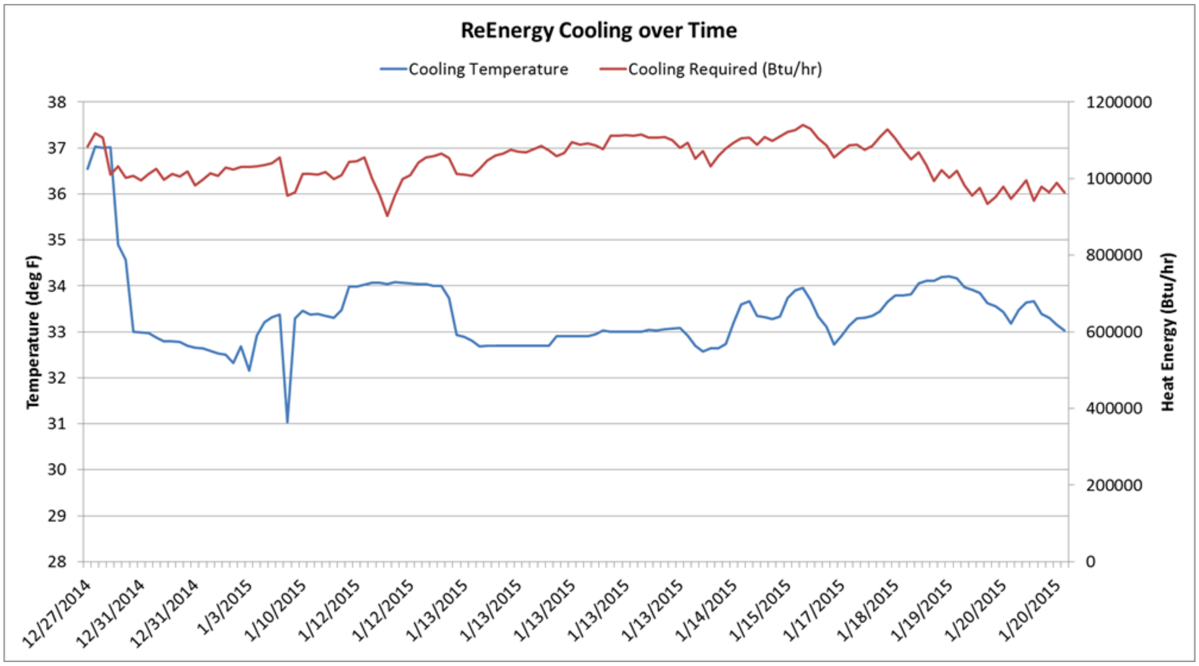


Figure 17. RE Energy Cool Side Fluctuations

5.6.2 Cost Results

Cost Results - Equipment

Because the fuel is free, the initial capital and installation costs are critical to the overall economic performance of the project. The capital equipment costs of the project include the ORCA system, condensing economizer, and air cooling unit as follows:

- $105,500 for the ORCA system as determined by the Bill of Materials when both systems were built
- $45,240 for a condensing economizer purchased from Condex
- $24,873 for an air cooler unit (1,546,412 BTU/hr capacity) purchased from Trane

Cost Results - Installation

Biomass - Installation costs were very different for the two installations. The biomass installation was paid for by RE Energy, so exact costs cannot be determined. That installation however had many features that reduced the cost including: proximity to the hot and cold sources to reduce piping needs, as well as an electrical box, having a concrete floor to sit on, and not requiring additional systems (air cooler and condensing economizer) to operate. We estimate that RE Energy spent less than $15,000 on the installation.

The hangar - For the hangar installation, the total installation costs were equivalent to the capital costs, or $175,814. In order to assist in the discussion to follow and serve as a template for other possible installations, we tried to break down these costs into two categories: system specific costs and site specific costs. System specific costs refer to installation costs that will be required to install any of the three major systems in any installation (or the cost to install under the best possible, hence cheapest, circumstances). Site specific costs are costs specific to the installation that may not translate to other sites. For example, because of the position of the gas line and the regulation that concrete pads could not be placed over gas lines (in case they need to be dug up), we needed to dig up and move the gas line next to the hangar. Another example is the need to bury the electrical lines from the installation to the electrical room where the connections were made. Additional structure was needed to support the exhaust stack with the addition of the weight of the economizer. We also spent development, capital and installation dollars on an expansion tank and other plumbing to accommodate refrigerant when the system needed to be shut down quickly and stay dormant – these expenditures turned out to be unnecessary, but were overprotective to ensure there was no interruption during boiler use.

The electrical and piping were cost more for the economizer and air cooler because in addition to those units, a pump and valves needs to be installed for their operation. Trying to parse all those costs into different buckets results in the following:

- $15,682 for installing the ORCA system
- $34,993 for installing the condensing economizer

- $31,121 for installing the air cooler
- $94,018 for other site specific costs

Later in the analysis we will allocate some of those site specific costs to the different units as costs for connecting the units to each other.

Other Costs

Because of the lack of steady run, no maintenance costs could be determined. However, we expect the ORCA to require the same maintenance as industrial chillers this equates to about $2,311 per year. [9]

There was not enough run time to make an assessment on equipment degradation. The ORCA is built to last 20 years, and the other components in the project are typical industrial components with similar life expectations provided proper preventative maintenance is performed.

6.0 PERFORMANCE ASSESSMENT

The output defines the benefits of the system and is a key determinant of the economics. The performance target was 80% of calculated output given the actual temperature and flow conditions. Another performance target was an average output of ~20kW.

- **Results:** The performance was >80% of calculated for the actual temperature and flow conditions and output averaged ~20kW.
- **Discussion:** The heat source produced on the low end of original expectations for BTUs/hr, but we were able to achieve the output goal at the biomass site. About one MM BTUs were passed through the system to produce that 20kW of electricity.

It should also be noted that the ORCA was built to be able to output as much as 60kW at peak, but with a nominal nameplate capacity of 50kW. That means that at 20kW the ORCA is not fully utilized which will affect the economics in the model later.

The system efficiency determines how much electricity can be generated from a particular heat source. It is an indirect measure of economics of the system. All ORC have distressingly low system efficiencies. For a state of the art electricity generating facility, numbers like 50% to 60% efficiency may be possible to obtain. The ORC is governed by the Carnot efficiency calculation which uses the hot source and cold source temperatures (in Kelvin) to calculate the optimal efficiency possible. This makes the calculation highly dependent upon the hot source temperature. Good ORC get between 5% and 15% efficiency. While this seems low, in comparison with other electricity generation cycles, using waste heat means the fuel is free make them comparable economically to other forms of electricity generation.

Our goals were 40% of the maximum Carnot efficiency and 6% system efficiency. A critical component of Carnot and system efficiency is that temperature of the heat source. The hotter the heat source, the greater possible system efficiency. The original plan was to have a 235F heat source which would provide 6% efficiency. We only had about 215F on the heat source, so the efficiency was lower. The change in operating conditions also affected our ability to achieve a high percentage of Carnot, because small efficiency losses are magnified under challenging operating conditions.

The two fixed costs, system and installation, and one ongoing cost, maintenance are key metrics in determining the economics. We have accumulated data on actual costs and have made some forecasts regarding long term capital costs for the ORCA system. We did not generate enough data to assess actual maintenance costs.

Those forecasts are necessary because the goals were defined in the long term with the expectation that costs for this project might not represent the expected future cost. For example, a goal was long term capital costs in <$2/W for the ORCA system. Current production level do not allow achievement of many economies of scale. It was previously mentioned that the bill of materials for the ORCAs used in the project was $105,500. At <$2/W, that means a sales price of less than $100,000 for a 50kW system. Given our detailed bill of material forecast (which is proprietary) and the general engineering rule of thumb that a prototype (our original bill of materials for the first prototype was $150,000) is three to five times the costs of production, we seem to be able to achieve the goal of selling with a reasonable margin at $2/W.

The long term goal for installation costs was <$0.60/W. At the biomass site, the costs was on the order of $0.15/W, although the installation costs for all three systems at the hangar was a total of $1.0/W, though that number drops to $0.42/W if the more expensive site specific costs are factored out.

Because of the lack of steady run, no maintenance costs could be determined. However, we expect the ORCA to require the same maintenance as industrial chillers. This equates to about $2,311 per year, or about $0.30 per hour of operation. [9]

7.0 COST ASSESSMENT

7.1 COST MODEL

Waste heat recovery systems have a very simple cost model. Fixed costs to implement the system, both capital costs for system acquisition and installation costs, dominate the expense line since there is not ongoing fuel or other operational costs. The electrical output and its value represents the benefits.

Table 2. Cost Model for an Energy Efficiency Technology

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Hardware capital costs	• $105,500 for the ORCA • $45,240 for a condensing economizer purchased from Condex • $24,873 for an air cooler unit from Trane	• $100,000 for the ORCA • $45,000 for a condensing economizer • $25,000 for an air cooler
Installation costs	• $12,487 for installing the ORCA system • $43,240 for installing the condensing economizer • $17,269 for installing the air cooler • $102,138 for other site specific costs	• $15,000 for installing the ORCA system • $45,000 for installing the condensing economizer • $20,000 for installing the air cooler • $?? Other site specific costs
Consumables	None	$0
Facility operational costs	Not relevant	$0
Maintenance	Not available	$2,300/year
Hardware lifetime	Not available	20 years
Operator training	None	$0

7.1.1 Hardware Capital Costs

There are three components to the hardware capital costs, the ORCA system, an economizer, and an air cooler. Of the three, only the ORCA is required to produce electricity.

ORCA – The ORCA is the fully functional system that turns a heat differential into electrical power and is required for any implementation. The costs of this system were recorded as the bill of materials was assembled, and the actual costs shown included all components. An equally important figure is the forecast for the sales price of the ORCA when production is on a higher volume commercial basis. That forecast of a $100,000 sales price is based on a detailed analysis of anticipated bill of materials costs when manufacturing and purchasing gains some economies of scale. That forecast is also consistent with the general engineering rule of thumb that a prototype (our original bill of materials for the first prototype was $150,000) is three to five times the costs of production. The resulting cost estimate from either analysis will provide Ener-G-Rotors with a sufficient margin to profitably sell ORCAs for $100,000 or $2/W for nameplate capacity.

That $2/W figure should be kept in mind for larger scale implementations as a reasonable heuristic for cost estimate. Although some economies of scale may be recognized with a larger system, $2/W for a waste heat recovery system is still very economical.

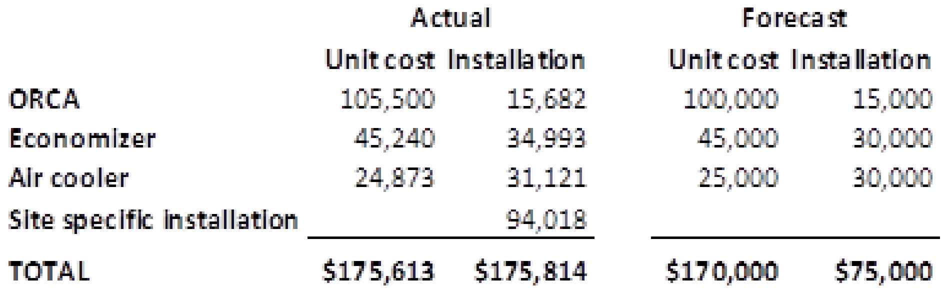
Economizer – A condensing economizer is only needed if the hot source that will supply the ORCA is a gas, typically exhaust from combustion. (The cost of the economizer includes the material necessary to withstand chemical attack from combustion residuals – air exchange would be cheaper) The invoiced cost for the economizer was $45,240. That device was sufficient to channel enough heat to the ORCA to reach nameplate capacity. Our understanding is that economies of scale are reasonably good for economizers, twice as a large a system would not cost twice as much.

Air cooler – An air cooling unit is only necessary if there is no cold water source for cold side of the ORCA system. The actual invoiced cost was $24,873. This unit might be undersized to allow an ORCA to reach 50kW of capacity, but we did not do enough testing to determine that. Other options for other air cooling approaches, including evaporative cooling, could change the economic equation. For our cost model however, we assumed a cost of $25,000 for an air cooling unit. We believe economies of scale are present as air cooling units increase in size, but we don't have an estimate for those benefits.

7.1.2 Installation Costs

Likewise, there are three components to the installation costs, the ORCA system, an economizer, and an air cooler.

ORCA – the ORCA only requires plumbing to four outlets (2 hot and 2 cold) and a single wire to an electrical box. The installation costs for the biomass site were an estimate as RE Energy considered the installation so simple that they paid for it themselves and did not provide us with a breakdown on costs. We estimate it still cost on the order of $5,000– $15,000. The details on installing the ORCA were reviewed earlier and determined to be $15,682. We are using an estimate of $15,000 for our model. Scale here does not matter as the size of the plumbing is the same and the electrical is the same regardless of size. Likewise, multiple units would not bring any economies of scale.



	Actual		Forecast	
	Unit cost	Installation	Unit cost	Installation
ORCA	105,500	15,682	100,000	15,000
Economizer	45,240	34,993	45,000	30,000
Air cooler	24,873	31,121	25,000	30,000
Site specific installation		94,018		
TOTAL	**$175,613**	**$175,814**	**$170,000**	**$75,000**

Figure 18. Cost Inputs for Model

Economizer – the economizer itself needs to be inserted into stack and plumb to and from ORCA with a pump in the loop to keep circulation. A rule of thumb we were given by the economizer vendor was that installation is at least 60% of the cost per unit. Although a number of site specific requirements added to the cost, namely the need for structural support of the weight of the unit, as well as lifts for the difficult placement, we are estimating $30,000 for the generic cost of economizer installation.

Air cooler – the air cooler needs to be placed near the ORCA system and then connected to the ORCA with a pump in the circuit somewhere to keep the flow between the two systems. The only data point we have for that system is the $31,121 estimated in installation expense for the hangar installation. As a result, we are estimating a $30,000 installation expense for an air cooler. We think there will be economies of scale on that expense for a larger air cooling system, but probably not much savings within the 30kW–50kW sized systems we are estimating.

Other site specific – clearly there were a number of additional installation expenses that were not unique to this site, but specific to this site. By that we mean, other sites may have the identical issues, but other sites may have other issues or no issues at all. Since there is no real average, we have not tried to model other site specific costs. That issue will dampen economic returns, but need to be addressed site by site.

Maintenance costs

Because of the lack of steady run, no maintenance costs could be determined. However, we expect the ORCA to require the same maintenance as industrial chillers. This equates to about $2,311 per year. [9]

There will be additional expenses for the other two systems as necessary. Likely the economizer is less expensive due to fewer moving parts and the air cooler is equally as expensive.

7.2 COST DRIVERS

There are four real variables that have a disproportionate effect on the economics of any given installation: (1) quality of heat source, (2) availability of hot and cold source, (3) utilization expectations, and (4) site specific installation costs.

Heat Source Quality – The quality of the heat source can be defined in several ways. First and foremost, there needs to be enough heat to generate 20kW to 60kW at a minimum. That calculation is relatively simple, but can get more complicated in practice. Secondary considerations include consistency of the heat flow. Brief staccato like bursts of heat, such as were evident at the hangar installation, make steady state operation difficult. Additionally, while three boilers at the hangar were producing enough heat to run our system, we had difficulty extracting it because of the exhaust piping layout which was oversized for less than five boilers running simultaneously.

Source availability – By availability, we mean whether the hot and cold sources are in a condition that can be readily input into an ORCA. This variable affects the cost of installation by defining the number of ancillary systems necessary. If the hot source is exhaust gas, an economizer is necessary. If the cold source is cold air, an air cooler is necessary. Preferable, the hot source is hot water or oil, and the cold source is cold water.

Utilization – Overall utilization is a critical factor in determining economics. Given most of the cost of the system is fixed, rather than variable if fuel costs were involved, the more the system is utilized the more economical it will be. Each installation has a potentially different value proposition, so there is not set utilization rate. Utilization and other economics parameters must be analyzed on a case by case basis.

Site specific installation – Different sites will have different requirements regarding installation. At another site, Ener-G-Rotors installed a 5kW device at, it was necessary to dig up the parking lot to lay down a cold water source to reach the device. That one installation requirement was almost twice the cost of our system. However, sites like the biomass site have minimal requirements except for the plumbing and electrical into our system.

7.2.1 Discussion

The two installations showed the variation in possible fixed costs. The biomass site was most economical with a consistent year round heat and cold source in hot water and with no difficult installation needs. The hangar was cold weather dependent heat and cold source both in gaseous form with several specific and expensive installation requirements.

Most installations will probably be somewhere in between. It was previously noted that a 350hp boiler would be sufficient to produce enough hot exhaust gas to power a 30+kW device. There are 381 such boiler on Army bases in North America. These each need to be evaluated for the quality of their heat source.

In our search for a new location for the demonstration, we encountered another opportunity both in West Point and New London, Connecticut. Larger boilers use a de-aeration tank (DA tank) where makeup water is heated and the oxygen is removed. Steam was used to heat the water lowering the efficiency of the boilers. Our system would fit nicely into that process by using the hot water coming out of the tank as our hot source and the makeup water as the cold source. The efficiency would be remarkably high since we would be heating up the makeup water and producing electricity, so no energy was lost. Since the boilers were run both for heating and cooling needs, utilization would also be high. An indoor installation where a concrete pad was not necessary was also a bonus. In the case of New London, demand charges were high because the submarine fleet would occasionally dock with each submarine requiring an additional MW of electricity to run while at dock. Essentially, New London was paying year round for that 5–10MW spike in electricity demand once or twice a year – any way to lower the demand charge was a money saver.

Beyond boilers, any Combined Heat and Power installation would also be a good fit. Our system can take advantage of the need to cool jacket water, which provides a year round source of heat in the form of hot water, and the possibility of piggy backing on air cooling systems that are already in place.

7.3 COST ANALYSIS AND COMPARISON

With the analysis of the cost structure, estimated costs of each system, and installation expense of each system we can create a model for different installations. The model compares the expense of buying electricity on the open market versus the installation of a heat to electricity system.

We will model a range of producing 30kW, 40kW and 50kW to determine the economics of using different combinations of systems with only the ORCA system being used in every combination as follows: ORCA only, ORCA and economizer, ORCA and air cooler, finally all three systems.

For a variety of reasons, focusing on a given output, i.e. 30kW, 40kW and 50kW, was easier to explain. However, we had already determined that 1.0MM BTU would produce about 20kW out of an ORCA system. Doubling the heat flow, will double the output. However, adding other systems, i.e. the economizer and the air cooler, will add parasitic load to the overall system because of the need to run pumps and fans. Therefore, the heat input should be considered as follows:

MM BTU Needed to Power Different Systems and Sizes

	30kW	40kW	50kW
ORCA	1.50	2.00	2.50
ORCA and economizer	1.61	2.11	2.61
ORCA and air cooler	1.74	2.24	2.74
All systems	1.86	2.36	2.86

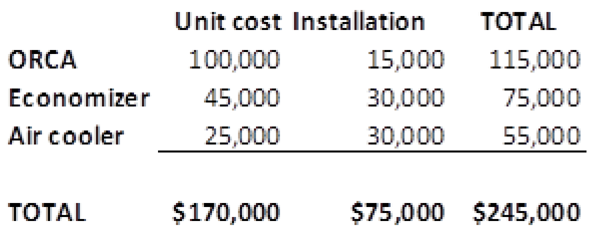
Figure 19. Heat versus Power

There are two main elements to the model: (1) the cost of the electricity purchases that were avoided, and (2) cost of the system both initial and ongoing.

Electricity purchases - For the cost of the electricity, we assume our standard $0.10/kWh. While costs vary throughout the US and the world, general agreement that modeling using that figure is acceptable to most representatives of commercial and industrial organizations we have spoken with and is in line with average costs reported to the US Energy Information Administration for most geographic regions. [10] Often local utilities will contribute to demand reduction even in regions with low electricity cost. And, for the DoD, some installations have very high electricity costs.

The other variable in electricity cost is utilization. For this iteration of the model, we will assume 90% utilization which is in line with other base load power generation sources (but, closest to geothermal because of the lack of combustion and the maintenance issues involved with combustion). [11] Clearly, a boiler that is only used for winter heating needs will have a lower utilization. Given the complexity of the model, we will start assuming year round usage and then discuss different utilization rates.

System costs – the costs we will use for our model were previously discussed and are shown in the figure on the right. Maintenance costs are modeled as $2,311 for the ORCA system, the same for the air cooler and half that amount for the economizer given the nature of those systems.



	Unit cost	Installation	TOTAL
ORCA	100,000	15,000	115,000
Economizer	45,000	30,000	75,000
Air cooler	25,000	30,000	55,000
TOTAL	$170,000	$75,000	$245,000

Figure 20. System Costs

7.3.1 Analysis

Using these assumptions, we used the Building Life Cycle Cost (BLCC) 5.3 application to model the economics and determine the comparative economics. The resulting Adjusted Internal Rate of Return (AIRR) for each scenario are shown in the figure below:

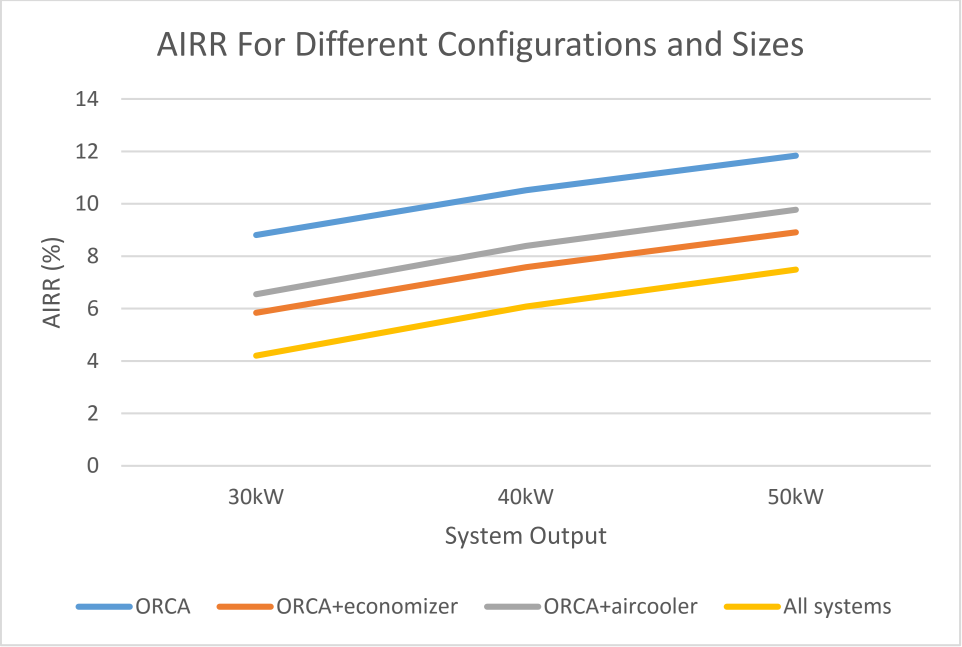


Figure 21. AIRR for Different Configurations and Sizes

Industrial electricity producers generally consider a project that has under a seven-year payback given their average return in invested capital of between 4%–8% with a 6% average. [12] The simple paybacks ranged from four years to thirteen, but generally anything above a 7.5% AIRR had better than a seven-year payback.

Other lessons to note include the need for air cooling or an economizer seem to affect the economics in similar ways, the ORCA system alone seems to meet the criteria for power generation return across all size ranges and even smaller than 30kW, and incorporating all system will only be economically feasible at the largest system size.

8.0 IMPLEMENTATION ISSUES

Ener-G-Rotors was able to utilize this project installation to gain a vast amount of knowledge about customer installations and how the ORCA system could work within the boundaries of that installation. A summarized review of some of our lessons learned is as follows:

1. Economizing off of an exhaust stack – a firm understanding of stack draft and temperatures is advised before implementation and temperature/flow measurement devices are suggested, the economizer itself has significant weight with structural support implications, an insulated holding tank between the economizer and ORCA may have been beneficial.

2. Air Cooling the ORCA – a wetted temperature probe is optimal, a control system to operate the unit from the ORCA system is advised, mounting on top of the ORCA system would save the cost of a concrete pad, and a holding tank may also be advised.

3. Outside Installation – the outside installation required a container for the ORCA and heating that climate control in that contain is important for the safety of any personnel that need to be working on the system.

4. Site preparation – Extraneous requirements, like moving a gas line so it is not under a concrete pad, need to be examined to maintain an accurate schedule.

5. Provisions for excess hot glycol temperatures and pressures with a drain-back system – a drain-back system is required when the ORCA is not running and the stack temperature gets too high, and a manual valve between the hot and cold loops for cooling is suggested.

6. Different manufacturers for Variable Frequency Drives – Disconnect boxes for VFDs are not necessary and should be avoided.

7. Lack of direct internet communication back to Ener-G-Rotors factory – best installation is tunneling devices to eliminate the need for a Virtual Private Network.

Page Intentionally Left Blank

9.0 REFERENCES

[1] Energy and Sustainability Priorities and Opportunities, Hon. Katherine Hammack, Assistant Secretary of the Army, IE&E, U.S. Army Journal of Installation Management, Spring 2011, pg 1

[2] http://www.militaryinstallations.dod.mil

[3] Mathias, James A., et. al., "Experimental Testing of Gerotor and Scroll Expanders Used in, and Energetic and Exergetic Modeling of, an Organic Rankine Cycle", Journal of Energy Resources Technology, March 2009, Vol. 131

[4] "The Chena Hot Springs 400kW Geothermal Power Plant: Experience Gained During the First Year of Operation", Prepared for the SMU Geothermal Energy Utilization Associated with Oil & Gas Development, June 12-13th, 2007 in support of presentation by Bernie Karl

[5] Marcuccilli, Frédéric and Zouaghi, Samuel, "Radial Inflow Turbines for Kalina and Organic Rankine Cycles", Proceedings European Geothermal Congress 2007, Unterhaching, Germany, 30 May-1 June 2007

[6] "Kalina & Organic Rankine Cycles: How to Choose the Best Expansion Turbine?", Dr. Frederic Marcuccilli, Senior Process Engineer, Electricity Generation from Enhanced Geothermal Systems, Strasbourg, September, 2006

[7] "Technology Characterization: Steam Turbines", Environmental Protection Agency Climate Protection Partnership Division, Prepared by Energy Nexus Group, Arlington, Virginia , March 2002

[8] C. Invernizzi, P. Iora, and P. Silva, "Bottoming micro-Rankine cycles for micro-gas turbines," Appl. Therm. Eng. 27, 100 (2007)

[9] http://www.alabamapower.com/business/save-money-energy/energy-know-how/compare-costs/chiller-maintenance.asp

[10] https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a

[11] https://www.eia.gov/forecasts/aeo/electricity_generation.cfm

[12] The Future of Electricity, Attracting investment to build tomorrow's electricity sector. World Economic Forum. January 2015 http://www3.weforum.org/docs/WEFUSA_FutureOfElectricity_Report2015.pdf

Page Intentionally Left Blank

APPENDIX A POINTS OF CONTACT

Point of Contact Name	Organization Name Address	Phone Fax Email	Role in Project
Ted Eveleth	Ener-G-Rotors	518-372-2608 x103 teveleth@energrotors.com	Principal investigator
Michael Newell	Ener-G-Rotors	518-372-2608 x102 mnewell@energrotors.com	Project management
Scott Gold	Ener-G-Rotors	518-372-2608 sgold@energrotors.com	Project engineer
Steven Rowley	Ft. Drum	315-772-5433 stephen.e.rowley3.civ@mail.mil	Site representative

ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605
(571) 372-6565 (Phone)
E-mail: estcp@estcp.org
www.serdp-estcp.org