19TH SYMPOSIUM OF THE INDUSTRIAL APPLICATION OF GAS TURBINES COMMITTEE
BANFF, ALBERTA, CANADA
OCTOBER 17-19, 2011

11-IAGT-204

COMBINED CYCLE OPPORTUNITIES FOR SMALL GAS TURBINES

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Keywords: *Waste Heat Recovery, ORC*

Abstract

There are a tremendous number of small simple-cycle gas turbines running in a variety of applications, such as oil and gas compression stations. Typically these applications do not have a use for the waste heat from the engines, and traditionally developing combined cycle plants at these sites was not feasible for such small units. However, recent projects have demonstrated the opportunity to develop combined cycle plants with these small gas turbines using the Organic Rankine Cycle (ORC).

This paper discusses the opportunities and challenges of developing an ORC plant at a site with a small simple-cycle gas turbine. The ORC process is described with reference to a case study of a 1 MW ORC plant that has been recently installed at a natural gas compressor station. The plant uses the exhaust heat from a Solar Centaur 40, a roughly 4 MW gas turbine.

1 Introduction

In the Natural Gas Transmission Industry, waste heat recovery from gas turbines at pipeline compressor stations has been identified as a key tool in improving system efficiency. There is rarely a use for the heat at these facilities or in neighbouring facilities and the only way to take advantage of this waste heat is to use a bottoming cycle that produces electricity from the waste heat. These waste heat to power plants typically use a Rankine power cycle, where a working fluid is evaporated and used to drive a turbine.

The Interstate Natural Gas Association of America (INGAA) identifies waste heat to power systems as the only economical opportunity for waste energy recovery in the industry [1]. In the last 5 years more than two dozen waste heat to power projects have been developed in North America at pipeline compressor stations [2]. The generating capacity of these plants have all exceeded 4 MW. An example of one these plants was detailed in the IAGT paper presented in 2009 by R. Bohl of Chinook Engineering [3]. The INGAA estimates that in the United States there are roughly 100 compressor stations with a compressor capacity of at least 11 MW (15,000 HP), and approximately 500-600 MW of power could be produced from the exhaust heat from these engines [1].

Until very recently the industry has focused solely on developing waste heat to power plants at large compressor stations with a minimum capacity of 11 MW (15,000 HP). In 2011, Found Energy and TransGas Limited developed a waste heat to power plant at the Rosetown, Saskatchewan gas compressor station with a 4 MW Solar Centaur gas turbine gas compressor drive unit, which is a relatively small gas turbine. Like the majority of waste heat to power plants, this plant uses the Organic Rankine Cycle (ORC). This project is used to illustrate the opportunity to recover energy from compressor station gas turbines with an emphasis on issues of interest to owners and operators.

1.1 Project Participants

TransGas Limited is a wholly owned subsidiary of SaskEnergy, a Saskatchewan Crown corporation. TransGas uses compressors to move natural gas through its 14,000 kilometres of high pressure transmission pipeline across Saskatchewan, as well as to inject gas into its 27 underground storage caverns and two storage fields. TransGas has a goal to become net zero in electricity consumption, and has identified waste heat to power plants as an important opportunity to achieve this goal. The TransGas Rosetown Compressor Station is the site of its first waste heat to power plant.

Found Energy was selected by TransGas to act as the single point of contact to develop the Rosetown waste heat recovery facility. Found Energy is a business unit of Innovative Steam Technologies (IST), an Aecon company. Aecon (TSX:ARE) is the largest publicly traded infrastructure and construction company in Canada. The Aecon Industrial Group, with their background in power plant construction is uniquely suited to provide coordinated engineering and construction services for Found Energy. Found Energy is able to draw on a breadth of experience throughout Aecon from cutting edge boiler design from IST to heavy construction expertise from Aecon Industrial.

Turboden, a Pratt & Whitney Power Systems company, is a European leader in ORC technology for the generation and cogeneration of heat and power from renewable energy and heat recovery. Turboden was selected by Found Energy to supply the ORC plant for the Rosetown Compressor Station because of its extensive experience and expertise in the field. Turboden has more than 200 ORC plants operating in 23 countries worldwide. The Rosetown plant is Turboden’s first plant in North America.

2 Plant Description

The waste heat to power plant is composed of the following four distinct systems:

1. The gas turbine exhaust system
2. The thermal oil circuit
3. The Organic Rankine Cycle (ORC)
4. The water cooling circuit

Figure 1 is a process flow diagram showing each of these four systems, and their interface points. The power cycle is driven by the exhaust heat from the gas turbine. This heat is recovered in a waste heat recovery oil heater, and used to heat thermal oil. The thermal oil is then pumped to an evaporator in the ORC cycle where the hot thermal oil is used to evaporate the ORC working fluid. The ORC working fluid then drives an ORC turbine to produce power before being condensed with cooling water in the ORC condenser.

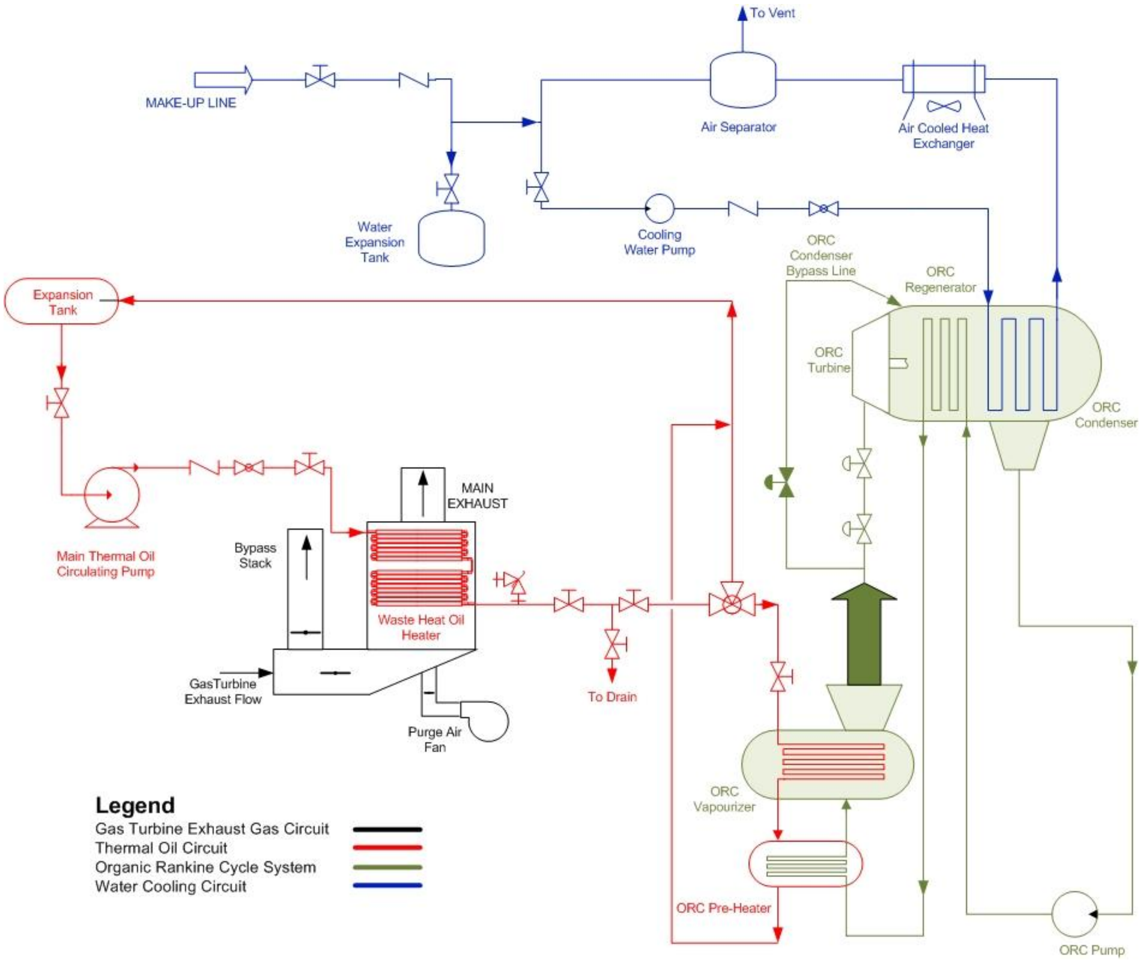


Figure 1: Waste Heat to Power Plant Process Flow Diagram

2.1 Gas Turbine Exhaust System

The guiding principle for the design of the gas turbine exhaust system was to ensure that the operation of the gas turbine gas compressor unit would not be disturbed by the operation of the waste heat power plant. Compressor station operators are chiefly concerned with achieving high plant availability, avoiding unplanned shutdowns, minimizing back pressure on the gas turbine, and maintaining operational flexibility.

The primary means of avoiding a plant shutdown is the bypass stack. During a trip or an unplanned shutdown of the waste heat to power plant, the bypass stack damper opens and the waste heat recovery oil heater damper closes. Figure 2 shows a photograph of the bypass stack and the waste heat recovery oil heater.

Figure 2: Waste Heat Recovery Oil Heater and Bypass Stack at the TransGas Rosetown Compressor Station

The waste heat recovery oil heater was designed and manufactured by Innovative Steam Technologies (IST) of Cambridge Ontario. Found Energy drew heavily on IST's expertise in waste heat recovery. IST has been recovering heat from exhaust gas for over 20 years and has over 140 units sold to date in 16 countries around the world. In addition to maximizing the performance of the waste heat recovery, the IST waste heat recovery oil heater was designed to minimize the backpressure on the gas turbine and to maximize the life of the thermal oil, which both reduce the maintenance requirements of the system and ensure the compressor station maintains its performance.

Figure 3 is a drawing of the IST oil heater. The oil heater is based on IST's Once Through Steam Generator (OTSG) design, which was adapted for heat recovery with thermal oil as the working fluid. Cold thermal oil enters the heater and passes through piping that is finned on the exhaust gas side to enhance heat transfer. The internal geometry of the heater has been designed to minimize the oil pressure drop while maintaining a sufficient flow velocity to reduce the oil film temperature. The unit is shipped in three stackable sections: an inlet plenum, the heat recovery module and an outlet plenum. The modular design allows for easy field erection.

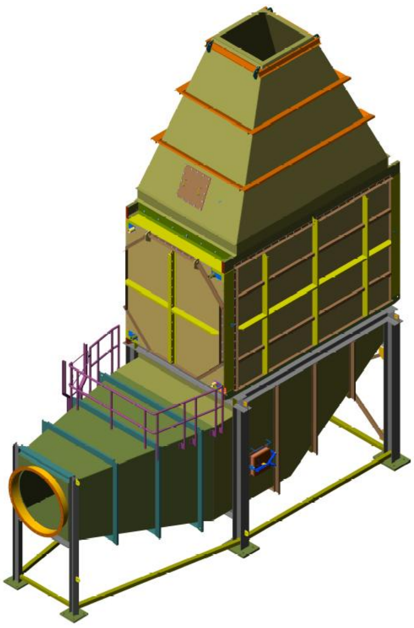


Figure 3: Waste Heat Recovery Oil Heater

One additional measure to improve the operational flexibility of the plant was to install an independent purge system for the waste heat recovery oil heater. Before the gas turbine can be started, the National Fire Protection Association (NFPA) requires that the exhaust system downstream of the gas turbine be purged with at least five volume changes and for a minimum of 5 minutes. This ensures that any combustible gases that may be present in the exhaust ducting are evacuated before starting the gas turbine. For this project, a purge air fan was installed directly downstream of the waste heat recovery oil heater damper. This allows the gas turbine's pre-existing purge system to purge the gas turbine through to the bypass stack, while the additional purge air fan purges the new exhaust system associated with the waste heat to power plant. This allows the compressor station plant operators to quickly startup the gas turbine without being delayed by the additional purge time required for the waste heat to power exhaust system.

2.2 Thermal Oil Circuit

The thermal oil circuit transfers the heat recovered in the waste heat recovery oil heater to the ORC plant. Thermal oil is circulated in a closed loop through the oil heater and then through the ORC evaporator before returning to the oil heater.

It is possible to eliminate the thermal oil circuit and directly evaporate the ORC working fluid in an evaporator that is heated directly by the exhaust gas. The thermal oil circuit increases the overall equipment complexity with the addition of pumps, piping, tanks, relief valves, instrumentation, etc; however, the thermal oil circuit does have the following key advantages:

- The thermal oil circuit operates at low pressures, which reduces the cost of the waste heat recovery oil heater.

- Many jurisdictions have lower operator requirements for plants with a thermal oil circuit, which reduces operating costs.
- It simplifies the ORC system by allowing for a much simpler evaporator to be used, and reduces the fill volume of the ORC working fluid.

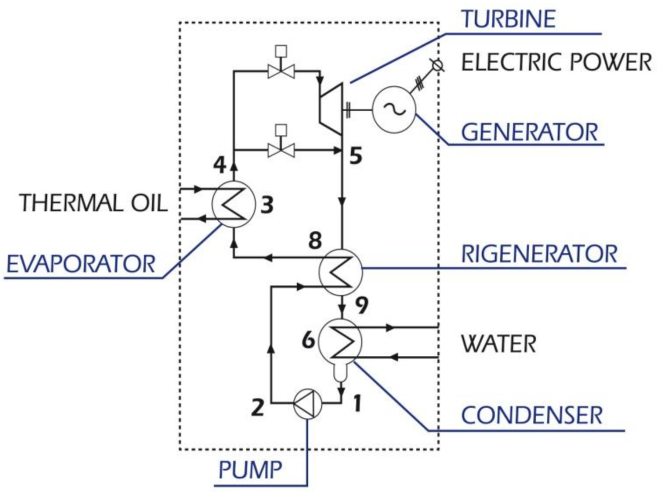
2.3 Organic Rankine Cycle (ORC)

The Organic Rankine Cycle (ORC) is the core of the waste heat to power plant. Conceptually it is similar to a conventional Rankine Cycle used at many thermal power plants, where water is evaporated and used to drive a steam turbine. An ORC plant uses an organic fluid instead of water as the working fluid. Examples of organic fluids are hydrocarbons, siloxanes, and many refrigerants.

The ORC cycle is depicted schematically in Figure 4 and is described here:

1. The liquid working fluid is pumped to high pressure and sent through the regenerator to the evaporator (State 1 to 2 to 8 to 3)
2. Hot thermal oil preheats and evaporates the pressurized working fluid (State 3 to 4)
3. The high-temperature, high-pressure vapor expands through a turbine which spins an electrical generator (State 4 to 5)
4. Lower-temperature, lower-pressure vapor exiting the turbine preheats the liquid working fluid in a regenerator (State 5 to 9)
5. Vapor is condensed to a low-pressure liquid by transferring heat to the low temperature cooling water stream (State 9 to 6 to 1)

ORC Process Schematic



ORC Temperature-Entropy Diagram

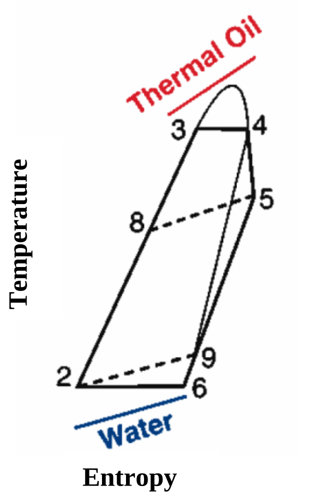


Figure 4: ORC Process Schematic and Temperature-Entropy Diagram

Organic fluids have a number of advantages over water for waste heat applications. They often operate at lower system pressures than comparable steam systems. Organic fluids have much higher molecular weights. These dense fluids allow for low speed turbines to be used, which increases the system reliability and efficiency. Many organic fluids are classified as 'dry fluids', which means they always leave the turbine in a supersaturated condition. Heat from the supersaturated, low pressure vapour leaving the turbine can be used to preheat the high pressure liquid before entering the boiler, which increases the cycle efficiency.

The Turboden ORC unit is shipped in three skids (Figure 5):

1. The Cold Module, which contains the turbine, generator, condenser and recuperator.
2. The Hot Module, which contains the preheater and evaporator.
3. The Pump skid, which contains the feed pump that is located below grade to ensure sufficient suction head for the pump.

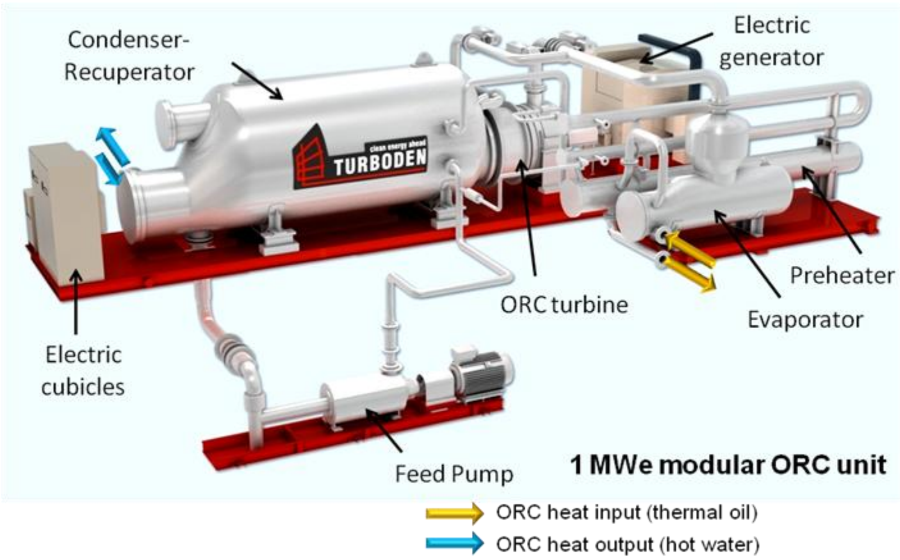


Figure 5: Layout of a 1 MW Turboden ORC unit

2.4 Water Cooling Circuit

In order to condense the ORC working fluid, heat must be rejected from the plant. A water/glycol mixture is used to transfer heat from the ORC condenser to air coolers shown in Figure 6. The water cooling circuit consists of a circulating pump, the air coolers, piping, valves, instrumentation and an expansion tank.

Figure 6: The glycol/water-to-air coolers for the TransGas Rosetown ORC Plant

2.5 Plant Performance

At the plant design point, the gross electrical power from the ORC generator is just under 1 MW. The system has reduced efficiency during high ambient temperatures when the cooling water temperature rises. Table 1 summarizes the plant performance at the design point and two extremes of ambient temperature.

Table 1: Summary of ORC Performance

		Cold Ambient	Moderate Ambient	Hot Ambient
Ambient Temperature	°C	-18	4	37
Exhaust Gas Temperature	°C	405	438	470
Exhaust Gas Flow	kg/h	62.6	58.5	52.0
Thermal Power Recovered	kW	4422	4730	4655
ORC Gross Electrical Power	kW	896	943	641

3.0 Construction

The Rosetown waste heat to power plant was the first Turboden power plant in North America. TransGas, Found Energy and Turboden worked closely throughout the project to ensure proper integration of the waste heat facility into the existing compressor station facility. A close working relationship was established to ensure that all engineering and regulatory requirements were satisfied.

Construction of the TransGas Rosetown plant was performed by Canonbie Contracting Ltd, which like Found Energy is an Aecon company. The construction phase of the project followed typical construction practices with the work starting with the civil work and followed by the installation of major equipment and interconnecting piping and wiring.

Typical construction time for a project of this size is 6 to 8 months and is dependent on the intricacies of integrating into an existing facility. Like any brownfield site, it can be challenging to locate equipment. Ideally, the compressor station has an area of land available where the plant can be located that is local to the existing facilities.

Figure 7: The ORC skid and Waste Heat Oil Heater Inlet Plenum are positioned by crane.

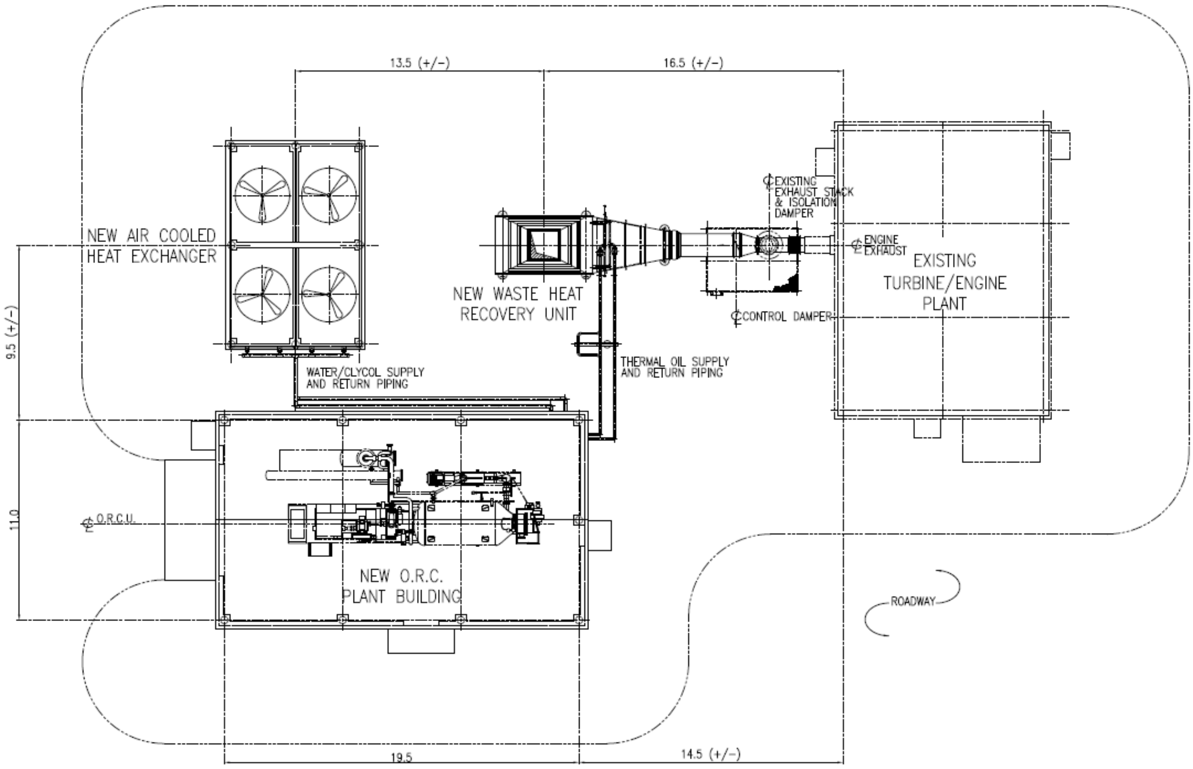


Figure 8: Waste Heat to Power Plant Site Layout (Dimensions in meters)

4.0 Application of ORC to Other Engine Exhaust

The TransGas Rosetown ORC plant is a nominally 1 MW electrical power plant. ORC technology can be applied to much larger plants and to plants with exhaust waste heat generated from reciprocating engines. Figure 9 and Figure 10 present estimates of the potential ORC power that can be produced from a variety of gas turbines and reciprocating engines. Each case assumed that the cooling subsystem dissipated energy to a 15 C (61 F) ambient.

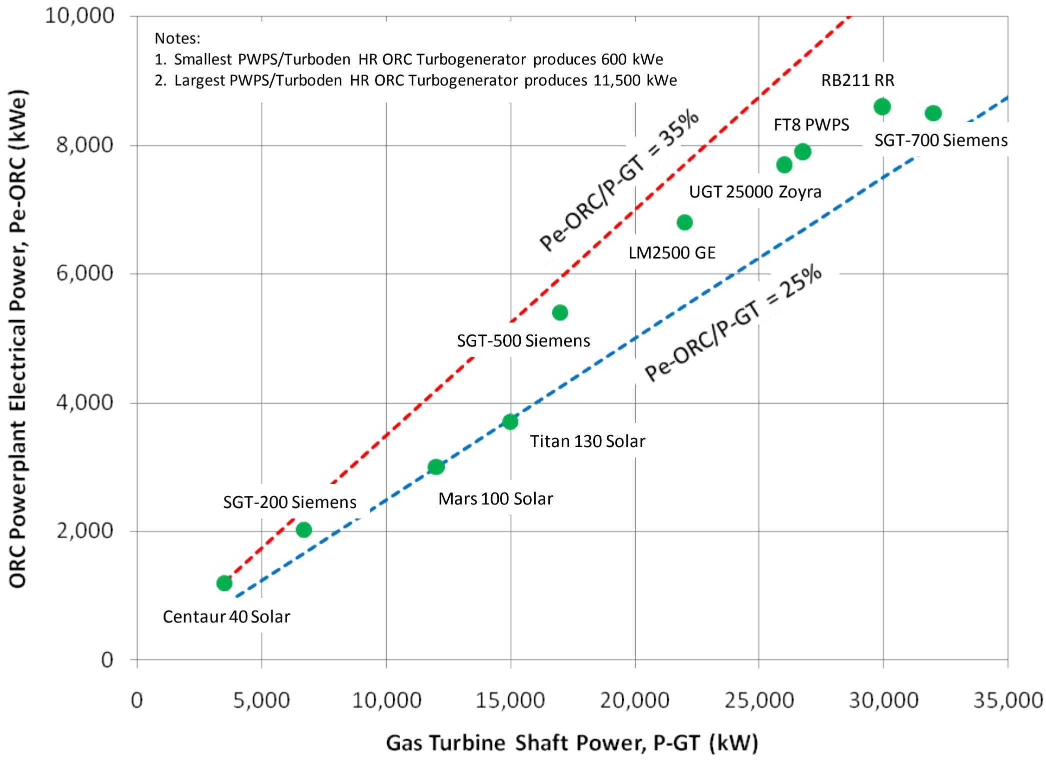


Figure 9: ORC Electrical Power v.s. Gas Turbine Engine Power

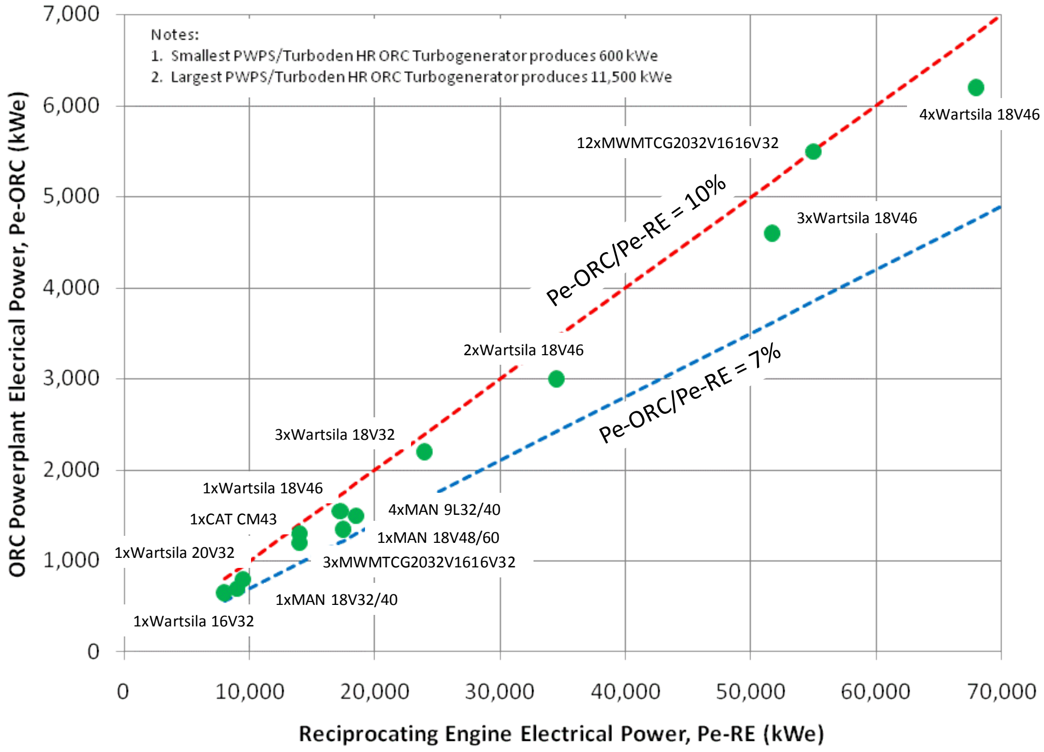


Figure 10: ORC Electrical Power v.s. Reciprocating Engine Power

As shown in the figures, the ORC powerplant output can be between 7~10% of the nameplate electrical rating of a reciprocating engine (or engine combination) and between 25~35% of the nameplate rating of a gas turbine engine. Proportionally more power is produced from a gas turbine than from a reciprocating engine because gas turbines in this size range generally have a lower thermal efficiency than a reciprocating engine or group of engines. Therefore, there is greater thermal power available in the gas turbine exhaust, and it is available at a higher temperature. Both of these characteristics favor higher ORC powerplant electric power production from gas turbine based plants.

5.0 Conclusions

The Natural Gas Transmission Industry is a large source of simple-cycle gas turbines that are used to drive natural gas compressors. The industry has identified these simple-cycle gas turbines as an opportunity to improve the efficiency of their compressor stations. In the last 5 years more than two dozen waste heat to power projects have been developed in North America at large compressor stations, most exceeding 11 MW (15,000 HP). TransGas Ltd, Found Energy and Turboden collaborated on a project to recover heat from a TransGas compressor station powered by a relatively small gas turbine.

The TransGas Rosetown Waste Heat to Power Plant produces approximately 1 MW of electricity from what would otherwise be wasted energy, i.e. the exhaust heat from a Solar Centaur gas turbine gas compressor drive unit. This type of project presents an opportunity for reducing carbon dioxide (CO_2) emissions of existing mechanical drive gas compressor stations or other similar waste heat sources. Waste heat to power plants are baseload when the heat source is baseload, reliable, and make use of a currently wasted energy resource. Waste heat to power plants are natural complements to a power generating portfolio of renewable power sources.

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