Final Outcomes Report

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1 EXECUTIVE SUMMARY

Global Power Technology's (GPT's) Remote Generator Compression System (RGCS) project endeavored to apply a new power generation technology for the compression of air at off-grid sites to replace instrument gas that is vented from pneumatic valves, thereby eliminating methane and other GHG emissions from gas production sites in Alberta. The new power generation technology that was selected was the Thermoacoustic Converter (TAC), which was at TRL 5-6 at the outset of the project and was provided by Etalim. GPT was responsible for product validation and product ramp up for the TAC, system design for instrument air compression, total system controls and enclosure, testing and field trials.

Through product validation testing and design improvement specifications, GPT was not able to apply the TAC to the RGCS system, and Etalim also ceased operations for similar business challenges. Despite this challenge, GPT demonstrated the performance and reliability of the instrument air compression design scope in its implementation of a thermo-electric generator (TEG) driven instrument air package installed at a multi-well pad site in British Colombia. TEGs provided reliable power at 1.5kW but with higher than desired fuel consumption and emissions, they are also not an economic solution for up to 5kW power that was being requested by industry.

To continue with the RGCS project, GPT rescoped with time to evaluate and select commercially available engines as prime movers for higher power to replace the TAC. Economic, high efficiency, low emissions, long run time, commercially available options were considered, and GPT decided on Combined Heat and Power (CHPs) and Internal Combustion Engines (ICEs) to proceed. System designs were updated to accommodate the new prime movers, internal validation was conducted, field trial customers were selected, and trials were supported and successfully run at client field sites.

The completed RGCS product portfolio includes the 1.5kW engine with a 2hp air compression and a 5kW engine with a 5hp air compression. Further system improvements are underway to offer an additional system with 6kW engine, 5hp air compression and auxiliary power up to 1kW, or to offer higher pressure or throughput instrument air options. GPT is continuing development beyond the ERA project scope to fully commercialize these RGCS designs. GPT's product offering has up to 60% lower fuel consumption and thus up to 60% lower emissions in power production than common competitor technologies (Stirling Engines). Further emissions reductions can be found through solar and battery hybrid options, but this doubles the cost of the power system and may not see strong market demand.

Greenhouse Gas (GHG) reductions from the systems that were installed during this project is 3,870 tCO_2e/yr. These reductions were achieved from the elimination of natural gas venting from pneumatic valves and from providing more efficient and lower emission power generation devices to sites. To estimate the future GHG commercial potential from the RGCs' developed in this project, GPT has taken a conservative estimate of forward looked demand and market share. While demand for emission reduction solutions is growing, overall oil and gas industry outlook will be challenged due to upcoming changes in environmental requirements, trends, and investor sentiment. Market share is estimated at 30% of based on competitor installed base or other technology options. Based on these estimates, the expected GHG impact up to 2025 for installed systems or products is 420,895 tCO_2e and 1.9M tCO_2e by 2030 (cumulative GHG abated, not annual rates). market share volume potential for power generation and instrument air compression systems.

GPT is grateful for the funding and learning opportunities that were granted by the funding from Emissions Reduction Alberta and would like to thank all the stakeholders who helped make the project a success.

2 PROJECT DESCRIPTION

2.1 Introduction and Background

Natural-gas-powered pneumatic devices vent natural gas (and therefore methane) to the atmosphere as part of normal operation. Methane is a powerful GHG with 25 times the Global Warming Potential of CO2 over a 100-year time horizon. Methane is the second largest source of GHG emissions in Canada, and the upstream oil and gas industry is Canada's largest source of methane emissions. In 2016, the Canadian Federal government - along with the US and Mexican governments – jointly announced their commitment to reduce methane emissions from the oil and gas sector by 40%-45% below 2012 levels by 2025. With the introduction of the Alberta Climate Leadership Plan, the Alberta Government set a 45% methane emissions reduction target for the year 2025. Methane emissions were targeted for regulations, taxes, and credits at federal and provincial levels.

GPT estimated based on average methane vent rates measured in British Columbia and a survey of oil and gas facilities in Alberta indicate that the methane emissions from pneumatic devices in Alberta is 44 million tCO2e annually. In 2021, it was estimated that up to 500M tCO2e/yr is vented globally from pneumatic devices in the oil and gas industry.

The Remote Generator Compression System (RGCS) was proposed to serve the oil and gas industry for methane reduction from venting of pneumatic devices in locations without access to grid power. Larger compression systems that run on grid power were well-known in the industry, so the challenge was to find a small and economic solution for both power and compression when it was not possible to connect to grid power. Challenges to providing an RGCS included low emissions / high efficiency power generation, smaller compression systems, buildings, or enclosures to withstand ambient temperatures and connectivity for remote operations. At the time of project kickoff, it was estimated that there was an opportunity to eliminate 2 million tCO2e/year through the adoption of an RGCS solution in Alberta.

With the RGCS, oil and gas operators can switch their pneumatic systems from natural gas to compressed air, and then use the existing natural gas feed to fuel the RGCS. Due to the efficiency of the TAC and the elimination of raw methane venting, the RGCS could reduce tCO2e emissions by 99.9%. Operators would not need access to grid power, and they could continue to use their existing pneumatic equipment.

Purchasing and deploying an RGCS would help gas operators meet GHG reduction targets while generating revenue when credits were available, leveraging funding to offset capital costs, decreasing carbon taxes where applicable and attracting new or different investors by prioritizing environmental projects. The targeted payback period for the planned system design was less than 2 years but could be better depending on funding available or cost efficiencies. In addition to the offset credit revenue, carbon levy savings and natural gas conservation, the RGCS provides gas facility operators with a source of reliable 24V DC power which facilitates the adoption of remote monitoring and control systems (i.e. SCADA) and the eventual digitization of the site.

The planned RGCS unit would provide 24V DC power in addition to the compressed air used to power pneumatic devices. Having electrical power available at remote, off-grid facilities provides operators with many more options for future site development. Operators can add digital monitoring and control systems with a telecommunications link to reduce the need for site visits, or operators can – over time – replace their pneumatic devices with fully electric/digital devices. If compressed air is no longer needed, the RGCS can supply up to a kilowatt of 24V DC power.

While operators will need to adjust the settings of their pneumatic controllers when they convert from natural gas to compressed air (due to the difference in density), the overall functionality of the pneumatic equipment is unchanged. Compared to the alternative methane emission reduction solutions (replacing pneumatic devices with electric/digital solutions or replacing high-bleed pneumatic devices with low-bleed devices), converting to compressed air is the least disruptive to facility operations.

Other advantages of instrument air systems include equipment life and safety. Natural gas often contains corrosive gases (such as CO_2 and H_2S) and can produce by-products of iron oxidation which can degrade and clog pneumatic devices. Using clean, dry instrument air to drive pneumatic devices increases their operational life and can reduce maintenance. Natural Gas is flammable and emitting natural gas through pneumatic devices into the atmosphere can create a potential fire/explosion hazard. Replacing natural gas with compressed air eliminates this hazard.

At the time of project proposal, commercial solutions were limited to valve changes (low bleed or electric), lower power off-grid instrument air or grid tie in, which at many sites was cost prohibitive. A summary of available solutions and potential limitations include:

- Replacing valves with low-bleed pneumatics (<6scfm/hr) could be considered on sites with only 1 or 2 valves, but above this, they are not economical and are still venting some gas (estimated at 23 tCO_2e/yr). The planned RGCS solution, at $50k, would break even if there are 5 or more valves on site, and would eliminate 99% or more of the site emissions.
- Solar power could also be applicable to small sites for device power on gas injection pumps for example. Space limitations and costs make solar power too expensive and too large for higher power instrument air applications.
- Solid Oxide Fuel Cells were available up to 1500W output, have high efficiency (25% - 35% conversion efficiency) and capable of continuous operation. However, they cannot be cycled frequently, don’t manage intermittent loads, cannot by hybridized and have a short fuel stack life (18 months). Also, the cost of the fuel cell alone ($54k) was greater than the total target system cost for RGCS.
- Direct methanol (PEM) fuel cells are also very efficient, and unlike solid oxide fuel cells, they cycle very well so they are suited to solar hybrid configurations. However, there are two key disadvantages are their limited life span (<4,500 hours run time) and they only run on pure methanol. The cost for a 110-Watt PEM fuel cell system with solar panels, batteries and enclosure is approximately $25,000, so is not an economic solution for instrument air.
- Thermoelectric Generators (TEGs) also are applicable for small power, where single units can offer up to 500W power, or multi-TEG systems can offer 1-2kW. However, due to the $/Watt cost, fuel consumption and emissions, TEGs would not be as cost effective as an RGCS solution for converting pneumatic devices to compressed air at larger oil and gas facilities (~5-20 pneumatic devices). It would also consume 10 times as much fuel and produce 10 times the emissions which would further erode the value proposition. As the leading international producer of TEGs, GPT was aware of the possibilities and limitations of TEGs and determined an alternate power source would be needed for this application.

The market was missing a higher power off-grid solution that could provide ample instrument air to single or multiple well-pads. GPT's proposed RGCS was a skid-mounted system that efficiently uses natural gas to produce dry, compressed instrument air and 24V DC electrical power. (See Figure 1.) To solve the gap in available and suitable power generation technologies, GPT partnered with Etalim to support the final test and development of the Thermo-Acoustic Converter (TAC) to provide 1kW power, efficiency, and emissions targets of the RGCS system. The TAC was a new and unique technology, being developed in Canada, that had the potential to efficiently convert heat from a fuel burner into electricity. Unlike typical ICE-based generators and fuel cells, the TAC had the potential to run non-stop for years without maintenance. Further details on the TAC technology are provided in Section 2 – Technology Description.

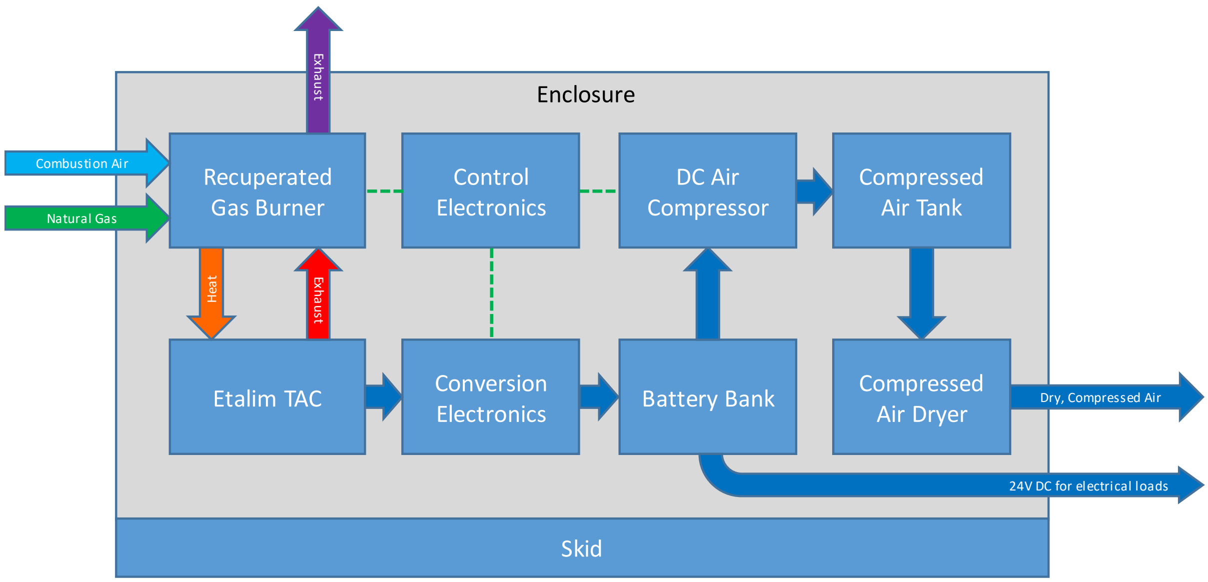

Figure 1 - Schematic diagram showing key elements of the RGCS

The compressed air produced by the system would be used in place of natural gas to operate the pneumatic devices. Instead of venting methane as a necessary part of normal operation, the existing pneumatic controls would vent only air. The TAC, or suitable alternative power source, is connected to a 24V battery bank to drive an air compressor. Compressed air is stored in a tank, and then run through an air dryer before it flows to the downstream pneumatic devices. The system is enclosed in a weatherproof, climate-controlled enclosure and mounted on a skid for quick and easy deployment in the field.

With the RGCS, oil and gas operators can switch their pneumatic systems from natural gas to compressed air, and then use the existing natural gas feed to fuel the RGCS. Due to the efficiency of the TAC and the elimination of raw methane venting, the RGCS could reduce tCO2e emissions by 99.9%. Operators would not need access to grid power, and they could continue to use their existing pneumatic equipment. The RGCS would also provide a source of 24V DC electrical power which the operator could use to add telecom communication equipment, SCADA and – over time – digitize the control systems. These conceptual ideas are demonstrated in Figure 2; in this example, the RGCS system is running at 50% compressed air capacity.

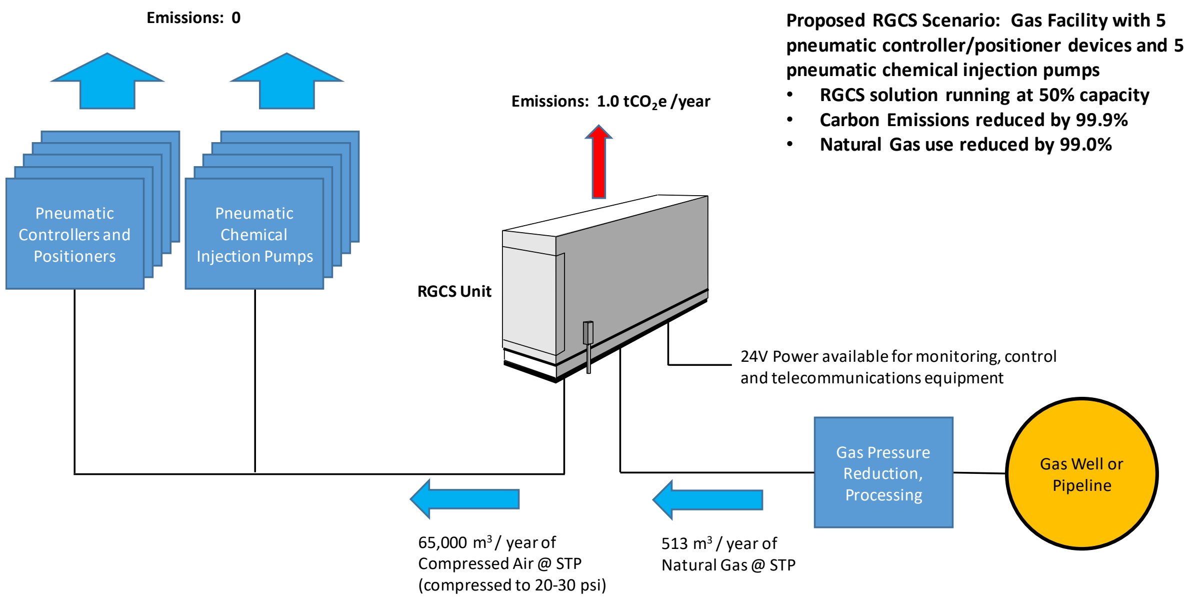

Figure 2 - Conceptual application of RGCS in the field

2.2 Detailed Technology Description

The original RGCS system was proposed to be powered by a Thermoacoustic Converter (TAC) Engine from Etalim and the balance of the RGCS was to be designed and integrated by GPT. A TAC converts any high temperature gradient to electricity, with high efficiency (20%-30%) and simplicity. The TAC represents a unique class of hybrid Stirling/Thermoacoustic device that combines principles of thermodynamics, high-amplitude acoustics, mechanical resonance, and materials science in a unique way. Advantages of a TAC would be reliability, cost, and fuel flexibility.

The Etalim TAC proposed a number of unique advantages over existing power generators:

- Extreme reliability, with no moving parts. The Etalim device utilizes high frequency vibration of steel diaphragms to completely eliminate sliding or rotating parts. The steel diaphragm flexure is the only moving part and operates well below the steel fatigue limit with a stroke of around 200 microns. The TAC contains no lubricants, refrigerants, or dynamic seals. The TAC is ruggedly welded shut at the factory and never opened again. These characteristics could potentially enable decades of predicted useful life, with no maintenance.
- Low cost through simplicity. The all-metal Etalim TAC design is simple, rugged, does not require expensive, rare, or toxic materials, and is well suited to mass manufacturing by the automotive sector.
- Fuel flexibility. The TAC can generate electricity from virtually any heat source or fuel. For fuel-fired applications, the TAC is heated from the outside by an external fuel burner. No fuel or exhaust passes into or out of the TAC. The TAC remains hermetically sealed to the environment and contaminants, for maximum reliability. The separate fuel burner can readily be designed as tolerant of a wide range of fuel grades or compositions.

A single TAC module produces 1 kW of electric power, multiple units could be used for higher power (2-3kW) and a larger 5 kW module was planned in the future product development roadmap. The 1 kW module consists of two cylindrical components, each approximately 40 cm long and 20 cm in diameter.

Thermoacoustics is the term used to designate the field of physics related to the interaction of sonic power with heat flows. Historically, there are many instances of a heated or cooled apparatus spontaneously producing very loud sounds and these are evidence for the strong interaction of sound with temperature gradients. Nikolaus Rott first put forth a firm theoretical mathematic foundation of thermoacoustic phenomena. Peter Ceperley realized that the gas cycle undergone in a travelling acoustic wave is the same as that in a classic Stirling engine, thus creating the basic idea of thermoacoustic engines. Shortly after this, LANL started working on both the theory and practical implementation of thermoacoustic engines and refrigerators culminating in many successful technology demonstrations, as well as publication of the definitive text on the subject. To date thermoacoustics had some commercial success in refrigeration in the form of pulse tube refrigerators for reaching cryogenic temperatures; however thermoacoustic technology had not yet been successfully commercialized for engines. Etalim had been slowly developing improved thermoacoustic engine concepts, culminating in the construction of several successful prototypes. From GPT's technology research, Etalim had developed the highest performance thermoacoustic engine in existence to date.

Compared to existing Stirling engines, the Etalim device utilizes high frequency vibration of steel diaphragms to completely eliminate sliding or rotating parts, obviating the need for lubrication. The steel diaphragm flexure is the only moving part and operates well below the steel fatigue limit. These characteristics enable a predicted useful life exceeding that of most applications, with no maintenance to the TAC. This is achieved without any close tolerance precision machining or exotic materials and is thus low cost as well. Etalim claimed that their design was simple, rugged, would not require expensive, rare, or toxic materials, and would be well suited to mass manufacturing. Etalim has six patents issued or pending, with several new applications planned to be filed.

At project kickoff, the TAC Thermal Module (TM) contained six discrete thermal amplifier modules. Each thermal amplifier consisted of a regenerator sandwiched between cold and hot heat exchangers. The regenerator is a porous structure ensuring optimal heat exchange between the solid and pressurized gas in order to let the thermal expansion and contractions to be in phase with the pressure and volumetric velocity oscillations. The level of thermal contact is achieved by building a stack-like structure with passages that achieve a hydraulic radius less than the thermal penetration depth of the gas. The regenerator has the full temperature gradient across it. As a gas parcel travels from the cold end to the hot end it will be heated and conversely as it travels from the hot to the cold end it will be cooled. With heat, the gas parcel expands, so a given volumetric flow entering the cold side of the regenerator will be amplified to a larger hot side flow at the higher exit temperature. Since acoustic power consists of gas parcels oscillating back and forth and the volumetric flow oscillation is smaller on the cold side than the hot side of the regenerator, the acoustic power is larger on the hot side than on the cold side.

Conservation of energy demands that amplifying the acoustic power requires power input and this is provided by the input heat flow. Heat has to be delivered to the hot side of the regenerator and removed from the cold side to maintain the desired temperature gradient. Without heat delivery and removal, the regenerator temperature gradient rapidly collapses and sound amplification ceases. In this regard, the heat exchangers deliver heat to the working gas at the hot end and remove it from the cold end. Essentially, the acoustic amplification is powered by accepting high temperature heat and rejecting low temperature heat as in classic heat engines. The higher the heat input temperature and the lower the heat rejection temperature, the higher is the achievable efficiency.

Within the Generator Module (GM), a transducer converts amplified acoustic power into mechanical power and then electrical power. The TM and GM are connected by acoustic power ducts, referred to in thermoacoustic literature as intertance tubes. The GM's transducer removes the power added by the acoustic amplifier section, leaving just enough residual acoustic power to restart the cycle. The transducer is coupled to an electromagnetic linear alternator, which converts the 200μm stroke of the transducer into electrical power. The GM (patent pending) is somewhat conventional in that it uses permanent magnets and electrical coils but unconventional as it is a flux switching arrangement that allows for the small motion of the transducer to cause large changes in magnetic flux. This component has been built, tested, and found to be 89% efficient. The GM has low vibration due to the use of two opposed alternators.

The TAC is self-starting. Once there is a temperature gradient applied to the thermal amplifier there will be acoustic gain; the acoustic oscillation starts spontaneously and rapidly grows until the losses exactly match the gain. These “losses” include the power removed by the transducer to produce electricity. The entire GM of the TAC is at ambient temperature, as are the acoustic ducts linking the TM to the GM. The SCL pipes are used for heat transfer from the heat exchanger, and thus must be thermally insulated. Both sets of ducts can be flexibly routed, offering good latitude to address packaging constraints of various platforms. A commercial 1 kW TAC system will have a mass of approximately 25-30 kg, and a volume of approximately 12 L (not including the exhaust heat exchanger).

Control of the TAC is extremely simple as all that needs to be done is to maintain the temperature gradient across the regenerators in the TM and to adjust the effective resistance of the electrical load to set the desired vibration amplitude of the GM transducer. No sensors or control actuators are required. The TAC can operate at temperatures hotter than vehicle exhaust is able to produce, so no exhaust by-pass valve is needed. The electrical load (power electronics) only needs to: 1) measure the output voltage, which is proportional to the vibration amplitude, and 2) be able to adjust its effective resistance to keep the voltage at the desired level.

The thermal amplifiers are frequency agnostic, but the TAC system is tuned by design so that it only runs at a single operating frequency (~500 Hz). The acoustic loop, the power transducer, and the electromagnetic alternator are all resonant structures tuned to the desired frequency. A patent pending feature of the TAC design is that it has considerable latitude in input and coolant temperatures due to its ability to passively adjust its operating frequency in response to changes in temperature. TAC acoustic connecting ducts can be insulated to remove any variability due to ambient temperature changes. The cumulative expected variation in tuning is small and within the automatic adjustment range of the electrical tuned circuit formed by the GM and associated power electronics.

At project kickoff, the TAC was at TRL 5-6 (Prototype Development and Testing). As such, technological risk was still present; the most recent prototype required test and validation, then design improvements for manufacturability, prior to being commercially available. GPT was responsible for TAC validation testing, TAC design support, and balance of plant for RGCS. Balance of plant challenges including ongoing development and hardening of the recuperated gas burner (material selection, sensor selection, control electronics and software), environmental testing, skid and enclosure design for ambient environment, sound abatement, passive climate control and security, development of cooling system and development of electronic system controls and associated software.

As described in Milestone 4 and as summarized below, the TAC engine was not able to overcome the product development and test hurdles in a realistic timeline to fulfil this project schedule and market opportunity. The technology focus for power generation turned to commercially available solutions which included combined heat and power systems (CHPs) and high efficiency, long run internal combustion engines (ICEs). This added new challenges to the balance of plant designs for cost management, control flexibility, enclosure heating and cooling, and off-grid start, stop and operation.

Combined heat and power (CHP) solutions were originally preferred for their ultra-high efficiency, especially when heat is required as is the case in Alberta winters. Technical challenges to create off-grid power from a commercial CHP exist because all the control logic and failure monitoring assumes that the device is connected to grid and will be kept within a narrow range of ambient conditions. GPT needed to create a micro-grid around the commercial CHP to use battery power and control logic to basically counteract the expected grid power presence for the CHP operation. This was estimated to be a technically manageable challenge, but in reality, was much more challenging since the “failure modes” and behaviour of the CHPs off-grid was not well documented, and many unpredictable problems arose.

Creating a bespoke internal combustion engine (ICE) generator became the preferred solution for better flexibility and fewer unexpected failure modes compared to the CHP. Although this design was larger in scope, it led to a better overall system with less complexity, better opportunity for GPT to add desired features, ownership of certifications, and a lower costs basis. Learnings from the CHP systems helped expedite the design and requirements for the ICE based systems.

2.3 Project Objectives

The original objective of this project was to develop and commercialize a cost-effective and reliable solution for gas operators looking to reduce methane emissions by converting pneumatic devices from venting instrument gas to instrument air, or by replacing them with electric alternatives. The specific objectives were as follows:

- Validate thermoacoustic engine technology in remote power applications
- Continue with market research and develop detailed product requirements and specifications
- Design the balance of plant, including skid, envelope, cooling system, recuperated gas burner, battery bank, air compressor, air dryer, air storage tank, control electronics and power electronics
- Develop and test one concept prototype including thermoacoustic engine and balance of plant
- Develop, test, and validate one alpha system prototype
- Develop, test, and validate five beta system prototypes
- Run field trials in representative customer sites using beta system prototypes
- Develop and build 5 pilot system units to test and validate the manufacturing process and prepare for mass production

During the market research phase, clients were starting to request higher than original pressures and volumes of instrument air. The first field trial for RGCS (2hp air compression system and 1500W from TEGs) was successful, but this client determined that they would standardize on a system with more compressed air (5hp) and auxiliary power (up to 1kW) as their preferred solution. While many clients were still evaluating what size of air compression and power they would need, it was confirmed by several clients that a range of air and power would be required to sites. As a result, two sizes of Combined Heat and Power (CHP) were selected (1.5 and 5kW) to accompany two sizes of Instrument Air (2hp and 5hp) Compression Systems.

Table 1 summarizes the original RGCS specifications as stated in the FPP, and the revised specifications based on client learnings and revised power technology after Milestone 3.

RGCS Initial Specifications		**Revised Specifications After Milestone 3**
Fuel	Natural Gas or Propane	Natural Gas or Propane
Generating Capacity	1 kW at 24V DC	1.5kW for smaller sites, up to 6kW for multi-well pads Auxiliary power up to 1kW is preferred
Conversion Efficiency	30% based on TAC theoretical (Fuel LHV to Electrical Output)	>25% target (with higher potential if both heat and power produced)
Compressed Air Capacity	8.7 scfm continuous flow 32 scfm peak	3 to 12 scfm continuous flow 32 scfm peak
Enclosure	All-weather, climate controlled	All-weather, climate controlled
Ambient Operating Temperature	-40 C to +50 C	-40 C to +40 C for Canada Temp derating >40C in hot locations for export opportunities
Emissions (full capacity)	0.613 kg CO_2e/hour (full pneumatic *and* electrical loading)	0.7 kg CO_2e/hour
Service Interval	1 year (inspection, filter changes)	>6 months (1 year preferred)
Generator Life	60,000 hours (almost 7 years running 24/7)	7+ years for continuous run 15+ years for solar hybrid solutions
Hybridization	A solar panel array can be added to the RGCS unit to further reduce emissions and fuel consumption	Solar hybrid capable
Remote Monitoring and Control	Ethernet interface supports SNMP and MODBUS protocols	Ethernet interface supports SNMP and MODBUS protocols

Table 1 - RGCS Specifications

The revised client preferences and shift in technological solution impacted the details of the system and required changes to the project plan, but the overall objective to provide an economical and robust RGCS for methane reduction remained. GPT lost some competitive advantage due to the sunk time spent on testing the TAC, but the revised project plan was still feasible, and the team remained committed to delivering a reliable system design. Unfortunately, GPT's delays to market created opportunities for new competitors and allowed other technologies to get a foothold in the market.

However, the project has delivered on a competitive design for RGCS and GPT has a commercialization plan to leverage the remaining large market opportunity in both Canada and internationally for this product application.

2.4 Work Scope Overview

The original project milestones outlined were:

- Milestone 1 – Detailed Requirements and Specification
- Milestone 2 – Instrument Air Conversion Field Trials
- Milestone 3 – TAC Pilot Design Release
- Milestone 4 – RGCS Concept Prototype Build, Testing and Validation
- Milestone 5 – RGCS Alpha Build, Testing and Validation
- Milestone 6 – TAC Pilot Build, Testing, Validation and Certification
- Milestone 7 – RGCS Beta Build, Testing and Validation
- Milestone 8 – Start of RGCS Field Trial
- Milestone 9 – RGCS System Certifications
- Milestone 10 – RGCS Pilot Build
- Milestone 11 – RGCS Production Ramp

Based on the outcomes of Milestone 1-3, the remaining milestones were then revised to reflect the shift in power generation technology due to gaps in TAC engine performance:

- Milestone 4 – Review Alternative Prime Mover Technologies
- Milestone 5 – Design Ruggedized CHP Solution
- Milestone 6 – Prototype and Test 5kW Prime Mover (M5)
- Milestone 7 – Prototype and Test 1.5kW Prime Mover (M1.5)
- Milestone 8 – M5 Field Trial
- Milestone 9 – M1.5 Field Trial
- Milestone 10 – Design 1.5kW and 5kW RGCS
- Milestone 11 – Prototype and Test 1.5kW and/or 5kW

The following information summarizes the activities as planned for Milestones 1-3, and then summarizes the activities per the revised Milestones 4-11.

Milestone 1 – Detailed Requirements and Specification

This milestone involved determining the commercial requirements (CREQ) for both the TAC engine as well as the complete Instrument Air Conversion (IAC) balance of plant, testing and validating the prototype TAC engines supplied to GPT, identifying the applicable certification standards, identifying one or more field trial partners, and developing a detailed technical specification (PSPEC). These activities were all completed by GPT through potential client meetings in Alberta, British Colombia, and the USA.

Deliverables in this milestone included Commercial Requirements (CREQ) from these interviews and Certification Requirements were defined. Etalim document detailed D100 specifications and GPT created detailed RGCS specifications.

Test plans were written, and results were logged for a subset of these on the D100 prototype Etalim TAC (See Figure 3) testing that was conducted by GPT staff at GPT's facility in Calgary, AB. Several significant non-conformances or deficiencies were found, documented, and communicated with Etalim. Prior to completing the full test plan, documented non-conformances included: D100 not making the specified power, D100 burner occasionally flashing back when burner is hot or warm, D100 system efficiency not meeting target, D100 coolant leak, and D100 internal helium leak. Based on these deficiencies, it was determined that the D100 prototype TAC did not meet the specified requirements and that further execution of the test plan was not warranted. The D100 prototype was returned to Etalim, and Etalim agreed to address the identified non-conformances in a future prototype release.

Figure 3 - D100 System (TAC prototype) being tested in GPT's Calgary, AB, Facility

Potential field trial partners were identified, and an agreement was made with Tourmaline Oil Corp. to conduct a field trial of a TEG-based instrument air conversion system as a preliminary step towards Milestone 2.

Milestone 2 – Instrument Air Conversion Trials

This milestone involved building and trialing a TEG-based Instrument Air Conversion (IAC) system at a customer site, namely Tourmaline Oil Corp. GPT designed, built, installed and commissioned a TEG-powered prototype IAC at one of Tourmaline Oil Corp.'s sites, located in Peace River Country near the Alberta/BC Border (see Figure 4 and Figure 5). This system includes a remote telemetry system to collect and monitor data on an ongoing basis.

Figure 4 - IAC TEG Based Field Trial (Alberta/BC border site)

Figure 5 - IAC Field Trial Instrument Air System

The RGCS had three 500W TEGs (S-8500s) with 24VDC. They were initially running on propane to prove the viability of the solution and were later connected to wellhead natural gas. Two 2hp oil-free scroll compressors with three phase, 208V were installed and connected via a variable frequency drive (VFD) with pressure transducer PID controller. There was a heatless desiccant dryer with purge economizer (energy saver mode) that was capable of measuring pressurized air dewpoint and controls purge. A programmable logic controller (PLC) was used to manage the system heating and cooling, drainage, and redundant compressor. Data acquisition was set up to monitor pressures, temperature, flow rate, humidity, voltage, current, power, and other key indicators in real time. Sample output data from this monitoring is shown in Figure 6.

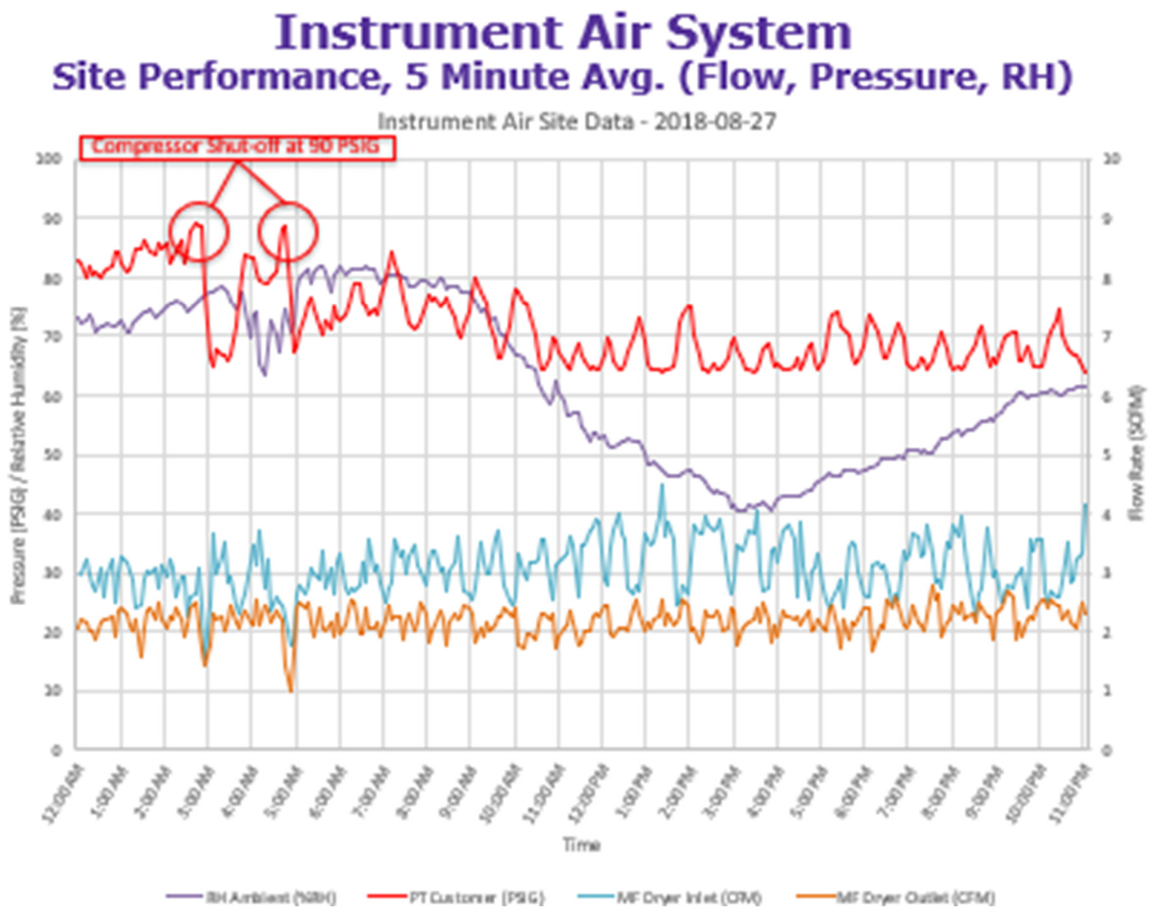

Figure 6 - Instrument Air Data from Tourmaline site

While GPT was monitoring the instrument air performance, it was noted that the site required air (3-4scfm specified) was much higher than actual being consumed (1.8scfm in August 2018). The lower flow rates were due to fewer wells operating because of H2S content that needed site remediation. With lower flow rates, the power required was 1.15kW and not the full 1.5kW available. Compressors were running intermittently due to lower air demand, and pressure was fluctuating between 63-90 PSIG. The VFD was noted to slow down to 30Hz when the pressure was above 65 PSIG.

Some noted challenges at site were poor cell phone coverage due to a nearby hill, and this impacted remote data monitoring at times. It was decided to add backup data storage via the USB port on the data acquisition device to capture data in case of cell phone data transmission failure.

It was noted that existing instrument gas lines were insulated but not heated, which confirmed that the dryer was indeed required in colder weather. Despite the lower air flow, the site operators confirmed that higher pressure would be preferred (100psig). These observations were used to confirm and update the RGCS specifications.

Client feedback noted that the system was easy to install with a picker truck. Tubing and fuel connections were simple to complete at time of installation. There were concerns for propane heating and drying in cold temperatures, so they switched to wellsite gas prior to winter. They raised a concern that the TEGs consumed a large amount of propane and would prefer a more fuel efficient power source on future systems.

Milestone 3 – TAC Pilot Design Release

This milestone involved the Etalim team taking the learnings from the testing and validation of the D100 beta prototype and updating the Thermoacoustic Engine (TAC) design for the pilot release. The pilot release TAC are referred to as early production or "EP" series. The first prototype, EP-1, was delivered to GPT's Calgary, Alberta, facility in April 2019 and was tested by GPT staff.

The key findings summarized in the test report were:

- A helium leak developed in the TAC system which caused reduced power and lower than specified efficiency. Without continual refilling, all the helium leaked out of the TAC, and it would cease to operate.
- The TAC is sensitive to the temperature of the duct cooling loop. The temperature of this loop determines the frequency of operation of the TAC. At cold temperatures, the TAC would resonate at an incorrect frequency which could damage the TAC internals. Heating the duct cooling loop to control the temperature of TAC operation was successful but required more electrical energy than the TAC was generating. Further improvements to duct temperature management are required.
- Improvements to the spark/flame sense electrode are required for a field-ready prototype.

The following summary was supplied by Etalim:

> *During Milestone 3, Etalim undertook a re-design of the TAC H10 1 kW power module. The intent of this design cycle was to 1) incorporate specific requirements relative to the Gentherm-Etalim ERA instrument air and other remote power applications, and 2) generally mature the design towards commercial production. Etalim's core thermal and generator design team were full time on this project, commencing with preliminary investigative design work in February 2018, followed by detailed design, component prototyping and testing, and culminating in core design completion in October 2018 and supporting component design completion (manufacturing jigs, etc.) in November 2018. The resulting TAC design is referred to as the "TAC H10 EP", where EP means early production. At the time of writing this report, all components are either on order or already landed at Etalim in support of a production run of 12 EP units schedule to commence in January 2019.*

Virtually all aspects of the TAC H10 Beta design were revisited during the EP design cycle, with an eye to improving reliability, performance, and manufacturability. Significant enhancements include the inclusion of high-performance foil regenerators, a high-recuperation gas combustion system, optimized manifolding, and fluid connections throughout, optimized electro-magnetic component designs, improved joining, and material selections. Relative to the older Beta design, this new EP design has 28% fewer parts, 35% lower assembly time and 30% lower bill of materials cost.

Various eligible expenses were not tallied nor included in the claim (fringe benefits, engineering subcontracting, ancillary equipment, and materials purchases) because the core labour and materials alone, which are claimed, exceed the budgeted amount for this milestone phase.

Another iteration of the EP engine prototype was planned based on the experience from tests in April 2019. The expectation was that the new version of the EP engine would be available for test at GPT's Calgary facility beginning mid-summer 2019, with the testing program extending into Q4 of 2019. A successful validation of this next EP system would enable the EP design to then be considered for IAC prototype integration.

The development steps towards advancing the prototype were not met in a timely manner, and Etalim fell into commercial issues due to a slow-down in funding. Without the cash flow to sustain or even increase their pace of engineering, GPT determined that it was not possible for Etalim to overcome the technical issues and meet the RGCS project schedule. GPT evaluated the overall situation, proposed a new path forward, and the remainder of the project scope, milestones and funding was reset.

Milestone 4 – Review Alternative Prime Mover Technologies

This milestone was required to redirect the team to other power generating technologies that could replace the TAC after it was established that the technology and company viability for the TAC would not meet the project goals for the RGCS project. The first step was to identify and compare available technologies in the required power range to create a short list of options to recommend in the path forward. The team considered some new technologies, but the TAC shortfalls drove the team to give considerable merit to commercially ready alternatives to de-risk schedule and project deliverables. While some solutions (e.g. internal combustion engines) could easily be studied, newer technologies with fewer suppliers (e.g. fuel cells or stirling engines) had limited publicly available information.

To fully understand the short-listed solutions, the team visited several vendors in person to evaluate technical and commercial viability. One visit was conducted to Microgen's (https://www.microgen-engine.com/) factory in China where Stirling engines are manufactured. This product is currently packaged for Asian and European cogeneration solutions with power grid tie-in. Although closer to commercialization than the TAC, the working power output was considerably lower than the theoretical planned power output for the engines and the work required to overcome this power shortfall in an off-grid system was estimated to be high.

Another visit was made to Upstart Power Inc (http://upstartpower.com/) in Massachusetts to study the commercial readiness of a Solid Oxide Fuel Cell (SOFC) fuel cell. At the time of the visit, the certification process was just getting started, but the product was preparing for multiple field trials. These fuel cells use propane which is an advantage in North America over Direct Methanol Fuel Cells (DMFCs), however still require solar and battery hybrid system configuration to extend the life of the product. Plans were in place to certify their product and modify the product to also run on natural gas. GPT is still in touch with this company today, and to date, their product is still not certified to industry requirements for commercialization.

Technology evaluation of internal combustion engine (ICE) solutions did not require supplier visits in person because the technology is well understood, and the key suppliers being considered were international manufacturers with proven global quality reputations. Several potential approaches to using an ICE were identified:

A) GPT to design an off-grid, long-run system for power production using ICE and motor controller from global supplier but all other scope designed and owned by GPT, including system environmental certifications. Toyota offers an 8kW long-run, low maintenance engine (https://key-components.toyota-industries.com/products/engine/chp_ghp/1ks/) that was considered best in class for development in this category. If higher system output power is available, larger instrument air systems could be powered, or excess electricity could be used to heat shelters or fuel lines in remote locations.

B) GPT to purchase a grid-tie Combined Heat and Power (CHP) system and make the necessary modifications for it to run off-grid in external elements. A CHP is deemed higher efficiency because it provides both heat (through a glycol heat transfer loop) and electricity (the engine's generator). The use of both heat and power could be attractive selling option for clients in colder regions who are looking for glycol heat trace solutions.

The first option would provide GPT with higher barriers to entry and more competitive costing but would take longer to bring to market. The second option would be the fastest path to market but could limit design flexibility depending on CHP control logic that is based on grid-connection and a moderate range of ambient conditions. GPT decided to pursue both these options but started with the CHP to get to market as fast as possible while learning more about the system control required for long run engines in remote environments. This two-step approach added scope for design but provided many technical learnings from the CHP operation that were applied in the ICE system design.

Based on technical requirements and project viability for cost and schedule, the team recommended to proceed with two CHP systems of different sizes with two different suppliers (Aisin and Yanmar) and the ICE engine from Toyota. The Aisin (https://www.aisin.com/product/energy/) would provide a 1.5kW modified combined heat and power system which we have named the M1.5. Aisins are distributed and supported by Atco in Western Canada. The supply chain is short and simple due to this local partnership.

For higher power, both the Yanmar CHP and Toyota ICE option would be developed. The 5kW modified CHP system was named the M5 using Yanmar (https://www.yanmarenergysystems.com/) in Japan as the supplier. This product has a much longer lead time and more complex development schedule due to a foreign supplier selection. The Toyota ICE was also considered for M5 development, but as differences in products were identified, it was decided to name the ICE product as the MX. There was less certainty around the power output of the MX in this stage of the project. The Toyota engines are stocked and shipped from a distributor in Germany, so total lead time was shorter than the 6-9 months required for Yanmar CHPs from Japan.

The three systems were included in the amended project schedule for design, prototype, and test in GPT's facilities. The amended milestones reflect the development of all these prime movers in the RGCS project plan.

The following accomplishments were completed in Milestone 4:

- A short list of potential prime mover technologies was created. This included Stirling engines, fuel cells, internal combustion engines (ICEs) and combined heat and power (CHP) systems.
- For the highest potential short list of prime mover technologies, a short list of potential suppliers were identified for further evaluation. Microgen, Upstart, Yanmar, Aisin, Marathon and Toyota were shortlisted.
- Key supplier visits were conducted to Microgen and Upstart. Yanmar's Canadian and American representatives visited GPT's Calgary facility. Meetings were held between Atco, Aisin, IMT (Toyota's distributor) and GPT.
- Aisin, Yanmar and Toyota/IMT were chosen to move forward with prime mover coverage in the required power range for the RGCS.

Milestone 5 – Design Ruggedized CHP Solution

To design a ruggedized CHP Solution, it was necessary to finalize the customer requirements and product definition of ambient conditions and remote operating expectations for our target market. Next, both 1.5kW and 5kW CHP models were purchased to begin running the CHPs "as is". This allowed us to determine which rugged ambient and operational parameters could be met with the "off the shelf" systems and which elements would need to be designed. As there was some overlap between Milestones 5, 6 and 7, the scope of Milestone 5 was focused on the mechanical design and testing to meet environmental conditions, while Milestones 6 & 7 were focused on electrical, electronic and control system modifications required. Furthermore, the mechanical design scope could be shared across M1.5 and M5 models, whereas the electrical, electronic and control scope was unique to each of the units.

Mechanical design scope was defined for heating, fresh air intake, exhaust, structural skid (lifting and operating) and overall enclosure. It was decided to use a reach-in enclosure rather than a walk-in building to decrease material, shipping, and logistics costs. As a custom option, the same equipment can be mounted in a walk-in enclosure for clients with higher budgets or additional equipment shelter requirements. Engineering models, prototypes and manufacturing drawings were created to either purchase or manufacture elements to build and test the ruggedized CHPs.

Specific deliverables included the design criteria for ruggedized prime mover, drawings, and bills of materials for the structural design scope, heat transfer calculations and cost estimates. The completed design for the ruggedized system was captured in a Solidworks 3D CAD model. Design details at this stage also included General Arrangement (GA) drawings, lifting diagrams, process, and instrumentation drawings (P&IDs), single line diagrams and wiring diagrams.

The following accomplishments were completed in Milestone 5:

- Designed mechanical scope for off-grid CHPs based on the selected OEM CHPs for 1.5kW and 5kW. Mechanical scope included:
    - Skid, structural support, and outer enclosure
    - Heating, ventilation, and air conditioning (HVAC)
    - Lifting (forklift/crane) design
    - Fuel conditioning and broader acceptable fuel specifications up to 1500BTU/scfm.
- With the mechanical scope complete, the ruggedized CHPs have an expanded temperature range to support fully off-grid start-up and operation.
- Completed mechanical design drawings and related documents for production and procurement.

- Designed, built, and tested the mechanical enclosure in GPT's Calgary, Alberta, facility with associated heating system for both M1.5 and M5 models.

Milestone 6 – Prototype and Test 5kW Prime Mover (M5)

Milestones 6 focused specifically on the electrical, electronic and control system modifications required to design an off-grid 5kW CHP to prototype and test. To begin the baseline testing phase, the CHPs were pushed to determine actual starting and operating limitations that would need to be overcome to allow off-grid operations. It was necessary to characterize the start-up, operating and shut-down modes that would be triggered by the OEM's control system when their system loses grid power.

Once the baseline was established, design requirements were defined to circumvent the on-grid operations and control of the CHPs, to add broader ambient starting and running conditions, and to modify shut down and start up capability in a remote environment under various failure modes associated with field operations (e.g. fuel outage, loss of pressure, etc.).

The first M5 prototype was built leveraging the rugged mechanical design scope from Milestone 5 (ruggedized mechanical design) and also the electrical design learnings from the M1.5 of Milestone 7 which was completed prior to Milestone 6. Test plans were documented and conducted, with troubleshooting and design modifications being made as required.

Relative to the 1.5kW unit, the 5kW posed a number of project challenges. First, the selected North American version of the OEM was purchased for development. Once this design progressed, GPT learned that this model was to be discontinued by the OEM. A similar Japanese market model was available but did not have CSA certifications and had slightly different architecture and design. Thus, the initial North American model design was complete, but another design was required to switch models with this OEM. Technical challenges also arose due to the OEM's control system logic in their CHP; GPT was essentially creating a control system to "undo" what the CHP system was built to deliver.

Commercial hurdles, such as long lead times from Japan, dealer agreement requirements and shipping delays also caused project delays and unexpected costs. These challenges expedited the plan to design the MX based on the ICE from Toyota. It was agreed to complete the M5 designs to capture the learnings, but to limit "perfecting" this unit with the knowledge that it was not the model to consider for higher volume production.

Deliverable documents supporting Milestone included user electrical connections and electrical Single Line Drawings (SLDs), detailed electrical implementation of the M5 prime mover, Process & Instrumentation Diagram (P&ID), General Arrangement (GA), test procedures and test records. GPT managed design development with Jira, an online, cloud-based issue tracking tool, to record and track defects and non-conformances for agile project management.

The following activities were completed in Milestone 6:

- Purchased and received North American model of Yanmar 5kW CHP. Designed and implemented electrical system and control software including micro-grid for the Yanmar M5. Completed all tests other than full cold-weather testing for the Yanmar M5.
- Yanmar discontinued the selected North American CHP model which had CSA certifications. The replacement Japanese model would require certification from Intertek, but there are some risks around scope and certainty of certification. Based on customer demand, GPT decided to switch to the model as a short term stop gap for product delivery, but re-design was needed to accommodate physical and control differences in the models.

- Purchased and received Japanese CHP model from Yanmar; redesigned 5kW off-grid CHP to accommodate model differences. Test plan was documented and completed through February and March 2021. Worked with Yanmar to plan best case lead time and schedule for production units for sales opportunities.
- Determined that GPT's product strategy with Yanmar CHP was not competitive enough:
  - Product lead time and shipping complications created logistical hurdles to achieving price and lead time targets for our clients
  - Technically, the scope of full on-grid CHP system added cost, complexity and size to our M-Series while limiting product options, certifications, and competitive advantages that are needed in the market.
- Purchased and received Toyota 1ks engine and generator for evaluation. Started product specification based on learnings from client field trials and internal learnings during design and test phase of M1.5 and M5

Figure 7 Shows the General Arrangement Diagram for the M5.

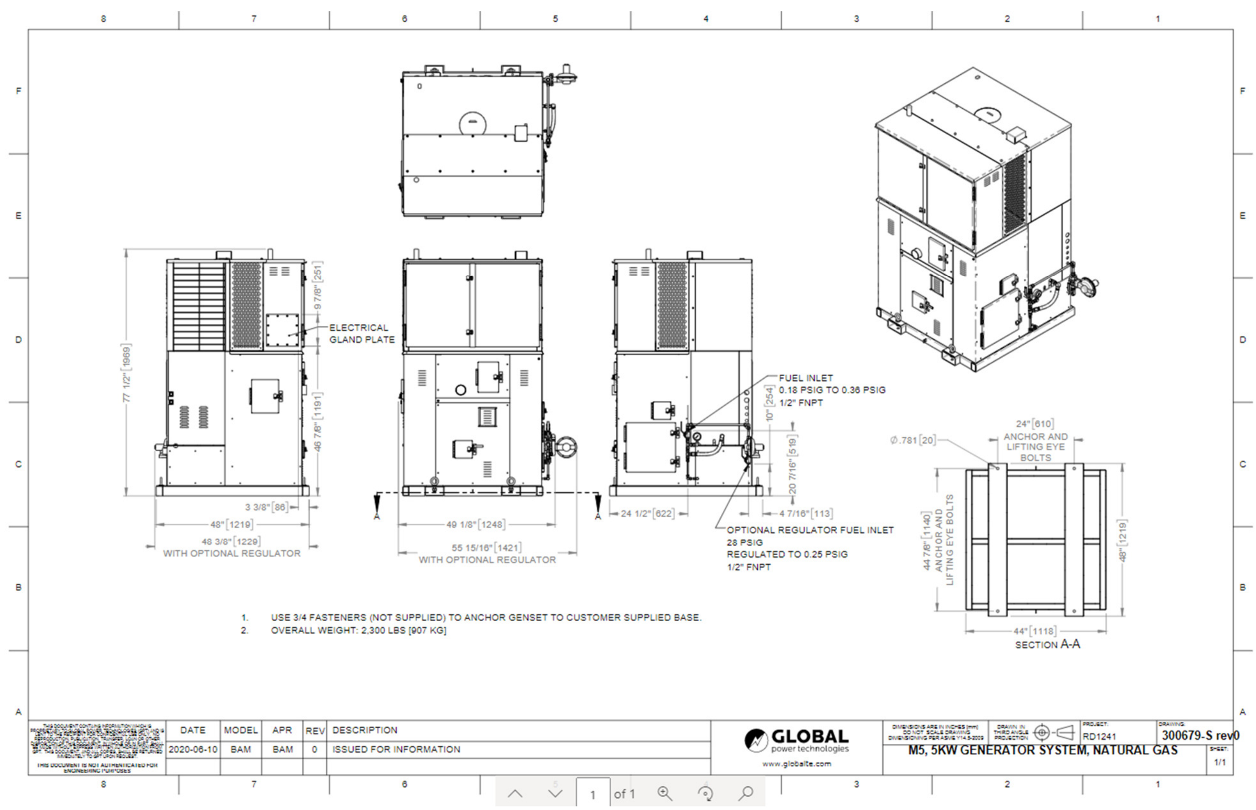

Figure 7 - M5 General Arrangement

Milestone 7 – Prototype and Test 1.5kW Prime Mover (M1.5)

Similar to Milestone 6 for the M5, Milestone 7 is for M1.5 prototype and testing. To begin the baseline testing phase, the CHPs were pushed to determine actual starting and operating limitations that would need to be overcome to allow off-grid operations. It was necessary to characterize the start-up, operating and shut-down modes that would be triggered by the CHP's control system when their system loses grid power.

Once the baseline was established, design requirements were defined to circumvent the on-grid operations and control of the CHPs, to add broader ambient starting and running conditions, and to modify shut down and start up capability in a remote environment under various failure modes associated with field operations (e.g. fuel outage, loss of pressure, etc.).

The first M1.5 prototype was built in GPT's Calgary, Alberta facility, leveraging the rugged mechanical design scope from Milestone 5 and incorporating the electrical design plans specific to the 1.5kW CHP. Test plans were documented and conducted, with troubleshooting and design modifications being made as required.

Deliverable documents in Milestone 7 included user electrical connections drawings, electrical single line drawings, detailed electrical implementation of the M1.5 prime mover and detailed wiring diagrams.

The following accomplishments were completed in Milestone 7:

- Purchased and received Aisin 1.5kW CHP (from Atco's Alberta distribution center).
- Designed and implemented electrical system including micro-grid inverter design.
- Worked with vendor to solve inverter grid parallel operation technical challenges.
- Selected and designed low-cost System Controller and control software.
- Completed generator system full electrical load range characterization testing.
- Completed testing including cold weather debugging.
- Completed system design drawings and related documents for production and procurement.
- Concluded that the Aisin 1.5kW CHP is a suitable solution to power the 2hp instrument air RGCS system. Noted that Atco inventory and distribution was major improvement for business viability in comparison to Yanmar Japanese production and shipping hurdles.
- Reviewed the suitability of M1.5 performance for integration with the 2hp instrument air package in Milestone 10 and 11.
- Test results from M1.5 shop testing

Milestone 8 – M5 Field Trials

Milestones 8 included four 5kW CHPs (Combined Heat and Power generators) for field trial at client sites. This was one more field trial than planned because of OEM's discontinuation of the North American model that prompted system redesign to replace with their Japanese model. The purpose of the field trials was to test the effectiveness of the systems at industrial client sites under different operating and ambient conditions.

Several sites were chosen for trials to allow testing in a variety of ambient conditions. Three northern Canadian sites were chosen, including two in Alberta, to determine how the units functioned in cold climates. Two units were installed near Edson, AB and a third was installed near Fort St. John, BC. The units installed near Edson, AB are shown in Figure 8 and Figure 9. Unfortunately, due to inclement weather, no pictures were taken of the M5 and the associated site for the unit installed near Fort St. John.

Figure 8 - M5 Unit (Edson, AB Site #1)

Figure 9 - M5 Unit (Edson, AB Site #2)

A fourth unit was installed near Haynesville, LA to determine how the unit functioned in hot weather. The unit installed near Haynesville is shown in Figure 10.

Figure 10 - M5 Unit (Haynesville, LA)

Overall, the field trials provided important information about client operating conditions and system design for an off-grid rugged environment application. As described in Milestone 6, GPT was already starting to learn that a CHP generator was adding unnecessary complexity in system design, and this complexity proved to continue to be a challenge when field issues arose. Since the field difficulties occurred after GPT had made the decision to redesign the generator around a Toyota internal combustion engine (ICE) engine, GPT took actions to address the field issues for the client but did not do major product redesign for CHP logic problems.

Deliverable documents supporting Milestone 8 included the list of defects or issues with the field trials, photographs, telemetry data from operating sites and client gas analysis.

The following activities were completed in Milestone 8:

- First North American M5 unit for cold weather field trial was shipped to client in December 2020 to a gas field near Edson, AB and was commissioned in January 2021. Some minor field debugging was required for fully autonomous cold weather operation. The M5 demonstrated reliable operation through the winter with periods of severe cold, snowfall, snow melt and freezing rain and spring pollen conditions. No client or operational concerns arose during the RGCS project period.

- First North American M5 unit for warm weather field testing was shipped to client in Louisiana, USA in November 2021. Support provided to client for installation, commissioning, and field troubleshooting. Client provided feedback on suggested improvements including enclosure gaps that needed to be blocked to avoid weather or vermin issues. Several technical issues occurred at this field trial including system overload requiring a modified startup procedure, a suspected exhaust engine issue that was replaced by Yanmar, and a corrosion issue due to insufficient sulfur filtration in the client's gas processing. Removed this system from operation because of issues related to H2S in gas that led to further operating issues. GPT was not able to replicate the issues in our Texas facility and the system was returned to Calgary for root cause analysis of issues in the future.
- Second North American M5 unit for cold weather field trial was commissioned in February 2021. No client or operational concerns arose during the RGCS project timeframe.
- First Japanese M5 unit shipped to client at the end of March 2021.

Milestone 9 – M1.5 Field Trials

Milestones 9 included three 1.5kW CHPs installed for field trials at client sites. The purpose of the field trials was to test the effectiveness of the systems at industrial client sites under different operating and ambient conditions.

Several sites were chosen for M1.5 trials to allow testing in a variety of ambient conditions. One northern Canadian site near Fort St. John, BC was chosen for cold weather testing and two in Texas were chosen to allow for hot weather testing. The unit installed near Fort St. John, BC is shown in Figure 11 and the units installed in Texas are shown in Figure 12 and Figure 13.

Figure 11 - M1.5 Unit (Fort St. John, BC)

Figure 12 - M1.5 Unit (Texas Site #1)

Figure 13 - M1.5 Unit (Texas Site #2)

The field trials provided important information about cold and hot weather capabilities for the M1.5. The extreme hot weather conditions demonstrated system limitations and led GPT to design a system for using solar panels to provide extra power and shading to carry load in extreme heat.

Deliverable documents supporting Milestone 9 include summary of troubleshooting to resolve warm weather field issues, photographs, remote monitoring dashboard output and telemetry data used for troubleshooting.

The following activities were completed in Milestone 9:

- M1.5 unit for cold weather field trial was installed and commissioned in Alberta in July 2020. Demonstrated trouble-free power generation through warm, cold, snow, rain, pollen, wind, and other harsh weather conditions. System shut off at 8,000 hours (CHP pre-programmed shut-down) for maintenance however the maintenance kit was not fully available due to Covid-19 related production delays from 3rd parties. The system was restarted without issue and the maintenance has been postponed until all parts in the kit were available.
- Two M1.5 units for field trial were installed and commissioned in Texas in August 2021 for cathodic protection on a pipeline. One of these systems had difficulty almost immediately in providing sufficient power during peak afternoon temperatures. Solar heat loading on the enclosure drove internal engine temperatures into “Avoidance Mode” where power decreased from 1.5kW to 800W to protect the engine. This behaviour is pre-programmed in the CHP logic. In order to address this, GPT designed a solar panel installation to float charge batteries and to carry the load in the hottest part of the day if the CHP goes into Avoidance Mode. The panels are positioned to provide shading to unit during the hottest part of the day (~3pm) in that region.

Milestone 10 – Design 1.5 kW and 5 kW RGCS

Milestone 10 involved designing RCGS compressor subsystems for use with the M1.5 and M5 prime movers. In order to better match customer terminology, these compression systems are referred to as 2hp and 5hp compressor systems. Two compressor systems (one 2hp and one 5 hp) were developed and prototypes were built for testing; these systems are called the EZ Air 2hp and EZ Air 5hp respectively for commercial sales. During system integration testing, it was found that the 2hp required a different compressor motor to run as an integrated system with the M1.5, so a DC motor system with lower inrush current was selected and tested. Details of this design phase are provided in Section 2.3.

Overall, this design phase resulted in the design of three basic RGCS compression systems that can be paired with the M1.5 and M5 prime movers. These systems are the EZ Air 2hp and the EZ Air 5hp systems for use with the M5 prime and the EZ Air 2hp with DC motor for use with the M1.5 prime mover.

Deliverable Documents for Milestone 10 included the design summary for EZ Air PLC logic, heat loss calculations for the EZ Air, and SLDs, P&IDs, and GAs for the three RGCS systems.

The following activities were performed in Milestone 10:

- Surveyed available compressor types. Types included reciprocating compressors, scroll compressions, etc. Scroll compressors were selected based on runtime between service and reliability. Commercial input is being considered for future generations of the EZ Air systems since some clients prefer lowest possible capital cost and are willing to have higher service intervals for lower purchase price.

- Developed EZ Air 2 hp compressor system consisting of two scroll type compressors, receiver, air dryer, flow meters, PLC w/HMI. A dual compressor architecture was developed to ensure 24/7/365 availability of the air system. A single compressor option was also developed as a cost saving option.
- Tested 2 hp RGCS in GPT's facility with the M5 prime mover and then the M1.5.
- During testing, it was found that the M1.5 prime mover was not capable of starting the 2hp RGCS compressor system. Although the M1.5 generated enough power to run the 2hp RGCS at steady state, the 2hp compressor motor requires high inrush current and the M1.5 could not supply adequate startup current. The M1.5 control system would go into an error mode and cause the generator to shut down whenever the 2hp RGCS attempted to start up. An extensive engineering analysis was performed, and a series of experiments were performed. These experiments included using Variable Frequency Drives (VFDs), soft starters and specialty motors to resolve the startup issue. The specialty motors are DC motors with an integrated AC to DC converter that was able to carefully manage and minimize the startup inrush current. As a result of these experiments, GPT selected the specialty DC motors for use in 2hp RGCS systems paired with M1.5s. A separate SKU (part number) was created for the 2hp RGCS system depending on which generator it is paired with.
- Designed a prime mover system (MX) based on the Toyota 1KS engine with lower cost requirements, flexible control system and less overall complexity. One unique feature is that this product design includes a generator that is optimized to drive a compressor motor through a VFD. Previous CHP systems had additional complexity (inverters) that created operational challenges and decreased overall efficiency of the generator.
- Developed PLC-based data acquisition system for use with GPT's remote monitoring system.
- Developed 5 hp RGCS compressor system (EZ Air 5hp). Consists of a single scroll-type compressor, receiver, air dryer, flow meters, PLC w/HMI. A dual compressor architecture was also developed to ensure 24/7/365 availability of the air system for high reliability; the single compressor option will remain as a cost saving option.

Figure 14 shows the General Arrangement drawing for the EZ Air system.

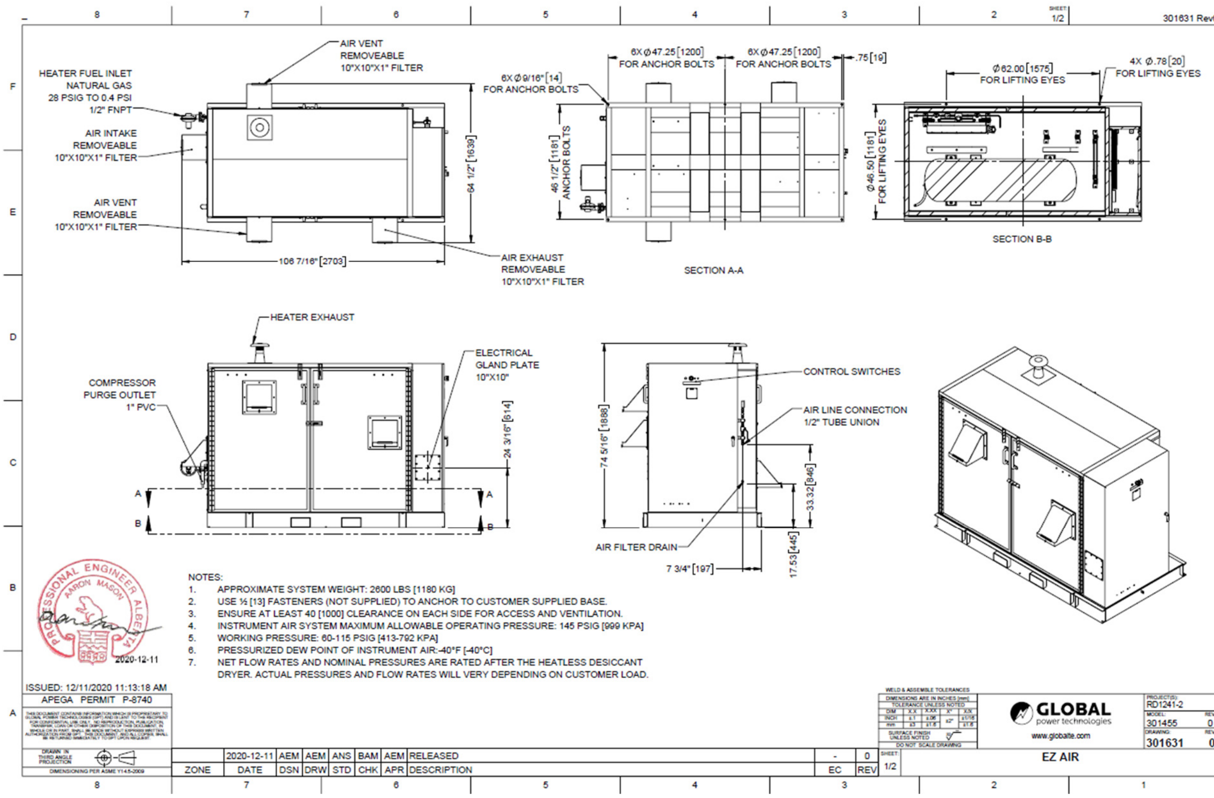

Figure 14 - General Arrangement Drawing for EZ Air

Milestone 11 – Prototype & Test 1.5 kW and/or 5 kW RGCS

Milestone 11 involved constructing two RGCS systems and testing them in the field.

The first was an EZ Air 2hp paired with an M5 prime mover. This system was installed and tested in Northern Alberta. It has been successfully running in the field since January 2021 and continues to be monitored by GPT service personnel via GPT's remote monitoring system. This unit worked flawlessly through the intense polar vortex of February 2021.

A second EZ Air 2hp was paired with an M1.5 prime mover. This system was installed and tested in the northeastern United States. It has been operating since summer 2021 and is also remotely monitored.

Deliverable documents supporting Milestone 11 include instrument air flow calculations, EZ Air test plans and results and system test reports from Initial State remote monitoring. Defects and concerns were logged in JIRA for agile project management.

The following activities were completed in Milestone 11:

- Constructed a 2hp RGCS with M5 generator which is being field trialed in northern Alberta, as shown in Figure 15. Commissioned system at client site and monitored by GPT team through remote monitoring; a screen shot is provided in Figure 16.
- Constructed a 2hp RGCS and M1.5 generator which is being field trialed in US location. Commissioned at client site and monitored by GPT team through remote monitoring.

Figure 15 - EZ Air 2hp with M5 installed in Alberta

Figure 16 - EZ Air 2hp with M5 screenshot from Initial State (remote monitoring)

2.5 Performance/Success Metrics Identified In The Contribution Agreement

Success Metric	Commercialization Target	Project Target	Achieved at end of project
System Efficiency (LHV to Watts)	25%	25%	24.8% for natural gas 27.5% for propane
Continuous Electrical Power Output	Original target 1kW but most clients requesting more than 5kW	1kW	Up to 6kVA net
Compressed Air Output	8.7 scfm avg continuous flow	5 scfm avg continuous flow	4.5 and 12scfm models (100psi, -40C dew point)
Maintenance Interval	1 year	6 months	9,000 hr with extended sump
Operation on Natural Gas and LPG	Operates with 800-2500 BTU/ft3	Operates with 800-2500 BTU/ft3	Natural gas 966-1181 BTU/SCF HHV Propane 2477 BTU/SCF (consumer grade)
Total System Cost	System cost to support $50k CAD	N/A	System cost higher than target but in line with market alternatives
RGCS Emissions	0.7 kg CO2e/hr	0.7 kg CO2e/hr	0.56 kg CO2e/kW-hr
RGCS Remote Monitoring & Control	Ethernet interface (SNMP & MODBUS)	Ethernet interface (SNMP & MODBUS)	IoT with cellular modem, Modbus Serial Connection for SCADA, hardwire dry contacts for remote start, system on/off, alarms, ESD
Ambient Operating Temperature	-40C to +50C	-40C to +50C	-40C to +40C Derating curves to be provided for >40C
Operating Conditions	Rain, snow, ice	Rain, snow, ice	Rain, snow, ice
Certifications	DOT, Transport Canada, CSA TIL R10	N/A	In process for EPA 40 and UL/ULC 2200 CSA SPE-1000 approval in the interim
Code Compliance CSA B149.3, AS3814	CSA B149.3, AS3814	N/A	CSA B149.3 compliant

Table 2 - Performance metric targets vs achieved in RGCS project

As Table 2 indicates, almost all technical metric targets for the project were achieved. The one exception is gas specification for British Thermal Unit (BTU) composition, where the CHP and ICE generators were not capable of the preferred gas specification that the TAC could have offered. This difference will be important to some upstream wellhead gas applications, where GPT's solution will be less cost competitive if expensive fuel conditioning equipment (filters, knock-out pots) are required for our solution but would not be required on a Stirling engine. There are many sites and applications where the gas composition will meet the RGCS design parameters and will not create any competitive disadvantage. Overall, this limitation is estimated to create an impact at 10-20% of the total market opportunity, and so will not be addressed in product development activities in 2022.

3 PROJECT OUTCOMES AND LEARNINGS

3.1 Overall Project Achievements

The original objective of this project was to develop and commercialize a cost-effective and reliable solution for gas operators looking to reduce methane emissions by converting pneumatic devices from venting instrument gas to instrument air, or by replacing them with electric alternatives. The RGCS project achieved this objective and is deemed a success by GPT. Key achievements included:

- Product validation and assessment of schedule and cost to bring a TAC engine to market
- Determination that further product test, design improvements and higher power output were needed from the TAC engine that rendered it impossible for GPT to use the TAC as the prime mover for this ERA project or to meet market timelines required
- Evaluation of commercially available engines to meet client power and compressed air demand
- Selection and evaluation of Combined Heat and Power and Internal Combustion Engines as the revised prime movers
- Robust design of instrument air system for off-grid Alberta wellhead gas applications
- Implementation of RGCS systems in the field for feedback on various applications and in various operating environments
- Improved understanding of client requirements and quickly shifting market realities that came about due to Covid (supply restrictions, cost increases, staffing challenges) and increased market competition (new entrants and subsidized product entry)

The achievements relative to the specific objectives (as summarized in Section 2.0) are as follows:

- Validate thermoacoustic converter technology in remote power applications. Validation and test activities raised several technical, schedule and quality concerns for the TAC. GPT concluded that the TAC could not be commercialized in the desired timeline for market demand and/or ERA project deliverables, so new power generation solutions were required.
- Continue with market research and develop detailed product requirements and specifications. Detailed product requirements and specifications were developed in Milestone 1, but requirements evolved and were modified as possible throughout the project to reflect developing client knowledge and preferences. GPT continues to modify the RGCS base design to offer higher pressure, higher throughput, and more data for GHG reporting requirements. Commercially, GPT continues to strive for lower cost and shorter lead time to compete as buyers shop to meet cost and schedule targets for their budgets.
- Design the balance of plant, including skid, envelope, cooling system, recuperated gas burner, battery bank, air compressor, air dryer, air storage tank, control electronics and power electronics. These objectives were completed and delivered. Balance of plant improvements that are ongoing include noise reduction on the MX unit, temperature control of the condensation pipe on CHPs, temperature derating curves for hot climates, compressor brand changes for client preferences, and tank size flexibility as requested by clients.
- Develop and test one concept prototype including thermoacoustic converter and balance of plant. GPT delivered the first 1.5kW RGCS to the field using 3x500W TEGs to meet client schedule goals. The plan was to replace these TEGs with a TAC prototype once available. Since the prototype TAC had quality and power output issues, a system prototype using TAC for power was never completed in GPT facility or installed in the field.

- Develop, test, and validate one alpha system prototype. Alpha system prototype was installed in BC with 3x500W TEG power generation for a 2hp, 30psi instrument air solution. This prototype is still successfully running for the clients in the field today. As noted above, it was planned to use a TAC in this system but since this technology was not ready for commercialization the TEG based system was used.
- Develop, test, and validate five beta system prototypes. This objective was not met in its original intent due to the modified Milestones after Milestone 3. However, five beta prototype systems (including power and instrument air) were developed, tested, and validated in GPT. As the power generation created the biggest challenge, multiple power units were tested with the same instrument air designs. The air systems were 2hp and 5hp. The 2hp air system was tested with 1.5kW CHP and 5kW CHP (North American model). The 5hp air system was tested with the 5kW CHP (North American model), 5kW CHP (modified Japanese model) and 6kW ICE. GPT considers this objective fulfilled even though the milestones and scope of when it was achieved was different than originally planned.
- Run field trials in representative customer sites using beta system prototypes. As above, this objective was not met in its original intent but was fulfilled in a modified fashion. There were two field trials using the full RGCS 2hp beta system prototypes. One was using the 1.5kW CHP and the other with the 5kW CHP (North American model). There were no 5hp system prototypes tested in the field as part of the ERA project. Under the revised Milestones, the objectives shifted to running field trials with alternative power sources even though not all client field trials required instrument air compression. The revised objectives were met, and summarized field trials are found in Section 3.7.
- Develop and build 5 pilot system units to test and validate the manufacturing process and prepare for mass production. This objective was not met in its original intent due to the schedule and scope change in the project. Post ERA project, GPT is finalizing pilot system testing in house and is ramping volume for mass production of the 1.5kW CHP, the 6kW ICE, and the 2hp and 5hp instrument air systems.

3.2 Knowledge Background and Development

Prior to project proposal, GPT conducted a full technology review on new power generation technologies. Commercial and academic sources with technology and market data were used to recommend the TAC for GPT's RGCS system. Various metrics were considered including efficiency, power output, cost, maturity of technology, emissions, footprint, and product life. An example of the comparative data collected for various technologies in the analysis is shown in Figure 17 which compares product efficiency at various output power ranges.

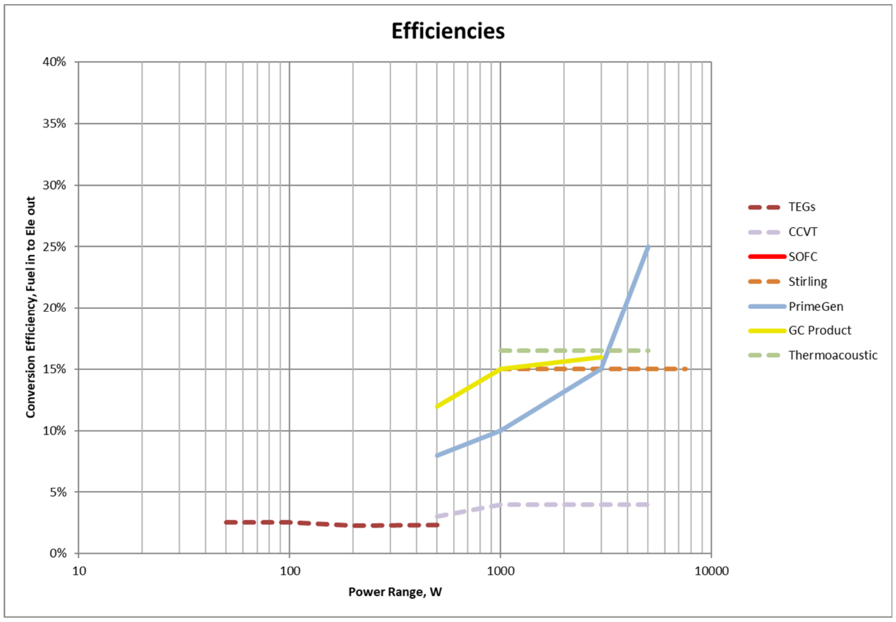

Figure 17 - Technology power range and efficiency comparison

Technologies that were commercially available at the outset of the project are summarized in Section 2.1 above. One of the technologies that was not considered in the FPP was the Stirling engine. GPT had evaluated Stirling engine prototypes prior to the project but estimated that the product had further control system design and development required for more reliable power. Since that time, Qnergy received significant funding towards Stirling engine development, resolved the product control issues and made a strong market entry.

Information on client requirements for instrument air was difficult to collect and confirm. While data was available on maximum emissions by instrument, the actual instrument air requirements (peak, average) were not well understood by clients. When site air requirements were not known, clients provided the worst-case air volume and flow rate estimates to ensure valve operation. This reduced downtime risk at site but vastly increased the air compression and power required in the system specification. From the initial estimate for power of 1-1.5kW, the client specifications increased to 5kW or more. This drove demand quickly for larger RGCS systems and created market opportunities for Qnergy and other competitors.

Qnergy gained first mover advantage; they are based in the USA, and they design and manufacture Stirling Engines up to 5.6kW. Qnergy partnered with local Alberta companies (e.g. OilPro) to sell and integrate their engines into instrument air systems for Canada. Stirling engines have good reliability in a wide climate range, can provide heat and power for better site efficiency and their costs have been decreasing due to economies of scale. Drawbacks to Stirling Engines are lower efficiency which means higher fuel consumption and higher emissions. GPT's M Series offer 50-60% lower fuel consumption and emissions compared to a Stirling Engine in the 5-6kW operating range.

[Qnergy | Reliable Remote Power | The world's leading clean technology manufacturer of Stirling energy systems.]

One solution that was initially eliminated from GPT's proposal was internal combustion engines (either diesel or natural gas powered) to power larger loads in remote power applications. Combined with a generator, they can be used to power electrical/digital controllers and pumps, or combined with an air compressor, they can be used to convert pneumatic devices to compressed air. Internal combustion engines are very efficient and have an established service network, but usually have limited lifespans (a diesel engine will run for approximately 15,000 hours) and require significant maintenance. In the 1-10 kW output range, a thermoacoustic engine was considered more cost effective and simpler to maintain so was not originally considered.

In 2019, Alberta-based engineers saw the opportunity to integrate internal combustion-based generators with compression and drying equipment at a low cost in a seacan. To address the maintenance and run-time issues, they used larger oil sumps selected higher power continuous-run engines and added solar panels and batteries. They formed Westgen Technologies and started manufacturing for this market space from Calgary (now Balzac) integration. Similar to GPT's solution, their system is based on internal combustion engines. The design philosophy is somewhat different, focused on lowest cost purchase price but anticipating higher operating cost with more regular system maintenance. Westgen uses standard sea-can for the enclosure to minimize cost and offers hybrid solutions for very low fuel consumption and low emission options. GPT does not have market data on what percent of their systems are hybrid solar vs pure power; this data would be interesting to know to understand how often clients are willing to pay higher price for solar and battery instead of continuous run power generation. Westgen has recently entered the USA market with resellers in target regions.

Energy Equipment & Solutions For Oil & Gas Industry // WestGen Technologies

GPT has learned that the market is changing very quickly and with it the specifications and expectations are changing quickly as well. GPT's initial power and air requirements were underestimated (2.5hp air systems) because clients prioritized their largest well sites to maximize instrument air changeover to reap the highest rewards from capital funding available and carbon credits to follow. These larger sites required 5hp and often request 1kW auxiliary power. While this specification became common in the market, in reality, it is often more than the clients require. Some clients prefer to have excess capacity, but other clients are beginning to shift specifications to decrease cost and lower fuel consumption. For this reason, GPT believes that offering two sizes of instrument air (2hp and 5hp) makes sense. Still others requests systems in between (3hp) and GPT may need to leverage current designs to make modifications and offer less air with more power.

As GPT is marketing the RGCS further afield, it is also being seen that specific pressures and conditions are required in various markets. For example, in the southern USA, high temperatures (>40C) create different operating challenges than those in Alberta. Different vermin and insects also need to be considered in the enclosure design. Higher pressure (120-145psi) is also seen in that region.

3.3 Technology Development and Selection

Customer system requirements and detailed test plans were defined early in the project based on the information available at that time from GPT's clients. Test plans were written to evaluate the performance of the TAC prior to system integration and field trials, then test jigs and monitoring were established to document the test results in GPT's Calgary facility. In parallel to TAC testing, GPT designed an Instrument Air proof of concept system using TEGs for power. Test plans were created and followed for the balance of plant that were separate from the outcome of the TAC engine at that time.

The first set of TAC tests were run (Milestone 1) using Etalim's D100 prototype. Significant non-conformances or deficiencies were found and communicated to Etalim. These included insufficient output power, burner flashback, low efficiency, coolant leak, and internal helium leak. Etalim worked to resolve these issues for the next set of testing on the pilot release (Milestone 3). The pilot EP-1 was tested and again there were unresolved deficiencies including helium leak, variable duct cooling, variable operating frequency, and quality issues with the spark/flame sensing. These issues ultimately led to low power, low efficiency, intermittent operations, and schedule delays in performing the tests, and led to concerns about quality, manufacturability, time to completion and overall performance of the TAC in the RGCS. Schedule delays, inability to raise further funding and technical uncertainty led to the termination of Etalim operations so no further testing of TAC engines could continue for this project.

The Instrument Air scope was successfully tested in GPT's facilities using three S-8500 TEGs (for net power of 1.5kW) and was installed at a Tourmaline site in Peace River county. The Instrument Air system met site requirements, but the multi-TEG installation led Tourmaline to look for lower fuel consumption and higher power output generators. Since the TAC was not progressing to schedule, GPT was not able to offer a solution and GPT's competitor, Qnergy Stirling Engines, were chosen on subsequent sites. Tourmaline leveraged GPT's Instrument Air system with Qnergy's integration partner, and there was no IP in place that would have allowed GPT to protect the engineering work and scope (lesson learned).

Etalim Test Report (EP1) at GPT

Tests on EP1 were summarized in GPT's Product Internal Test Report, dated May 2, 2019. EP#1 is the Engineering prototype for Etalim's "Early Production" release of the H10 Thermoacoustic Converter (TAC). This prototype is heavily instrumented and is intended to be used for initial validation of engine low temperature operation at GPT's facility. The test article will only be available to GPT for 2 weeks (maximum).

The main objectives of this testing were as follows:

1. Verify Etalim's test results at room temperature.
    a. Maximum steady state output power.
    b. Ability to maintain Hot Core temperature.
    c. Maximum coolant temperature (Duct (tuning) Loop and Thermal Module (TM)).
2. Ensure burner starts at cold temperature.
3. Verify pressure losses & confirm low temperature pumping.
4. Measure inertance duct heat / cool loads vs T and P.
5. Examine overall engine performance at very low temperature.
    a. Maximum steady state output power.
    b. Maximum coolant temperature (Duct (tuning) Loop and Thermal Module (TM)).
    c. Ability to maintain Hot Core temperature.

The test method was:

1. Receive EP#1, unpack and setup in chamber.
2. Commission all cooling loops, burner control system and Etalim provided instrumentation.
3. Perform room temperature baseline run – verify operation is similar to Vancouver testing.

4. Cold soak overnight at ~-10°C, verify starting ability, test performance.
5. Cold soak overnight to -30°C, verify starting ability, test performance.
6. If time permits, cold soak overnight to -40°C, verify starting ability, test performance.

GPT was not able to repeat the 900WAC achieved by Etalim in Vancouver. There are 2 known factors that hindered the engine in Calgary:

1. Helium leak in the system – any leak will cause a decrease in efficiency and reduce the power output of the engine [RISK].

2. Combustion tuning – emissions were measured, and it was determined that these tests were run in a slightly fuel rich condition. O2 in the exhaust gas was low and CO was higher than TIL R10 would allow. This will be corrected for the next round of testing with the EP#3 engine.

Another concern with EP#1 is the temperature of the duct cooling loop. With a target of 40°C, the engine would only be capable of running in an ambient of 35°C or lower [RISK]. Our intent is to have a prime mover that can operate in ambient from -40°C to +60°C. EP#3 is expected to have a higher duct temperature target for this reason.

At Room Temperature, there were no issues observed with ignition, but challenges were seen at -10°C. Suspected condensation may be fouling the flame holder knit or causing issues with flame sensing. Burner removed for inspection, nothing apparent observed. Burner reinstalled into system without sealing material at nozzle. Correct depth of electrode verified and marked on ceramic of electrode. Continued to have issues with ignition. Rotating electrode seemed to solve the issue and ignitions became far more reliable. Burner temperatures (and flame position) appear to be uneven within the burner [RISK]. At start-up there is a 10°C difference between the 2 hot core thermocouples. This difference lessens to 5°C at peak power output, but the hot core appears to always be hotter to one side.

At -30° ignition, even with electrode rotation corrected, ignition still had challenges. Electrode 'sunk' into burner from previous test. Electrode holder not effective in maintaining position of electrode[RISK]. Once set, ignitions were more consistent but not sustained. Took many retries to maintain a flame. Exhaust temperature increased to 60°C then plateaued for ~2 minutes before continuing to increase to operating temperature. This is a challenge with the recuperative design [RISK]. In cold start cases, the heat sinking in the recuperator will pull heat away from burner and hot core.

The Hot Core gains some temperature from the initial unsustained ignition. Once flame is sustained exhaust temperature increases quickly to 60°C, then holds. During this period, the flame sensing signal was most unstable. Once exhaust temperature continued to increase, flame sensing stabilized. This phenomenon was also observed in the -10°C test data.

The first attempt to run cold soaked at -30°C, the Engine came online at a frequency of 380Hz and an overstroke condition was observed. The engine had to be shut down and inspected before proceeding with testing. This is one of 2 frequencies coupled with mechanical failure modes. 380Hz leads to a horizontal resonating of the GM spring tube and rod and 430Hz leads to a vertical resonating of the same tube and rod [RISK]. These failure modes determined the limits of the operating frequency of the TAC. In order to mitigate starting at 380Hz, the temperature differential between the hot side and the cold side needs to be >= 400°C when the engine starts. In the case of this test, the engine came online before such a differential was reached. Duct coolant heater was insulated, further insulation was added to the inertance ducting and the radiator was removed from the duct cooling loop in order to reduce the number of losses in the system in an attempt to keep the duct loop warmer. Table 3 summarizes EP#1 engine performance at cold temperature.

Gross AC Power achieved (WAC)	845
Natural Gas Flow Rate (SLPM)	8.5
Air Flow Rate (SLPM)	90.4
Ambient Temperature (°C)	-28
Helium Pressure (PSIG)	1503
Hot Core Temperature (°C)	657
Maximum TM Coolant Temperature (°C)	14

Table 3 - EP#1 Engine Performance at Cold Temperature

Power achieved at -30°C ambient was slightly higher than that achieved at room temperature and at a lower fuel flow rate. Challenges were had with ignition and maintaining the inertance duct temperature target as outlined above.

Summary of risks identified from GPT's Internal Testing of EP#1, and assessment of risk to RGCS project:

1. Helium leak in the system – any leak will cause a decrease in efficiency and reduce the power output of the engine. The engine was dismantled and inspected by Etalim. The helium was leaking from O-ring fittings on the inertance ducting. The fittings are not intended to be part of the final design, this should be considered low risk.

2. Temperature of the duct cooling loop. With a target of 40°C, the engine would only be capable of running in an ambient of 35°C or lower. EP#3 is intended to have a higher duct target temperature, this should be considered low risk.

3. Burner temperatures (and flame position) appear to be uneven within the burner. Etalim is aware of this issue as they continue to iterate and improve the burner design. This should be considered low to moderate risk.

4. Electrode holder not effective in maintaining position of electrode. Etalim is aware of this issue as they continue to iterate and improve the burner design. This should be considered low risk.

5. Exhaust temperature increased to 60°C then plateaued for ~2 minutes before continuing to increase to operating temperature. This is a challenge with the recuperative design. In cold start cases, the heat sinking in the recuperator will pull heat away from burner and hot core. Etalim is aware of this issue as they continue to iterate and improve the burner design. This should be considered low to moderate risk.

6. The amount of energy required to heat the coolant is excessive and will only get worse as the Duct cooling loop temperature target increases. Etalim is aware of this issue and discussions are ongoing. There are several solutions for this, some at the engine design level and others at a system packaging level. This risk must be managed and at this time should be considered a moderate risk.

7. Further improvements in insulation or heat sharing with other loops will be necessary to keep the temperature balanced and in the required range in the duct cooling loop for optimal performance of the engine. This risk is heavily coupled with #6.

8. This is one of 2 frequencies coupled with mechanical failure modes. 380Hz leads to a horizontal resonating of the GM spring tube and rod and 430Hz leads to a vertical resonating of the same tube and rod. Etalim is aware of these failure modes and is now aware that it is possible to start at the ‘wrong’ frequency in cold ambient with the current design. This will be largely influenced by design choices made to eliminate/mitigate risks 6 & 7. This should be considered a moderate risk.

9. During the TM coolant pump loss, the engine stopped its stroke and the Hot Core temperature rose immediately. This behaviour was not anticipated by Etalim. They have been made aware of the issue and will provide details as they investigate. This should be considered moderate risk until root cause is determined.

As combined learnings from TAC testing and Instrument Air TEG system demonstration at Tourmaline, GPT revised the customer specification and project plans. Higher power would be required to meet larger well site instrument air requirements, and if available, excess power from the system was requested. Large well sites were being prioritized based on company goals to reduce methane emissions as quickly as possible. It is anticipated that once the larger well sites are complete, smaller systems will be requested if they are available at lower relative cost and have lower total emissions. GPT’s revised system design requirements and test plans were based on smaller (2hp air) and larger (5hp air) models to capture these opportunities.

GPT conducted in depth evaluation of several technologies as alternatives to the TAC. These included a Stirling engine from Microgen Engine Corporation (MEC) and a Solid Oxide Fuel cell at Upstart.

<u>MEC Stirling Engine Analysis</u>

GPT’s senior mechanical engineer visited MEC’s production and development lab on September 10th, 2019. One complete 1.6kW Free Piston Stirling Engine (FPSE) Generator startup, steady state test run, thermal cycling and shut-down cycle was carried out smoothly in this Factory Acceptance Test (FAT). The test was done at free air environment on a FAT test setup inside MEC plant, at room temperature, which is around 30 Celsius most of the day.

The main objectives of this testing observation are as follows:

1. Witness MEC 1.6kW/60Hz FPS Generator FAT test.
2. Witness MEC 1.0kW/50Hz FPS Generator FAT test.
3. Evaluate overall Free Piston Stirling Engine/Generator/System performance:
    a. Maximum steady state Generator output power
    b. Generator System Electrical Efficiency at maximum output power
    c. Generator System power turn down performance (Efficiency vs Power curve)
    d. Ability to start at low ambient temperatures
    e. Ability to operate at wide ambient temperature ranges
    f. Repeatability of FPS Engine performance
    g. Engineering prototype system test setup

The Generator FAT test stand setup is controlled by a computer running Labview. Operator HMI and control software all reside on this computer. Fuel flow and air flow set points could be controlled via Operator HMI, by communicating with Burner controller, but in the standard FAT test process, the fuel flow and air flow are controlled by Burner controller itself. Higher level PID control loops are used to control engine head temperature. Software loads batch parameters (flow set points, Micro Grid AC frequency and AC voltage set point, etc), when transition through different states during start-up, thermal cycling, load changes, and shut-down process.

The Generator FAT test is started by following the system startup procedure (simplified):

1. Burner ignition, and flame guarding;
2. Engine quick heat-up;
3. Alternator start power generating (when head temperature reach 180C);
4. Maintain ramping up of Engine Head temperature;
5. Maintain maximum Engine Head temperature less than 525C;
6. Reach Maximum loading and maximum power output;

After peak power is reached, the FAT test software will start the standard cycling test process.

The standard FAT test process includes lots of test steps, for example:

2. AC voltage changes.
3. AC frequency changes.
3. AC power output changes.
4. Coolant temperature changes.
5. Power rolls down when coolant-in temperature reach 70C.

Highlights on the 1kW/50Hz standard FAT test process:

1. Data recorded: 14400 seconds (240 minutes, or 4 hours).
2. Cold start: warm up to generate 900W takes less than 600 seconds (10 minutes).
3. Power (Gross AC) reached 1000W.
4. Shut down process is an accelerated cool down process <120 seconds (2 minutes).
5. Power turn-down to 650W is tested with lower head temperature when coolant temperature reached 70C.

Figure 18 demonstrates the test data plot for the 1.6kW/60Hz generator FAT test.

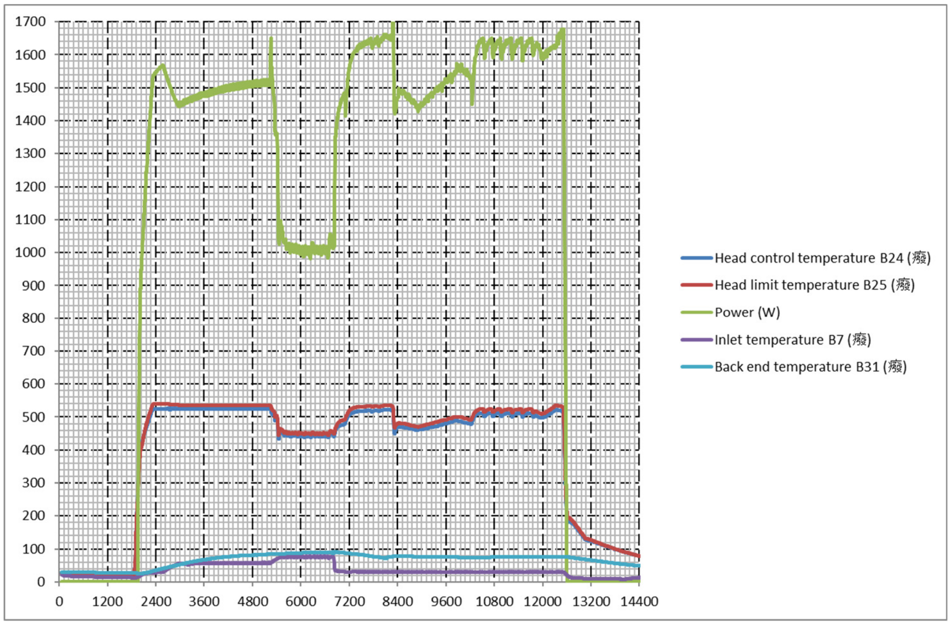

Figure 18 - 1.6kW/60Hz FAT test data

Based on GPT's observation of the FAT at MEC, a summary of advantages, disadvantages and risks were provided to the RGCS project team.

Advantages in MEC's Stirling Engine:

- Integrated single unit generator design (Engine and Linear Alternator in one unit);
- Low Helium Charge Volume
- Low Helium Charge Pressure (23 Bar) and Hermetic Seal design
- High Generator Efficiency (25% Heat to Gross AC Power)
- Large engine head surface area to interface with Burner
- Mature Burner Design and Burner Integration
- Several Burner and Engine Head options
- Fast start-up and shut-down
- Good Thermal Cycling Life

Disadvantages:

- Low Burner Efficiency (Current Burner Design is low in efficiency)
- Low System Efficiency (Current ThermoGen's, APU's and Engine Kit's system efficiency are low)
- Alternator is Grid-tie design, can NOT operate without grid (? to be evaluated)
- Grid-tie engine control design, sync to grid is slow (need shut-down then re-start when disconnected)
- Engine Control Unit's control and protection parameter are relatively fixed and tight

Major risks identified for Microgen Generator applications:

- Microgen 1kW and 1.6kW Generator economic production volume
    - Remote Power application is unlikely to generate large quantity order of the generators.
    - The plant size will likely need a relatively large annual production volume to sustain.

- Generator System Cost could be higher than target for RGCS applications
  - A packed Remote Power Generator System will need to run standalone.
  - Micro-Grid is required for Grid-tie system in a standalone setup.
  - Balance of Plant for wide temperature range operation could cost more.

Coolant pump failure will force the generator system shut-down, so system design would need to consider this risk. A dual coolant pump system could alternate the running pumps and extending overall coolant pump life, also the second pump could be used as a redundant pump in case of one pump failure.

If the major risks listed above can be addressed, the Microgen Generator will be a really good candidate as a prime mover for Remote Power applications.

<u>Upstart Solid Oxide Fuel Cell evaluation</u>

A senior GPT mechanical engineer visited Upstart Power's primary technology development center in Massachusetts, USA in March 2019 to conduct a technology assessment.

Upstart has a relatively long history in the development of SOFC technology, starting with the acquisition in May 2007 by Protonex of Mesoscopic devices, subsequent purchase of Protonex by Ballard Power Systems in June 2015 and subsequent divestment of the Protonex SOFC team in August 2018 that then formed the basis of the current Upstart Power. The company is still effectively a start-up, so business processes are early stage and informal. The ownership group is comprised primarily of the current management team, all former employees of Protonex.

Upstart is the assignee on key, but limited IP related to SOFC stack integration and dry catalytic partial oxidation reforming (CPOX) as well as some system control equipment (from Mesoscopic Devices) and system controls. Upstart has invested significant resources into building strong relationships with primarily Japanese suppliers of SOFC ceramic cells and stack, without which they would have no product. Strategies to mitigate supply concerns revolve around cross licensing of system IP back to the supplier.

The fundamental cells and stack technology are state of the art and being used successfully in Japanese Combined Heat and Power (CHP) systems as part of a Japanese national drive to reduce energy demands for a country that currently imports all hydrocarbon fuels and still feeling the aftereffects of to the nation of the Fukushima nuclear disaster in 2011. Stack life with ultra clean fuels are warranties to 10,000h but expected to last 80,000h (with "no life degradation"), withstand 400 full thermal cycles and 10 redox cycles (reduction – oxidation, emergency shutdown without protective reducing atmosphere for the anode).

Upstart's end goal is to be successful in the residential CHP market. Industrial remote power is an acknowledged path to market entry for all such technologies. Upstart has been making connections with potential customers in the industrial space and these overlap markedly with our current and intended customer base. Upstart recognizes the effort and resources required to pursue the industrial markets and is committed to developing channel relationships to be able to focus on the core technology development and end goal in mind. Ideally, the current Management Buy Out (MBO) team are looking for their Japanese ceramics supplier to acquire the company. Other partners Upstart is working with in non-remote power applications also have options to buy into the company. Primarily these are a Natural Gas to Ammonia SOEC (Solid Oxide Electrochemical Conversion) play and a residential back-up "triple hybrid" play in Puerto Rico. Upstart is currently well funded through 2021 with a burn rate of $3 Mio / year.

The current technology demonstrator is designed to cost and so volume cost of $10k at volumes of 100’s and $5k in the 1000’s is likely a solid point to start from in assessing cost curves. The largest unknown for GPT is the stack cost. The major hurdle for Upstart to overcome is certification of their device to the CSA / ANSI FC1 standard. They are just beginning this journey.

The primary focus of the technology assessment was to determine the current reliability of the Upstart UPGEN 5, 500 W SOFC demonstration unit as well as assess the current team’s ability to realistically see where they are in the technology development and how the team solves problems, all leading to an assessment of the probability of success. As is the case with most tech assessments, actual life test data for the Upstart system’s degradation and less so cycling is limited and will be presented in detail in the coming weeks.

Test stand area contains 5 bench test stands for UPGEN 5 SOFC device. Also showed 8 or so SOFC cell test stands currently not in use (as SOFC Stack / Cell supplier chosen, but they have the capability.) The test stands are quite rudimentary, simply benches under fume hoods, approx. 8 ft wide, back to back with some ducted exhaust and inert cover gas for emergency shut down. Unsure of test stand controls but system and its BOP used for most testing, Spoke of test stand failures due to frozen USB connection and also gas sensors tripping fuel. All tests are performed using UHP propane, not Natural gas. When asked why, the team thought remote applications, especially SOFC, would use propane and propane provides hurricane resistance. System CPOX should be able to reform NG, but controls adjustments required and concern around impurities, gas quality and changes in energy content.

The SOFC system works in conjunction with battery only. Required for start-up, load following and controlled shut down without leading to oxidation of anode (and likely thermal management). Battery also desired for autonomy. The battery is not integrated into the system, neither is any fuel treatment. Desulphuriser canisters are external to the device. Current system contains a full graphic HMI, Ethernet, embedded web server. DC/DC is non-isolated from Synqor, and system is negative grounded, although the stack is floating. Many questions were asked why an isolated system would be required, little information was provided in return to protect our applications (CP, offshore ground fault etc.). Looking to eliminate graphic HMI in future and replace with App on phone.

System demonstration conducted; key parameters observed:

- Uf 62% @ 1.25 slpm fuel
- 420 W
- 39.6V or 0.8V/cell (need to keep above 0.7V/cell) Just under 50 cells in stack
- 10.5A
- Exhaust temp 400 to 450 oC
- DC/DC converter losses 20 W (low 90’s for efficiency. Off the shelf converter, non-isolated.
- Balance Of Plant 30 to 50 W
- 24V system (standardized to reduce the test matrix).

Based on the technical summary provided, GPT evaluated the option of testing an UPGEN but decided not to proceed for the RGCS project. The decision not to proceed was based on risk of development delays to commercialization (similar to TAC project risks), assessment needed on the applicability of the ceramic fuel stack in a wide range of ambient conditions, lower than desired target power and time to certifications.

Available technologies were compared in Milestone 4. Options were evaluated based on technical and commercial attributes. Technical metrics included power output, turndown ratio, fuel consumption, efficiency, noise, ambient operating temperatures, and others. Commercial metrics included price, size, life, maintenance, and other factors. Table 4 is provided as an example of this analysis for CHPs, ICEs, and competitor (Qnergy Stirling).

System Composition	2xYanmar 0.7L	1xYanmar 0.7L	1xQ5650
System	CP5W CHP	CP5W CHP	PowerGen 5650
Complete System Cost/Price	Cost: $65,000	Cost: $33,000	Price: $65,000
System Integration Cost (Mat.+Hrs)	$30,000	$15,000	
Engine + Alternator Cost	$17,000	$17,000	?
Engine + Alternator Cost	$17,000		
Battery Cost	$1,000	$1,000	
Maintenance/Service Material Cost	$500	$500	$100
Maintenance/Service Time	4 hrs	4 hrs	1 hrs
Weight (kg)	400kg (Net 882lb)	400kg (Net 882lb)	393kg (Dry 866lb)
Dimension (DxWxH, cm)	75x150x150	75x150x150	72.5x176x145
Enclosure Environment Rating	IP44, Outdoor/Indoor	IP44, Outdoor/Indoor	IP54, Outdoor
Operating Ambient Temperature	(-40C) to (+50C)	(-40C) to (+50C)	(-25C) to (+50C)
Start-up Ambient Temperature	(-15C) to (+40C)	(-15C) to (+40C)	(-15C) to (+50C)
~~Optional Cold Start Temperature~~	~~(-40C) to (+50C)~~	~~(-40C) to (+50C)~~	~~(-40C) to (+50C)~~
Available Heat Output	5.6kW To 10kW	5.6kW To 10kW	2.5x to 3.5x Npwr
Acoustic Noise (@1m)	< 55dbA	< 55dbA	< 75dbA
Exhaust (Flue Gas) Emissions, CO2	(50%) ? g/kWh	(50%) ? g/kWh	? g/kWh
Exhaust (Flue Gas) Emissions, NOx	EPA, Tier 3	EPA, Tier 3	NOx, 5% O2: 30ppm
Exhaust (Flue Gas) Emissions, CO	EPA, Tier 3	EPA, Tier 3	CO, 5% O2: 9ppm
Engine	Yanmar 0.7L	Yanmar 0.7L	Qnergy QB80
Maximum Net AC Power Output	4.9kW	4.9kW	5.6kW
Minimum Net AC Power Output	1.3kW	1.3kW	1.2kW
Engine Running Mode	2 Engine Alternating	1 Engine Continuous	1 Continuous Run
Load Turn Down Ratio	4 to 1	4 to 1	TBV 5 to 1
Max Fuel Consumption (Natural Gas)	40.1 m^3/day	40.1 m^3/day	112.2 m^3/day
Min Fuel Consumption (Natural Gas)	19.8 m^3/day	19.8 m^3/day	40.6 m^3/day
Max Fuel LHV Power (Natural Gas)	17.8kW	17.8kW	49.8kW
Min Fuel LHV Power (Natural Gas)	8.8kW	8.8kW	18.02kW
Maximum Net AC Efficiency	28.0%	28.0%	TBV 15% (?11.2%)
Minimum Net AC Efficiency	14.4%	14.4%	6%
System/Engine Life (Refurbishment)	60,000 hrs	30,000 hrs	?TBV > 60,000 hrs
Start to Full Load Time	< 2 minutes	< 2 minutes	TBV < 60 minutes
Stop to Service Time	< 1hr	< 1hr	< ?hr
Maintenance/Service Interval	Annual/2 Year	Annual/2 Year	Annual

	2xYanmar 0.7L	1xYanmar 0.7L	1xQ5650
System	Integrated ICE	Integrated ICE	PowerGen 5650
Complete System Price	?	?	$65,000
Maintenance/Service Material Cost	Est. $100/$500	Est. $100/$500	Est. $100
Maintenance/Service Time	1 hrs/4 hrs	1 hrs/4 hrs	1 hrs
System/Engine Life (Refurbishment)	60,000 hrs	30,000 hrs	TBV > 60,000 hrs
Maintenance/Service Interval	Annual/2 Year	Annual	Annual
Operating Ambient Temperature	Opt: (-40C) to (+50C)	Opt: (-40C) to (+50C)	Opt: (-40C) to (+50C)
Start-up Ambient Temperature	Std: (-15C) to (+40C)	Std: (-15C) to (+40C)	Std: (-15C) to (+50C)
Max Fuel Consumption (Natural Gas)	40.1 m^3/day	40.1 m^3/day	112.2 m^3/day
Min Fuel Consumption (Natural Gas)	19.8 m^3/day	19.8 m^3/day	40.6 m^3/day
Maximum Net AC Power Output	4.9kW	4.9kW	5.6kW
Minimum Net AC Power Output	1.3kW	1.3kW	1.2kW
Available Heat Output	5.6kW To 10kW	5.6kW To 10kW	2.5x to 3.5x Npwr
Weight (kg)	400kg (Net 882lb)	400kg (Net 882lb)	393kg (Dry 866lb)
Dimension (DxWxH, cm)	75x150x150	75x150x150	72.5x176x145
Enclosure Environment Rating	IP44, Outdoor	IP44, Outdoor	IP54, Outdoor
Engine Running Mode	2 Engine Alternating	1 Engine Continuous	1 Continuous Run
Start to Full Load Time	< 2 minutes	< 2 minutes	TBV < 60 minutes
Load Turn Down Ratio	4 to 1	4 to 1	TBV 5 to 1
Max Fuel LHV Power (Natural Gas)	17.8kW	17.8kW	49.8kW
Min Fuel LHV Power (Natural Gas)	8.8kW	8.8kW	18.02kW
Maximum Net AC Efficiency	28.0%	28.0%	TBV 11.2%
Minimum Net AC Efficiency	14.4%	14.4%	6%

Table 4 - Sample technical and commercial comparison for power generation

After comparing options, system requirements and test plans were written for proof-of-concept development on Combined Heat and Power (CHP) solutions with two vendors. CHPs were selected over other technologies to decrease time to market, offer high efficiency and low emissions, provide familiar technology for commissioning and maintenance and to decrease technical risk that hampered our schedule to capture the growing market opportunity. Aisin was selected for 1.5kW and Yanmar for 5kW. Both these generators are designed to run with grid power, so design and development was focused on over-riding the grid power requirement and packaging the devices for off-grid and rugged ambient operation. Tests were conducted in GPT's Calgary facilities to demonstrate the power output and operation under various loads in preparation for integration to the instrument air systems for RGCS.

The most challenging technical aspect of integrating the CHP with the instrument air balance of system was to overcome the start-up power required to the air compressor. Although the M1.5 generated enough power to run the 2hp RGCS at steady state, the 2hp compressor motor requires high inrush current and the M1.5 could not supply adequate startup current. The M1.5 control system would go into an error mode and cause the generator to shut down whenever the 2hp RGCS attempted to start up. An extensive engineering analysis was performed, and a series of experiments were performed to find a solution. These experiments included using Variable Frequency Drives (VFDs), soft starters and specialty motors to resolve the startup issue. The specialty motors are DC motors with an integrated AC to DC converter that was able to carefully manage and minimize the startup inrush current. As a result of these experiments, GPT selected the specialty DC motors for use in 2hp RGCS systems paired with M1.5s.

Despite achieving a working system with the CHP engines, GPT's RGCS was more complex and higher cost than desired. There were also supply chain constraints, further exasperated during Covid, that made it impossible to commercialize the 5kW Yanmar product to scale. A Toyota gross power 8kW high efficiency, long-run internal combustion engine (ICE) was selected to replace the Yanmar 5kW CHP. Total development time was longer, but the final product offers lower complexity, lower cost, higher power output and greater flexibility for future development. Furthermore, GPT found a reliable partner who could supply the required volume at the desired lead time to meet market potential.

3.4 Technology Risks At The End Of The Project (Both Retired Risks And Risks To Be Retired)

Major technology risks have been closed in this project and remaining risks are more commercial in nature (pricing, competition, technology preference, emissions priorities). Technology risks that were closed in the project include:

- TAC power output, reliability, production ramp and costs were major risks that GPT assessed. It was decided these risks could not be reliably overcome economically and on-schedule for both the ERA project and market opportunity at hand. GPT decided to discontinue the partnership with Etalim on TAC engines and moved to other prime mover options.
- System design and equipment selection to start and run the compressors. High in-rush load at startup limits the equipment integration options, and various solutions were tested and compared to find the optimal solution with the best start up performance with the lowest efficiency losses in operating mode.
- Solar heat load on the enclosure drove CHP systems into "avoidance" mode which drops power from 1.5kW to 800W, effectively causing system shut down on sites with loads >800W. Solar panels were installed to shade the enclosure and also provide power to carry the load on the hottest days.
- CHP systems require drainage of condensation. This water is clean and does not pose an environmental hazard but creates a slip hazard in the winter. Operators have tried to collect water to avoid the hazard, but if not drained frequently, the water freezes up and into the engine causing major engine issues. Site modifications were made on Canadian CHP M5s and M1.5s using heat trace. The MX does not require any condensation drain and will replace the M5 in Canada in Q2, 2022. An evaporator system is being designed to support remote clients for M1.5 systems with slippage concerns in the future.

Remaining technology challenges in the RGCS are not related to basic operation of the RGCS but are driven by the need to increase competitiveness by adding features, decreasing cost, and managing lead time.

In terms of features, hot weather operation for export opportunities needs to be better understood. This will be done by testing the system in GPT's temperature chamber to simulate operations and power output from 30-50C. Results will provide GPT with power derating at higher temperatures, which is common practice for generator sales into these ambient conditions. This was not a high priority for RGCS development in Alberta but is very important in southern USA, Latin America, Australia, Middle East, and other target regions for export.

Other features to be added include data capture of fuel consumption as required by operators for carbon credit reporting, system redundancy options for air compression as requested by a smaller market niche, higher air pressure (120psi) throughput as requested by certain gas fields and walk-in shelter options. None of these are seen as technical risk, rather engineering scope that will be completed in due time based on capacity and demand.

For cost competitiveness, GPT continues to consider design improvements for decrease in material cost, lower cost components or instruments, shorter labour times and lower cost logistics. Having the higher power MX makes it easier to consider lower cost equipment alternatives since there are fewer start-up power limitations compared to the M5.

3.5 Corporate Structure Changes Since Commencement Of The Project

In October 2019, three executives from Gentherm Global Power Technologies Inc. purchased the company and privatized it as Global Power Technologies Inc. (GPT). The three equal owners are based in Calgary, AB and continue to be employed in the company in the following roles: Laura Kennedy, President, Collin Newman, CFO, and James Bolen, USA Sales Manager.

3.6 Technology and Commercial Advancement

Various configurations of the full RGCS were tested in house and several were tested in the field. Table 5 summarizes the RGCS systems that were tested including final testing that was completed in house using the 6kW “MX” internal combustion engine for power. That system testing was completed after the ERA project was complete due to supply chain delays for the integration of the MX with the 5hp instrument air system.

RGCS System Evolution	Suitability to Targets & Specs	Benefits found / Gaps to Resolve
2hp air system with 1.5kW TEG power (Milestone 2)	Demonstrated low-maintenance, cold weather, dry air pressure and flow for small well site. 2hp scroll duplex compressor, 80-gallon tank, 30psi, 4.5scfm, -40 to +30C.	GHG emissions, fuel consumption and power cost ($150k) too high. Met original air and power specs, but client wanted more air (5hp) and auxiliary power (1kW) for larger well pads.
2hp air system with 5kW CHP power (Milestone 11)	Lower GHG emissions, fuel consumption and system cost with higher air pressure and additional power. 2hp scroll duplex compressor, 80 gallon tank, 100psi, 4.5scfm, -40 to +30C, 3kW AC power.	Lower cost than TEG system but still higher than target for total system. First winter without issues, second winter engine issues due to condensate pipe freezing in extended cold period (after ERA project closed).
2hp air system with 1.5kW CHP power (Milestone 11)	Lower cost solution and lower emissions if less on-site power is required. 2hp scroll duplex compressor, 80 gallon tank, 60psi, 3scfm, 200W AC power, -40 to +30C.	Meets technical requirements for smaller instrument air sites that have need for off-grid power. Lowest emissions for small sites. Continue cost-out improvements for market.
5hp air system with 6kW ISE power (post-project in house testing)	Cost effective, high efficiency, low emission, higher air throughput with available power. 5hp scroll simplex compressor, 80-gallon tank, 100psi, 12scfm, 1kW AC power, -40 to +30C.	Meets larger site requirements based on shop testing. Other options for higher pressure or duplex compressor are being tested. Continue cost-out improvements for market.

Table 5 - RGCS systems testing

A summary of the performance/success metric outcomes from the contribution agreement is provided in Section 2.5.

The technology readiness level (TRL) at the beginning of the project was deemed to be at TRL 5-6 Prototype Development & Testing. At the end of the ERA project scope, GPT is finalizing product design for production release, certifications are underway, market literature is being developed and field trials are proposed. There is one open sales order for six units and several other projects being quoted or considered by clients in Alberta and in the USA. Materials have been ordered and internal production has started on a commercial batch of 30 units. For these reasons, the product is rated as TRL 9 Commercial Implementation and Market Rollout at the close of the project.

GPT's RGCS has demonstrated the efficiency, low emissions, field run-time and reliability of applying CHPs or ICEs to compress air to eliminate gas venting on pneumatic valves. Technology challenges have been resolved, but future opportunities exist in decreasing total system cost or adding more data to provide operators with full emissions reporting requirements. Although GPT was not able to commercialize the TAC, the alternative power generation solutions will serve the 500W to 6kW space for instrument air compression or other off-grid power requirements.

Alternative new technologies that could be risk to supplanting the RGCS include batteries, longer life fuel cells or other engine integrators. Battery technology is rapidly increasing, but costs and lead times for batteries are rapidly escalating, making it difficult for developers or suppliers to offer cost competitive solutions with short lead times in this space in the near term. Longer life fuel cells have been researched for many years, and GPT is currently evaluating a natural gas fuel cell partner that we have been aligned with for 5 years. They are nearing commercialization and will aim for certifications in 2022 or 2023. This would provide a market advantage to GPT if they do reach commercialization. Their initial product is 1.5kW so could serve the 2hp instrument air space with a solar hybrid system. Other engine integrators, especially those with local client followings, could offer competitive packages if demand continues to increase. GPT currently offers a shorter lead time and more proven solution than local integrators, and based on client feedback, local integrators also have a learning curve to find acceptable systems for off-grid power production and air compression.

GPT continues to monitor the performance of M Series relative to other competitors and technologies. Qnergy released a smaller version of the Stirling Engine that offers lower fuel consumption under 1kW to compete with 500W TEGs and the M1.5. GPT has remained in contact with Upstart to evaluate the development of their 1.5kW natural gas fuel cell, which could provide an advantage for solar hybrid applications from 500W to 1.5kW. However, certifications have still not begun, so this is likely not an available option until late 2022 or 2023 at best. Table 6 summarizes the most recent fuel efficiency and emissions data for technologies being monitored. This table demonstrates the benefits of the M5 vs Stirling Engine and shows even further improvement in the MX with higher power output.

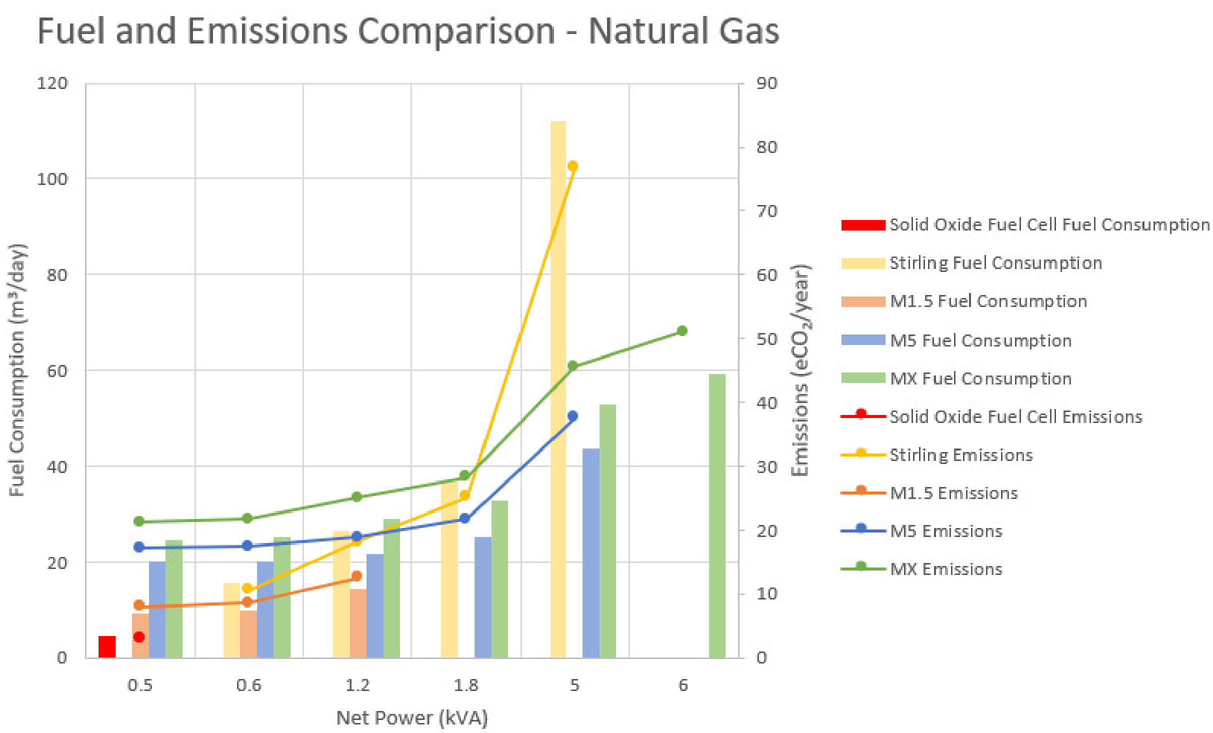

Table 6 - Technology Comparison, January 2022

3.7 Field Test Summaries

Field tests were conducted throughout the project to demonstrate system reliability in the field. Various ambient conditions and technical applications were tested to provide a broad range of operating experience. A summary of field tests and learnings are provided in Table 7.

Date	Client	Region	Field Trial Scope	Learnings	Milestone
Aug-18	Tourmaline	Peace River Country, BC	3x8500 TEGs with 2hp instrument air. Demonstrate instrument air system operation and reliability with off-grid power.	Instrument air system met specifications and provided reliable, dry air to instruments. System power and air exceeded site requirements but future well development could drive more air demand. TEG cost, efficiency and fuel consumption were attractive in multi-well instrument air systems.	2
Jul-20	BlackSwan	Fort St. John, BC	M1.5 ambient weather BC trial. Commission in summer and run through winter.	Minor field debugging for autonomous cold weather operation. System unexpectedly turned itself off at 8,000 hours for maintenance but restarted. Service and parts planning improved to prepare for service intervals.	9
Nov-20	GeoSouthern Energy Corp (GEP)	Louisiana, USA	M5 - North American model. Demonstrate power generation with CHP in hot climate at multi-well pad.	Operational challenges due to client's gas composition. H2S filtration was inadequate and poisoned engine cylinder without client recognizing gas variability issues. Recognized risks to solution for well-head applications if gas conditioning inadequate. CHPs and ICEs will have lower gas composition range than Stirling engines or TEGs in these applications.	8
Dec-20	Tourmaline	Edson, AB	M5 - North American model. Cold weather operation of CHP.	Positive field experience with no operational issues during polar vortex in February, 2021.	8
Jan-21	Tourmaline	Edson, AB	M5 North American model with 2hp instrument air system (RGCS).	Positive field experience with no operational issues for power or instrument air system during polar vortex in February, 2021. Intermittent monitoring issues were experienced and attributed to unreliable cellular coverage. Client to study and resolve if required.	11
Mar-21	BlackSwan	Fort St. John, BC	M5 - Japanese model. Confirm system integrity after OEM model changes.	Model change had new control logic that was not well documented and understood for system redesign. OEM tests and documents focused on on-grid operation, so off-grid controls less understood and predictable. Longer test time was required to address these differences in the factory but field performance was acceptable once the system was shipped. M5 CHP contains a condensing exhaust system and freeze off issues occurred post ERA project in Dec 2020/Jan 2021 during extended and extreme cold period; resolved with heat trace on condensation drain. As a result of this learning, MX models do not have condensing exhaust system.	8
Aug-21	Enbridge	Texas	M1.5 in hot location, high load, no tree shading available.	M1.5 output power drops from 1.5kW to 800W when internal unit temperature exceeds 40C (called Avoidance Mode) in afternoon. Unit enclosure in full sun causes shutdown and site power inadequate. GPT added solar panels to shade enclosure and to provide extra power when CHP drops to "avoidance" mode.	9
Aug-21	Enbridge	Texas	M1.5 in hot location, lower load, some shade.	M1.5 output power drops from 1.5kW to 800W when unit exceeds 40C (called Avoidance Mode). This unit was able to carry client load even in avoidance mode and went into avoidance mode less often due to tree shading at site.	9
Aug-21	ECI	Northeast USA	M1.5 with 2hp instrument air RGCS using alternate motor for compress for start-up power requirements.	Positive field experience of power and air compression with no known operating issues. Cellular communication was less reliable than desired due to remote location but was resolved with higher gain antennas. GPT will leverage this solution in remote site system applications.	11

Table 7 - Summary of learnings from field trials in all milestones

3.8 Challenges, Delays, or Obstacles Encountered During The Project

As previously described, the shortfalls in TAC prototype performance and the subsequent termination of Etalim operations created a major scope change for the project. This drove new scope and strategy for GPT's RGCS project and also impacted the timing of GPT's solution to market. GPT believes we lost a number of opportunities due to these delays, and other competitors won market share that will now be difficult to win back.

Another supplier hurdle was the product change and lead time extension from the Japanese supplier, Yanmar. Discontinuation of a North American product led to extra product design work to accommodate their Japanese product version but lead time extensions through Covid led to a team decision to move all efforts for >=5kW power generation to the Toyota engine instead. This added scope to the project and have created delays to full volume commercial offering to the market.

Covid was an obvious disruption that slowed the project during work from home mandates and created schedule delays. Logistics delays, material shortages, lack of capacity and employee absenteeism all contributed to a slower project pace and higher project costs than usual. GPT mitigated many delays by insourcing production where possible and leveraging long-standing supplier relationships for support.

3.9 Summary of Major Lessons Learned

Major lessons that GPT has learned:

a) The importance of speed to market with new industry solutions. By selecting a technology that was not market-ready, GPT's instrument air systems were later to market than other competitors. Competition was able to leverage GPT's initial systems in the field, which led to further learnings about the importance of IP strategies, and their market share growth has made it difficult for GPT to compete.
b) Client priorities for procurement need to be clearly understood when defining product requirements. GPT underestimated the amount of power and air that clients would want for initial RGCS installations and overestimated the importance of fuel efficiency and emissions in decision making by clients. Capital cost is more important than system emissions, so lowering cost must be high priority for system design.
c) Government policy and investor behaviour both influence company decisions for capital expenditures. In Alberta, carbon rebates drove some clients to move early on methane emission abatement, while others decided to wait for lower cost solutions or mandated environmental targets to take effect. In USA, investor expectations for Net Zero commitments drove a rapid increase in environmental spending without clearly defined government requirements.
d) Taking risks in technology development don't always lead to better solutions. Despite the research done in TAC engines, the product was not as ready for commercialization as originally assessed, so time was lost testing and waiting for products. Had GPT selected CHPs or ICEs from the outset of the project, this would have decreased total development cost and resulted in an earlier solution to market.
e) GPT has observed new competitors, such as Westgen Technologies, come to market sooner with an integrated system. Time to product development, and the value added by manufacturing as opposed to integration, needs to be evaluated. GPT has long believed that adding value through design and managing costs through insourcing would provide lasting market advantages. GPT has taken a more aggressive approach to outsourcing for cost advantage as a result of this learning.

4 GREENHOUSE GAS BENEFITS

By completing this project, GPT now has technology available to deploy systems for direct and indirect GHG reductions. The largest benefits are in instrument air systems. Table 8 summarizes the GHG reductions of three sizes of instrument air systems. To calculate GHG reductions for instrument air conversions, the total volumetric air potential of the system is used to estimate the GHG reduction potential. This may be higher than the actual volumetric air utilization of the system but is the best estimate available based on clients' purchasing specifications and decisions.

GPT EZ-Air System CO_2e Reduction					
	I/A (Reduced NG) Flowrate: scfm	Reduced Methane (95% of NG) Flowrate: scfm	Reduced Methane: lb/yr	Reduced Methane: t/yr	Reduced CO_2e: tCO2e/yr
EZ-Air 2HP	4.5	4.3	100,438	45.6	1139
EZ-Air 3HP	8.0	7.6	178,557	81.0	2025
EZ-Air 5HP	12.0	11.4	267,835	121.5	3037.25

Table 8 - GPT EZ-Air Greenhouse Gas Benefits (tCO2e/yr)

For power production, greenhouse gas benefits depend on the baseline being referenced. A full summary of emissions by model and technology is provided in Table 9.

Emissions for Natural Gas Fuel TEGs, M-Series, Stirling, SOFC

Model	Natural Gas Usage (m3/day)	CO_2 Emissions (kg CO_2/hour)	Unburned Hydrocarbons (kg CH_4/hour)	N_2O (kg N_2O/hour)	CO_2e (kg CO_2e/hour)	CO_2e (t CO_2e/year)
030	2.1	0.1628	2.914×10^{-6}	0.2914×10^{-6}	0.1630	1.43
5060	4.4	0.3412	6.105×10^{-6}	0.6105×10^{-6}	0.3415	2.99
5120	8.8	0.6824	12.21×10^{-6}	1.221×10^{-6}	0.6831	5.98
1120	8.8	0.6824	12.21×10^{-6}	1.221×10^{-6}	0.6831	5.98
5220	19.7	1.5277	27.33×10^{-6}	2.733×10^{-6}	1.5292	13.40
8550	48.0	3.7222	66.60×10^{-6}	6.660×10^{-6}	3.7258	32.64
1500	48.0	3.7222	66.60×10^{-6}	6.660×10^{-6}	3.7258	32.64
P-5050	4.8	0.3722	6.660×10^{-6}	0.666×10^{-6}	0.3726	3.26
P-5100	9.4	0.7289	13.04×10^{-6}	1.304×10^{-6}	0.7296	6.39
S-1100	8.4	0.6514	11.66×10^{-6}	1.166×10^{-6}	0.6520	5.71
S-8500	50.4	3.9083	69.93×10^{-6}	6.993×10^{-6}	3.9121	34.27
M5 Max.	43.0	3.3345	59.66×10^{-6}	5.966×10^{-6}	3.3377	29.24
M5 Min.	21.0	1.6285	29.14×10^{-6}	2.914×10^{-6}	1.6301	14.28
M1.5 Max.	13.5	1.0469	18.73×10^{-6}	1.873×10^{-6}	1.0479	9.18
M1.5 Min.	6.6	0.5118	9.158×10^{-6}	0.9158×10^{-6}	0.5123	4.49
Typ. 5kw Stirling Max.	112.2	8.7044	155.7×10^{-6}	15.57×10^{-6}	8.7129	76.33
Typ. 5kw Stirling Min.	40.6	3.1467	56.3×10^{-6}	5.63×10^{-6}	3.1497	27.59
Typ. 1.2kw Stirling Max.	26.5	2.0531	36.74×10^{-6}	3.674×10^{-6}	2.0551	18.00
500W SOFC	4.6	0.3536	6.327×10^{-6}	0.6327×10^{-6}	0.3540	3.10

Table 9 - Emissions from various power generation products and technologies

Using data from Table 9, GHG benefits will vary depending on amount of power required, appropriate baseline to select, and turndown for the required load. Two examples can be provided.

For a 1.5kW load, clients could use 3x8500 TEGs (for 1.5kW) with 102.81 tCO2e/yr which would be worst case scenario. This baseline could be used today, especially for a brownfield operation with existing TEGs. For greenfield operations, a suitable baseline may be the 1.2kW Stirling Engine with 18 tCO2e/yr but noting that maximum power is 1.2kW; or a turned down 5kW Stirling Engine for 1.5kW at 27.59 tCO2e/yr. GPT's new M1.5 solution with a power range of 500-1.5kW output ranges from 4.5 – 9.2 tCO2e/yr. So, at 1.5kW, the M1.5 reduces GHG by the following depending on baseline:

M1.5 emissions reduction vs 3x8500 TEGs	93.61 tCO2e/yr (91% less emissions)
M1.5 emissions reduction vs 5kW Stirling	18.39 tCO2e/yr (67% less emissions)
1.2kW load on M1.5 vs 1.2kW Stirling	9.36 tCO2e/yr (52% less emissions)

For a 5kW load, clients would likely not use TEGs as a baseline since TEG systems of this size were never used in onshore installations in Alberta. The appropriate current market baseline would be the 5kW Stirling with 76.33 tCO2e/yr. The emissions from GPT's M5 is 29.24 tCO2e/yr. So, the GHG benefits of installing GPT's M5 in place of a 5kW Stirling Engine are:

M5 emissions reduction vs 5kW Stirling Engine	47.09 tCO2e/yr (62% less emissions)

This project enables GPT to compete in the instrument air market with higher power, lower emission generators for off-grid applications. These systems enable gas companies to continue operations with lower GHG emissions on brown-field and green-field sites in the following ways:

- Displace vented gas with vented air by powering for air compression to drive pneumatic valves
- Displace vented gas by providing off-grid power to digital valves in place of pneumatic valves
- Provide off-grid power with lower emissions (e.g. replace TEGs, diesel gensets, Stirling engines)
- Further emission reductions available with solar hybrid but at higher total cost

The field trials in this project all offer annual GHG reductions (Table 10). To calculate GHG reductions for power generation, the most relevant baseline for emissions was selected based on most common alternatives for that power range today. For lower power, TEG emissions were used as the baseline and for higher power, Stirling Engines were used.

Client	Region	Field Trial Scope	Baseline and calculation for GHG	Annual GHG Reduction tCO2e/yr
Tourmaline	Peace River Country, BC	3x8500 TEGs with 2hp instrument air. Demonstrate instrument air system operation and reliability with off-grid power.	GHG reduction from displacing vented gas with vented air less GHG emissions from 3x8500 TEGs.	1036
BlackSwan	Fort St. John, BC	M1.5 ambient weather BC trial. Commission in summer and run through winter.	GHG reduction from 3x8500 TEGs to M1.5	89
GeoSouthern Energy Corp (GEP)	Louisiana, USA	M5 - North American model. Demonstrate power generation with CHP in hot climate at multi-well pad.	System decomissioned due to site gas and load issues.	N/A
Tourmaline	Edson, AB	M5 - North American model. Cold weather operation of CHP.	GHG reduction from 5.6kW Stirling Engine to M5	69
Tourmaline	Edson, AB	M5 North American model with 2hp instrument air system (RGCS).	GHG reduction from 5.6kW Stirling Engine to M5 and displaced vented gas.	1208
BlackSwan	Fort St. John, BC	M5 - Japanese model. Confirm system integrity after OEM model changes.	GHG reduction from 5.6kW Stirling Engine to M5	69
Enbridge	Texas	M1.5 in hot location, high load, no tree shading available.	GHG reduction from 3x8500 TEGs to M1.5	89
Enbridge	Texas	M1.5 in hot location, lower load, some shade.	GHG reduction from 3x8500 TEGs to M1.5	89
ECI	Northeast USA	M1.5 with 2hp instrument air RGCS using alternate motor for compress for start-up power requirements.	GHG reduction from 3x8500 TEGs to M1.5 and displaced vented gas.	1228
			Total Annual GHG Reduction from Project	3879

Table 10 - Annual GHG reductions achieved from field installations of units from ERA project

Estimated annual GHG reductions in Alberta from commercial roll out of the technology are difficult to forecast. Rapid changes in the gas industry such as drivers for investments, purchasing priorities (capital, emissions, alternate energy), regulatory, gas demand and new technology development are difficult to predict. GPT has taken a conservative estimate to volume potential for power generation and instrument air compression systems that have resulted from this project and estimated market size to forecast the annual GHG reductions in Table 11.

Product Sales	**GHG Reduction**	**AB Volume sold/year**				**GHG Impact**	**AB Volume sold/year**					**GHG Impact**
	TCO2e/yr	2022	2023	2024	2025	Up to 2025	2026	2027	2028	2029	2030	Up to 2030
3 TEGs (1.5kW)	103											
M1.5 (no air)	89	2	4	10	10	4,466	5	5	0	0	0	17,951
M1.5 + 2hp air	1228	2	8	12	16	88,438	8	5	0	0	0	353,753
5kW Stirling	112											
M5 (no air)	69	2	6	12	16	4,567	20	20	20	20	20	35,707
M5 + 2hp air	1208	2	6	12	12	74,908	12	12	12	12	12	449,450
M5 + 5hp air	3106	2	12	12	12	248,516	12	8	4	4	0	1,056,193
TOTAL						420,895						1,913,055

Table 11 - Forecast Emissions reduction in Alberta based on projected sales volumes

5 ECONOMIC AND ENVIRONMENTAL IMPACTS

Environmental impacts of this project have been summarized in Section 4, Greenhouse Gas Benefits. There are no other known impacts for air contaminants, land use, soil or water consumption that apply to this project.

Project economic impacts and plans are described in greater detail in GPT's Commercialization Plan and next steps information in Section 8. To summarize, the forecasted revenue impact over the next 10 years ranges from $112MCAD to $224MCAD. Differences in revenue outcome will depend on market share, industry spending, pace of new technologies, international development, and major accounts. As volume grows, costs will decrease with economies of scale, and it is assumed that cost savings will need to be passed on to clients due to price competition in this market segment. It is estimated that 80% or more of revenues will come from export markets including USA, Latin America, Australia, and Middle East.

Jobs created by market growth for the top range of revenues will include 18 new hires as follows:

a) Manufacturing labour in Bassano, AB (4 employees for welding, enclosure metal fabrication, enclosure assembly and paint)
b) Manufacturing labour in Calgary, AB (4 employees for wiring, integration, and test)
c) Technical labour in Calgary, AB (2 employees for engineering, technical writing)
d) Sales team (4 in Calgary for business development, inside sales, and international sales, 1 in Houston for USA reseller sales development)
e) Service team (1 in Calgary, 1 in Houston)
f) Supply Chain (1 in Calgary)

Through this project, GPT's two facilities have developed broader knowledge in the design, manufacturing and system control of higher-power off-grid generators and smaller air compression systems. Knowledge diversification is important to GPT because traditional TEG products are lower efficiency and thus need to be revised or replaced for GPT to remain competitive in the shifting gas industry. GPT has formed technical partnerships with various international firms for knowledge development and product development including an engine partner in Germany, an alternator partner in Italy, and air compression expert in USA. The Etalim relationship was a learning experience and would have led to a positive partnership with a start-up company if the product goals were met.

To track environmental contributions of the RGCS systems in the field, GPT can create a log of systems sold and anticipated environmental savings. GPT will offer remote monitoring to determine the operating status of systems in the field, and to flag when maintenance or support is required. Some clients are beginning to request remote data collection for environmental reporting, and with privacy agreements, GPT could aggregate this data to report on some environmental achievements. However, many other clients treat their data and monitoring as confidential so not all data could be collected in this fashion.

Economic outcomes for GPT from the RGCS project can be measured in terms of systems sold and serviced on an annual basis including M Series and EZ Air products.

6 OVERALL CONCLUSIONS

This project demonstrated that the Etalim TAC engine was not commercially ready to the meet the performance criteria and schedule for instrument air compression in Alberta for the desired timeline. GPT is not currently considering TAC power based on economics for the desired power range (>5kW), unmanned site performance reliability, efficiency, emissions improvement over commercially available alternatives and product life. GPT would consider TAC power if further product development shows progress to meeting performance specifications for broader gas composition at sites with power needs in the 1kW power range.

In Alberta, initial instrument air projects were selected at the largest multi-well pad sites a higher instrument air and power requirements than estimated in the project specifications from 2017. First movers to implement instrument air systems required >5kW power for 5hp air compression and GPT was not able to meet this need. GPT's instrument air system integration was leveraged by clients and competitors to provide Stirling Engine systems at that time. From 2022, GPT's 5kW and 5hp systems will be available to compete economically in this space with up to 60% lower fuel consumption and up to 60% lower emissions. The commercial challenge will be for GPT to switch clients away from Stirling Engines which are currently considered the market leader. GPT will also be competing with another Alberta company, Westgen Technologies, who has a similar internal combustion engine (ICE) solution.

GPT anticipates that once the largest sites are moved to instrument air, the market demand will shift to lower power, lower compression, and lower cost requirements on smaller well pad sites. $100-120k systems will no longer be economic solutions to deliver lower GHG reductions, especially if and when government subsidies diminish in this area. Smaller systems at a lower price point will be required, and GPT is positioning to be competitive in this area.

International demand is expected to increase and GPT is positioning these systems to launch in USA, Australia, Latin America, and the Middle East as emissions targets evolve worldwide. Higher oil and gas prices along with increasing market demand (further exasperated by the Russian invasion of Ukraine) has increased overall demand for production expansion, workovers and maintenance activities and higher spending for green initiatives. All of these factors combined create a positive outlook for domestic and export demand potential for the RGCS.

Target markets in Canada for GPT in the next 3 years include:

- Instrument Air Systems to Gas producers on brownfield sites where operators have not yet adopted large (5hp) instrument air systems, or smaller (2hp) instrument air systems. Competition in smaller systems will be with Qnergy's smaller system, but Westgen does not currently have smaller system offerings on the market.
- M Series products to pipelines (e.g. TransMountain) looking for higher power, lower emission generators for small instrument stations, cathodic protection, or other power (no EZ Air)
- M Series products to gas producers looking for lower emission, higher efficiency power and heat to sites requiring glycol or electric heat trace and greenfield multi-well pads where electric valves will be specified in place of pneumatic valves
- M Series products to telecom applications to displace diesel generators as backup power to solar and battery (generally tanked propane operation)
- MX-Hybrid power solutions to small industries including agriculture, off-grid homes, or small resorts (GPT's hybrid solution is under development in 2022)

In the United States, adoption of instrument air systems has been slow, with most companies looking only at economic return for spending capital. Loss of investor confidence, falling commodity prices and lower gas demand during Covid were all reasons not to implement environmental projects in the USA. However, starting in late 2020 and ramping up in 2021, there is growing public pressure for investors and publicly traded companies to have environmental strategies with Net Zero carbon impact targets. This change in investor sentiment, backed by changing political views in the United States has driven a shift in project priorities. GPT is seeing rapid growth in demand for instrument air systems, lower emission projects and higher efficiency products in the USA.

Target markets in USA for GPT in the next 3 years includes the list of markets for Canada as listed above but with the following differences:

- MX requires EPA certification in the USA; testing is underway as of January 2022 and certification is targeted for completion in May 2022.
- Larger portion of market is still available for larger systems (5kW and 5hp) since not as many projects completed in last three years compared to Canadian market
- Compression company partnerships to leverage exclusive compressor brands with regional loyalty for sales and service

GPT has a strong network of international agents for sales in other markets. A high-level summary of some key markets:

- Latin American market potential in pipelines with higher power cathodic protection demand and telecom companies who share ownership or operation of right of way with gas distribution. Low demand for emissions reductions but solar projects are growing for smaller power.
- Australia market opportunities are similar to Canada, but producers are somewhat slower to adopt new solutions. Covid-19 lockdowns have delayed many gas production improvements so critical infrastructure maintenance will likely consume manpower and budget available in the near team. M Series will require Australian type certification for gas and electrical safety and would require EPA or better certification.
- Middle East market potential for larger power cathodic protection on pipelines where cost potential and emissions may meet market demand. This region takes a very long time to qualify new products (GPT has worked for 5 years to be a qualified vendor for TEGs). Market potential exists but time to recognizing revenue could be very long.
- Southeast Asia market is not likely to adopt M Series generators or instrument air systems in the near term due to cost focus and slower adoption of environmental commitments. Regional low cost suppliers for generators are typically preferred unless local technology does not meet business requirements.

End-users for GPT’s M Series, EZ Air and Instrument Air will prioritize gas emissions, have gas available on site, and capital available to cover purchase and operating costs. These end-users are most likely to be publicly traded companies in the gas industry who have investor pressures to meet Net Zero goals yet still have access to affordable gas supplies on site. For users who do not have access to natural gas, tanked propane and eventually tanked hydrogen are alternatives to consider but would only make sense in solar hybrid system applications to minimize tanked fuel consumption.

7 SCIENTIFIC ACHIEVEMENTS

GPT's project was starting from TRL 5-6, so scientific challenges with pure research and design was mostly complete. Technical and commercial learnings focusing on system architecture and system integration delivered the largest achievements in this project.

There have been no IP filings submitted to date on this project scope, and GPT does not currently see a strong technical rationale for IP. Barriers to entry are based on time to achieve certification requirements. In the longer term, GPT continues to conduct research and development to identify potential advantages with IP protection to guard market share and create competitive advantage.

A commercial overview of instrument air solutions for methane emissions was submitted as a "poster presentation" for the 2021 APEGA Nexus Conference Poster Showcase (an online only posting due to Covid limitations). Another commercial overview was presented at the 2020 Onshore Oil and Gas Conference in Houston, Texas. GPT was invited to present at this event as a member of the Methane Emissions Leadership Alliance (MELA).

8 NEXT STEPS

In 2022, GPT is focused on completing final project design, decreasing cost of goods sold, ramping volume production capabilities and driving sales for commercialization of the systems developed in this project. It is anticipated that unexpected field issues will arise, so service and support are planned to retain a quality brand perception through the new product launch. Commercialization specifics in the next two years includes:

- Ramp up to production capability of 4 units per week in 2021
- Establish OEM lead time, quality, and support expectations to support larger commercial roll-out
- Hire for better sales coverage and develop more reseller/agent sales channels
- Train existing and/or new sales channels and service providers to support the new products
- Stock maintenance and repair spares in regional inventory locations
- Leverage targeted trade shows and conferences for product demonstrations

Capital cost is still the priority for purchasing decisions, so driving material and labour costs down on the total solution provide the best return for time spent on product improvements. Compressor selection (type, size, and brand) can offer major savings on instrument air, and GPT has partnered with air compression companies to find lower cost alternatives. GPT will consider selling instrument air systems with power, selling power only for compression companies to integrate into their offering, or selling air systems only for clients who have other power generation available.

Follow up projects include offering a solar hybrid remote solution. Hybrid operations can decrease fuel consumption and therefore emissions by up to 90% (depending on region, solar sizing, and battery capability). However, solar systems over 1kW are expensive and can almost double the power system cost. Market demand for higher cost solar systems needs to be better understood before major project development in this area.

GPT has started testing hydrogen power generation with the MX generator OEM partner in Germany. Hydrogen systems can be developed, and the technical risk is estimated to be low. The major challenge with hydrogen investments is understanding the market size, willingness of clients to switch gas type and timing for commercial hydrogen gas distribution. If tanked hydrogen is expensive or difficult to supply to a site, then solar hybrid option to conserve hydrogen may be an attractive option. However, if only small amounts of fuel are needed in a hybrid option, then clients may prefer to continue with natural gas (if available on site) or tanked propane if distribution is simpler.

9 COMMUNICATIONS PLAN

During Milestones 1 and 3, GPT shared knowledge about product validation, testing, manufacturability, quality, and design feedback to help Etalim accelerate their product development of the TAC engine. Etalim was struggling with funding at the time, so not all knowledge transfer could be applied towards their product development or the RGCS outcome. Other project stakeholders included field trial partners, air compression suppliers and engine OEM partners. Project communications with these groups were focused on specific project outcomes and future product development potential.

GPT has followed and will continue to follow the Contribution Agreement guidelines on proper acknowledgements to ERA in communications for publications, promotions, or advertising on the project. Most of GPT's future communications will not reference the project as a whole. Future communications will include various stakeholders:

Clients – Communications may reference internal test results or applicable field test results but will not reference the project in its entirety. Test results will focus on performance and reliability, preferably leveraging positive customer testimonials.

Suppliers – Communications with suppliers were commercial and technical in nature during the project and will continue in that manner going forward. The relationship with Etalim was unique as a partner in the project technology development. Once the TAC failed to meet performance and schedule requirements, subsequent suppliers provided commercial products and support.

Government agencies – ERA will be credited with prior product development support if any future funding is requested for product development or commercialization.

For protection of Intellectual Property, GPT plans to limit project technical details to public audiences. Certain aspects of the system design are simple to copy by studying photos of instruments and equipment (e.g. compressors, dryers, tanks, enclosures, engines) so photos and information will be limited to keep the design as competitive as possible.

EMISSIONS REDUCTION ALBERTA	Project Emissions Reductions	ID: F0160201

Recipient Organization	Gentherm Global Power Technologies Inc.
Title	Remote Generator Compressor System

GHG Emission Reductions (ERs): 2011–2050

2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0
2020	0
2021	1,126
2022	1,126
2023	1,126
2024	1,126
2025	1,126
2026	1,126
2027	1,126
2028	1,126
2029	1,126
2030	1,126
2031	1,126
2032	1,126
2033	1,126
2034	1,126
2035	1,126
2036	1,126
2037	1,126
2038	1,126
2039	1,126
2040	1,126
2041	1,126
2042	1,126
2043	1,126
2044	1,126
2045	1,126
2046	0
2047	0
2048	0
2049	0
2050	0

Please Refer to ERA's Website For the Quantification Methodologies
https://www.eralberta.ca/calculating-ghg-emissions-reduction/