

ERA Final Outcomes Report - Natural Gas Mobile Unit for Drilling Rig Power Generation - Tourmaline Oil Corp.

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Project Information

Project Title:	Natural Gas Mobile Unit for Drilling Rig Power Generation
ERA Project ID:	F0160831
ERA Project Advisor:	Sanah Dar
Recipient Organization:	Tourmaline Oil Corp.
Project Collaborators:	Precision Drilling Corporation Caterpillar Inc.® Finning CAT
Recipient Project Lead:	Scott Volk, Technology & Innovation Lead Scott.volk@tourmalineoil.com 403-767-5925
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Project Cost Breakdown

Milestone Name & Description	Budget Cost	Actual Eligible Cost	Actual Ineligible Cost	ERA Funds Received	ERA Holdback	Total ERA Funds
Milestone 1: Rig Upgrades & Demonstration	\$1,089,000	\$1,561,489	\$0	\$348,800	\$87,200	\$436,000
Milestone 2: Mobile Power Unit Fabrication and Assembly	\$6,044,000	\$5,248,273	\$12,569	\$1,936,000	\$484,000	\$2,420,000
Milestone 3: Mobile Power Unit Demonstration	\$850,000	\$783,214	\$0	\$275,200	\$68,800	\$344,000
Total	\$7,983,000	\$7,592,976	\$12,569	\$2,560,000	\$640,000	\$3,200,000

Project Description

Tourmaline Oil Corp. (Tourmaline) is Canada's largest natural gas producer. Our goal is to have the largest, lowest-development-cost and lowest-emission natural gas supply in North America. We've set aggressive targets to further reduce our emissions and have undertaken many initiatives to help reach them, including our collaboration with Precision Drilling Corporation (Precision), Caterpillar Inc.[®] (Caterpillar), and Finning CAT (Finning) to develop a mobile natural gas generator and energy storage system (ESS) for drilling rig power supply.

The project involved upgrading two existing drilling rigs to the Electronic Modular Control Panel (EMCP) 4.4 Dynamic Gas Blending[®] (DGB) system, fabricating a natural gas mobile power unit, and demonstrating the single system on two different upgraded rigs. The demonstration objectives were to prove the system reduces GHG emissions and the cost of power generation by substituting diesel fuel for raw natural gas. Adoption of this technology will help increase the utilization of drilling rigs and the amount of job opportunities in Alberta.

Typical rigs in Alberta have some major drawbacks. Most rigs generate power from diesel fuel or were modified to burn a combination of diesel (~60%) and natural gas (~40%). This modification results in incomplete combustion, wasting fuel and increasing GHG emissions. Rig power generation is also very inefficient. The generators produce significantly more power than is consumed by the rig, resulting in wasted power. Today's power generation is integrated as part of the rig and is not a standalone unit or mobile.

Our designed system uses three lean burn, 100% natural gas engines that fully and efficiently combust the natural gas. The system includes a 1 MW Energy Storage System (ESS) to store power that would otherwise be wasted. The unit uses a Smart Engine Management System (SEMS) to automatically start and stop generators in conjunction with the ESS to match the power demand of the rig without wasting power. It functions in synchronization with the active rig, allowing it to operate like a plug-and-play unit. The standalone unit moves to any active rig with a reliable natural gas supply. The mobile system allows the rig to operate with the existing diesel engines if the gas supply is interrupted.

The power generation system significantly reduces GHG emissions by:

- Switching from diesel to lower-carbon natural gas fuel;
- Fully combusting the natural gas in the lean burn engines;
- Storing and re-using excess power generated;
- Automatically turning off generators when power demand is not required; and
- Reducing the need to truck fuel to location.

Three Precision rigs were included in the scope of this project, two for the project level assessment and one for the baseline level assessment. The natural gas generator and ESS package were integrated into the first Precision rig for a period of approximately five months and then moved to the second Precision rig for a project period of approximately six months. Project performance metrics were measured by comparing the project and baseline rigs.

The system was projected to save 3,950 tonnes of CO₂e emissions per rig, per year. After all the system bugs were worked out during the initial installation phases, it is expected that the system is currently saving ~3,650 tonnes of CO₂e emissions (~39% reduction) per year, with room for further reductions once battery performance can be optimized.

This technology solution takes advantage of Alberta’s abundance of natural gas and helps to increase natural gas demand into the future. Commercializing this technology will benefit Alberta by increasing capital into our economy, increasing the utilization of our inactive rigs and jobs, reducing GHG and non-GHG emissions, decreasing road traffic, and improving the social image of Alberta’s oil and gas sector.

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Abbreviations

BHA	Bottom Hole Assembly
CNG	Compressed Natural Gas
DGB	Dynamic Gas Blending®
DLE	Diesel Litre Equivalent
EMCP	Electronic Modular Control Panel
ESD	Emergency Shutdown
ESS	Energy Storage System
GHG	Greenhouse Gas
HMI	Human-machine Interface
HVAC	Heating, Ventilation, and Air Conditioning
LNG	Liquefied Natural Gas
MMC	Microgrid Master Controller
PT	Potential Transformer
SEMS	Smart Engine Management System
TAM	Total Addressable Market
TRL	Technology Readiness Level

Executive Summary

The project involved upgrading two existing Precision drilling rigs to the Electronic Modular Control Panel (EMCP) 4.4 Dynamic Gas Blending® (DGB) system, fabricating a natural gas mobile power unit, and demonstrating the single system on the two upgraded rigs. The designed system uses three lean burn, 100% natural gas engines that fully and efficiently combust the natural gas. The system includes a 1 MW Energy Storage System (ESS) to store power that would otherwise be wasted. A Smart Engine Management System (SEMS) is used to automatically start and stop generators in conjunction with the ESS to match the power demand of the rig without wasting power. It functions in synchronization with the active rig, allowing it to operate like a plug-and-play unit. The rig can operate with existing diesel engines if the gas supply is interrupted.

Initial performance targets of baseline to project-level improvements for this system were as follows:

- <5% Utilization of Backup Diesel
- >30% Reduction of Engine Run Hours
- >40% CO₂e Emission Reduction by Diesel Displacement

The package was successfully integrated into both upgraded rigs for a project period of approximately one year. After addressing issues due to battery maintenance, system upgrade requirements, and interrupted fuel gas supply, the following performance targets were met:

- 4% Utilization of Backup Diesel
- 30% Reduction of Engine Run Hours
- 39% CO₂e Emission Reduction by Diesel Displacement, Trucking Reduction, Life Cycle Emissions, and Methane Slip

By the end of the project, the mobile hybrid power generation package was consistently displacing all the diesel that would otherwise be used for power generation. Fuel consumption reduction was determined to be ~4300 L/day. Interruptions in fuel gas supply were mitigated by improved controls and better positioning of gas conditioning equipment around the rig. Communication between the ESS and SEMS is still not perfect. We expect to see further improvement in fuel gas consumption once the battery can more effectively shave off the rig's peak load demands. This testing period was focused on maintaining rig reliability over battery efficiency. Improving efficiency will be addressed moving forward.

After quantifying all emission sources as part of this project analysis, we determined that this package was reducing emissions by 10.66 tonnes CO₂e/day (~3650 tonnes CO₂e/year, assuming 343 rig operating days). The main project cost savings come from having available produced raw gas available on each drilling location vs hauling in diesel.

Project Description

Introduction/Background

Historically, Canada's drilling rig fleet was built with 100% diesel-fueled generator engines to supply power to the rig. Over recent years, a large portion of the Canadian fleet has been retrofitted with dual-fuel conversion kits that allow for the blending of natural gas and diesel for engine fuel combustion. On average, these dual fuel conversion kits consume 40% natural gas and 60% diesel to power the rig. These modifications have helped to reduce the use a higher-carbon-intensive fuel (diesel) but still cause major drawbacks. Incomplete combustion with fuel blending results in wasted fuel and added GHG emissions, and power generation runs inefficiently by supplying more power than is typically consumed during normal drilling operations.

Power generation for a rig is not like typical power generation (i.e. not like that for houses, hospitals, or other industrial applications). The loads of a drilling rig are significant and are mostly consumed by four electric motors: Drawworks, the electric winch that lifts and lowers the drill pipe; Top Drive, the electric motor that rotates the drill pipe; and two Mud Pumps, the electric drive piston pumps that circulate drilling fluid. These four motors are turned on and off during every connection, making the power load peaks and valleys extreme. A 'connection' occurs when the rig crew needs to add a length of pipe to the entire drill string to continue drilling. Unknown downhole variables make the loads more variable and unpredictable. Poor hole conditions cause increases in drag, increases in torque, and variable pump pressure spikes. Variations during on-bottom drilling also cause huge variations in load. Simple changes in formation from sand to shale can result in large pressure and torque spikes. These large, unpredictable swings in power load are what power generation companies refer to as transient load. The large amount of transient load is what makes drilling rig power generation extremely difficult and often wasteful.

At the beginning of this project, there were no drilling rigs in Canada that used 100% dedicated natural gas engines to generate electricity for their equipment. This is because a lean burn natural gas generator set cannot support the transient load demands of a drilling rig. Furthermore, dual-fuel engines do not consume natural gas during transient demand periods, like tripping pipe in and out of the wellbore. 'Tripping pipe' is when the entire drill string is either pulled from the hole or replaced in the hole. Therefore, engines are run on 100% diesel to handle the transient load.

The technology developed in this project is a mobile plug-and-play, 100% natural gas power generation system, equipped with a 1 MW ESS that is used to store power that would otherwise be wasted. The system uses a SEMS to automatically start and stop natural gas generators in conjunction with the ESS to match the power demand of the rig without wasting power. It is a hybrid technology that combines natural gas and electric battery power. Excess generated electricity is stored in batteries rather than discharged and wasted, as is the case with current contemporary drilling rigs. The mobile package model was designed to be integrated with an existing stationary dual-fuel system and can be switched back to diesel supply if gas supply is interrupted.

Tourmaline, Caterpillar, and Precision collaborated to form the group responsible for the execution of this project. Tourmaline is Canada's largest natural gas producer; Precision Drilling is the largest drilling

rig provider in Canada; and Caterpillar is one of the largest engine providers in North America. The companies involved in this project have extensive technical and subsequent commercialization experience within their respective fields of expertise. The collaborating group will drive this proposed technology to help minimize environmental impacts and decrease costs of the drilling rig business. As the consortium companies operate globally, our efforts will first help Canada, specifically Alberta, promote sustainable efforts in the industry, with the possibility for commercialization globally.

As for the project design, three natural gas generators and the 1 MW battery pack were housed in separate storage containers and integrated into a conventional rig layout (Figure 1). Each generator was housed in a sound-attenuated building, with lighting, electrical, controls, and engine radiators to ensure they are always functioning in an optimal environment (Figure 2). The buildings were built on rugged skids that allow them to be winched onto a standard rig moving truck for transportation.

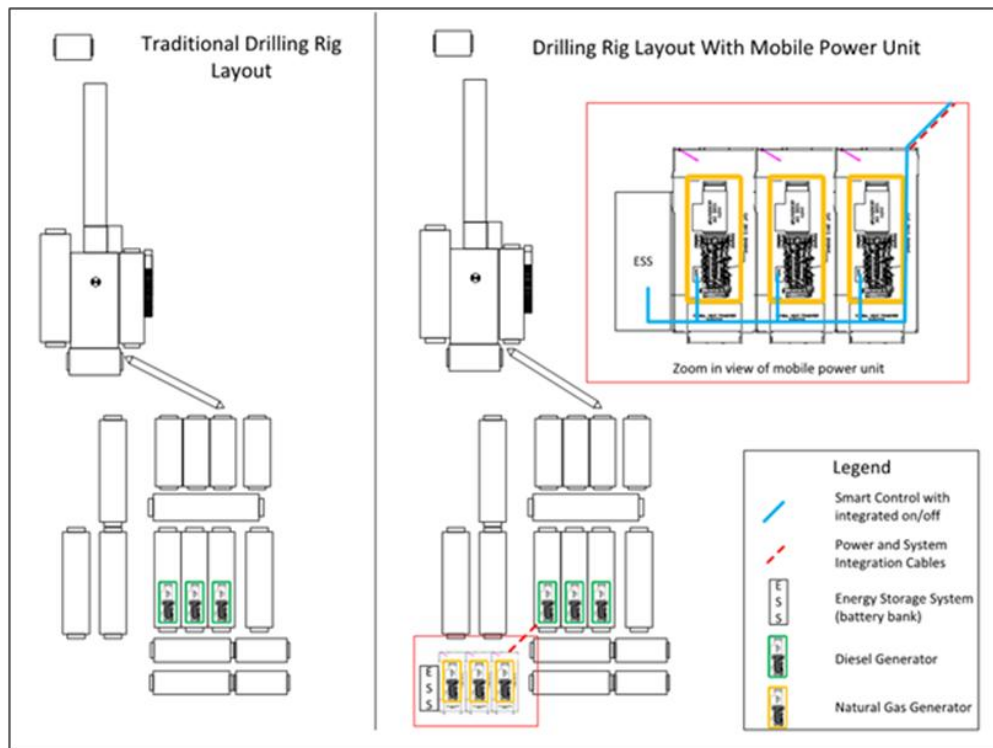


Figure 1: Conventional Technology vs. Mobile Natural Gas Power Generation System



Figure 2: Inside of the Natural Gas Generator Building

The ESS was housed in a separate climate-controlled shipping container (Figure 3). The ESS is comprised of lithium-ion batteries, bi-directional power inverters, a transformer, a heating and air condition system, a fire suppression system, and a controller, all housed within an intermodal container. The ESS is capable of the following power supply times:

- 1000kW – 30 min
- 1175kW – 15 min
- 1225kW – 10 min
- 1260kW – 5 min

Electric loads on a drilling rig can fluctuate by more than 2 MW in seconds. The 1 MW ESS was sized to provide sufficient response to meet this demand and the requirements that fall outside the generators' capabilities. The ESS container was mounted on a flat deck trailer for ease of transport. Between rig moves, the heating, ventilation, and air conditioning (HVAC) runs off the internal batteries. If the unit is to be stored for long periods of time, it can be plugged in to maintain the HVAC and tend the batteries.



Figure 3: ESS Container and Trailer

This system is designed to have a diesel backup solution in the event the natural gas supply is interrupted. However, the natural gas generators and the diesel generators are not integrated into one system such that the diesel generators start automatically if gas supply is interrupted. Further work beyond the scope of this project will include getting all six engines (diesel and natural gas) to work and synchronize together automatically.

The natural gas generators are specifically designed to read the load demand directly from the rig and react by talking to the controller (i.e. Microgrid Master Controller) and adjusting the fuel consumption. The controller was developed to communicate with the software on the drilling rig, decipher the power requirements, and assign the appropriate tasks to the natural gas generators or ESS (Figure 4). Transient load capabilities were also developed on the controller to selectively choose the ESS over bringing on additional generators when quick power supply is required. Having a controller capable of optimizing a transient load will ensure the generators use the minimal amount of fuel needed as opposed to sharing the load equally. The ESS can respond to the transient load instantaneously and provides immediate power within a narrow frequency range. Keeping a tight frequency range is key to ensuring the rig's circuit breakers do not trip and cause a blackout. The ESS has been measured at +/- 1 Hz when responding to a demand spike, which is superior to a conventional diesel generator at +/- 3 Hz (Caterpillar Inc.).

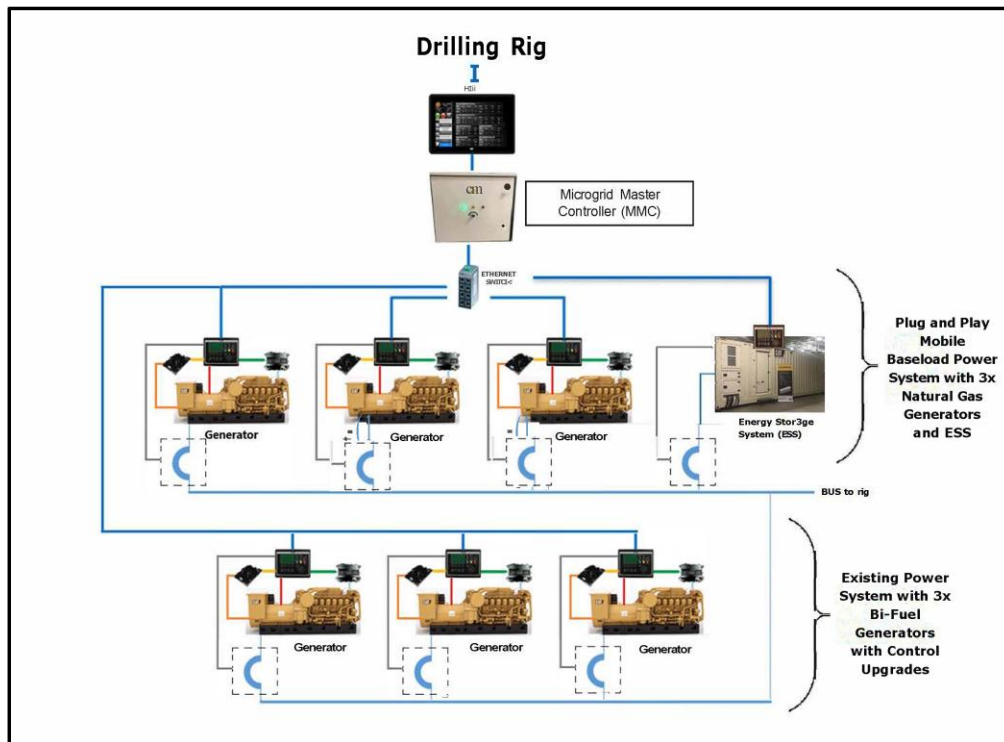


Figure 4: Process Flow of Plug-and-Play System Integrated with Current Drilling Rig

The system accepts an inlet feed of 0 to 882 Nm³/h of fuel gas combined with 0 to 14.7 Nm³/h of air. The system can accept any fuel with a calculated methane number more than 70% and no H₂S can be accepted. The inlet pressure and temperature at the system manifold for full load conditions is designed at 276 kPa and 58°C with a tolerance of ±5%.

This project involved pipelined natural gas to the drilling rig as its fuel supply. A pipeline to the pad is installed early and prior to any drilling activities. Gas is pipelined to the location for the drilling and completion phases. The raw gas is then conditioned with a small treatment skid to drop out the liquids and reduce the pressure. The gas is then considered engine-ready for the drilling rig. Once the pad wells are ready to be brought on production, the wells are tied into the same pipeline and the flow is changed to go back to the gathering line (i.e. to the nearest facility).

Raw gas from gathering lines can have variable composition as it comes from numerous locations. This can cause the fuel supply to be of poor quality and not meet specifications to be engine ready. For example, the gas could contain H₂S. If this happens, a dedicated fuel gas line can be run with processed gas to location and only require a pressure drop skid.

The outputs of the system include 0 to 4 MW of electricity or 1 MW per natural gas generator set along with 1 MW of stored power through the ESS. The exhaust is between 0 to 15.6 Nm³/kWh with mass compositions typical of natural gas engines. Figure 5 summarizes the inputs and outputs of the system.

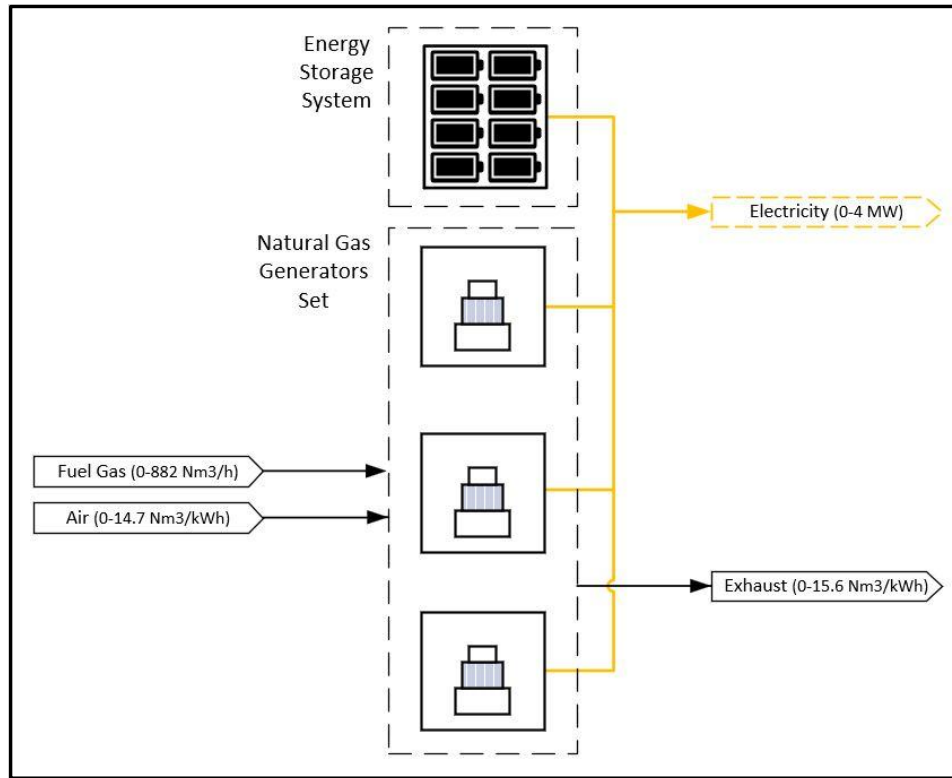


Figure 5: Process Flow Diagram

The mass energy balance of combustion is well understood, but this new process emphasizes the energy capture and storage of excess electricity that is produced above the demand curve. Quantification of this storage relative to the wasted energy from traditional rig power generation systems is represented in Figure 6 and Figure 7. These graphs were created to represent a typical rig power demand for various operational instances; they are not to be taken as actual generator output data. Figure 8 describes the comparison of the project system to current practice based on operating stages.

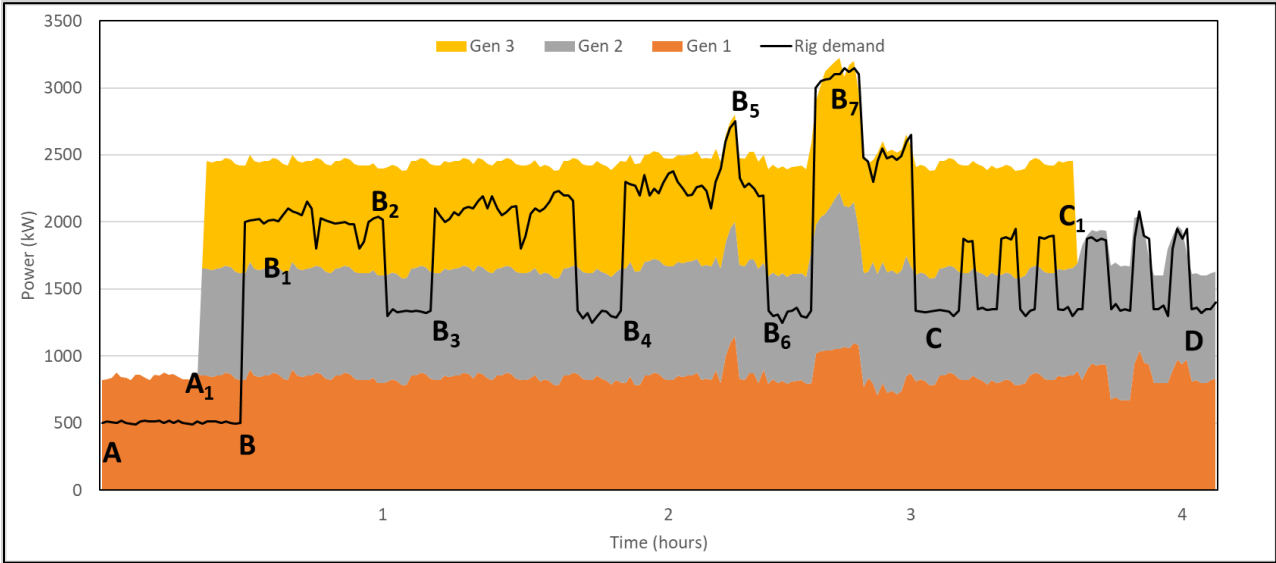


Figure 6: Rig Power Demand and Supply Curve for a Traditional 3 Generator System

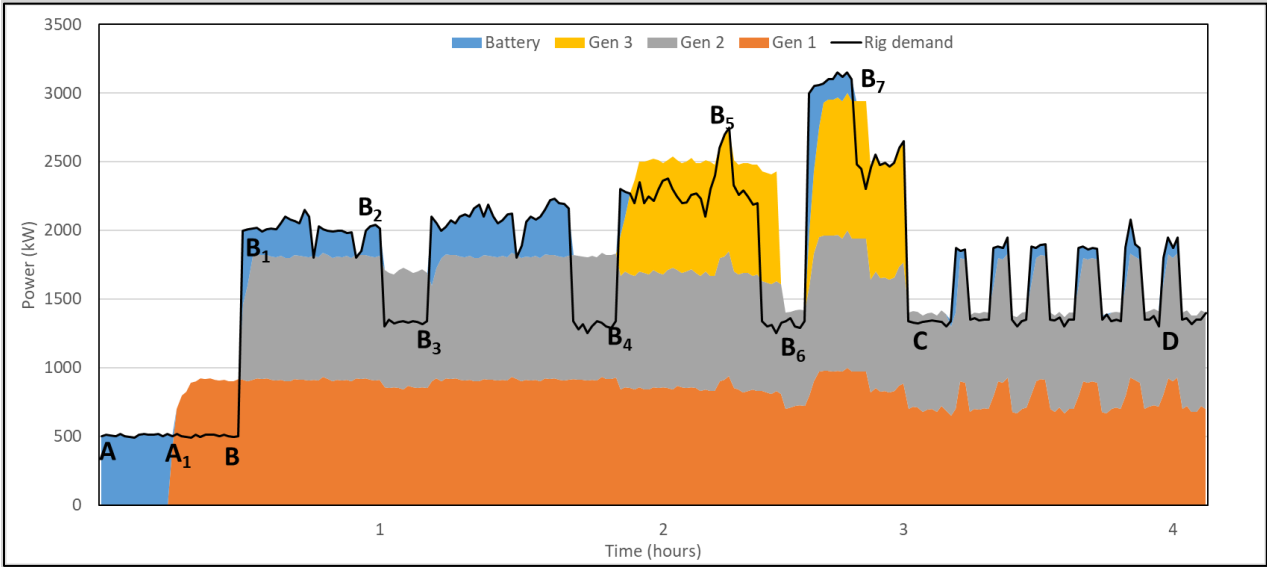


Figure 7: Rig Power Demand and Supply Curve for the Mobile ESS and Natural Gas Generator System

		Points on Diagram	Rig Operations	Current System "Conventional Rig"	Project System "Mobile Natural Gas Power Unit"
A-B	Hotel Power "Hotel Power" - the rig is not drilling. Power is used for lights, controls, and heating.	A-A1		One generator running for hotel power. About half the power is wasted. Gen 1 is on idle with low natural gas substitution.	Rig is running on battery. No fuel is being consumed.
		A1	The rig is between operations and getting ready to drill - only hotel power is being used	Driller expects to begin drilling; starts gen 2 and gen 3	Battery becomes depleted. Gen 1 starts automatically.
		A1-B		All 3 generators are on low idle waiting to start drilling. Large energy waste to the environment, and low natural gas substitution at low idle.	One natural gas generator is running to charge the battery and power the rig (if the battery charges, the generator will shut down).
B-C	Drilling During drilling operations, the rig is under high power load. Drill fluid pumps are circulating at high rates and pressures, and the topdrive is rotating the drill pipe. After drilling a section of drill pipe, the pumps are shut off, the pipe rotation is stopped, and a "connection" is made. Drilling loads are very erratic with large variations.	B-B1	The rig turns on pumps and starts pipe rotation. The power required ramps up extremely quickly.	The transient load is not an issue as the generators are at idle and producing more load than required.	The system responds automatically by starting natural gas gen 2. Gen 2 is slow to ramp to full power and the battery compensates for the transient load.
		B1-B2	The rig is drilling on bottom. There is variation in the rock and power load, but the load is relatively low in this section	The power load is low. The generators remain on idle. Extra power is wasted and the natural gas substitution is low at low idle.	The power load is low. Two natural gas generators are running at optimum fuel economy rpm. The battery is making up the remaining load.
		B2-B3	The rig has finished drilling and needs to add a section of drill pipe (make a "connection"). Pumps are turned off and pipe rotation is stopped to connect a new section of pipe.	With the pumps off and the pipe rotation stopped, the generators are extremely wasteful, but the driller knows the connection will only take a few minutes so he keeps all the generators running.	The system notices the drop in load, but has been consuming battery power during the drilling phase. It provides extra power to charge the battery to prepare for the next drilling phase.
		B3-B4	The rig drills another section of drill pipe and makes a second connection. It drills similar to the last phase.	All 3 generators are still on low idle wasting the excess power. The driller could shut down a generator during connections, but that is not practical to do manually.	The system drills and completes this connection much like before, but the battery is being depleted and the connections are too fast for it to fully charge. It keeps the two generators at high idle to charge the battery during the connection.
		B4-B6	The rig drills another section of drill pipe and makes a third connection. This section requires a higher pump rate at B5 increasing the load.	All 3 generators are mostly on low idle wasting the excess power. The pump increase at B5 causes the generators to temporarily idle up to compensate for the load.	This section is slightly harder drilling and the battery does not have capacity, so natural gas gen 3 is started. Since the power spike B5 was gradual, the generators were able to ramp up to power the spike. Gen 3 keeps running to top up the battery for part of the connection, then shuts off.
		B6-C	Another connection is made, but while going to bottom, the hole becomes unstable. The drill pipe torque increases and the pump pressure spikes, adding significant load (B7).	All 3 generators must ramp up quickly to respond to the hole conditions. These engines are not quick to respond at transient load, so the driller notices a delay in power response. The bi-fuel engines at high rpm are burning an optimum 70% natural gas and 30% diesel.	After the connection, the system responds to the load spike by starting gen 3. Gen 1 and gen 2 ramp up. The battery compensates for the transient power while the engines ramp to high rpm. The battery provides the remaining load gap. All 3 engines stay at high rpm after the load drops to top up the battery.
C-D	Tripping "Tripping" is the action of pulling the drill pipe in or out of the hole. This is done to change bits or at the end of a hole section.	C-D (The diagram show a 6-connection trip)	Tripping the pipe is a series of continuous connections. The pumps are off and the top drive is off. There is a spike of load while the pipe is pulled out of the hole. Tight sections in the hole cause additional spikes of load.	The driller trips out the first 3 sections of pipe and at C1 remembers that he has all 3 generators running. He chooses to shut one off (some drillers may choose to leave it running for higher performance). The bi-fuel engines do not consume natural gas during trips; the load spikes are too frequent, so the engines need to run on 100% diesel to handle the transient load.	During tripping, the system runs two natural gas generators. The transient power spikes are compensated for with the battery bank. Once tripping at shallow depths with lower loads, the system will automatically compensate and shut down the second generator. Near-surface trips may be performed on 100% battery power.

Figure 8: Detailed Description of Operating Stages

Objectives

The objectives of this project were to successfully complete a pilot demonstration on a mobile power generation system and fully understand the reliability, efficiency, and environmental benefit of implementing the package. Project and Strategic Objectives are outlined in the tables below:

Objective Title	Objective Description	Deliverables	Result
Pilot Demonstration	The overall objective of this project is the pilot demonstration of a mobile power generation system plugged into AC electricity-powered drilling rigs. The fuel source supplied to the system will be by natural gas pipelined to location from Tourmaline's facilities.	Understand the relationship between the power demand and the size of the unit during drilling	✓
		Validate the reliability and efficiency of the plug-and-play mobility of the unit during field operations.	Ongoing
Ongoing Techno-economic and Environmental Assessment	A key component of the work plan of this project is to conduct an ongoing techno-economic and environmental assessment. Experimental and measurement data will be gathered during the project to perform the analysis. Additional flow meters will be installed on the rig to measure fuel consumption.	Understand the volume of diesel reduction and backup usage	✓
		Understand the reduction in trucking	✓
		Understand the reduction in methane slip	✓

Table 1: Project Objectives

Objective Title	Objective Description	Result
GHG Reduction	Validating the potential GHG emissions reductions from developing this technology that meets performance criteria as identified by Tourmaline; i.e. a minimum reduction of 40% per CO ₂ e emissions in the base case, supporting Alberta's climate change legislation and decreasing per barrel equivalent GHG emissions from hydrocarbon production operations.	✓
Environmental Benefits	Validating the potential environmental benefits from developing this technology that meets performance criteria as identified by Tourmaline; i.e. reduction in volume of diesel consumption and backup usage, reduction in trucking and reduction in methane slip.	✓
Economic Benefits	Validating the potential economic benefits from developing this technology that meets performance criteria as identified by Tourmaline; i.e. reduction in drilling CAPEX to allow for additional corporate revenues and royalty revenues due to increased economic activity.	✓
Communicating Results	Communication of lessons learned, technical gaps, and future opportunities.	Ongoing

Table 2: Strategic Objectives

The objectives outlined at the start of the project remained consistent throughout the entire project period. When analyzing the drilling rig diesel and natural gas consumption at the early stages of the project, it did not look like we would reach our target of 40% emissions reductions. It was understood that the initial data was showing less of an emissions reduction because the system was operating inefficiently. Once we were able to upgrade the ESS and reduce the overall generator run-time, we were able to reach emission reductions closer to what was projected. The >40% emission reduction target was assuming the battery would be able to “peak shave” as outlined in Figure 7. Load peak shaving would require less generator power output than what is required by the rig at a given time and excess power would be covered by the battery.

Given the new technology, the group was more concerned about maintaining power reliability than focusing on efficiency, at the expense of using more fuel. As further progress is made with this technology, an increasing focus will be made on system efficiency once reliability can be sustained. Emission reductions of nearly 40% were still obtained, but after including life cycle emissions, trucking, and methane slip on top of the standard exhaust emissions. More detail on GHG reductions can be found in Emission Reduction Impact.

The project data has provided a strong understanding of the economic and environmental benefits, which can be found in the Environmental Benefits and Economic and Social Impacts sections of this report. Communication of lessons learned, technical gaps, and future opportunities is ongoing. Sharing this report and presenting the project are important steps for communicating the learnings to other interested parties.

Success Metrics

Table 3 outlines the success metrics from the Contribution Agreement. The metrics were not changed throughout the project’s life. Data used to measure the success metrics were focused on the same period for the second Project Rig (Project Rig #2) and the Baseline Rig. Data from the first Project Rig (Project Rig #1) was not included in the comparison for several reasons:

- The ESS and generator package were not operating efficiently while major tweaks and maintenance were still being done. Dual-fuel engines were used regularly during this period.
- Seasonality would impact fuel consumption and emissions comparisons.
- Well design and pad plans varied compared to the Baseline Rig.

Project Rig #2 and the Baseline Rig were drilling in the same area of Northeast British Columbia (NEBC), and the mobile unit was performing similarly to what was expected during the end of the project period.

Success Metric	Commercialization Target	Project Target
Utilization of Backup Diesel	< 1%	< 5%
Reduction of Engine Run Hours from Spud to Rig Release	> 30%	> 30%

CO₂e Emission Reduction by Diesel Displacement and Trucking Reduction	> 40%	> 40%
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Table 3: Success Metrics

Utilization of Backup Diesel

The table below outlines the utilization of backup diesel for a few different scenarios. If all the project period drilling days for Project Rig #2 (Dec 19, 2021, to Jun 30, 2022) are considered, the utilization of backup diesel is 10%. During that period, there were days that the system either had issues with the ESS or fuel gas supply and dual-fuel engines would need to be swapped in place of the natural gas engines. Through reviewing daily rig reports, it was understood that any days under 90% substitution would indicate a day that had these issues arise. Considering only the days that the system was operating properly, the utilization of backup diesel was 4%.

Scenario	Drilling Days	Diesel Consumed (L/day)	Natural Gas Consumed (E3m3/day)	Total Fuel Consumed ((Diesel + DLE)/day)	Natural Gas Substitution (%)	Utilization of Backup Diesel (%)
Project Rig #2	186	787	6.37	8,504	90%	10%
Project Rig #2 (>90% Substitution, System Operating)	139	339	7.03	8,800	96%	4%
Project Rig #2 (<90% Substitution, System Down)	47	2,113	4.42	7,627	70%	30%
Baseline Rig	167	4,611	3.12	8,282	42%	58%

Table 4: Drilling Days, Fuel Consumption, and Utilization of Backup Diesel in Different Rig Scenarios

Reduction of Engine Run Hours from Spud to Rig Release

Logging the generator engine hours manually was determined not to be accurate. In January 2022, Precision implemented a new data monitoring system that can track a variety of generator operating parameters. Sensors were installed on the Project #2 and Baseline Rig's in April 2022. May 2022 was a good starting point for analyzing the reduction in engine hours since the ESS went through a series of system upgrades in May. A summary of engine run hours for Project Rig #2 and the Baseline Rig are outlined in Table 5.

Rig	Month	Days	1x Engine Running (hrs)	2x Engine Running (hrs)	3x Engine Running (hrs)	Total (hrs)	Reduction (%)
Baseline	May-22	30	12.3	764.2	976.7	1753.3	
Project #2	May-22	30	62.1	699.3	924.3	1685.6	4%

Baseline	Jun-22	30	2.7	719.9	1072.0	1794.6	
Project #2	Jun-22	30	213.4	897.5	168.6	1279.5	29%
Baseline	Jul-22	30	28.9	719.6	880.8	1629.3	
Project #2	Jul-22	30	272.1	787.9	76.1	1136.1	30%

Table 5: Engine Runtime Reductions

Once the ESS was operating more efficiently, the reduction in engine run hours was directly at the target level. During July 2022, Project Rig #2 had no engines running for 5% of the time, which represents approximately 55 hours of rig down time for a pad move. Excluding this data would indicate that the system is now at a >30% reduction in engine hours.

CO₂e Emission Reduction by Diesel Displacement and Trucking Reduction

The same project period and operating scenarios used in the backup diesel comparison were used for measuring emission-reductions performance. If only diesel and natural gas fuel consumption emissions are considered, the reduction from Baseline to Project Rig #2 was 21%. If life cycle upstream, trucking, and methane slip emissions are all considered in the comparison, the reduction was 39%. The 40% target for diesel displacement and trucking emissions alone was assuming the battery would be peak shaving any excess load, and much less natural gas supply would be required for the engines. As the technology progresses further, the focus will move to increasing these battery efficiencies, once the system is more reliable. Table 6 below outlines the emission reductions. More detail on emissions can be found in Emission Reduction Impact.

Scenario	Exhaust Emissions	Life Cycle Upstream Emissions		Trucking Diesel Emissions	Methane Slip Emissions	Total Emissions
	CO ₂ e Total (tonne/day)	CO ₂ e from Diesel (tonne/day)	CO ₂ e from Natural Gas (tonne/day)	CO ₂ e Total (tonne/day)	CO ₂ e Total (tonne/day)	TOTAL (tonne/day)
Project Rig #2	15.0	0.66	0.71	0.01	0.59	17.0
Project Rig #2 (>90% Substitution)	14.9	0.28	0.79	0.01	0.59	16.6
Project Rig #2 (<90% Substitution)	15.1	1.77	0.50	0.03	0.59	18.0
Baseline Rig	19.0	3.87	0.35	0.06	4.35	27.6
Reduction (%)	21%					39%

Table 6: Emissions at Different Rig Scenarios

Risk Analysis

The following technical risk analysis and mitigation strategy (Table 7) was developed at the beginning of the project. The identified risks were classified as low or medium, given that majority of the project scope incorporated known technologies with minimal developmental risks.

Key Risks	Prob.	Impact	Risk	Risk Mitigation and Response Strategy
Technical				
System inability to function as proposed in design specifications, in terms of integration of existing diesel generators, natural gas generators, and ESS	Low	High	Med	Schedule routine and additional meetings to manage the technical development of the microgrid with Caterpillar. Review alternatives to troubleshoot technical development issues or timeline delays (e.g., adding internal or external resources).
Pipeline natural gas composition does not meet specifications for input to the power generation system	Low	Low	Low	Setup measures for availability to truck CNG or pipe in processed gas.

Table 7: Technical Risks

System Functionality

Integration of the natural gas generators, ESS, and SEMS into both Project Rigs went as planned. Initial feedback from the field crews was positive, with the package providing a noticeable improvement in the responsiveness of the drilling rig. The main functionality risks came from the ESS not performing as designed. The main issues were with how the battery operated in conjunction with the natural gas generators. This resulted in more generators running and at a higher load than what was required. Overall, this issue did not create much of a risk but rather over-supplied the rig with available power, creating an environment of higher fuel consumption. Upgrades to the ESS were performed in Q1 and Q2 of 2022 to address these issues. Since the upgrades, the system has been operating closer to design and fuel consumption has decreased.

Fuel Gas Supply

One of the main goals of this project was to use available raw field gas to supply the natural gas generators and ultimately keep the project costs low. During winter months, extremely cold temperatures would allow hydrocarbon condensates to form in the gas lines, as well as water vapours to condense and freeze. These liquids would build up in the fuel gas scrubber until the unit would shut down, eliminating the gas supply to the generator engines. Regardless of which alternative fuel source (Diesel, CNG, LNG) is available for backup power generation, the main risk is all the generators going down at once and the rig “blacking out” (total loss of power). Mitigation strategies included using extra

controls on the fuel gas scrubber to drain liquids automatically and placing the fuel gas conditioning unit closer to the engines to decrease the risk of condensation occurring in longer gas lines. Total loss of power to the rig means the mud pumps can't circulate cuttings out of the hole. This event allows cuttings to fall and pack off the drilling assembly, creating a risk for getting the pipe stuck in the hole. Being stuck in the hole can be time consuming and costly. For this reason, the risk level should be raised to "High".

Other Challenges

Part of the project scope was to install one natural gas and two diesel flow meters (one inflow and one return) on the Baseline Rig, to allow for more accurate fuel consumption data comparisons between the Baseline and Project Rigs. These meters initially had data transmission issues, which limited our ability to quantify fuel efficiency and associated emissions on the Baseline Rig. This challenge did not pose an overall risk to the project, as natural gas and diesel consumption could be collected manually by recording diesel tank volumes and natural gas metering that is installed on each gas conditioning unit.

Project Work Scope

Milestone 1

The first steps of the project included the controller upgrades of the two Project Rigs to an EMCP 4.4, DGB system (Figure 9) and a SEMS to automatically start or stop generators. The tasks in this milestone included procuring and installing rig upgrade equipment, conducting field demonstrations, performing data analysis to understand upgraded rigs' performance, and procuring power generation equipment. It should be noted that the EMCP 4.4 controller and SEMS upgrades were required before the mobile power system could be integrated into either rig. The timing of the rig upgrades, meter installation, and equipment procurement are outlined below:

- Project Rig #1 engine upgrades (on all three 3512 engines) began on Oct 15. and were completed on Oct. 31, 2020.
- Project Rig #2 engine upgrades (on all three 3512 engines) began on Oct. 15 and were completed on Oct. 26, 2020.
- Flow meters for GHG emission data the Baseline Rig were installed on November 6, 2020.
- Equipment order placed with Caterpillar for three natural gas engines and ESS.



Figure 9: Project Rig #1 Upgraded EMCP 4.4 DGB Unit

Natural gas and diesel flow meters were installed on the Baseline Rig; for each engine, one natural gas flow meter (Figure 10) and two diesel flow meters (one inflow and one return, Figure 11) were installed. Meters were installed to allow for baseline fuel consumption data. During this period, there were data transmission issues with the meters which caused inaccurate readings. Replacement meters were eventually installed in Milestone 3 that allowed for integration into Precision’s continuous fuel and power monitoring system. Diesel and natural gas consumption was also collected manually throughout the project’s life. This was done by recording the rig diesel tank volumes and recording the value from the natural gas metering that was installed on each gas conditioning unit.



Figure 10: Baseline Rig - Natural Gas Flow Meter

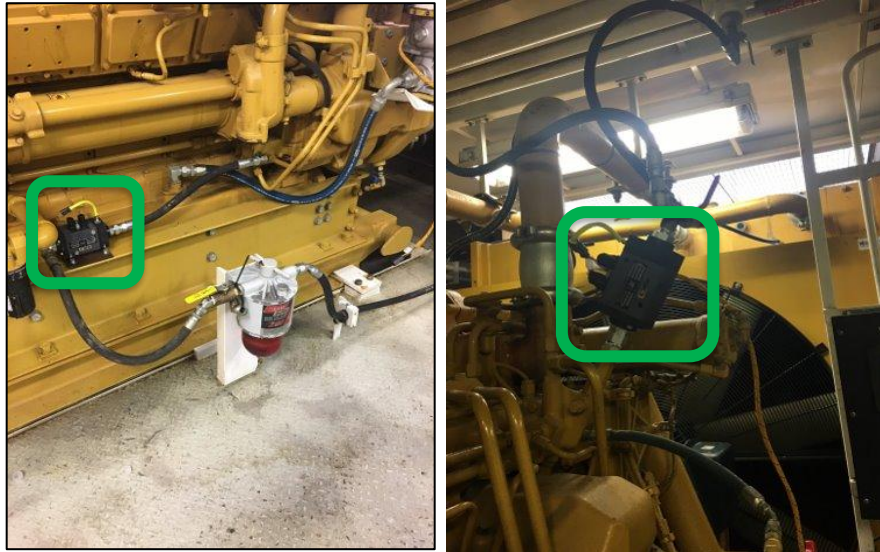


Figure 11: Baseline Rig - Diesel Flow Meters (Left - Inflow, Right - Return)

Milestone 2

The second stage of the project involved building the power generation system along with the respective buildings for each piece of equipment. This also included commissioning the system into the drilling rig. The tasks in this milestone included delivery of all assembled buildings and the successful installation of the power generation system into the drilling rig at the initial demonstration location.

- The hybrid power system (Figure 12 and 13) was delivered to the field on July 21, 2021, and commissioned by July 27, 2021.



Figure 12: Natural Gas Engine Buildings Unloading at Project Rig #1



Figure 13: Inside View of ESS at Project Rig #1

Overall, the initial commissioning of the hybrid system into Project Rig #1 went well. No major bugs or issues occurred during start-up. For the first 17 days after the system was installed, the rig continued drilling with no diesel usage. The field crews enjoyed working with system and noticed there was an improvement in the rig responsiveness by having the battery power available. The Project Rigs were also equipped with diesel and natural gas flow meters (Figure 14) that were used to help analyze performance and emission data during Milestone 3.



Figure 14: Natural Gas Flow Measurement on Project Rig #1

Milestone 3

The final stage of the project was to conduct field demonstrations on Project Rig #1 and successfully move the mobile system to Project Rig #2. The original plan was to make this move during the 2022 spring break-up (March/April). Due to rig schedule changes, Project Rig #1 shut down for an extended time in December, therefore we decided to move the system to Project Rig #2, which was operating in BC, to maintain higher utilization of the package. The timing of the move is outlined below:

- The hybrid power system was trucked from Project Rig #1 to Project Rig #2 on Dec 15, 2021
- The hybrid power system was commissioned and operating on Project Rig #2 on Dec 19, 2021

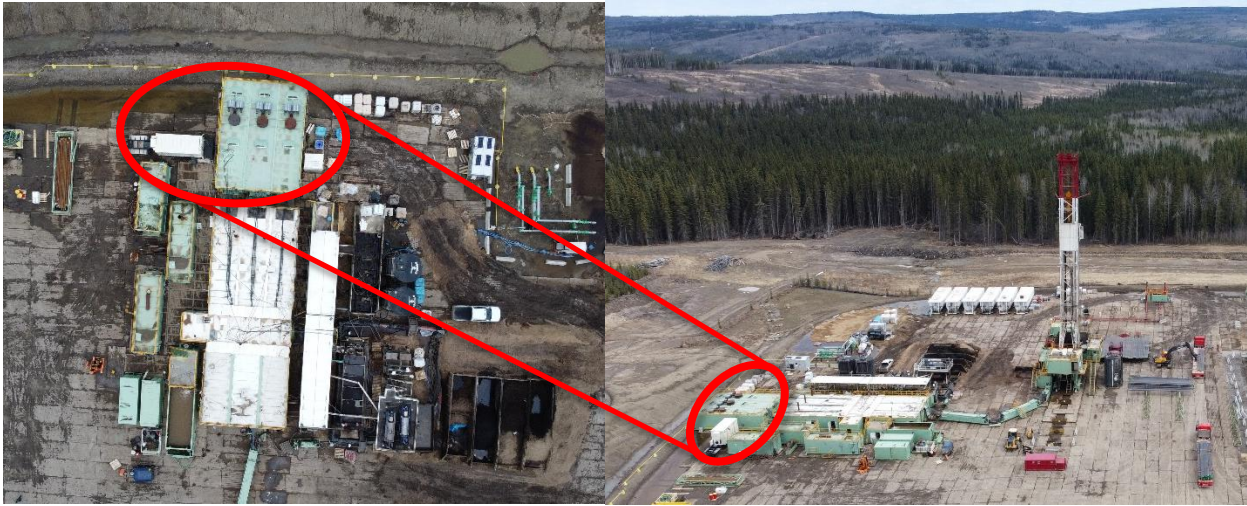


Figure 15: Mobile Power Unit on Project Rig #2

Again, the commissioning of the package into the new Project Rig went smoothly. However, shortly after starting up, extreme cold weather affected the natural gas supply to the rig, and there were prolonged periods when the dual-fuel engines were used for power generation while maintenance was performed on the fuel gas scrubber. Additionally, more ESS issues and maintenance occurred during this project period than expected. Further detail on the fuel gas supply and ESS issues can be found in Lessons Learned.

Both the Baseline and Project Rig #2 were drilling wells in the Gundy field of NEBC. Comparing the fuel consumption and emission data head-to-head beginning on Dec 19, 2021, allowed for the most accurate baseline to project comparisons. The rigs were drilling to similar depths and well design, temperature in the area would be consistent and, after a few initial maintenance issues, the hybrid system was operating more closely with the expected project level vs the performance on Project Rig #1.

Results

Fuel consumption data beginning in 2019 and ending at the project end date (June 30, 2022) was collected manually on a per well basis by measuring diesel tank volumes (diesel quantification) and by recording readings from the metering on the gas conditioning units in the field (natural gas quantification). As no well is the same, the data could be erratic from well to well. This data (Figure 16, 17, and 18) shows a significant trend downward in diesel usage while the natural gas generators and ESS were installed on the two different project rigs. Any diesel used during the hybrid system uptime is used by auxiliary lease equipment such as track hoes or front-end loaders; this is typically between 300-400 L of diesel/day. Any other large amounts of diesel used correspond to system downtime (switching power supply to dual-fuel engines).



Figure 16: Project Rig #1 Drilling Metrics and Fuel Consumption over the Project Period

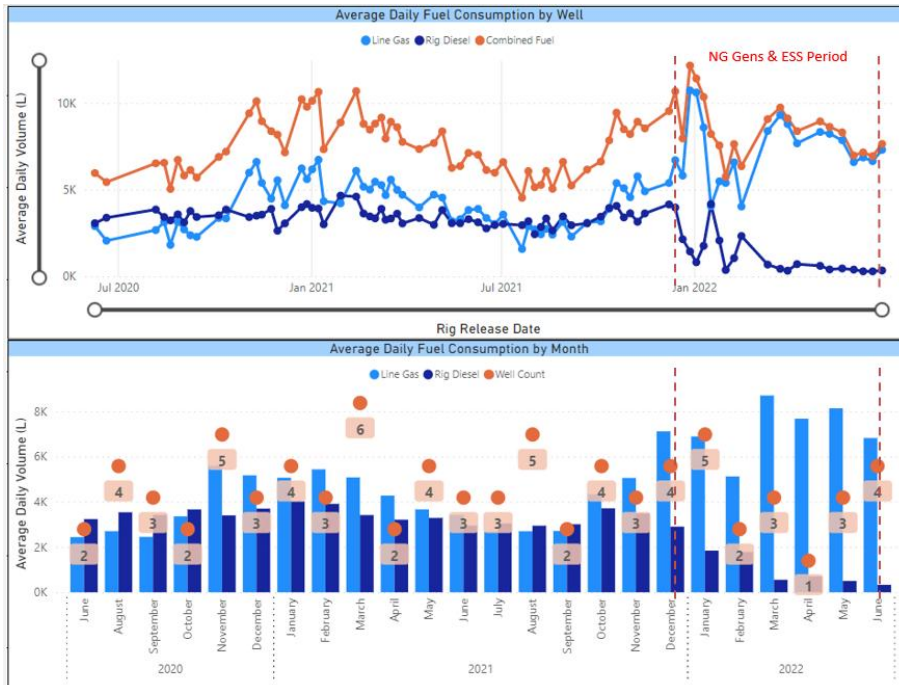


Figure 17: Project Rig #2 Drilling Metrics and Fuel Consumption over the Project Period

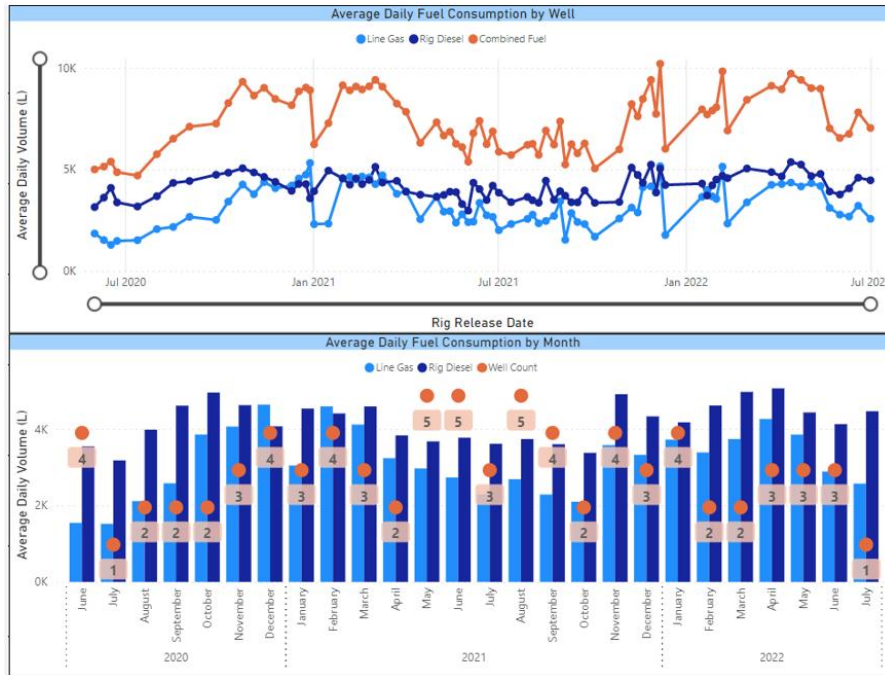


Figure 18: Baseline Rig Drilling Metrics and Fuel Consumption over the Project Period

Figures 16, 17, and 18 represent the historical fuel consumption from Project Rig #1, Project Rig #2, and the Baseline Rig. When possible, a specific data period was analyzed over a full calendar year to help eliminate any error that would be caused by seasonality temperature changes (i.e. more fuel being consumed on colder days). The data is summarized into Table 4.

Drilling Rig	Data Period	Period Description	Avg Diesel Consumed (L/day)	Avg Gas Consumed (e3m3/day)	Avg Total Fuel (DLE)	Gas Substitution (%)
Project Rig #1	Oct 13, 2019 – Oct 12, 2020	Pre-project	4,530	2.72	7,726	36%
Project Rig #1	Oct 31, 2020 – Jul 28, 2021	DGB Upgrade	3,195	3.85	7,693	53%
Project Rig #1	Jul 28, 2021 – Dec 12, 2021	NG Gens & ESS	195	6.36	8,504	97%
Project Rig #2	Oct 20, 2019 – Oct 19, 2020	Pre-project	3,962	2.58	7,000	40%
Project Rig #2	Oct 20, 2020 – Oct 19, 2021	DGB Upgrade	3,600	3.75	8,015	51%
Project Rig #2	Dec 19, 2021 – June 30, 2022	NG Gens & ESS	787	6.37	8,504	90%
Baseline Rig	Dec 19, 2019 – Dec 18, 2021	Pre-project	4,350	2.71	7,536	38%

Table 8: Project Rigs Fuel Consumption Summary

As discussed, the period used to make a direct comparison of baseline vs project level emissions was Dec 19, 2021, to Jun 30, 2022. During this period, the Baseline Rig and Project Rig #2 were drilling wells in the same area of NEBC. Most of the major issues occurring from fuel gas supply and the ESS performance had been addressed during this period, and the system was operating closer to what was expected. Figure 19 shows the comparison of average daily diesel consumption per well, on both rigs. Average fuel consumption and associated emissions for this period are outlined in Table 5.

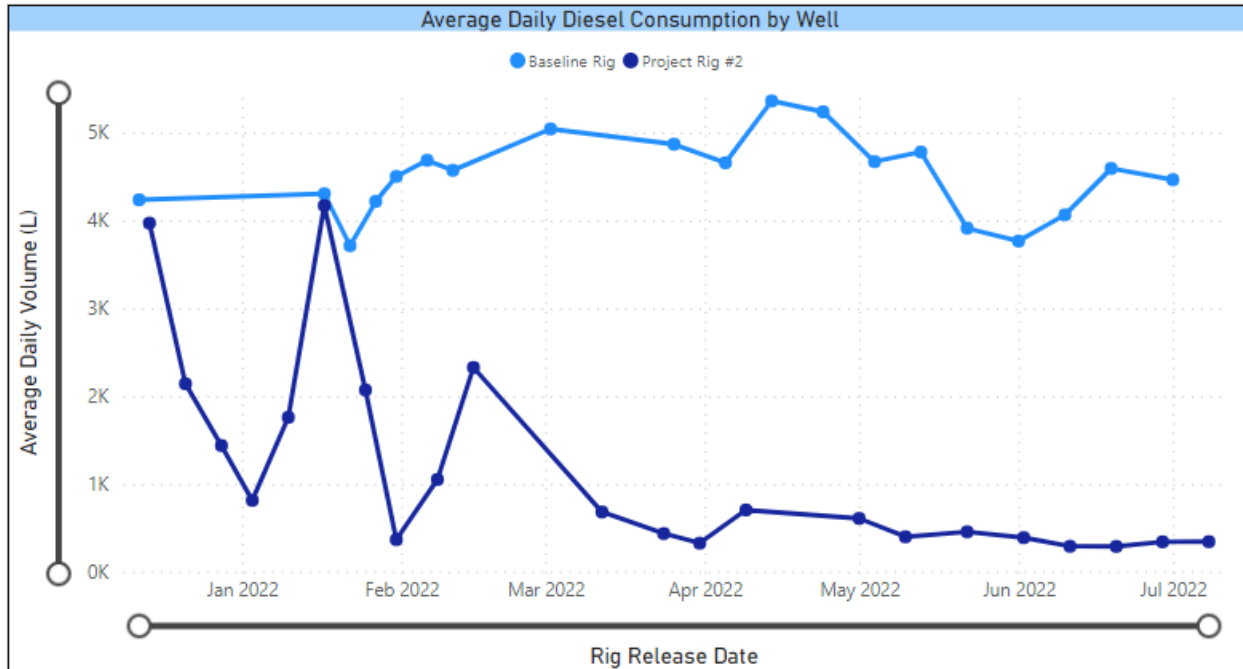


Figure 19: Average Daily Diesel Consumption per well on Project Rig #2 and the Baseline Rig

Drilling Rig	Data Period	Period Description	Avg Diesel Consumed (L/day)	Avg Gas Consumed (e3m3/day)	Avg Total Fuel (DLE)	Gas Substitution (%)	Diesel CO ₂ e (T/day)	Gas CO ₂ e (T/day)	Total CO ₂ e (T/day)
Project Rig #2	Dec 19, 2021 – June 30, 2022	NG Gens & ESS	787	6.37	8,504	90%	2.2	12.8	15.0
Baseline Rig	Dec 19, 2021 – June 30, 2022	Pre-project	4,611	3.12	8,282	42%	12.9	6.1	19.0

Table 9: Average Daily Fuel Consumption and Emissions – Project Rig #2 and Baseline Rig

In April 2022, continuous monitoring fuel and power meters were installed on the drilling rigs to apply additional data analytics and observe learnings from trends. Figure 20 shows an example of the Precision data monitoring dashboard. This has helped to establish a fuel efficiency understanding for the project (fuel reduction per power consumption). It has also helped to identify when excess power is

being generated and during what specific drilling operation that is occurring. This will ultimately help to reduce unnecessary engine run-time and make the rig power generation more efficient. This platform was used to analyze the engine run-time hours for both the Baseline Rig and Project Rig #2. Figure 21 highlights how beneficial the upgrades to the ESS were in reducing the overall engine run-time. The red line indicates the power available to the rig based on zero to three generators running. Project Rig #2 engine run-time was 1,686 hours for May 2022 and 1,280 hours for June 2022.

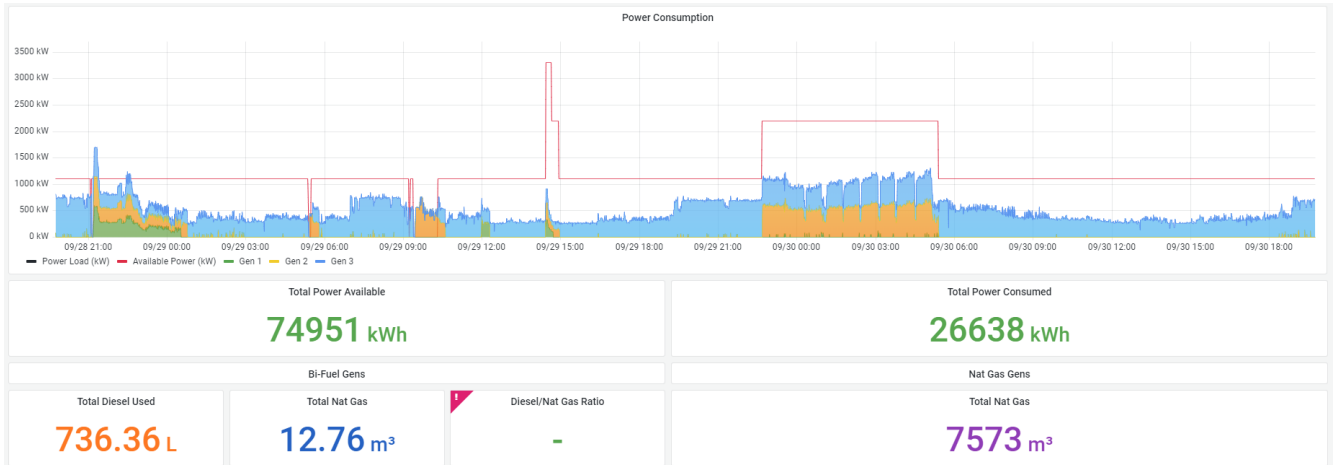


Figure 20: Precision Fuel and Power Monitoring Dashboard



Figure 21: Project Rig #2 Power Consumption in May (Top) and June (Bottom) 2022

Analysis

The hybrid package integration into both Project rigs resulted in a significant reduction in diesel fuel usage. Project Rig #1 had an average reduction of 4,335 L of diesel per day when comparing pre-project vs gas generator and ESS integrations. Project Rig #2 reduction was 3,175 L of diesel per day. The differences in reductions on the two rigs could be due to:

- Differences in rig total consumption at pre-project levels based on operating area (i.e. location, well design, formations encountered, etc. could increase overall fuel consumption). For example, Gundy hole sizes are smaller (251mm x 159mm – Monobore) compared to Kakwa (311mm x 222mm x 159mm – 3 String).
- Differences in how fuel usage was being tracked for auxiliary rig equipment such as track hoe and front-end loaders.
- Differences in date periods (i.e. temperatures) for each upgrade stage. The ESS was installed on Project Rig #1 during warmer months (Jul – Dec) and the ESS was installed on Project Rig #2 during colder months (Dec – Jun), with prolonged periods of extreme weather. Colder weather created higher overall fuel consumption and caused more fuel gas supply issues with the natural gas generators.

In the original project application, we assumed a baseline rig would consume an average of 6,150 L of diesel per day. Over the past two to three years, Tourmaline has placed greater focus on reducing diesel consumption – a goal well-understood by our field personnel. Simply by changing our attitude towards diesel use, we saw reductions occur in the field without any physical technology changes to equipment. New baseline projections would be around 4,500 L daily diesel consumption given this new outlook.

Comparing the Baseline Rig and Project Rig #2 for the same six-month period, the average reduction in diesel consumed was 3,824 L/day and the increase in gas consumed was 3.25 e3m³/day. Using emission factors outlined at the beginning of the project, this represents a 21% reduction in GHG emissions. Data from Dec 2021 to Apr 2022 was still showing higher-than-expected diesel and natural gas consumption, as represented by data points in Figure 19. Diesel would still be used when fuel gas liquid buildup would shut down the scrubber, forcing the rig crew to switch back to the dual-fuel generators. Gas consumption was higher than expected since the battery was still not peak shaving as designed, which meant more gas engines running. This would also indicate why there is still a high total fuel being used after the hybrid system was installed on either rig. Analyzing the data for engine run hours during June and July 2022 indicate that the reduction in engine run hours is now meeting the 30% target that was outlined at the beginning of the project, proving that the battery is starting to operate as expected. The May reduction in engine hours was only 4%.

Commercialization

At the beginning of the project, the technology was at a Technology Readiness Level (TRL) 7, given the prototype was ready for demonstration in an operational Canadian environment. Now that the technology has been proven successful under real-life conditions, it has reached TRL 9. It took until the end of the project to get the system operating under the expected conditions. This project was successful in getting the package to a technology level that can be adopted in the North American market.

The project collaborators have already realized more market adoption in this technology. Caterpillar's hybrid drilling solution has been successfully deployed on multiple drill rigs in North America with over 50,000 hours of operation to date. Precision has experienced an increasing market uptake of drilling with packages that include a hybrid power generation system.

By year end, Precision is expecting to have eight hybrid systems deployed, six in Canada and two in the US. Most of the hybrid packages include a combination of a battery with dual-fuel engines for power generation. Two of the eight systems deployed by the end of 2022 will have a mix of two natural gas generators, one diesel and a battery for power supply. This technology is an iteration of the plug-and-play system and can nearly eliminate diesel usage. Tourmaline also plans on commissioning a similar package with another rig provider in the coming months. Tourmaline's goal is to have our entire drilling rig fleet running off natural gas by 2025.

The two key operating conditions for success of the proposed alternative model is fuel gas conditions and ESS reliability. Fuel gas containing excessive liquid content will trigger high-liquid-level alarms on the inlet fuel gas scrubber and eliminate the gas supply to 2/3 generators. Diesel would be available to supply the third generator, but overall power for the rig would be limited until the fuel gas system is back online. If the battery is operating as designed, the two natural gas generators would run to supply enough power for normal drilling operations, and any power requirement exceeding the two-generator capacity would be supplied by the battery. All diesel use would be eliminated if the system operated consistently in this manner. This solution will undergo further testing in the coming months.

The current market outlook for Canada is to have nine units with either the plug-and-play system or a stationary system containing and battery and two natural gas generators by the end of 2023. Tourmaline's projections are that we could reach 24 rigs with this technology in Canada by 2025.

Lessons Learned

Procurement of the equipment and package commissioning into both Project rigs went smoothly. Majority of the challenges faced occurred during the field demonstration portion of the project. Given the nature of the new technology, we had to troubleshoot problems that had not been seen or understood before.

Energy Storage System

One of the main issues encountered was the battery system experiencing ground faults. This is referring to electricity inadvertently taking a path to ground rather than to the power system. Another key issue was around potential transformers (PTs) not operating correctly, requiring regular maintenance or replacement parts. A trained Finning technician came to site to troubleshoot; this technical support and troubleshooting expertise is currently limited, as it is a new technology. As this system operates longer and similar packages are deployed in the field, this knowledge gap will continue to decrease in the industry.

System upgrades were performed primarily through Q1 2022. Some of the key improvements were:

- Power distribution: actively keeps the generator load factors at 0.9 (90% load), while the battery contributes to the rest of the power demand
- Load distribution strategy: the timing of battery charge/discharge
- Transient response time: how quickly the system responds to changes in rig power demand
- Human-machine interface (HMI): improvements such as better programming, instant feedback, diagnostics, and alarms

- Proactive drop: adjusted so that if two extra engines are running, it will drop both rather than one at a time

After these upgrades were made, there was higher system utilization and less engine runtime. The battery was being utilized properly for optimum peak load shaving, with one to two engines running most of the time instead of two to three. However, there are still concerns with the battery performance as there are noticeable periods when two to three engines are operating at a much higher load than is required to sufficiently supply the rig. The system is performing better than when the project started but further battery upgrades will be needed. More optimizations can also be made with adjustments to load thresholds and engine start/stop timing by the rig operators.

Fuel Gas Supply

Shortly after the system was integrated into Project Rig #2 on Dec 17, 2021, there was a prolonged stretch of extremely cold temperature that negatively affected the natural gas supply to the rig. On-lease piping takes field gas from the gas conditioning unit and directs it to the natural gas engines. Since the conditioning unit was a relatively long distance from the engines, the lower ambient temperatures allowed for hydrocarbon condensates to form in the gas lines, and for water vapours to condense and freeze. This resulted in more system downtime than initially planned. Since understanding these problems, the conditioning units have now been placed much closer to the engines on new drilling locations to decrease the risk of condensation occurring. Heat wrap was also put on the fuel gas lines.

Key learnings from this were to install automatic dump valves to mitigate shutdowns occurring due to high liquid levels in the engine inlet scrubber. Before the gas enters the engine, it goes through a scrubbing vessel (Figure 22) to allow any liquids to drop out before the gas enters the engine intake. Normally, there are so few liquids that rig personnel can occasionally empty the vessel manually. However, with the extreme cold, more liquids were dropping out of the line than anticipated, such that the inlet scrubber vessel was often triggering the high-liquid-level alarm, shutting the engines down. By automating the emptying of the vessel before the alarm, this issue was mitigated.



Figure 22: Before and After Automatic Dump Valve Installed on Engine Fuel Gas Scrubber

Rig Blackout

When enough liquids accumulated to shutdown the fuel gas scrubber, rig personnel would have to manually switch the system back to the dual-fuel engines until the scrubber could be drained and reset. This would result in a short window when the rig would lose power. On one occasion, an emergency shutdown (ESD) on the fuel supply resulted in a rig blackout. A blackout on a drilling rig can quickly lead to the pipe getting stuck in the hole. After power is lost to the rig, the mud pumps are unable to circulate. This allows drilled cuttings to fall down the hole and pack off the drilling assembly. In this instance, the crew had power up and running within a few minutes, and the risk of getting stuck was not significant. However, it is a serious operational problem that requires a mitigation plan to prevent it from occurring in the future. Furthermore, a minor controller and electronic issue arose from the commissioning of the system that resulted in a five-day shutdown of the hybrid power unit.

As mentioned in the Commercialization section, future Tourmaline packages will have two natural gas generator engines and one dual-fuel generator engine for added reliability with diesel as a backup fuel. A sensor will be installed on the fuel gas scrubber, which would indicate a decrease in fuel gas line pressure (i.e. liquids starting to accumulate or water vapours freezing) that would communicate with the MMC and initiate a start of the dual-fuel engine. This would ensure that at least one generator would always be available to power the rig and a blackout would not occur. To address the blackout concerns for this package, further investigation will be made into synchronizing all six engines (diesel

and natural gas) automatically. If synchronization cannot be made and reliability is still an issue, the package could be retrofitted to include one dual-fuel engine.

Environmental Benefits

Emissions Reduction Impact

This technology reduces natural gas's emission intensity by reducing the greenhouse gas emissions during the production life cycle of the fuel. By decreasing the emissions produced to drill a well, we are demonstrating a continuous improvement in the environmental footprint for Alberta's natural gas sector. This will further enforce Alberta's image as an ethical energy source and a global leader in low emission intensity oil and gas production. Specifically, we are reducing the amount of fuel required to generate power (electricity) for a drilling rig and substituting all diesel fuel with natural gas – a cleaner-burning fuel that further reduces greenhouse gas emissions.

To measure emission reductions most accurately, the Baseline Rig and Project Rig #2 were compared over the same period (Dec 19, 2021, to June 30, 2022). There are numerous variables that contribute to drilling rig emissions, including well design, drilling days, formations encountered, ambient temperature, and more. An effective way to minimize differences in these variables is to compare rigs that are drilling the same type of well, targeting the same zone, at the same time. To that end, both rigs were drilling Montney wells in the Gundy/Aitken/Nig Creek area from December 19, 2021, to June 30, 2022. Over this period, Project Rig #2 had 186 total drilling days and the Baseline Rig had 167 total drilling days. Four emission categories were quantified as part of the comparison:

- Exhaust emissions, based on recorded diesel and natural gas consumption. Standard natural gas and diesel emission factors used at the beginning of the project were used again for these calculations (Government of Alberta, 2019).
 - o Natural Gas (1.939 CO₂e kg/m³)
 - o Diesel (2.804 CO₂e kg/m³)
- Life cycle upstream emissions, based on the amount of natural gas and diesel consumed. The diesel life cycle emission factor was pulled from GHGenius (Squared Consultants Inc.) while a Tourmaline-specific natural gas life cycle emission factor was used from a third-party study conducted in 2021.
 - o Natural Gas (2.46 CO₂e kg/GJ)
 - o Diesel (21.53 CO₂e kg/GJ)
- Trucking emissions for hauling diesel to a drilling location. A standard diesel emission factor and a trucking fuel efficiency value were used in these calculations (Government of Canada, 2019).
 - o Diesel (2.804 CO₂e kg/m³)
 - o Fuel Efficiency (39.5L/100km)
- Methane slip emissions, based on third-party engine exhaust emissions testing and analysis conducted on Baseline Rig and Project Rig #2. Flow rate and gas sampling conducted to determine the amount of methane in the exhaust stream.

Using all the data for the project period, the reduction in emissions from the baseline to project level rig was 10.66 TCO₂e/day. Additional detail on emission reduction calculations can be found in the GHG Summary file. The results are summarized into Table 6.

			Exhaust Emissions		Life Cycle Emissions		Trucking Emissions	Methane Slip Emissions	Total
Drilling Rig	Data Period	Period Description	CO ₂ e from Diesel (T/day)	CO ₂ e from Natural Gas (T/day)	CO ₂ e from Diesel (T/day)	CO ₂ e from Natural Gas (T/day)	CO ₂ e from Diesel (T/day)	CO ₂ e from Methane (T/day)	CO ₂ e (T/day)
Project Rig #2	Dec 19, 2021 - June 30, 2022	NG Gens & ESS	2.2	12.8	0.66	0.71	0.01	0.59	16.95
Baseline Rig	Dec 19, 2021 - June 30, 2022	Pre-project	12.9	6.1	3.87	0.35	0.06	4.35	27.61

Table 10: Baseline and Project Rig Emissions Summary

In May 2022, a third party was brought to the Baseline Rig and Project Rig #2 to perform engine emissions testing. Between the two rigs, the exhaust emissions from the baseline system, an upgraded bi-fuel system, and the full hybrid natural gas and battery system were tested. The primary goal was to determine the non-combusted methane differences in the exhaust streams and overall GHG emissions between bi-fuel engines and 100% natural gas engines, as outlined in the project proposal.

Figure 23 shows the methane percentage in the exhaust stream for all bi-fuel and natural gas engines as a function of engine load. There is a very clear, significant decrease (-86%) in methane emissions from the exhaust streams on 100% natural gas engines. In the bi-fuel engines, the methane percent in exhaust ranges from 0.2-0.5% while the natural gas engines are about 0.06%. This speaks to the combustion efficiency of the engines and the engine design that minimizes any unburned methane escaping. In both engine types, there is a decrease in methane slip with increased load. This decrease is not obvious for the natural gas engines in Figure 23 but, when the scale is adjusted in Figure 24, the trend is evident. Note that there is one outlier at low load (200kW); in this case, the gas substitution dropped, and the bi-fuel mixture was primarily diesel, resulting in less methane in the fuel overall.

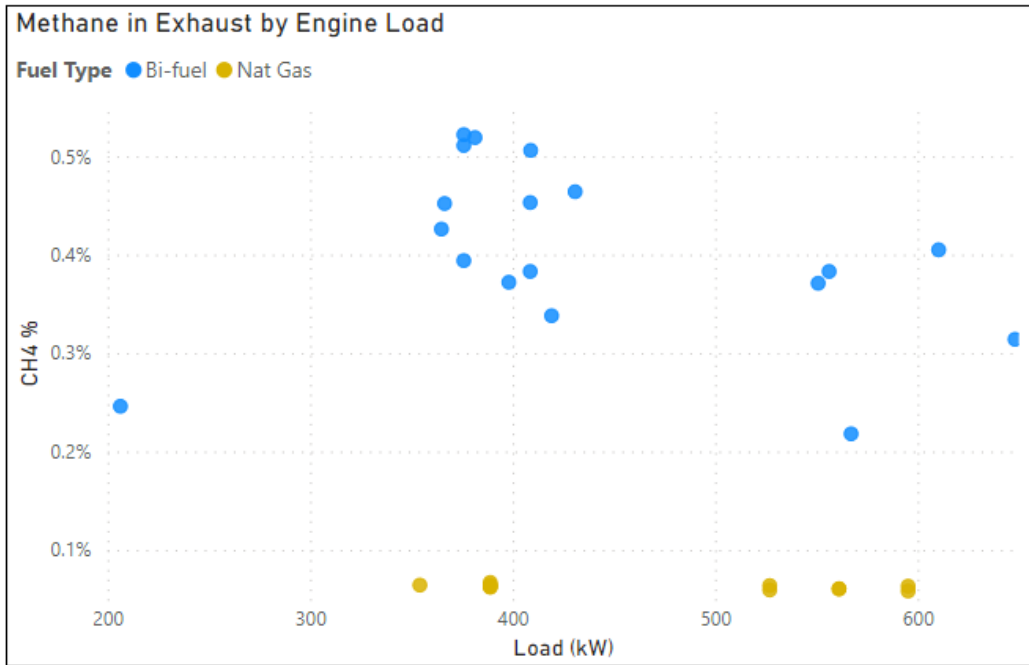


Figure 23: Methane Percentage in Exhaust for Bi-fuel and Natural Gas Engines (Baseline and Project #2 Rigs)

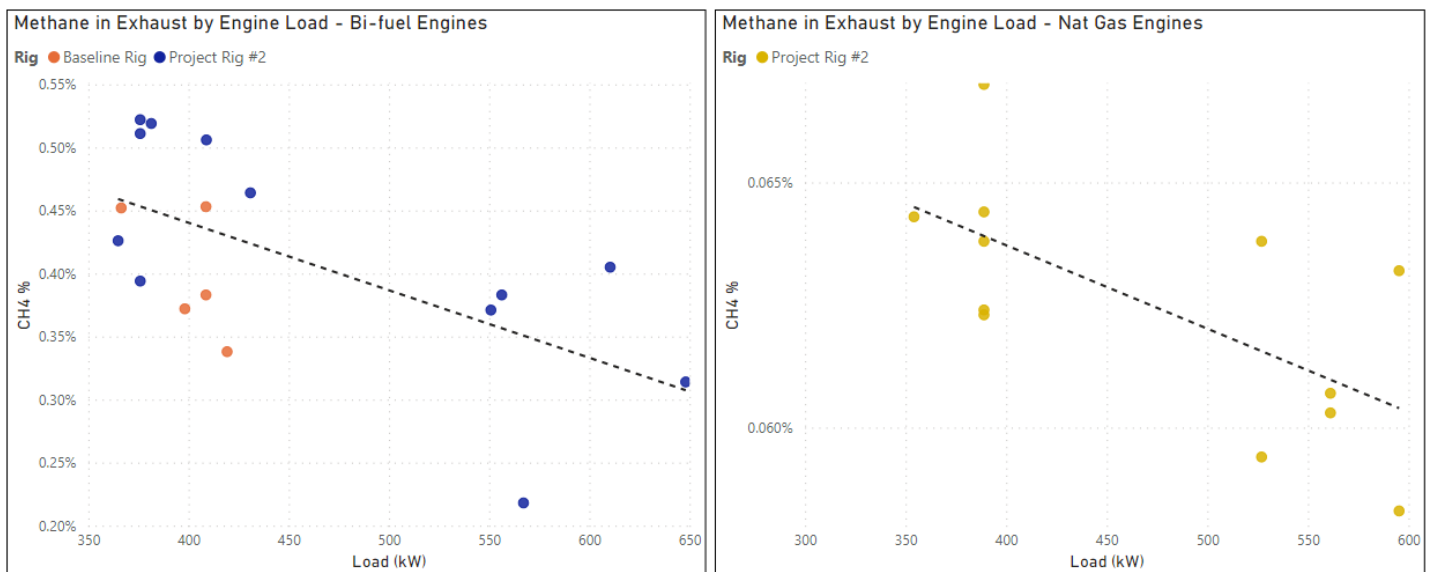


Figure 24: Methane Percentage in Exhaust for Bi-fuel and Natural Gas Engines

In Figure 25, the overall GHG emissions between the bi-fuel engines and natural gas engines are displayed both as an average and at different loads. As methane is a greenhouse gas with 25x the global warming potential of CO₂, the impact of reducing methane has a significant impact on overall CO₂ equivalent emissions. When both combustion emissions and methane slip emissions are considered,

there is an average ~30% decrease in GHG emissions by going to the fully natural gas engines from bi-fuel engines.

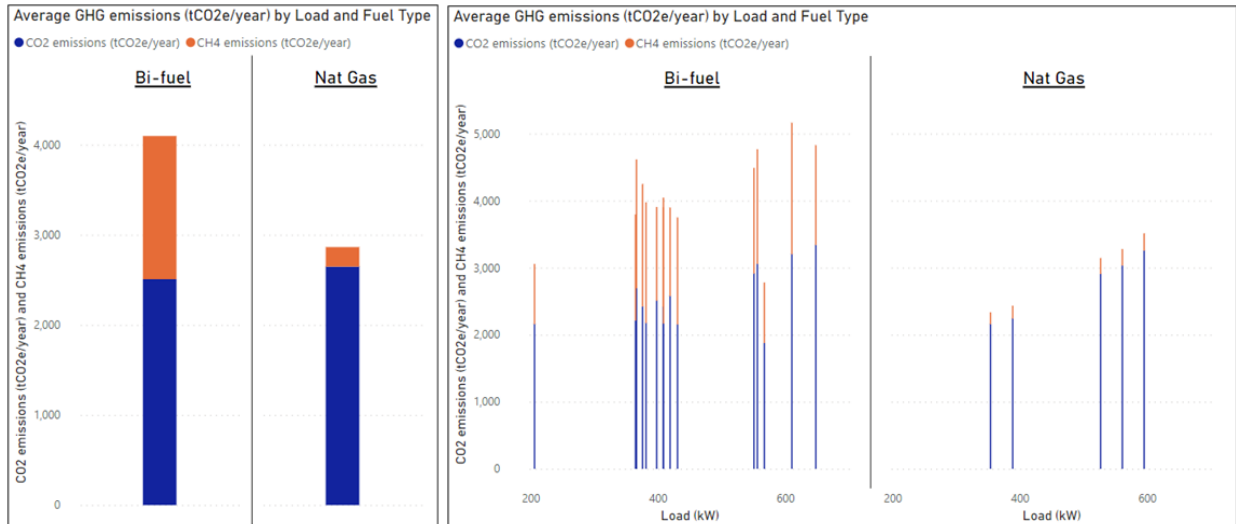


Figure 25: Methane Percentage in Exhaust for Bi-fuel and Natural Gas Engines (Baseline and Project #2 Rigs)

From December 19, 2021, to June 30, 2022, Project Rig #2 was consuming an average of 6.37 e3m3 of natural gas and 787 L of diesel per day. The Baseline Rig was 3.12 e3m3 of natural gas and 4,611 L of diesel per day. It is expected that the gas consumption on Project Rig #2 could be reduced 1-2 e3m3 further after the ESS is more efficiently shaving off any peak load spikes. However, the real results from this period were used to forecast the emission reduction potential in Alberta and Canada for commercialization of this technology. More optimism could be applied to this scenario once the battery technology is performing better.

The real current rig count data was used for the Alberta greenhouse gas (GHG) reduction projection. The potential emission reduction focuses on natural gas and battery hybrid systems. Bi-fuel and battery hybrid systems are removed from the below projections.

There are currently 462 rigs in the Canadian fleet, 344 of which reside in Alberta (JWN Energy, 2022). The utilization rate of active rigs is 44% for Alberta and 46% for Canada. In 2022, it's estimated that about 70% of the marketable rigs are AC powered and could be equipped with a natural gas hybrid power generation package. By 2030, it's projected that 95% of the marketable rigs will be AC powered, with a few DC rigs remaining in the fleet. Of the available AC powered rigs, we expect 25% of those to install a natural gas power generation package by 2030, reaching 30% by 2040. It is expected that a larger portion of the fleet will remaining running on a bi-fuel engine type, eventually being equipped with a battery for further reduction in fuel consumption. With these projections, the cumulative emission reduction potential in Alberta for natural gas specific is 0.74 megatonnes (Mt) CO₂e by 2030 and 4.65 Mt by 2050. Figure 26 shows the annual CO₂e emission reduction potential for Alberta and Canada. Figure 27 shows the cumulative emission reduction potential for Alberta and Canada.

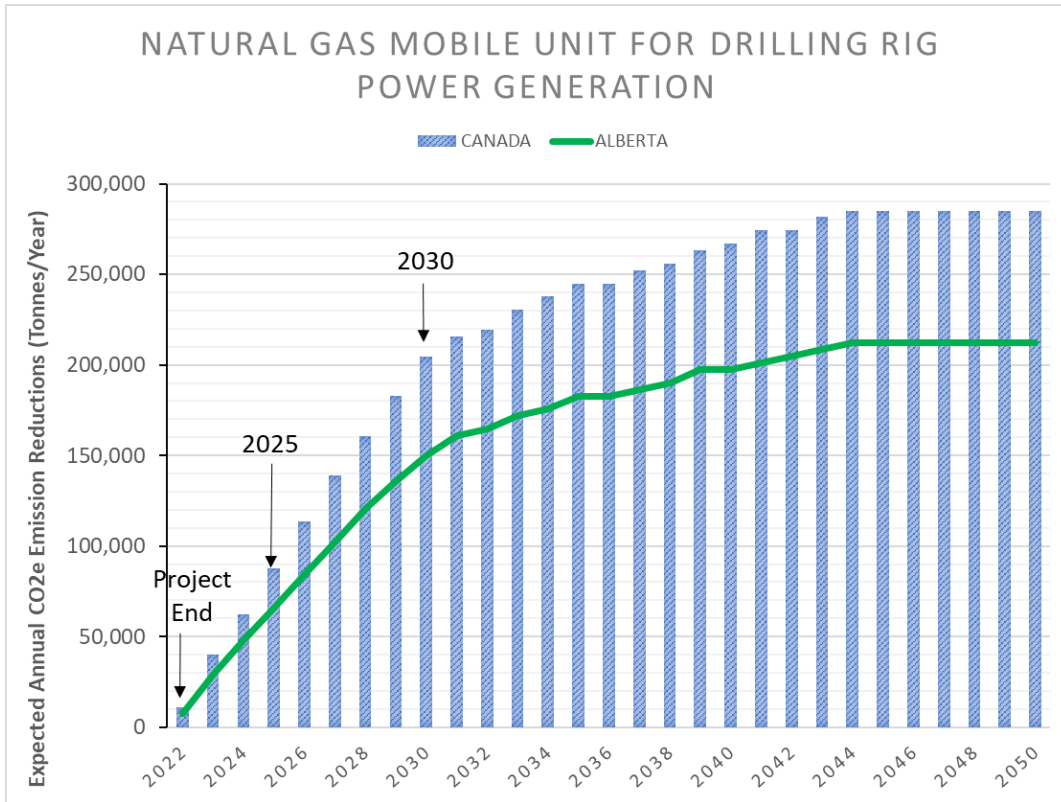


Figure 26: Annual CO₂e Emission Reduction Potential for Alberta and Canada

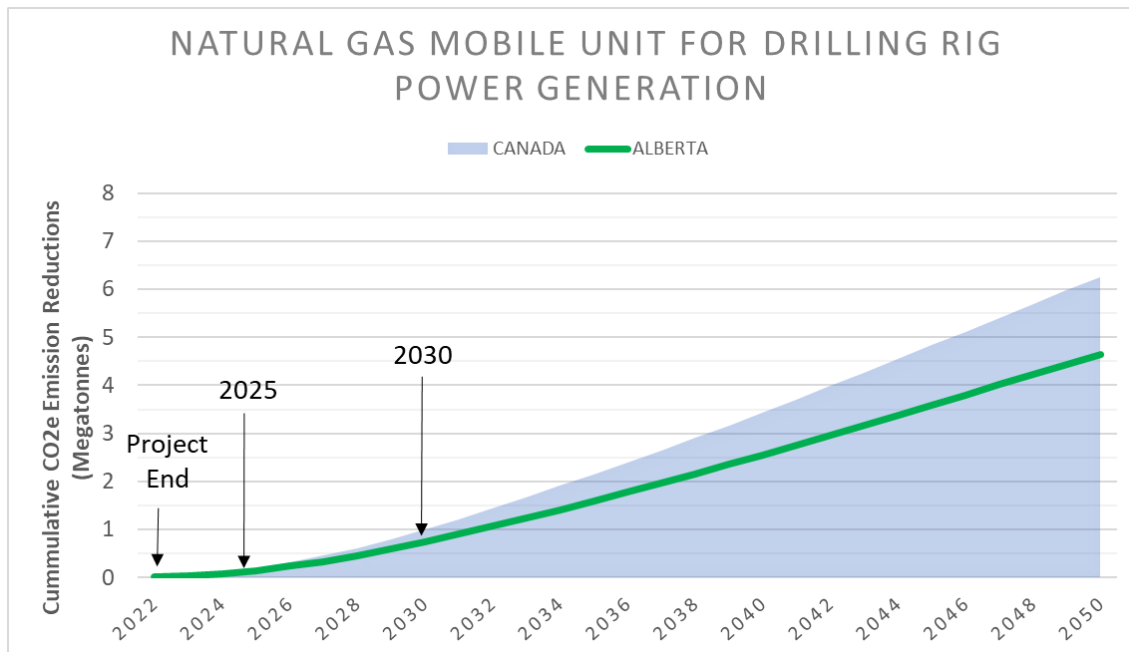


Figure 27: Cumulative CO₂e Emission Reduction Potential for Alberta and Canada

Displacing diesel is an important corporate goal for Tourmaline and can play a critical role in further reducing oil and gas industrial emissions. Drilling and completions activities are typically large consumers of diesel fuel and present a great opportunity for using hybrid power generation systems. This completed project will help others in the industry understand the environmental and economic benefits of using gas for power generation and could help pave the way for technology adoption into completion activities such as hydraulic fracking and service rigs.

Other Environmental Impacts

The project and technology offer several benefits that are beyond GHG emissions reductions, with no significant potential negative impacts relative to current practice. From an environmental perspective, the technology uses less fuel and substitutes all diesel for cleaner-burning natural gas. The combustion of natural gas compared to other fossil fuels produces negligible amounts of sulfur, mercury, and particulate matter (Union of Concerned Scientists, 2014). The result is less fine particulate matter and nitrogen oxides injected into the air through the exhaust, thus improving overall air quality related to oil and gas drilling operations.

The adoption of this technology across the province will also provide a safety benefit. With all fuel requirements being supplied at the rig site by existing pipelines, we are minimizing fuel trucking and associated highway traffic from local roads. This improves Alberta's environmental footprint, economy, and community relations through improving our operational procedures related to safety.

The oil and gas industry suffers from an image problem in Canada. We need to continue demonstrating to the public that we are constantly improving our way of doing business with clear priorities set on reducing environmental impacts. Our goals and benefits achieved through this project illustrate that Canada is the ethical choice for hydrocarbon production and a global leader of low emitting production.

Economic and Social Impacts

Developing Alberta's natural resources in a more cost-effective and sustainable way will grow the provincial economy, create good jobs, improve the industry's competitiveness, and help meet climate goals. This project supports a clean technology solution to Canada's low-carbon future, while also bringing economic growth to Alberta in the form of:

- Increased operator activity due to the incremental capital realized from this technology;
- Increased oilfield service activity due to the incremental capital realized by operators;
- Investment attraction due to improved profitability of the resource to world markets;
- Consumption of natural gas to help relieve the market distribution bottlenecks that contribute to suppressing commodity prices relative to competing world markets;
- Direct and indirect jobs created from increased field activity; and
- Increased corporate revenue and royalty revenues due to increased economic activity.

Exploration and production companies do not traditionally sit on incremental capital from implementing cost efficiency projects or technologies. Depending on market conditions and investor expectations, companies may use the capital to restore dividends, shore up balance sheets, or increase activity by drilling more wells and adding more future cash flows through production. This may lead to increased

corporate revenue and royalty revenues paid to government. More jobs will also be created, including direct jobs to oilfield service and operator companies and indirect jobs created within the hospitality and retail sectors, such as hotels or restaurants. It is projected that each new active rig creates 20 direct jobs and 200 indirect jobs (Canadian Association of Energy Contractors, 2022).

Since the beginning of this project period, the Alberta active rig count alone has increased from 114 to 153 rigs (JWN Energy, 2022), creating 8,580 more direct and indirect jobs. This change is primarily due to the industry downturn during 2020 from the COVID-19 pandemic and the more recent increases in commodity pricing sparking more drilling activity. It is expected that the industry will continue to increase rig counts in the short-term, creating more jobs, revenue, and royalties.

We expect to see an increasing share of the total addressable market (TAM) start upgrading their rigs to a natural gas hybrid power system. It is projected that ~20% of the serviceable active rigs will be upgraded over the next five years. Further commercialization of this technology will lead to incremental jobs, both temporary and permanent to Tourmaline, Caterpillar, Precision, third-party vendors, and any other end-users or distributors competing in the space of this technology.

Using this technology during a period of inflated fuel pricing, while having the infrastructure available to supply our own produced raw gas, has proved the cost savings to be greater than anticipated. Tourmaline plans on installing these packages across 11 more serviceable rigs over the next five years. Considering equipment costs, installation, and fuel savings (assuming pricing of \$1.75/L of diesel, \$5.00/GJ of natural gas or \$0.19/Gas - DLE), the cashflow model in Figure 28 was created.

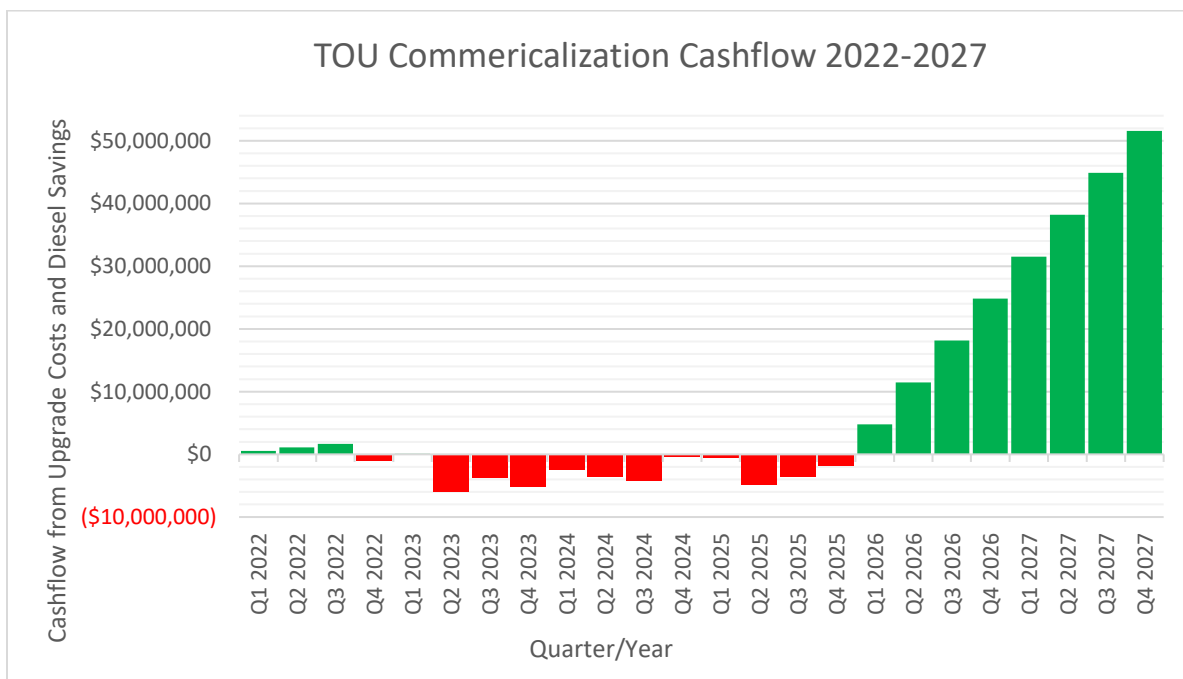


Figure 28: Cash Flow on System Implementation on Tourmaline's Serviceable Rig Fleet

Overall Conclusions

In summary, the Natural Gas Mobile Unit for Power Generation project was a success. The group was able to meet the project objectives by successfully:

- Understanding the relationship between the power demand and the size of the unit during drilling;
- Validating the reliability and efficiency of the plug-and-play mobility of the unit during field operations. Ongoing work is still being done to improve reliability and efficiency;
- Understanding the volume of diesel reduction and backup usage;
- Understanding the reduction in trucking;
- Understanding the reduction in methane slip; and
- Validating the potential economic benefits from developing this technology.

When eliminating the data error that was caused from ESS and natural gas generator downtime, we were able to meet the <5% target of backup diesel usage but fell just short of the >40% emission reduction target. We expect to reach this >40% emission target once the ESS can more effectively offset any rig peak power demand. The >30% reduction in engine run-hours was met by pulling engine data from the end of the project, after the ESS battery went through a series of updates. Reaching these performance metrics indicate that the project is on the right path towards future market adoption.

The emission reduction potential from the project indicates that a reduction of 10.66 tonnes CO₂e/drilling rig operating day can be met, with further reductions being realized after system tweaks are worked out. Considering the factors for commercialization into the Canadian drilling rig fleet, the cumulative emission reduction potential is 0.99 MtCO₂e by 2030 and 6.25 MtCO₂e by 2050.

Next Steps

The focus of this hybrid package will continue to be improving system reliability and battery efficiency. The package still has a few tweaks that need to be worked out before full scale commercialization can be implemented. As mentioned, Tourmaline plans to implement this technology (or an iteration of this technology) across our entire drilling rig fleet. There will be ongoing work with Caterpillar, Precision, and other third-party contractors to first get the system running optimally and then evaluating any supply constraints that would delay our three-year plan of fleet integration. Comparing different technology iterations will be an important follow-up project that Tourmaline will prioritize.

Scientific Achievements & Knowledge Transfer Plan

The primary marketing medium for sharing the successes of this technology trial is public reporting, word-of-mouth, and presentations. Details about the project have been shared with other drilling contractors. A replica package of this system was built with a different Tourmaline drilling contractor, and the equipment has been ordered to build a third package, with a third drilling contractor of Tourmaline's. There have been non-formal lessons learned discussions with Tourmaline's NGIF partners about the project details, which has helped promote hybrid drilling rig integration into our industry

peers' operations. Additionally, Scott Volk joined Mark Summers on the ERA Carbon Copy Podcast. [Episode 14 – Single and Doubles](#), which outlines the details and success of this project.

Going forward, further testing of the hybrid rigs will be conducted through the NGIF Emissions Testing Center (ETC), which is operated by Tourmaline. The ETC now has a Continuous Emissions Monitoring System (CEMS) trailer that will be used to further evaluate emission performance of hybrid vs conventional drilling rigs. All the reporting results from the ETC projects are posted on www.cerinprojects.ca/projects, once they are reviewed and made publicly available. This testing is expected to be conducted in 2H 2023, with reports made available on the CERIN website by the end of the year.

Precision presented at the SPE Canadian Energy Technology Conference, March 15-16th, 2023 on the Use of Battery Energy Storage Systems to Reduce the Environmental Footprint in Land Drilling Operations. Precision is also planning to make a presentation about Hybrid Drilling Rigs at the SPE Drilling and Completions in Canada Workshop on May 25th, 2023.

Caterpillar markets their hybrid drilling solutions primarily through the global dealer network including public and private demonstrations, word-of-mouth, and advertising through marketing communications. Knowledge dissemination will continue through presentations, discussions with industry peers, and through testing and reporting from the ETC.

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Recipient Organization

Tourmaline Oil Corp.

Title

Natural Gas Mobile Unit for Drilling Rig Power Generation

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	0
2022	0
2023	0
2024	0
2025	0
2026	0
2027	0
2028	0
2029	0
2030	0
2031	0
2032	0
2033	0
2034	0
2035	0
2036	0
2037	0
2038	0
2039	0
2040	0
2041	0
2042	0
2043	0
2044	0
2045	0
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/>