Genalta Power

Project F101216

Waste Heat to Power Conversion
Final Outcomes Report

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Genalta Power

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November 6th, 2018

Dear Mr. Summers:

Subject: Final Outcomes Report for Project F101216

Genalta Power respectfully submits the Final Outcomes Report for the Waste Heat to Power Conversion project, Emissions Reduction Alberta reference number F101216. Within this report, please find:

- The outcomes as they relate to the learnings of the project;
- The financials from inception to project close; and
- The document list outlining the supporting documents and designs to the learnings of this project.

Genalta Power was unfortunately not able to construct and commission the project due to an unexpected decline in source energy and the thereof resulting economics. Nevertheless, it was possible for Genalta Power to gain expertise throughout the design process with significant resources invested, which Genalta Power is eager to share in the spirit of the program.

Equipment had been designed and procured for the Waste Heat Conversion and the project was ready to begin construction, when the decline of the source energy was identified. The equipment was designed and fabricated specifically for the parameters and site conditions of the project, and as such, alternate utilization was, despite efforts invested, not possible.

The Organic Rankine System units remain with the original equipment manufacturer for potential future use. The ancillary equipment such as the transformer, heat exchangers and condensers are stored within other Genalta operating facilities. The project has evaluated the option of receiving costs for scrap, however the estimated return value is far below the cost of equipment.

The project has endeavored to utilize ancillaries, such as the transformer for other project applications, however, the result remains the same, the project specific design conditions inhibit the transfer of technology. Genalta will continue the efforts to utilize or sell the equipment.

Genalta wishes to extend its gratitude to the ERA and Alberta Innovates teams for their guidance and support through the project development process.

Regards,

Allison Taylor

Confidential

FINAL OUTCOMES REPORT

EMISSIONS REDUCTION ALBERTA

Waste Heat to Power Conversion

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Executive Summary

In December 2010, Genalta Power ("Genalta") entered into a Contribution Agreement with Emissions Reduction Alberta ("ERA"), formally known as Climate Change and Emissions Management Corporation ("CCEMC"). Under its energy efficiency stream, the ERA provided funding to Genalta Power for a 1.3 MW Waste Heat to Power Project ("Project").

Genalta understands that the objectives of the ERA in providing funding were two-fold: 1) support the development of projects that reduce CO_2 emissions; and 2) create a shared knowledge base regarding waste heat to power technology for use in Alberta.

Genalta successfully applied for an Alberta Utilities Commission ("AUC") approval for the Project in 2013. However, due to an unexpected decline in the waste heat at the partnering gas plant, the proposed project for waste heat to power became uneconomic. Due to the change in project economics the construction of the power plant was discontinued. Although the first objective of the ERA grant was not attained, Genalta has met the second objective. Significant value was generated over three years of analysis from project conception through detailed design; with an overall investment by Genalta of $4 million to identify an economic solution for implementation. With this experience, plus the implementation and operation of an existing Organic Rankine Cycle ("ORC") power plant in Alberta, Genalta is one of the few organizations within Canada that can bring the level of experience and expertise regarding the design, implementation, and operation of ORC systems.

The following report summarizes the knowledge gained and associated documentation to allow the ERA to apply Genalta's learnings and unique perspective to evaluate future proposals and to help drive the commercialization of future projects.

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1 Introduction

In 2010, a joint waste heat to power project referred to as the "Project" was initiated to apply an Organic Rankine Cycle (ORC) system to heat sources found in the steam and amine processes of a gas plant and generate 1.3MW of electricity.

The project was expected to achieve sustainable greenhouse gas (GHG) emissions reductions, improve operational efficiencies, reduce the load on the Alberta Interconnected Electric System (AIES), and validate a distributed power generation model utilizing clean alternative energy in Alberta.

Prior to construction, the industry partner confirmed source energy streams were no longer available in the volumes required to operate the ORC. The project was placed on hold for further investigation and ultimately cancelled due to the changed project economics.

From Genalta Power's (Genalta) learnings, this report summarizes the key steps, tools, and conditions required for an economic ORC application and the resulting dollar per tonne to remove CO_2. The information could be used by Emissions Reduction Alberta (ERA) for future grant application assessment, to support commercialization of ORCs in Alberta, and as a shared knowledge base for other companies to successfully implement waste heat to power solutions. There are a range of waste heat recovery technologies, although an ORC was selected as the optimal technology for the Project. Genalta has experience designing, installing, and operating ORCs at other facilities in western Canada, so the report predominantly focuses on Genalta's direct learnings and experience with ORC technology applications.

The key documents that could be utilized for assessing and developing plants are identified in brackets as a corresponding Document List number when referenced in this report. Other supporting detailed documentation has been provided with the report and summarized in the Document List, but are not all expressly referenced within this report.

2 How Waste Heat to Power Projects Support Provincial Objectives

This section outlines how ORCs are aligned with the ERA's fundamental objectives and their progress in support of targets and deliverables defined in the Climate Leadership Plan. ORC projects support three of the four strategic investment areas including; reduced GHG Footprint of Fossil Fuel Supply, Low-emitting Electricity Supply, and Industrial Process Efficiency. ORCs reduce the footprint of fossil fuel processing, are a zero-emission electricity supply, and improve industrial processing efficiency as they create 'something from a traditional waste product'. The addition of ORC facilities would diversify the power sector, create new employment opportunities, and circulate investment within Alberta.

Emissions reduction was a primary driver of the Project. ORC technology itself has no net carbon or other GHG emissions. For the ORC system, the estimated quantifiable GHG reductions and clean air emission reductions for the project were estimated to be the following:

- 6,166 tonnes CO_2e/year of GHG reduction;
- 123,320 tonnes CO_2e of GHG reduction over the project 20-year lifespan;
- 13 tonnes/year of NOx reductions; and
- 19 tonnes/year of SOx reductions.

The Project was modeled to recover wasted energy from low temperature heat sources that are typical for the oil and gas industry in Alberta, but the benefits and knowledge are applicable across industrial sectors. Genalta has summarized the following research on the opportunity for, and impact of, ORCs within Alberta and Canada, regarding alternative power generation, reduced GHG emissions, and process efficiency improvements.

ORCs offer potential for producing power from waste heat sources and thus replacing power generation from carbon intensive fossil fuels. The efficiency of generating power from waste heat depends on the temperature of the heat source. In general, economically feasible power generation from waste heat is limited primarily from low to medium temperature waste heat sources (i.e., > 120°C). Below are several key areas where heat recovery, such as an ORC, could be used to capture wasted thermal energy, turn it into electricity, and lower the emissions footprint.

Reciprocating Engines Sector

There are approximately 5,000 reciprocating engines in Canada that produce at least 1,000hp[1]. Assuming that each engine produces 1,000hp, the total power produced by gas engines of 5,000,000hp, equates to approximately 3.73GW. An ORC system can convert heat from engine exhaust into power and has the potential to increase the overall electrical efficiency of an engine by at least 10%. Assuming a 10% efficiency improvement, approximately 373MW of green power would displace power generated by fossil fuels.

Steam Assisted Gravity Drainage Sector

Heat recovery from depleted Steam Assisted Gravity Drainage (SAGD) process wells has the potential to generate between 1.3 and 2.0 TWh/year of electricity by 2060 using an ORC[2]. This corresponds to GHG emissions reductions between 0.39 and 0.58 Mt/year by 2060, which accounts for 19-28% of emissions associated with electricity use in the SAGD facilities[3]. Research authors of heat recovery from depleted SAGD processes note the high cost of implementing an ORC as the greatest challenge to the adoption of this technology. Updating the current SAGD approval process to mandate heat recovery after completion of SAGD production would cause earlier adoption of waste heat recovery.

Alberta

Alberta primarily relies on burning coal and natural gas to generate electricity. Natural gas results in more than 46 million tonnes of CO_2e of emissions annually[4]. These technologies can only capture 30 to 50 per cent of the fossil fuel energy in the electricity product. The remaining energy is lost as heat and is released to the atmosphere. In Alberta, this wasted heat totaled 388 petajoules (PJ, i.e. 12.3GWt) in 2013, which is more than all the energy consumed each year by residential, commercial and institutional buildings in the province (Figure 1Figure 1). Figure 1 shows the percentage of power generated from traditional technologies including the heat wasted in providing electricity for Alberta.

[1] http://www.nrcan.gc.ca/energy/funding/current-funding-programs/cef/4961
[2] Sarjana A., Bexte K., Pickett T., Waidson E., and Zhao T., "Heat Recovery From Depleted SAGD Reservoirs to Generate Green Electricity" poster Scie529
[3] Bilozir et al, Cenovus Energy Inc, "Waste Heat Recovery From Depleted Reservoir", US Patent 20140144337, May 28 2015.
[4] http://www.cesarnet.ca/blog/oil-sands-can-help-reduce-alberta-s-ghg-emissions

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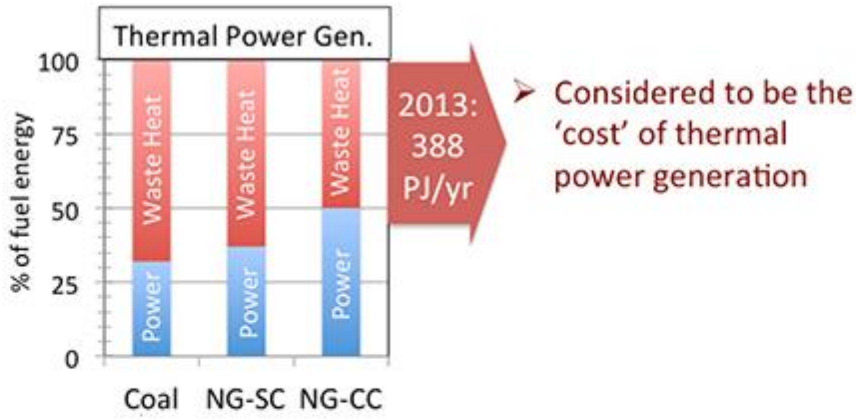

Figure 1: Waste heat from Coal, Natural gas Simple Cycle and Combined Cycle power plants in AB

To highlight the amount of un- or underutilized thermal energy, Genalta assumes that ORC plants could be used to capture this heat and convert it to power. Assuming the energy sources are of low to medium temperatures, and using a conservative ORC thermal efficiency of 15%, there is a potential of 1.8GW of electricity recovered from heat loss alone. This is an estimated value, which may differ based on:

- Some energy sources may be uneconomical due to the source temperature, size, and location;
- Some of the waste heat referenced is from coal plants which will be decommissioned;
- Some of the simple cycle generation plants that emit waste heat may have reduced uptime; and
- Some energy sources may have too low of temperatures to recover (less than 77°C) and an ORC can be difficult to deploy due to poor economics.

The investment to deploy more ORCs in Alberta would also attain economic benefits for Alberta. In Genalta's experience, around 40% to 45% of the required equipment can be provided by Alberta based organizations. For the Project, engineering was provided by Calgary based firms, allowing these firms to expand their product offerings outside of the Oil and Gas sector and diversify the risk associated with supporting a single industry. All services for the project would be provided by Alberta based organizations, from the employed operators, service work, and retail power. A financial report has been prepared and provided in conjunction with this report that includes capital costs associated with the Project. In addition, an ORC operational expenditure guide (DL 001) has been provided which outlines a general ORC equipment list and the capital upgrades and operating costs associated with an operational ORC plant. Future ORC projects could utilize the capital and operating costs presented as a framework and scale of the economic potential for Alberta companies, invested initially and ongoing over the life of an ORC project.

There is a significant opportunity for the application of ORCs within Alberta. ORC technology aligns with the provinces short and long-term goals for a lower carbon future, while diversifying the province from fossil fuel generated power, improving efficiencies for existing facilities, and encouraging investment within Alberta. With the ERA's support and communication platform, the following sections offer key tools and recommendations that can be shared to aid in the removal of barriers to commercializing ORC technology within Alberta.

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3 Key Tools in Assessing Waste Energy Recovery Opportunities

This section outlines initial steps taken by Genalta to verify feasibility of waste heat recovery opportunities prior to proceeding with significant resource investment. The same steps and tools could be utilized by the ERA to assess feasibility of future grant applications for waste heat to power projects. Alternatively, this report and subsequent documents could be shared as a foundation for other companies to use when assessing waste heat to power opportunities.

3.1 Minimum Technical Requirements

To assess operational facilities for waste energy recovery opportunities, Genalta first presents the various available technologies, key features of each, and corresponding requirements of energy sources to an industry partner. Collaboratively, potential energy sources are identified through discussing the partner's existing sites, assets, and processes. A summary of waste heat recovery technologies (DL 002) and a high level sizing comparison of the technologies (DL 003) have been provided and can be utilized for each type of energy source to narrow down candidate sites for further validation on the energy sources.

Genalta utilizes a custom designed spreadsheet (DL 004) referred to as a site data form to screen the energy source information provided to ensure accuracy and feasibility. The industry partner inputs the relevant data for each energy source and host site. Completed site data forms are used by Genalta to evaluate the economic potential of the energy sources based on a high-level generation output size. If the generation output meets Genalta's minimum requirements related to energy source size, access to the energy source, and process conditions, the project is designated as feasible and proceeds to a formal proposal stage.

A table has been provided (DL 005) that outlines Genalta's minimum technical requirements that must be met prior to proceeding to the proposal stage. In the case of the Project, the energy sources that were determined to be feasible were waste heat from steam condenser exhausts and pressure from the amine process.

The technology summary, sizing comparison, site data form, and minimum technical requirements could all be used by the ERA, or as a shared knowledge base for other companies, to assess waste energy opportunities for application to existing industrial processes.

3.2 Minimum Economic Requirements

A proposal is developed following Genalta's internal acceptance of minimum technical requirements. A waste heat to power proposal incorporates everything learned to date regarding the project. Need identification, technical data, potential power output, technologies to consider, economic summary, environmental benefits, and project risks are all summarized for stakeholders in the proposal.

The first step to develop a proposal involves a high-level analysis of available technologies capable of capturing and converting the specific waste heat to power. For the Project, an ORC system was identified as the first-choice technology due to the energy source parameters, site specifics, and ability to meet the required project economics. An in-depth summary for the process and tools for selection of waste heat recovery systems is covered in Section 4.1. Although utilized by other industries and countries for over 20 years, ORC systems continue to be considered a novel technology in Canada, and specifically, Alberta's oil

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and gas industry. To minimize risks inherent with new applications, Genalta's technology selection primarily focuses on mature heat to power technologies. The results of the high-level analysis and selection of equipment allow for a more accurate expected generation output size and cost.

The following Table 1 summarizes approximate ranges of capital costs and operation and maintenance (O&M) costs dependent on generation output size that can be used for preliminary and general analysis of economic feasibility.

ORC Generation Output Range	1 to 2 MW	4 to 6 MW
Net $/W for Capital Costs	6 to 10	3.25
Net $/MWh for Operational Costs	25 to 35	

Table 1: General CAPEX and OPEX Cost for Preliminary ORC Financial Analysis

The generation output, capital costs, and O&M costs are all factored in to a pro forma (DL 006) to assess the project economics. Other key factors to include in the pro forma are estimated efficiency, number of individual turbines, decline profile of the energy source, GHG offset credits generated, GHG offset price, GHG transaction fees, Utility Tariff rate, and administrative costs. The inputs of the pro forma continue to be refined throughout project development. Section 5 outlines other in-depth considerations for a final pro forma.

Genalta's most notable learning for proposals and final contractual agreements is to agree on an energy source guarantee prior to proceeding with an energy recovery opportunity. ORC systems are sensitive to energy source fluctuations and require steady state operation. These technologies recover heat, any fluctuation in the energy source can significantly impact the efficiency and power generated. A requirement for a stable energy source will be expanded on in further sections as it is critical for the selection of equipment, detailed design, final contractual agreements, and ongoing economic operation of the plant.

When assessing a waste heat to power opportunity, ensure that the energy source can be guaranteed in terms of flow (GJ/hour) and minimum / maximum source temperatures are defined. This will significantly improve the uptime of ORC systems as well as ensure the economics are properly modelled for the life of the plant and/or agreement.

The cost table and proforma could be used by either the ERA or as a shared knowledge base for other companies assessing the potential economics of waste heat to power opportunities based on the identified energy sources available in their existing industrial processes.

4 Key Design Considerations for Developing a Waste Heat to Power Project

Once an opportunity meets the minimum technical and economic conditions, including the partnering facility's acceptance of a proposal, a Design Basis Memorandum (DBM) is developed (DL 007 to DL 016). This section outlines key lessons learned by Genalta through the design and operation of multiple ORC facilities that should be incorporated into a DBM or other equivalent early engineering stage of a project. The lessons learned will support companies in attaining an economic dollar per tonne to remove CO_2

through the design and operation of the ORC plant. A recommended range for dollar per tonne is expanded on and provided in Section 4.10.

4.1 Energy Recovery Equipment Selection and Sizing

As part of the Project and other Genalta waste heat to power project development, Genalta has completed a thorough literary review of heat to power technologies. The review utilized published case studies and journals that focused on both mature heat energy recovery technologies and several experimental technologies and materials. A list of the literature reviewed have been provided (DL 017). For the Project, only mature waste heat to power technologies were considered, including Rankine cycle, Organic Rankine cycle and Kalina cycle. Genalta prefers to pursue mature technologies due to the increased risk associated with new technologies due to operational uncertainty. In addition, new applications of ORCs can carry more risk associated with successful integration into an operational facility, compatibility of auxiliary equipment, finding qualified personnel and ultimately potential for scope creep, rework and increased costs. A summary of and table with key requirements of the various heat to power technologies has been provided (DL 002 and DL 003) and could be used by companies for refining the most suitable type of recovery technology based on the project specifics.

The Organic Rankine Cycle (ORC) system was identified as the most compatible technology for the Project predominantly due to the attainable efficiencies for the given heat sources at the facility, technology maturity, and being within the initial economic requirements. An ORC model guideline (DL 018) and an ORC model utilizing Excel and fluid modelling software Refprop (DL 019) were developed as part of the Project. These were used by Genalta and could be utilized by the ERA or other companies to model and refine required working fluid and generation output for an ORC system. The models provided account for individual inputs per project including energy source availability, temperature, and flow. Other details in the model would need to be estimated or obtained from equipment suppliers for further refinement.

Throughout the development of the Project the source energy available decreased significantly in terms of heat energy and temperature. The original models did not account for the source energy decreasing below 50% of the original value. The decrease in energy and dramatic shifts in the Alberta electricity market rendered the project unfeasible. It is important to consider the energy source fluctuations when sizing an ORC system, including temperature and/or flow. For example, if the amount of source energy decreases significantly but the temperature stays the same, it is possible to use several smaller ORC units. If a single unit is used for the stated scenario, it can result in a project failure due to inability to generate any or little power due to partial load capability. However, if several smaller ORC units are used, the power output can be maximized by running those units that have enough input energy to efficiently generate power.

The host's heat source needs to be investigated in detail to understand its maintenance cycle for availability and how it's temperatures vary (if at all) with ambient temperatures, as well as the economic drivers that keep the host providing the energy source. For example, gas turbine energy outputs vary by 10-20% in a year, and at times can do so within a day, with refurbished turbines often running at lower exhaust temperatures than mid-life units. Reciprocating engines have frequent short duration outages, whereas gas turbines have fewer, but longer outages. Where possible, the combination of 3 or more heat sources online together reduces the potential for the ORC tripping if one of the heat sources trip.

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The technology summaries provided could be used by companies to refine technology type and, determine if an ORC is compatible, then the models may be used to refine working fluid (covered in section 04.2) and ORC size. The models provided should be used as a foundation to work with ORC suppliers and further refine an optimized configuration of the ORC, including the number of units and ancillary equipment such as heat exchangers best suited for the solution. When assessing the number of ORC units, ensure the configuration aligns with source energy supply stability and O&M limitations of the project. In Genalta's experience, once the configuration includes multiple ORCs the complexity and operational costs become a key determining factor in project viability. Genalta recommends selecting ORC suppliers with a proven record with multiple installations having historical operational data demonstrating the performance and operational cost data of the systems in a given application. Final equipment and working fluid selection would typically depend on the required project economics and the specifics of the source energy at the host facility.

4.2 Optimal Working Fluid Selection

Another key consideration for selecting equipment, as mentioned in Section 4.1, is the working fluid. There are several working fluids available for waste heat recovery systems. Each working fluid offers unique properties for a given energy source with a key measure being its thermal efficiency (i.e. how much energy can be converted into work in a given ORC system). Thermal efficiency of the working fluid dictates the potential ORC system efficiency, which can be further reduced by process non-idealities, site specific parameters (e.g. ambient temperature, cooling source temperature, etc.), and equipment used in the full ORC plant (e.g. isentropic efficiency of turboexpander, cooling type-water, air, hybrid; etc.). The choice of fluid also affects the cost of major components (e.g. expander and heat exchangers), plant layout, size of the major components, and safety requirements. The following list of properties of working fluids need to be evaluated when selecting the optimal fluid for an ORC:

1. Thermodynamic properties:
    a. Boiling point;
    b. Latent heat;
    c. Critical temperature and pressure;
    d. Molecular mass (inversely proportional to the turbine enthalpy drop; heavy molecules require lower number of stages and/or lower peripheral speeds and mechanical stresses) and surface tension (ease of vaporization; kinetic energy of must exceed the work function of cohesion at the surface);
    e. require lower number of stages and/or lower peripheral speeds and mechanical stresses;
    f. Molecular complexity (dry/wet/isentropic); and
    g. Thermal conductivity and chemical stability.
2. Flammability and hazard classification of the Partner's adjacent plant;
3. Non-corrosiveness;
4. Viscosity;
5. Environmental Impact:
    a. Global warming potential;
    b. Ozone depletion potential; and

   c. Potential impact on water courses.
6. Fluid compatibility:
   a. compatibility with available lubricants and with common metallic and polymeric materials of equipment construction used in Oil and Gas industry (e.g. pipe materials, valves, etc.); and
   b. with commercially available ORC turboexpanders and other rotary equipment used in an ORC system.
7. Individual efficiencies of major ORC components for a given fluid and overall ORC thermal efficiency;
8. Cost of the working fluid;
9. Impact working fluid region of operation has on the overall plant cost:
   a. Subcritical wet;
   b. Subcritical dry; and
   c. Supercritical.
10. Availability of working fluid now and in the foreseeable future, including location of distribution depots.

As part of the working fluid evaluation process, a report was created on state of the art ORC fluids (DL 020). This report lists and evaluates the most commonly used and commercially available ORC working fluids. Genalta has also researched state of the art working fluids that are being developed by major companies in the R&D segment of the ORC market. Based on this report, and to assess the thermal efficiency of various working fluids, an ORC Excel model with Refprop add-on was developed (DL 019).

Moreover, Genalta has investigated the potential of blending working fluids to improve the thermal efficiency of the ORC system. As a part of this investigation, an Excel spreadsheet model was developed with a Refprop add-on to assess the efficiencies of working fluid mixtures. During this investigation, Genalta determined that blended working fluids, despite offering higher thermal efficiencies (1-4%), would require a significantly more complex ORC system and would also increase the project cost to a level that would render it unfeasible. Genalta selected R245fa as a working fluid for the Project, meeting the necessary performance criteria and evaluation metrics for an optimal working fluid.

A key learning for Genalta was that the models developed were limited. Manual adjustments were required to the process parameters and fluid selection. Due to the model simplicity and utilization of the Refprop Excel add-in that only allows the modelling of thermodynamic properties of the working fluids, some key working fluid selection parameters could not be simultaneously evaluated. For example, environmental impact, compatibility of the fluid with existing turboexpanders and ORC systems, and toxicity had to be evaluated in separate steps. This significantly prolonged the evaluation time. Genalta recommends using a more sophisticated software package for ORC working fluid selection such as Matlab or Hysys. Another avenue would be to collaboratively work with academia to develop a full ORC model, likely in a visual basic or similar software.

Genalta also learned that it is practically impossible to satisfy all the requirements listed above (working fluid properties 1 through 7) with an organic fluid suitable for ORC applications. ORC plants must renounce some of the properties listed. The ORC working fluid evaluation process should anticipate the limitations on selection of the working fluids and prioritize the key evaluation metrics on the cost, thermal efficiency, and environmental impact. The overlap between operating properties of thermal fluids needs to be understood as the size of heat exchangers can be adjusted; typically, by increasing size to give more contact time and a closer temperature approach. The permissible levels of exhaust “pluming” this could generate must also be discussed and accepted by all Stakeholders.

Another important lesson learned was from the blending of working fluids. It may appear to be an attractive solution to blend the fluids as it can offer thermal efficiency improvement. However, a strictly Excel based thermodynamic model cannot account for complexities associated with designing and operating such a system. Working fluid mixtures will likely differ in their process parameters and these complexities would have to be incorporated into the design. There is not a commercially available turboexpander in Canada that would be capable of accepting a working fluid mixture aside from a R&D prototype. Genalta believes that the exercise of blending working fluids was beneficial to understanding that there are potential approaches to develop further ORC systems and increase their efficiencies. However, currently, this is strictly an R&D matter, which is not commercially feasible of this project size and type of application.

Some ORC fluids have a limited number of suppliers with a long lead time that can range anywhere from 5-30 days depending on the fluid type. In the case of refrigerant based ORC fluids, special permits, equipment, and training is required when handling the working fluid. Cost, availability, and handling requirements of the working fluid are very important and should be included in the evaluation analysis of the working fluids.

The working fluid utilized in the ORC system can help or hinder the pursuit of emission reduction. For traditional ORC systems, the working fluid is a refrigerant that contains GHG compounds that are reportable, if a release were to occur. The working fluid itself, and therefore the ORC system, are dependent upon the heat source available. If refrigerants are required, further consideration needs to be taken into account for system design, controls, and safety procedures to mitigate risk with the use of this working fluid. An alternative fluid, with more benefits than risks to consider when selecting technology, is Supercritical CO2. This fluid would support climate change initiatives and is beneficial for heat recovery from an energy source at low temperatures (200°C-600°C) without the risk of toxicity and harmful residues.

4.3 Engineering Experience

There are significant opportunities for, and benefits of, integrating ORCs with existing facilities in Alberta as noted in Section 2. However, due to the complexity, local engineering expertise to design the system is not readily available. Responsibility for the Project design was transferred multiple times between engineering firms due to the knowledge base of the companies. The ongoing transfer of scope between engineering firms resulted in significant cost and schedule increases.

For future ORCs, Genalta would recommend collaborating with both a local engineering firm and one with direct experience designing, installing, and operating the selected ORC system in similar applications. This would balance the merits of an engineering firm experienced with the implementation of ORCs and a firm with local industry knowledge, while also building the talent and knowledge base in Alberta for ease of application of future waste heat recovery projects and emission reduction goals.

Genalta's recommendations and the Project DBM (DL 007 to DL 016) and detailed design package (DL 021) could be utilized as a foundation for companies during the initial stages of developing an ORC plant.

4.4 Minimized Impact to Partner - Operational Philosophy

ORC technologies were being applied for the first time in Alberta for the particular application at the gas plant (recovering heat from steam condensers) in the oil and gas industry. Significant resources were required for operational philosophy development as the philosophy could not benchmark a previous engineering experience. Stringent safety and control measures were considered for safe and reliable plant control without impacting the host's existing operations. Normal operating conditions through to upset and anomalies were also considered. The project tie-in points, DBM, and Control Narrative led into the engineering design. The Project only reached the initial engineering design, including necessary drawing packages, equipment specifications, and documentation supporting the integration of an energy recovery system into an existing facility.

Usually for ORC systems deployed in Oil and Gas facilities, the major revenue comes from the oil and gas production where ORCs mostly serve the role of an efficiency improvement. ORC design has to offer a reliable bypass system to eliminate any impact ORC downtime could have on the host sites existing process. Within the ORC plant design, Genalta recommends a full bypass system that allows the host's processes to stay intact upon ORC shutdown or during routine maintenance.

In the case of multiple take-off points from the energy source, it is important to include the flexibility of being able to run each take-off point independently. If a waste heat to power plant comprises several small ORC systems, each ORC system should be capable of independent operation. This maximizes the operational uptime, which is a crucial factor for ORC projects to maximize the power generated.

ORC systems are typically controlled by temperature and flow sensors located at the host's energy source. This approach significantly delays the ORC response and does not capture the intricacies associated with the heat source fluctuations. Genalta recommends the ORC system be designed to allow direct control between the host's combustion system and the ORC system control. This recommendation is also supported by the very latest ORC case studies (DL 022).

Start up and shutdown of the system greatly impacts the output of the ORC system. The full cycle from cold to becoming hot enough to circulate the fluids properly and taking heat from the source and generating electricity is approximately 8 hours. The heat source needs to be consistent and predictable as in the event of an interruption to the heat source during start up it can take over 8 hours to complete the start up cycle. In addition to the long start up time, the system will require more operator intervention along with the system piping experiencing fatigue, which both increase operational costs.

Improving the base control system to increase response times, making an ORC plant fully automated, would be complex and difficult to implement in reality. The operation of an ORC is driven by the thermal inertia of the system it is connected to, and the selected working fluid for the plant. Control is designed around the steady state operations of the ORC which has a large time constant compared to the transient start-up response of the plant. Advanced control algorithms could be used but the actual benefit in start-up time would have to be compared with the cost in implementing the strategy and the overall maintenance of the devices. It is for this reason that energy sources that are constantly changing should not be used with the current ORC systems available on the market.

Below are the key factors to consider when developing the operational philosophy and corresponding integration into a host's facility:

- There are only 30 years of research into optimal strategies for ORC plant Operations & Maintenance. With implementing a new application of ORC technology, Genalta recommends a full turnkey solution;
- Collaborate with the ORC technology provider in the development of procedures to integrate the ORC plant within the host facility;
- Develop a bypass strategy to not cause impact on the host site processes;
- An ORC plant operates with low temperature energy sources, and are sensitive to source changes;
- Alberta's fluctuating temperatures (+35°C and -40°C) needs to be factored into the solution design along with unplanned shutdowns and restarting of the host plant. The colder the temperatures, the longer the start up cycle required to reach steady state operations.

Genalta's recommendations, the Project DBM, and control narratives (DL 023) could be utilized as a foundation for future companies pursuing ORC technology when developing an Operational Philosophy.

4.5 Geographic Considerations

Ambient conditions significantly impact the performance and operations of ORC systems. ORC projects are usually custom-designed for a particular application and site. It is not possible to replicate an ORC design from one plant and bring it to a geographically different location, regardless of the base source energy. There are numerous design and operational challenges that have to be considered. For example, a cold start scenario of an ORC plant in Texas is very different from a cold start in Alberta. The design and operational procedures need to take this into account. Hence, in a case of retrofitting an existing ORC plant from one site to another, Genalta recommends taking a site-specific approach. The following list summarizes the top parameters that should be considered when applying ORC's across varying geographic zones.

1. Site Elevation;
2. Weather History;
3. Heat Source Fluctuations;
4. Heat Source Composition;
5. Heat Source Location;
6. Hear Source Pressure and Temperature;
7. Site Access (impacts equipment selection);
8. Cooling Sources Available; and
9. Site Conditions (dusty, wet, etc.).

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Genalta's Site Data Form includes requests for the information required to assess the parameters listed above. This tool can be utilized as a foundation for preliminary assessment of opportunities, selection of equipment, and detailed design.

4.6 Method of Deployment

There is a significant amount of integration required between the ORC equipment, auxiliary equipment, and host facility's infrastructure. Complexities of integration was a root cause for the engineering scope changes, rework, and multiple changes between engineering firms for the Project. As recommended in section 4.3, Genalta has experienced more success with, and recommends that, ORC design and installation be closely collaborated with the supplier and industry partner.

Cost, schedule, and scope risks can be mitigated through obtaining a turnkey solution and modularizing the ORC as much as possible and feasible, allowing the experienced supplier to coordinate and manage the integration of the remaining auxiliary equipment to the package for the design and manufacturing. Although generally a "stick-built" approach to installations can result in lower costs, this approach is not recommended for novel technologies used for the first time. Aside from complexities during the design phase, stick building carries several other challenges, including:

- Complexity to troubleshoot during installation and commissioning;
- Lack of familiarity for personnel with such installation and associated equipment;
- Difficulty in management of multiple third-party groups; and
- Unclear delineation regarding responsibility in plant performance and scopes of work.

Genalta recommends avoiding the stick-built approach for an ORC installation when being integrated into existing industrial processes, particularly in oil and gas facilities. Modular design and installations are not without risks either. Scope of supply and accountability for equipment should be requested of the company coordinating the packaged solution.

4.7 Balance of Plant Equipment Selection and Sizing

Challenges in identifying ideal ORC equipment for the Project centered on complexities of source energy fluctuations, available footprint for the plant, tie-in points to the process, cooling type, and the requirement to utilize the multiple heat streams independently. Although there is a variety of vendors with technology optionality, the practical implementation of the specific equipment configuration required was not available. New evaluation spreadsheets had to be developed to evaluate the various technology options and configurations for the multi-stream heat recovery application. Equipment list, data sheets, bid documents, and bid analyses (DL 024 to DL 027 packages) were prepared and have been provided with this report.

Although the Project did not reach operations, Genalta has extensive experience with the design and operation of ORC facilities in Alberta and in BC. The information shared in this section are from day-to-day lessons learned from operating ORCs.

An ORC system, by its very nature, is a steady state process with any upsets to the inputs to the system impacting performance. This translates into a living, breathing system. Unlike simple cycle combustion, which follows a mechanical process, the ORC involves capturing and moving heat, which is more of an abstract concept. With an ORC, the heat source medium transfers the heat to a working fluid that can absorb heat and the pipework and support structures expand. While the system is hot, the system remains tight and operates as expected. When the ORC is down, the system becomes cold and the pipework and equipment cool down and contract. The more hot\cold cycles that the facility goes through the maintenance costs increase and the life of the facility is shortened as components can fail prematurely, bringing the system closer to an overhaul. High quality gasket and valve material are needed as these are prone to leaks and cracking if the heat source is not consistent.

A crucial item to consider is auxiliary equipment that is required for various ORC fluids. In the case of ORC systems with refrigerants, for example R245fa, a seal recovery unit for the turboexpander is required. This is due to gas lubricated mechanical face seals or dry face seals reliance on inert gas sealing to prevent leakage of refrigerant into the environment. However, residual leakage of the working fluid mixes with the flow sealing gas. Therefore, an additional step is required in the process to separate both gases in a seal gas recovery unit. Seal recovery systems for ORC systems are still considered a relatively new technology. Genalta recommends having an oil-less turboexpander system (i.e. NREC). This simplifies the overall ORC system, lowering the operational expenses.

To reduce maintenance, consider utilizing variable frequency drives (VFD) for the ORC system pumps. The pumps are not designed to ramp up and down in upset conditions. The VFD will allow the system to ramp up and down gradually reducing the stress and degradation of the pumps.

A key to maximizing operational output is ensuring the liquid header tank for the working fluid is sized appropriately. A smaller tank is acceptable when the plant is running at a steady state, however the tank needs to be sized for enough volume to start all processes. The ORC system does not like rapid changes in the operating conditions and will trip should the working fluid volumes not flow at a consistent rate that allows each process to seamlessly activate in sequence.

Additional considerations include the ability to operate under part load, the turboexpander design, and the overall objective of minimizing costs to ensure an economical application of the ORC.

There are many factors that impact the efficiency of an ORC, the following should also be considered when selecting balance of plant equipment:

- All units should have well controlled dampers, with dampers open on all working heat sources to minimize the ORC tripping;
- Thermal oil flow rates varied to maximize temperatures;
- Condenser fans should be operating with low fan tip clearances and good control to minimize over-cooling and minimizing parasitic energy used;
- Vibration monitoring of pumps and the expander wheel is recommended to catch early imbalances; and
- A PLC with historical logging in a Historian environment assists in fault finding.

4.8 Interconnection Strategy

As part of the Project, an advanced electrical study (DL 028) was conducted to determine the ORC's impact on the AIES and confirm provincial and federal certification standards.

The results of the study indicated that a UL 1745 certificate was required to finalize the interconnection requirements, although the ORC supplier selected was not able to provide the certificate. The certificate primarily pertains to anti-islanding requirements. Genalta worked with the Distribution Facility Owner (DFO), Fortis, to confirm the driving requirements of the certification standards and identify an alternate approach to connect. Fortis indicated that the Alberta DG Interconnection guide states that if the inverter could be proven to not island, it could be accepted on the system.

Each generator unit for the project was equipped with an inverter, which adhered to UL 1741 and CSA C22.2 #107.1 for anti-islanding requirements. By definition, a current source inverter is not capable of islanding. Without grid voltage, the current source inverter will open the contactor within 2-3 cycles. The resolution to the certification challenge was for the technology provider to provide a stamped report (DL 029) identifying the generator utilized cannot be islanded, which allowed the generator to meet the necessary anti-islanding safety assurances.

During the feasibility stage, and prior to finalizing major equipment contracts, ensure that certification requirements are confirmed in detail with the relevant Transmission or Distribution Facility Owner to avoid increased costs, impacts to the schedule, or risk in obtaining approval to connect.

The test report and interconnection studies have been provided with this report and could be utilized for developing future interconnection strategies or reference for documentation inclusions when procuring major technology.

4.9 Operator Requirements

An ORC system is expected to operate in a steady state 24 hours a day, assuming a stable energy source. Due to the limited ability to automate an ORC plant and critical requirement to minimize impact to the host facility's operations, an ORC requires timely attention by operators in the event of any upset in operating conditions. An ORC plant either requires multiple operators on a rotation or a nearby operator on call. If the plant is in a remote location, an operator must be present 24 hours a day, seven days a week. The Alberta Boiler Safety Association (ABSA) mandates that operators of an ORC must hold a Power Engineer certificate dependent on the size of the installation and whether the thermal oil is pressurised or not. All the ORC specific operator requirements contribute to an increase in O&M costs for the plant, further increasing the cost per tonne of CO_2 removal. The plant operators will routinely need to isolate and drain down fluids to remove valves, pumps, etc., as well as receive additional fluids and therefore must be certified to work with those fluids.

There is limited availability of operators with ORC experience in western Canada. In Genalta's experience, it can take 3-6 months to train an independent operator. With the resources required to train an operator, ideally the operators would remain with the plant for a minimum of five years and have broad experience operating and maintaining facilities.

With strict availability and certification requirements and investment required for long term customized training of operators, a strategy for attaining and maintaining operators should be accounted for when developing the operational philosophy and site infrastructure. Having operators with different skill specialties (mechanical and electrical/instrumentation) limits the number of contractors required to support the site and increases productivity.

4.10 Cost Per Tonne Summary

Through Genalta's learnings with the design and operation of ORC's, a guideline cost to remove each tonne of CO_2 has been developed. The cost per tonne baseline is significant for the ERA in that it could be used in their analysis and definition of pathways to achieve desired climate change policy outcomes. In addition, the information could be utilized by the ERA to evaluate future ORC grant submissions for cost validity. Should the costs for the project fall under or dramatically exceed this range, Genalta recommends due diligence regarding the submission.

Genalta's cost per tonne assessment regarding the Project and Genalta's existing ORC assets assume a baseload, steady state operation. Factors impacting the baseline are the varying capital cost of the project. If the technology utilized is a turnkey solution or multiple parties involved are minimized, a 1MW project could see a capital cost of 9 million at $56/tonne, not including power prices or other sources of revenue while in operation. For a stick build approach, with an estimated capital cost of $10.7 million, the cost/tonne increases to $93/tonne. In either scenario, the costs associated with ORC development in Alberta is uneconomic given the current environment. Further evaluation on the provincial policy and market conditions to efficiently commercialize ORC technology is provided in section 5.1.

5 Key Contractual and Market Conditions Required for an Economic Project

This section outlines the contractual and market conditions required to achieve a profitable ORC, as well as Genalta's recommended opportunities for ORC applications.

5.1 Recommendations to Confirm the Profitability of an ORC

The profitability of a waste heat recovery plant is no different than any other power plant: pool price, utility tariff savings, and GHG offset credit sales all make up the revenue line items and operating costs and administrative costs make up expense line items.

The financial proforma (DL 006) used to assess the profitability of a waste heat recovery plant is included with this report. The ERA can use this template to assess the profitability of future plants that plan to sell electricity into the grid. Pool price, tariffs, and GHG revenue in the provided pro forma spreadsheet are all reflective of what was known when the model was built in 2010. Forecasts should be updated based on the planned in-service date of the future project.

Based on the conditions at the time and the known capital costs, the Project was expected to earn a 6.5% unlevered return on capital deployed. The grant brought capital costs down to $4.5MM and the unlevered return on capital deployed was 11.1%.

In the case of the Project, it would not be viable with less than a 20 year term as payback would not have been achieved until year 11. The term of the project is a risk, due to a potential requirement for a major overhaul of the plant in the last half of the project life, if not properly budgeted for. When assessing the profitability of future waste heat recovery plants, the ERA should consider payback period relative to the term of the project and risk future years accordingly. Without sufficient funds allocated to the O&M budget and reserve, the likelihood of actually reaching the final five years of a 20 year term are reduced.

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Another important element to look for in the profitability of a plant is a guarantee of the energy source, which in this case is waste heat. It is important that the energy (as a function of minimum/maximum temperature and minimum/maximum flow rate) is clearly committed in the contract before design and construction begin. The energy commitment will determine the design of the plant and any unexpected variances will alter the amount of electricity that can be produced. When considering another waste heat to power plant, the developer and the ERA should look for a financial guarantee equal to lost revenues as penalty for non-delivery of source energy.

Finally, the ERA should determine the accuracy of revenue forecasts before pursuing a waste heat to power project. For example, the power forecast has changed drastically since 2010 and the current price environment is likely no longer supportive of a waste heat to power investment. However, the introduction of capacity markets could provide another revenue stream on what looks like a 1 year contract basis. Utility tariff savings can be forecasted through the AESO's planning documents and consideration should be given to whether a plant will earn Coincident Peak Demand payments or not.

Generally speaking, plants that are exporting power into the distribution system (but not out onto the transmission system) are eligible for CPD payments if the plant is running during the month's peak demand window. Payments are currently about $11,000/MW/Month and are forecasted to rise to $13,000/MW/Month by 2019. Rates can be found in the current ISO Tariff.

The GHG Offset Credit price has also changed drastically since 2010, with credits now being worth twice as much as originally forecasted. This revenue stream comes with a level of political and regulatory risk, which should be factored into the economics, and attention should be paid to verification and transaction costs.

As stated above, the Project would likely not be economic in today's power environment. If Genalta is to define the term "economic" as an 11% cash on cash IRR, Profitability can be defined a number of different ways. The ERA has the proforma and can run their own sensitivities on economic conditions.

Here are some of the changes required to make this possible for other ORCs of 1 to 2 MW:

- Power Purchase Agreement with either a utility or with a Provincial entity for at least $99.50 /MWh on a 20 year term, indexed to inflation. The term could be shortened if the power purchase price was higher. It is important that the holder of the PPA be a credit worthy, bond rateable partner to obtain project financing. This assumes all other inputs, such as GHG revenue, tariff savings, and O&M are unchanged from our original project assumptions (as outlined in the proforma).
- Realized carbon price of at least $47/tonne. This is in addition to the power revenues forecast in our 2010 model, which start at $61.49/MWh. If using today's power price forecast, starting at $20/MWh, the carbon price required is closer to $93/Tonne.
- Capital cost of $4,500,000 or $4.06/watt (gross). This assumes a $61.49/MWh power price in year 1 and the original estimate of GHGs and utility tariff savings. At a $20/MWh power price, capital cost would have to be as low as $1,884,000 million. This highlights the importance of grants from organizations like the ERA – capital costs appear prohibitive in today's price environment.

Based on these sensitivities, Genalta has gathered recommendations on where an organization should look to build waste heat recovery plants covered in the following section.

5.2 Recommended ORC Applications

First, Genalta would recommend building waste heat to power plants in jurisdictions with defined programs for selling electricity generated from waste heat into the grid. Until recently, British Columbia had a Standing Offer Program for waste heat plants with long term PPA's starting at approximately $125/MWh. This is important in the development of a waste heat plant, as it provides revenue certainty and long-term guarantees.

Second, Genalta recommends building waste heat to power plants at industrial locations with 20+ years of planned operations, such as compressor stations, mine sites, and oil & gas facilities. Extra diligence should go into the vetting of a site before deciding feasibility – political risk and changing economic conditions can all compromise the planned life of a site, which jeopardizes the viability of a waste heat plant.

Finally, Genalta recommends building waste heat to power plants with partners that can comfortably guarantee the supply of heat to the power plant. Generally the operating temperature of an ORC requires a heat source over 200°C. You also want to make sure there is a low risk of heat source having unplanned fluctuations over time.

While the Project was specifically tailored toward a gas plant application, the lessons learned and shared in this report can be applied across many power generation alternatives. The most notable of these alternatives may be the applicability of our learnings to geothermal applications. There have been announcements regarding the applicability of Geothermal in western Canada, specifically targeting the heat that can be recovered from abandoned oil and gas wells. ORCs could be the prime technology for converting this heat into electricity and many of the learnings from the Project can be applied to a geothermal investment.

For example, one of the risks associated with geothermal application is fluctuations in the quality of the heat source delivered. As there is no counterparty associated with heat delivery in a geothermal case, other considerations should be made to account for this risk, such as project term, capital cost, and operating cost. Provided, that geothermal is included in the Renewable Electricity Program (REP) Round 2 with the Government of Alberta, there will be no fixed price Power Purchase Agreement available to these applications. Given the risk associated with the price of power, as seen in Genalta's project economics, a geothermal project would be best backed by a private buyer such as a municipality or corporation. This type of agreement would provide revenue certainty to the project and help the investment get off the ground.

6 Conclusion

Waste heat to power projects, specifically ORC technology, aligns with and supports the attainment of the ERA and Climate Leadership Plan objectives. Supporting the commercialization of ORCs within Alberta would aid in reaching defined targets, through reducing GHG emissions, increasing the amount of low

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emitting power plants, improving industrial process efficiencies and creating jobs and investment in Alberta.

The learnings and recommendations of this report cover key business areas to support complete and validated waste heat to power solutions, including improvements to design and technology, and requirements for regulatory approvals, financing and public policies.

The current provincial economic climate is not conducive for ORC applications. Genalta views that the ERA could support successful applications of ORCs through ongoing support, both financially and with knowledge resources, to reduce the cost of installation and operation. The ERA and Genalta could collaboratively drive additional research and analysis, either for improvements to ORC and ancillary technology, or to further validate the opportunity and positive impact of ORCs in Alberta. Potential inclusion in the ERA's Technology Roadmap and communicating the benefits of ORC's and distributing Genalta's knowledge and tools to the industry would aid in future ORC applications, including understanding of the successful economic requirements and generation output ranges of ORC facilities.

If possible, the ERA could support by influencing the ongoing development of public policies. Given how dependent ORC's are on GHG credits and carbon levy exemptions, the ERA could lobby to have qualification periods extended out to match the life of the project to guarantee revenue and increase investor certainty. Alternatively, the ERA grant structure could be reviewed to take into consideration the latest draft policy changes around the carbon levy to increase the economics for entities implementing ORCs.

Genalta looks forward to future opportunities in working with the ERA and removing the barriers to commercialization of ORC's and achieve short and long term provincial targets.

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