NGIF
ACCELERATOR

NGIF Emissions Testing Centre Program

PERFORMANCE REPORT 2023 – PART II

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Acknowledgement

NGIF Accelerator (NGIF) would like to acknowledge the funding contribution provided by Natural Resources Canada through its Canadian Emissions Reduction Innovation Network (CERIN) Program, which was established by Natural Resources Canada (NRCan) and Alberta Innovates (AI).

We are also grateful for the continued support and funding provided by PrairiesCan to the NGIF Emissions Testing Centre (ETC) Program. Through this initiative, the NGIF Accelerator will be able to continue to support innovative clean technologies in the natural gas industry aimed at detecting, quantifying, and reducing methane emissions.

NGIF would also like to acknowledge our partnership with and in-kind contribution and assistance provided by the University of Calgary (UCalgary), Tourmaline Oil Corp. (Tourmaline), and Perpetual Energy (Perpetual). As program partners, UCalgary and Tourmaline have provided lab and live site testing facilities, resources and the valuable insights into validation and testing of cleantech startups and their methane solutions for the natural gas industry.

Finally, NGIF would like to thank and acknowledge multiple individuals for providing technical, financial, or general support and/or participating in the various meetings, webinars, and stakeholder discussions for the NGIF ETC Program. Our report was prepared through a collaborative effort involving Tourmaline, the UCalgary, Modern West Advisory, and the NGIF Accelerator's ETC Program staff.

John Adams
President and CEO, NGIF Accelerator

Message from the CEO

I am excited to share our NGIF ETC Program 2023 Performance Report. The NGIF ETC Program enables innovation across the methane management spectrum. Increasingly stringent methane emissions regulations require urgent solutions; the path from the government's current 45% to the newly proposed 75% methane emissions reduction from oil & gas operations is not linear and will require significant effort and collective commitment to achieve.

Technology development and commercialization must occur at an accelerated pace to achieve these stringent targets. This report focuses on the progress we have made in 2023 in validating and accelerating the commercialization of multiple clean technologies to reduce methane emissions and provides a path forward to accelerate the de-risking and support the deployment of methane management technologies at scale.

The NGIF ETC Program is unprecedented in its ability to put technology vendors first and provides a "free-to-user" model to de-risk and deploy their technology rapidly. Technologies are de-risked at two program partner facilities: field testing at Tourmaline wells and facilities or at the heavily instrumented West Wolf Lake Gas Process Plant jointly owned by Tourmaline and Perpetual Energy. Additionally, controlled environment testing takes place at laboratories at the University of Calgary.

The NGIF ETC Program is administered by the NGIF Accelerator, the not-for-profit arm of NGIF Capital. The NGIF Accelerator also operates our Industry Grants (IG) Program, a technology and innovation program with a mandate to de-risk and accelerate technology development and deployment in the natural gas industry. The IG program offers a non-dilutive grant supporting startups through their pilot projects, field trials, and industry validation. The program also coordinates with Federal, and Provincial governments to co-fund

projects to advance market commercialization.

The NGIF ETC Program has established a strong brand presence in the natural gas industry, with a steady pipeline of startups applying to test their clean technologies at NGIF ETC Program facilities. For the NRCan/ CERIN funding period, 20 startups have completed testing for this reporting period, 20 more are currently conducting lab and field trials, and more are in the intake funnel. We have also seen some NGIF ETC Program users like Qube, Convrg, and Kinitics progress to commercialization after validating their technology through the NGIF ETC Program. The NGIF ETC Program continues to evaluate opportunities to optimize its capabilities to support the proposed amendment to the existing methane regulations by the Government of Canada.

We thank NRCan and PrairiesCan for their financial support and commitment. We also thank our Program partners, Tourmaline and the UCalgary, for their in-kind support, without which the NGIF ETC Program would not be possible. We are proud of our achievements and excited for the future as we continue to lead the way in clean technology innovation and emissions reduction.

John Adams
President and CEO, NGIF Accelerator

NGIF ETC Program | Executive Summary

The mandate of the NGIF ETC Program is to de-risk and support the commercialization of new technologies that detect, quantify, and mitigate methane emissions. The NGIF ETC Program was formed under the Canadian Emissions Reduction Innovation Network (CERIN) program funding, which was established by Natural Resources Canada (NRCan) and Alberta Innovates (AI). Continued funding from PrairiesCan will progress the program to March-2024.

The following key outcomes were expected from the development of the NGIF ETC Program:

1. Establishment of a world-class emission management network to position Canada as a leader in developing technologies to achieve cost-effective methane emissions reductions and creating exportable methane emission management solutions.

2. Development of a unique free-to-user testing system that will allow technology developers and end users a direct, quantitative way to test their products in a live, real-world operating facility while providing commercialization support to accelerate market adoption.

3. Support an environmentally sustainable future for Canada's oil and gas sector while contributing to the development of a strong, resilient workforce.

4. Support Canada's commitment to lower GHG emissions.

We are excited to report that these key mandates have now been met through the development of the NGIF ETC Program and the various technologies that have been trialled through this program, as detailed within this report.

The NGIF ETC Program is a one-of-a-kind program that provides simulated emissions testing in a fully instrumented lab and live testing at an operating natural gas facility. The program allows cleantech start-ups to test and validate their technology to detect, quantify, and control methane emissions. NGIF Accelerator administers the NGIF ETC Program, assisting the program users by expediting the adoption and commercialization of technology as well as the dissemination of knowledge.

The primary hub of these operating facilities is the West Wolf Lake Gas Plant in Alberta, which is co-owned by Tourmaline and Perpetual (instrumented between January and November 2021). The secondary testing hub (built in 2022-2023), is a Controlled Release East Edson Wellsite (CREEW) designed for testing and developing methane detection and quantification capabilities.

In addition, Tourmaline has provided a network of midstream facilities, upstream wellsite facilities, and drilling and completion operations for technology testing purposes. A recently commissioned Continuous Emissions Monitoring System (CEMS) mobile trailer is used to measure methane slip from natural gas-fired engine exhaust.

The simulated environment at the UCalgary lab provides controlled testing and highly qualified personnel (HQP) support in data analytics and reporting. Further details of the NGIF ETC Program testing facilities are provided in the Performance Report 2022 - Part 1.

This current report covers technology validation trials completed through the NGIF ETC Program. From November 2021 to March 2023, a total of 21 technology providers participated at either the NGIF ETC Program Lab or NGIF ETC Program Field - live operating sites. One of these projects was cancelled and 19 public reports were published. NGIF ETC Program also contributed to three additional CanEric projects, and the creation of a detailed framework for evaluating cleantech Marginal Abatement Costs (MAC).

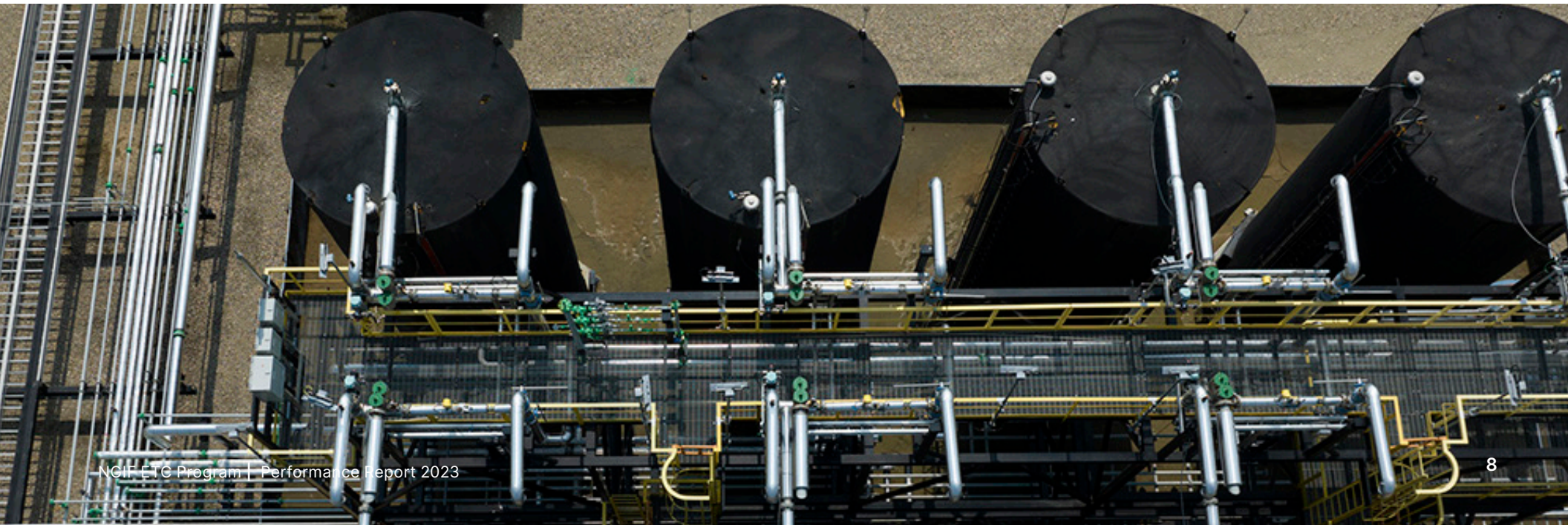
NGIF ETC Program | Executive Summary (Cont'd)

Technologies for methane detection and quantification, methane venting reduction from well site facilities, and methane mitigation were evaluated. Opportunities for emissions reduction in diesel engines for drilling and completion operations through natural gas blending were also evaluated. This report details the outcomes of these tests.

Despite the success in implementing low-hanging solutions and achieving significant reductions in emissions to date, the challenge of achieving further reductions to meet the proposed Federal 75% emission reduction target by 2030 underscores the necessity for innovations beyond incremental technology improvements. Rigorous multi-season testing is essential to de-risk technologies for commercial deployment, ensuring they meet safety and reliability standards for widespread adoption.

Furthermore, to achieve material emissions reductions, it is crucial to accelerate the commercialization of technologies across the natural gas value chain. The NGIF ETC Program's collaboration with academia, industry, and technology developers aims to build high-fidelity science-based digital simulation models to support rapid, cost-effective commercial deployment. Supporting the development and sharing of certification best practices and standards is another gap that needs addressing, facilitating the detection, measurement, and mitigation of methane emissions. Expanding collaboration with government, industry, academic partners and financial institutions is vital for scaling up the deployment of operational technologies.

We thank NRCan for the financial funding and commitment. We also appreciate the in-kind support from Tourmaline, Perpetual, and the UCalgary, without which the NGIF ETC Program would not have been brought to life. We are excited about the future of the NGIF ETC Program, where cleantech solutions that have been validated at our program go on to commercialization and reduce methane emissions across the natural gas industry and beyond.



About the NGIF ETC Program

NGIF ETC Program | The Consortium

NGIF ACCELERATOR:

NGIF Accelerator is a national not-for-profit funding agency the operates technology and innovation programs for the natural gas industry providing access to funding, resources, and expertise.

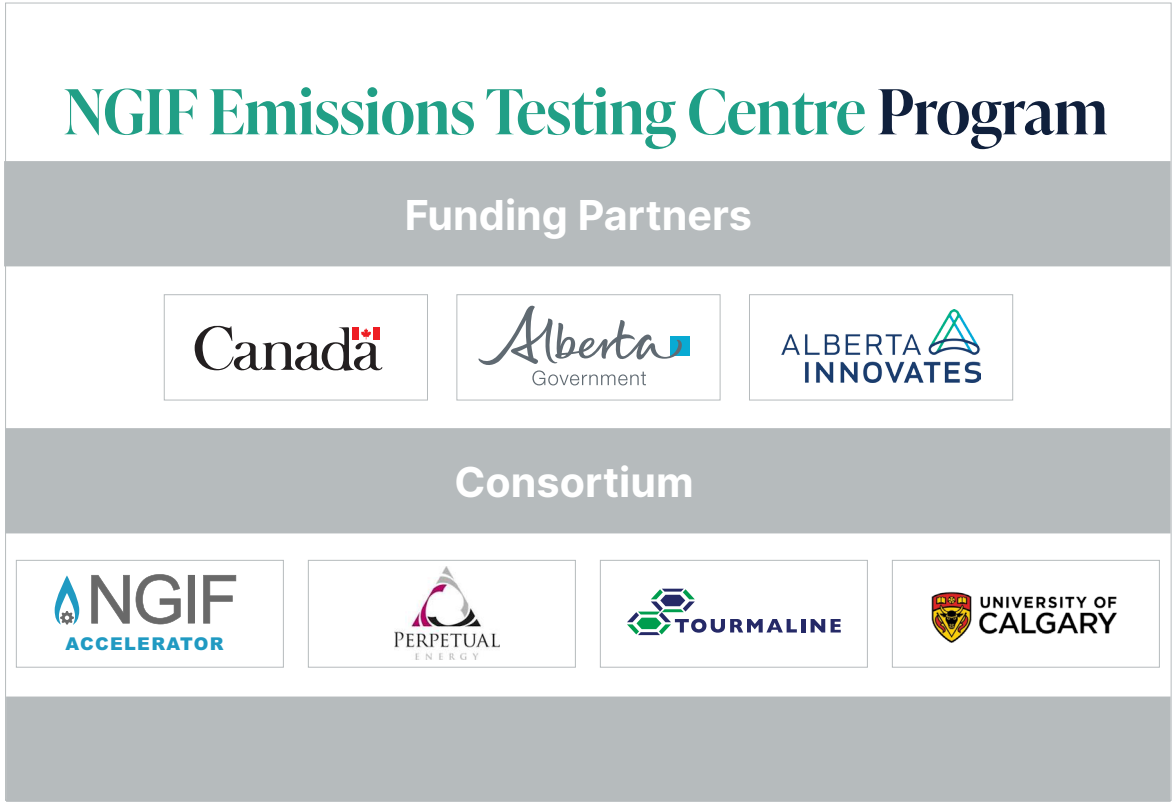
TOURMALINE:

Tourmaline is Canada's largest natural gas producer focused on long-term growth through an aggressive exploration, development, production and acquisition program in the Western Canadian Sedimentary Basin. Tourmaline continues to be a leader in responsibly developing low-emission and low-development cost natural gas.

UNIVERSITY OF CALGARY:

The University of Calgary (UCalgary) is one of Canada's top comprehensive research universities, combining the best of university tradition with the city of Calgary's vibrant energy and diversity. UCalgary has over 26,000 undergraduate students and over 6,000 graduate students in more than 250 programs. UCalgary's strategies are focused on ensuring growth and acceleration in energy systems and sustainability, entrepreneurship and innovation, Indigenous engagement, and global impact. The NGIF ETC Laboratory at UCalgary is a set of labs and highly qualified personnel (HQP, i.e., graduate students, post-doctoral scholars, and technicians) where technology start-up companies can bring their emission reduction technologies for testing in controlled environments. This enables a safe environment for the 'fail-then-fix' approach, the minimization of risk, and the acceleration of testing.

NGIF ETC Program | The Consortium



NGIF ETC Program | Testimonials

Scott Volk
Director of Emissions and Innovation, Tourmaline

"As Canada's largest natural gas producer, Tourmaline is focused on producing a reliable, affordable, and clean resource that meets the world's energy security needs. The NGIF ETC Program is critical in helping to validate methane-abatement technology and expedite it to market. Tourmaline is proud to play a leading role in such an important initiative. Partnering with the NGIF ETC Program provides a unique opportunity to test and develop the best, emerging technologies while collaborating with our peers and elevating our industry as a whole."

Wayne Hillier
Chief Technology Officer and VP Decarbonization, Modern West Advisory

"The NGIF ETC Program is an unprecedented initiative that brings together industry, cleantech service providers, and academia. The NGIF ETC Program helps accelerate the deployment of methane detection, quantification, and control technologies in oil and gas operations. It has been a successful couple of years, but the best work is ahead, and we look forward to continued growth and influence."

Ian Gates
Professor and Director, Global Research Initiative Energy, University of Calgary

"The NGIF ETC Program Lab at the UCalgary uniquely provides a research and training environment for technicians, graduate students, and post-doctoral scholars (highly qualified personnel, or HQP) who can interact directly with the start-up company staff. This enables the HQP to both learn from the technology start-up staff as well as contribute to the start-up's technology testing and development – this instills training in innovation, entrepreneurship, and technology development."

NGIF ETC Program Process

NGIF Emissions Testing Centre Program

The NGIF ETC Program, is a collaborative industry, government, and academia initiative, providing startups with a dedicated space to develop, test and field-validate technologies to measure, monitor and reduce methane emissions. The program is unique by providing technology innovators with free-to-user access to support rapid scale-up of technologies from concept to commercial-ready deployment. The NGIF ETC Program offers technology providers two environments to test and validate their technologies. The NGIF ETC Program Lab at the UCalgary and the NGIF ETC Program field testing at Tourmaline provide capabilities to test and de-risk technologies in a controlled environment, and live operations.

The NGIF ETC Program was created with the financial support of $9.25MM from Natural Resources Canada provided by CERIN, followed by $1.95MM from PrairiesCan and in-kind support provided by NGIF ETC Program partners. CERIN established a governance framework that encompassed the NGIF ETC Program and PTAC's CanERIC Program and facilitated the sharing of results and activities between both programs. The NGIF ETC Program focuses on methane quantification and methane technologies to reduce and eliminate emissions from the following emission source areas.

Area 1 – Fugitive leaks across the production facilities

Area 2 – Emissions from flare systems

Area 3 – Vents from liquid storage tanks and compressors

Area 4 – Wellsite vent emissions

Area 5 – Well Drilling and Completions (D&C) emissions

Depending on the Technology Readiness Level (TRL), de-risking and validation of a new technology can be done in a controlled laboratory environment or directly at an operating natural gas facility or well.

The NGIF ETC Program has three partners including, University of Calgary, Tourmaline Oil Corp. and NGIF Accelerator. Each partner plays a critical role in ensuring the program's effectiveness in technology testings and accelerating market implementation.

University of Calgary - Lab testing: The NGIF ETC Program Lab at the UCalgary includes a controlled release chamber, a controlled temperature chamber, and the ability for customized testing of emissions measurement or reduction technology.

Tourmaline - Field testing: As a consortium member in the NGIF ETC Program, Tourmaline manages all aspects of field testing at its owned and operated facilities. These sites are selected based on their suitability for specific technology validation trials. Testing is primarily centered around the West Wolf Lake (WWL) Gas Plant (the Hub), a jointly owned facility with Perpetual Energy, and the Controlled Release East Edson Wellsite (CREEW).

The Hub is equipped with, top-down methane measurements, and fixed sensors around its perimeter. The facility also features a vapour recovery unit to manage site-level emissions more effectively, offering the potential to simulate larger releases for technology providers as needed.

The CREEW facility replicates emissions expected at a wellsite, utilizing pneumatic pumps to circulate methanol in a closed loop, enabling controlled releases ranging from 5 to 360 m^3/day. This setup provides a

realistic environment for technology companies to test the quantification and localization capabilities of their emissions measurement technology, before deploying sensors at the gas plant. The presence of unique background emissions from a combustor at this site underscores the importance of perimeter monitors accurately.

The Continuous Emissions Monitoring System (CEMS) is a mobile analytical lab, specifically engineered for assessing methane slip from engine exhausts. This mobility enables the CEMS to easily transition between engines, providing a broad spectrum of data across different units.

NGIF Accelerator - Commercialization Support: Through active commercialization support, NGIF Accelerator helps technology developers scale up and advance to market faster. It engages with the government, the broader natural gas industry, subject matter experts, investors, and innovation ecosystem players to accelerate emission reduction in the energy sector.

Additionally, NGIF Accelerator collaborates with NGIF ETC Program partners to provide seamless support to cleantech companies, helping them reduce risks and eliminate barriers to commercialization. It fosters knowledge dissemination through promotional content, performance reports, webinars, and industry events, creating pathways for cleantech companies to reach global markets.

NGIF ETC Program Workflow:

Figure 1 (*page: 16*) shows the workflow diagram of technology trials at the NGIF ETC Program. The process begins with an online intake application where applicants specify their need for lab testing, field testing, or commercialization support. Successful applicants will advance to the next step, as indicated in their intake application, for testing or commercialization support. Upon completion of the project, a report will be generated in collaboration with the program user and program partner. The process concludes with sharing the experience and outcomes through knowledge dissemination activities, such as webinars, conferences, poster presentations, exhibitions, or white papers.

The program workflow is broken out below, with detailed descriptions for each step.

1. Intake Process

The NGIF ETC Program intake process requires applicants to complete an intake form that outlines their technology, value proposition, test objectives, and desired outcomes (hypothesis) or the need for commercialization support beyond an experimental trial. This information is used to ensure that the technology is within the mandate of the NGIF ETC Program and can be executed safely with the available resources.

Once submitted, the intake form is reviewed by the relevant consortium parties, with UCalgary evaluating lab applications, Tournaline assessing field applications, and NGIF Accelerator reviewing requests for commercialization support.

If an experimental trial is necessary, the applicant must fill out a lab or field site access agreement and proceed to test planning. Depending on the Technology Readiness Level (TRL) or testing needs, the technology will move to either the NGIF ETC Program Lab or the NGIF ETC Program Field facilities.

There's also an opportunity for a technology to be first tested in the lab simulation environment and then in the field as a second project. For

Figure 1: *NGIF ETC Program - Workflow.*

commercialization support, NGIF Accelerator collaborates closely with the applicant to identify needs and develop a detailed plan.

2. Technology Validation and Commercialization Support

i. **Lab Testing and Reporting:** The NGIF ETC Program Lab functions as a controlled simulation space to help lower TRL companies develop their products or ideas. The NGIF ETC Program Lab site is located at the UCalgary Research Centre. The NGIF ETC Program Lab contains a suite of hardware, analytical equipment, and modelling capabilities. Tests can be customized for NGIF ETC Program users' needs. Within the testing period (January 2021 to March 2023), the NGIF ETC Program Lab performed several types of tests:

- Evaluation of methane sensor technologies through the NGIF ETC Program Lab - controlled release chamber. In this apparatus, methane is released at known rates within an enclosed structure, and measurement devices are placed in proximity to these releases to detect and measure the methane rates. Metered release rates could be provided to site users for algorithm development, or kept blind for technology trials testing measurement capabilities, or a combination of both.

- Evaluation of methane control devices or measurement sensors at extreme conditions (-40°C to +40°C). These tests are accomplished in the NGIF ETC Program Lab control temperature chamber, which is an insulated chamber that can be rapidly heated or cooled, thus exposing the technology to a wide temperature swing over a relatively short period of time. The outcome of these tests is an evaluation of technology's robustness to changing ambient temperatures as might be expected under field operating conditions.
- A range of technology assessment tests measured parameters such as the power requirement of methane technologies or even the technical feasibility of low-TRL products to work as expected.

ii. Field Testing and Reporting:

- West Wolf Lake Gas Plant (the Hub)

The main NGIF ETC Program Field testing facility, the Hub is located just south of Edson, Alberta, at 10-03-052-17W5. This plant is operated by Tourmaline and jointly owned with Perpetual. The Hub is a live operational environment where methane releases occur from process equipment as part of operational changes or events happening within the plant.

The Hub can measure many of the known methane releases at the site and feed this information back to NGIF ETC Program users and technology developers looking to detect and measure methane emissions.

The Hub also contains instrumentation to meter these known release points and has fixed methane detection sensors mounted around the perimeter of the plant to record methane concentrations in the air continuously. All this data is available to be reported back to site users as needed. Details of the testing abilities of the NGIF ETC Program main gas plant are provided in (Performance Report 2022 - Part I).

The major addition to the Hub in Fiscal 2022 was the installation of a vapour recovery unit (VRU) at the tank farm, which effectively eliminated venting emissions from the tanks. Fugitive emissions from thief hatches remain. The VRU can also be bypassed as needed to simulate uncontrolled tank venting. This is useful to evaluate methane detection, location, and quantification technologies that may require venting emissions or perhaps a large single-source emission from the combined tanks.

- Controlled Release East Edson Wellsite (CREEW)

The CREEW was constructed in 2023 as a replacement for the original Spirit River-controlled release site (SRCRS), which had stopped exhibiting continuous surface casing vent flow. The site will be used to test the quantification of emissions measurement technology, either in parallel or before bringing the sensors to the complex environment at the Hub.

The controlled releases are accomplished through a skid that contains a set of pneumatic pumps that circulate methanol in a closed loop. These pumps are run from field-produced gas and can be operated to give a range of controlled releases from 5–300 m^3/day. Further details of this controlled release site are provided in (Performance Report 2022 - Part 1).

- Wellsite Facilities, Drilling & Completion (D&C) Operations

To date, emissions control technologies at the NGIF ETC Program have mainly been focused on the elimination of gas venting from pneumatic instruments at wellsite facilities. To this end, Tourmaline has also made available for testing its network of upstream wells in Alberta and British Columbia; specific site locations are selected based on ease of testing and the needs of the specific technology.

Technologies focused on the elimination of methane venting all require long-term testing to prove stability and cannot be easily removed from these operations the way a methane measurement sensor can at the

gas plant.

This meant that all the technologies trialled to date have had to be placed permanently into these operating systems, and the cost of these have been covered by Tourmaline and/or NGIF Accelerator's Industry Grants Program provided in-kind to the program.

Details of wellsite testing capabilities are addressed further in (Performance Report 2022 - Part 1).

The NGIF ETC Program also encompassed a focus area looking at technologies for reducing emissions from D&C operations. These are once again detailed more in (Performance Report 2022 - Part 1). Tourmaline provided the testing of engines for replacing some diesel fuel with natural gas to the program, and the NGIF ETC Program was involved in data collection and reporting of the effectiveness of these engines. Tourmaline will continue to make these fleets available on a go-forward basis, so work on emissions reduction in energy-intensive D&C operations will also continue.

- Continuous Emissions Monitoring System (CEMS) Mobile Trailer

The final major addition to the NGIF ETC Program made in Fiscal 2022 was the addition of a mobile CEMS trailer, which is shown in Figure 2. The CEMS mobile lab measures methane slip from engine exhausts and gives a wide range of data across many units. Such an extensive range of engines offers a unique opportunity to assist various technology providers in validating their methane slip quantification and mitigation solutions. Through the CEMS, precise and reliable data are gathered, playing a crucial role in the validation process of these technologies.

iii. **Commercialization Support:** Through active commercialization support, NGIF Accelerator helps technology developers scale up

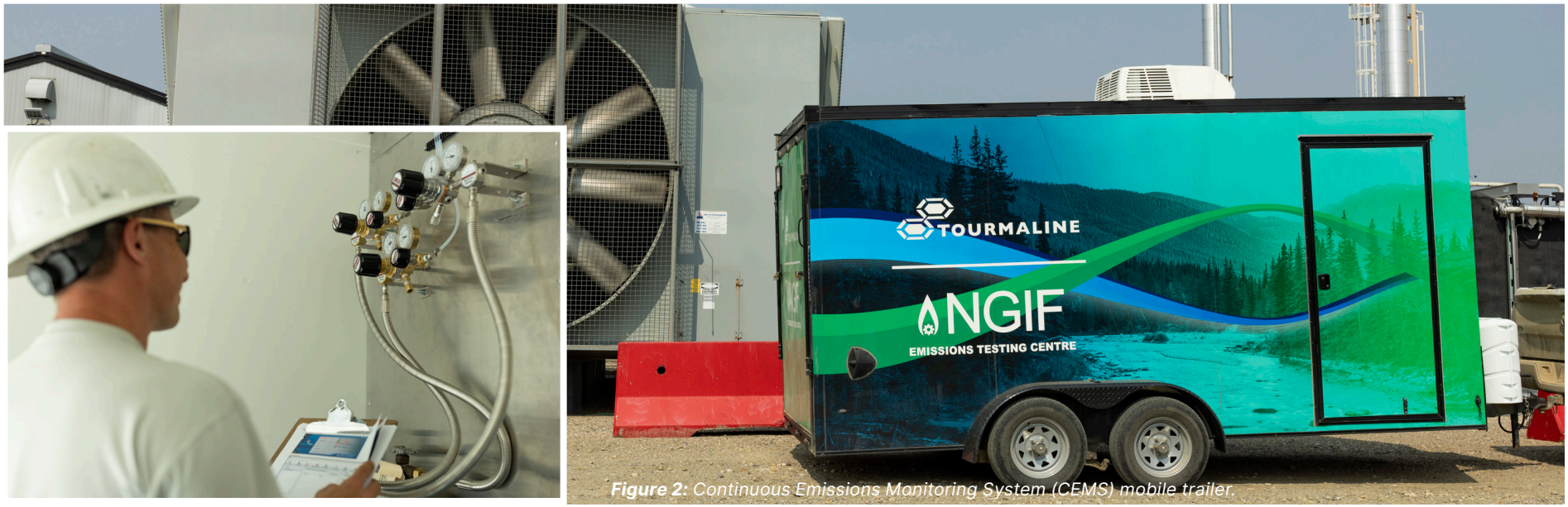


Figure 2: *Continuous Emissions Monitoring System (CEMS) mobile trailer.*

and advance to market faster. It engages with the government, the broader natural gas industry, subject matter experts, investors, and innovation ecosystem players to accelerate emission reduction in the energy sector.

Additionally, NGIF Accelerator collaborates with NGIF ETC Program partners to provide seamless support to cleantech companies, helping them reduce risks and eliminate barriers to commercialization. It fosters knowledge dissemination through promotional content, performance reports, webinars, and industry events, creating pathways for cleantech companies to reach global markets.

NGIF Accelerator supports cleantech companies by accelerating their commercialization journey, enabling faster acquisition of scaleup capital (dilutive and non-dilutive), helping them with customer creation, getting them to global markets, etc. through developing a robust innovation eco-system support network.

3. Knowledge Dissemination:

NGIF ETC Program partners create and use promotional content, annual performance reports, and host webinars, industry events, technology demos, panels, conferences, sponsorships, and other speaking engagements to increase awareness about the technologies being tested through the program and drive market adoption.

All projects run at the NGIF ETC Program are documented and used for knowledge dissemination. The public-facing reports are accessible through the CERIN data portal. The program reports and other resources can be accessed at the NGIF website.

NGIF ETC Program Users (2021 - 2023)

Overview: NRCan-Funded Technology Evaluations

Overview: NRCan-Funded Technology Evaluations

Provincial and Federal methane regulations introduced in 2020 prescribed a goal to cut methane emissions by 45% by 2025 from a 2012 baseline. However, the ambition has been heightened by a Government of Canada announcement on December 16th, 2023, in the (Canada Gazette Part 1), which proposes amendments to existing regulations. These amendments underscore that those efforts aimed at achieving a 40-45% reduction by 2025 will fall short of Canada's enhanced commitment to a minimum 75% reduction in oil and gas sector methane emissions by 2030.

The NGIF ETC Program aims to accelerate the development, de-risking, and commercial deployment of methane emissions management technologies to minimize the financial impact of Canadians while achieving Federal and Provincial targets. The NGIF ETC Program enables innovation across the methane management spectrum and is unprecedented in its ability to put technology vendors first and provide a "free-to-user" model to de-risk and deploy technology rapidly.

As part of the NGIF ETC Program deliverables, NRCan specified some discrete benefits to stakeholders (industry, site users, and government) in the definition of the NGIF ETC Program contract:

1. Creation of enhanced emissions management technology development centres across Canada to address the emissions management needs of the oil and gas community.
2. Establishment of emissions management technology accelerators, developed in collaboration with stakeholders.
3. Efficient, cost-effective means of identifying the most promising emissions management technologies for advancement.
4. Creation of an open data portal to house relevant emissions management technology performance and emissions data.
5. The training of highly qualified personnel.

Work on all 5 of these deliverables continue as the NGIF ETC Program builds although all have been satisfied as part of the original funding agreement.

The NGIF ETC Program functions as a technology validation center, and through its partnership with the UCalgary (NGIF ETC Program Lab and Gates Research Group), the NGIF ETC Program is also advancing the development of HQP. Specific to HQP funding, NRCan funds were used as leverage for Mitacs funding to augment studies and student projects that will support the NGIF ETC Program over the next few years.

Details of the funding (3-year term) are shared in Table 1. NRCan funds have been leveraged by 1.65, giving the NGIF ETC Program access to HQP projects over the next three years.

Funding Source	Funding Amount
NRCan (CERIN Program)	$700,000
Mitacs (HQP funding)	$960,000
Total (*3-year period)	$1,540,000

Table 1: *HQP Funding Top Up from NRCan Contribution*

A key performance metric specified for the NRCan-funded NGIF ETC Program was the execution of a minimum of 32 projects (technology trials) by March 2023. The list of site users (technology providers or cleantech SMEs) is provided in Table 2 (*page: 23*).

Project no.	Tech Provider	NGIF ETC Program Testing Location	Test Concept	Fiscal 2021	Fiscal 2022
1	Qube Technologies	NGIF ETC Program Field - the Hub	Perimeter sensors	✓	✓
		NGIF ETC Program Field - SRCRS & CREEW	Perimeter sensor	✓	✓
2	Kuva Systems	NGIF ETC Program Field - the Hub	Fixed IR Camera - Tanks		✓
		NGIF ETC Program Field - SRCRS & CREEW			✓
3	Project Canary	NGIF ETC Program Field - SRCRS &CREEW	Fixed Sensor - Priemeter		✓
4	Luxmux	NGIF ETC Program Field - the Hub	Perimeter sensors – Long term monitoring	✓	
5	4Blue Energy Services	NGIF ETC Program Lab	Simplifies OGI camera Perimeter Monitoring	✓	
6	TransRail Innovation Group	NGIF ETC Program Lab	MeOx Fixed Sensor		✓
7	LiDAR Services International	NGIF ETC Program Field - the Hub	Fixed wing aircraft sensor	✓	✓
		NGIF ETC Program Field - SRCRS andTemporary CRS		✓	
				✓	✓
8	Alto Maxx Technologlies	NGIF ETC Program Field - the Hub	Drone sensor		✓
		NGIF ETC Program Field - the Hub Temporary CRS			✓
9	GHGSat	NGIF ETC Program Field - the Hub Temporary CRS	satellite- based sensor		✓
10	Eosense/Vertex	NGIF ETC Program Field - The Hub	Truck-Based sensor		✓
11	mCloud Crop	NGIF ETC Program Lab	Acoustic Fugtive Detection		✓
12	Westgen (now Convrg)	NGIF ETC Program Field - Wellsite	Electrical Power on Demand	✓	✓
13	Marathon Compression	NGIF ETC Program Field - Wellsite	Instrument air compressor		✓
14	Packair Industries	NGIF ETC Program Lab	Instrument air compressor	✓	
15	Kinitics Automation	NGIF ETC Program Lab	Electric valve actuator	✓	✓
16	CH4NGEnergy	NGIF ETC Program Lab	Solid Sorbant for Methane Capture		✓
17	mFlow	NGIF ETC Program Field - Wellsite	MultiPhase Flow Meter	✓	
18	Weatherford	NGIF ETC Program Field - Wellsite	MultiPhase Flow Meter	✓	
19	NAIT	NGIF ETC Program Field - Wellsite	Battery Warmer		✓
20	Precision Drilling	NGIF ETC Program Field - D&C	Hybrid Engines	✓	
21	Trican	NGIF ETC Program Field - D&C	CAT Tier 4 verses Tier 2 Performance	✓	

Table 2: *Technologies Deployed at the NGIF ETC Program in 2021 and 2022*

Project no.	Tech Provider	Test Description
1	Qube Technologies	Sensors for methane detection & quantification - live site (NGIF ETC Program Field - the Hub) Sensor quantification development (NGIF ETC Program Field -SRCRS) Sensor quantification and localization development (NGIF ETC Program Field -CREEW)
2	Kuva Systems	Sensors for methane detection & quantification - live site (NGIF ETC Program Field - the Hub) Sensor quantification development (NGIF ETC Program Field -SRCRS) Sensor quantification and localization development (NGIF ETC Program Field -CREEW)
3	Project Canary	Sensors for methane detection & quantification - live site (NGIF ETC Program Field -SRCRS) Sensor quantification and localization development (NGIF ETC Program Field -CREEW)
4	Luxmux	Sensors for methane detection & quantification - live site (NGIF ETC Program Field - the Hub)
5	4Blue Energy Services	Sensor proof of concept: ability to image methane release in scaled-down OGI (NGIF ETC Program Lab) Sensor development data collected in images vs.varying emission rate for AI development (NGIF ETC Program Lab)
6	TransRail Innovation Group	Sensors validation / proof of concept (NGIF ETC Program Lab) Sensor development sensitivity to variying distances and measurement angles (NGIF ETC Program Lab)
7	LIDAR Services International	Live enviroment in the presence of snow (NGIF ETC Program Field -the Hub) Sensor quantification testing (NGIF ETC Program Field - Temporary CRS)
8	Alto Maxx Technologles	Live enviroment testing - validation of ability to see tank releases and flare (NGIF ETC Program Field - the Hub) Drone sensor quantification testing (NGIF ETC Program Field - Temporary CRS)
9	GHGSat	Satellite quantification testing (NGIF ETC Program Field - Temporary CRS)
10	Eosense/Vertex	Sensor calibration against fixed sensor data - (NGIF ETC Program Field - the Hub) Sensor testing mounted on heavy haul trucks vs. small truck-mounted sensor- liquid unload runs (NGIF ETC Program Field - the Hub)
11	mCloud Crop	Proof of concept test for ultrasonic detection device - detection limits, false reading, quantification constant tuning. (NGIF ETC Program Lab) Testing of device reliability: varying angles, system orifice sizes, impact of interfering noise (NGIF ETC Program Lab)
12	Westgen (now Convrg)	Field testing of emissions reduction from EPOD unit- 6kW power , 5HP compressor, 10 scfm air at 0-150 psig (NGIF ETC Program Field - Wellsite) Field testing of emissions reduction from EPOD unit- 20kW power , 7.5 HP compressor, 15 scfm air at 0-150 psig (NGIF ETC Program Field - Wellsite)
13	Marathon Compression	Field testing of compressor configured for 10 scfm air at 100 psig, using 1.5 kW power (NGIF ETC Program Field - Wellsite)
14	Packair Industries	Testing of 5-piston compressor - 6.3 scfm at 40 psig - ambient,hot, cold conditions (NGIF ETC Program Field - Wellsite) Testing of 10-piston compressor - 11.9 scfm at 40 psig - ambient,hot, cold conditions (NGIF ETC Program Field - Wellsite)
15	Kinitics Automation	Evaluate valve actuator to maintain a closed state even under high differential pressure (NGIF ETC Program Field - Wellsite) Evaluate response of valve actuator make ver small oscillation motions at a variety of temperatures (NGIF ETC Program Field- Wellsite) Field implementions- pressure relief valve and dump valve applications (NGIF ETC Program Field - Wellsite)
16	CH4NGEnergy	Testing of CH4 adsorption using four different potential porous media (NGIF ETC Program Lab)
17	mFlow	Testing of multiphase meter (NGIF ETC Program Field - Wellsite)
18	Weatherford	Testing of multiphase meter (NGIF ETC Program Field - Wellsite)
19	NAIT	Testing of different battery warming solutions (NGIF ETC Program Field - Wellsite)
20	Precision Drilling/CAT	Mobile gas generator and energy storage system for drilling rig power - replace traditional disel and bi-fuel power generation systems (NGIF ETC Program Field - D&C)
21	Trican/CAT	Dual fuel frac pumpers - Tier 2 vs. Tier 4 engines (NGIF ETC Program Field - D&C)

***Table 3**: Test Description for the Technologies Deployed at the NGIF ETC Program Testing Facilities*

In total, twenty (20) individual companies completed testing at the NGIF ETC Program during this period. Of these 20 technologies, 10 technologies detect and quantify methane releases, and 10 reduce or eliminate methane releases. Not surprisingly, many of the companies used the NGIF ETC Program for multiple tests, and these are summarized in Table 3 (*page: 24*).

A study was conducted as part of this collaboration:

- Modern West Advisory built a document laying out a transparent and reproducible framework to determine the marginal abatement cost (MAC) of a given technology to be deployed (shared on the CERIN data portal (MWA Marginal Abatement Cost CERIN Report). The emissions portion of the abatement cost calculation is based on direct measurement of emissions avoided or saved, i.e., this report is focused on emissions mitigation technologies.

- The NGIF ETC Program provided data for three other PTAC CanERIC studies:

  - Phase 3 electrical generation technology demonstration (Electrical Generation Phase 3), wherein the NGIF ETC Program contributed one of the tested power systems to the study.

  - Clean combustion technology showdown Phase 2 (CanERIC Combustor Showdown Phase 2), wherein the NGIF ETC Program contributed one of the combustors tested in the study.

  - Arolytics Optimized Leak Detection Program for Tanks and Other Key Equipment (Arolytics CERIN report), wherein the data for modeling of tank emissions came from the Hub.

Including these three additional tests, the total is 23 site users conducted projects, either directly or indirectly, at the NGIF ETC Program from 2020 – March 2023, and 37 individual outcomes either as test results or report.

The evolving methane emissions regulations present both challenges and opportunities for technology development. Concerns arise over the efficiency of phased reductions, from high to low and then to zero-emitting devices, highlighting potential inefficiencies and higher costs compared to direct transitions to zero-emission technologies. As the industry shifts, there's a decreasing number of high-emitting and an increasing number of low-emitting devices, indicating a gap in innovation for zero-emission solutions, especially for new facilities mandated to use such technologies.

This regulatory environment creates significant opportunities for innovation in methane reduction. To succeed, new technologies must demonstrate not just environmental benefits but also cost-effectiveness and reliability. The best avenue for proving these attributes is through extensive, real-world field trials. The NGIF ETC Program provides an ideal platform for such validation, offering technology providers a chance to test and refine their solutions under actual operating conditions for free. This approach not only helps navigate regulatory hurdles but also positions innovative technologies as essential for the industry's sustainable evolution.

1. Technologies to Detect and Quantify of Methane Releases

Methane releases are often intermittent in nature. Many feel that the only way to detect, locate, and quantify intermittent releases is with continuous fixed sensors, but the technology is not yet mature enough. While continuous fixed sensors can detect methane, locating and quantifying methane emissions has proved challenging.

10 technologies for detection and quantification were deployed at the NGIF ETC Program facilities. The following list groups the technologies by method of deployment.

- Six (6) Continuous Fixed Sensors
- One (1) Aerial Sensor – Plane

- One (1) Aerial Sensor – UAV
- One (1) Satellite Sensor
- One (1) Truck Sensor
- One (1) Handheld Sensor

The NGIF ETC Program provides long-term access to operating facilities with metered and controlled releases. This will prove valuable to companies as they develop new, lower-cost, intrinsically safe sensors and algorithms to locate and quantify releases. Preliminary observations from the deployment of specific continuous fixed sensors at the NGIF ETC Program include:

- Most fixed sensors are challenged with accurately locating and quantifying methane releases.
- There have been advancements in sensor technology that are smaller, cheaper, and intrinsically safe. Power requirements have dropped substantially, thereby reducing or eliminating solar panels in favour of long-life batteries.
- Three (3) companies (Baker Hughes, Luxmux, and Project Canary) are no longer marketing fixed sensors. Baker Hughes and Luxmux have not shared their reasoning. While Project Canary still has its own sensors, its core business is now the development of an emissions quantification platform (software) that is now sensor-agnostic and can integrate with an operator's hardware choices.
- Qube remains deployed at the Hub and the CREEW as it continues to improve its algorithm. Within the NGIF ETC Program, Qube has experienced significant growth, successfully commercializing its products. To date, Tourmaline has fully deployed Qube's solutions across 6 additional facilities.
- Kuva's optical fixed sensor camera stands out for its ability to visualize and locate emission sources. Its continued deployment at the CREEW, aims to refine quantification algorithms and enhance detection in low sunlight conditions. This deployment along with other deployment at the Hub has significantly advanced the team's understanding of the sensor's capabilities and limitations across different seasons.

Preliminary observations from the deployment of aerial, satellite, truck, and handheld technologies to detect methane at the NGIF ETC Program testing sites include:

- Aerial surveillance for methane release has become increasingly common in Canada. LSI Inc., a Calgary-based aerial company specializing in 3D LiDAR, partnered with Telops Inc., a Quebec-based optical sensor company, to develop their own technology for fixed-wing emissions testing. LSI/Telops maiden flights in Canada were over several NGIF ETC Program Field testing locations in November 2021. LSI/Telops revisited the ETC's April 2022 and March 2023.
- LSI/Telops gained valuable insight into the strengths and limitations of their technology from these flights. They have demonstrated that they can detect methane with snow on the ground, which is a limitation for other aerial technologies. Furthermore, the temperature differential between the ground and the air is very important, with higher differentials improving the probability of detection. LSI/Telops ability to quantify releases improved with each campaign. LSI/Telops now deems their technology commercial.
- AltoMaxx's drone technology proved effective at detecting methane releases. However, quantification is expected to require at least two years of additional field work. AltoMaxx is evaluating an alternative Fugitive Emissions Monitoring Program (altFEMP) pilot, based on screening with the drone followed by ground inspection to quantify emission rates as a faster path to commercialization.

There is growing interest in deploying methane sensors on corporate trucks and service vehicles, and there is at least one altFEMP pilot authorized by the AER.

- Eosense has developed a mobile version of a continuous fixed sensor designed to be mounted on a truck. Eosense has partnered with Vertex, an oil field service company. With the Eosense sensor installed on trucks, methane can be detected and quantified at a facility level.

If the AER approves mobile detection and quantification technologies (truck-based, aerial, etc.), there will likely be broader deployment; the initial data collected at the NGIF ETC Program has played a role in improving these technology commercialization pathway.

2. Technologies to Reduce or Eliminate Methane Emissions

Pneumatic devices are the largest source of methane emissions in Alberta. In 2021, 5.5 Mt expressed at CO_2e, or 34% of the total of 15.4 Mt CO_2e, came from venting pneumatic device venting[1]. The project conducted by the NGIF ETC Program have helped to advance theses technologies through validation trials. This effect has directly helped in meeting the current 45% reduction target that was achieved by the province of Alberta.

Ten (10) technologies that reduce or eliminate methane emissions were evaluated at the NGIF ETC program. Seven (7) technologies reduce emissions associated with pneumatic controllers. Two (2) technologies reduce emissions from engines used at wellsites for power generation drilling and completion (D&C) operations. One (1) technology was an early-stage, novel low preassure methane capture system. The following list further groups the technologies addressing pneumatic controller emissions:

- Three (3) Instrument Air Compressor Packages to eliminate Natural Gas for Pneumatic Devices.
- Two (2) Multiphase Flow Meters to eliminate the need for 3-phase separators and associated pneumatic devices at wellsites.
- One (1) Non-Emitting Electric Actuator to replace brownfield and greenfield pneumatic actuators.
- One (1) Improved Power Storage for electric controllers.

Observations from the deployment of Instrument Air technologies that reduce emissions from pneumatic devices include:

- Three (3) technologies deployed under the NGIF ETC Program replaced natural gas with instrument air through the use of electricity produced from generators driven by internal combustion (IC) engines and/or solar panels.
- Packair, a NGIF ETC Program Lab deployment, is an inexpensive plastic compressor driven by an electric motor. The draw of this technology is its size and its ability to generate air flow rates with minimal power required. This technology was effective in the lab environment, but it does not have the required classification for field use. Also, the low compressor capacity was applicable to only a small number of sites, which continue to lessen as operators move to larger multi-well pads. Due to the declining market potential, Packair exited the market in 2022.
- Marathon and Convrg Innovations produce instrument air to replace natural gas traditionally used by pneumatic devices. Convrg Innovations deployed at two Tourmaline sites. Marathon was deployed at a single Tourmaline site. Both technologies produce electricity from a natural-gas-fueled IC Engine driving a generator that drives an electric compressor. Convrg Innovations has options to add solar power and battery storage.
- Both Convrg Innovations and Marathon successfully produced instrument air to meet the needs of an operating facility. They

1 MWA, "Methane Mitigation Pathways Part 1: The Road to 45", pg 9

reduced GHG emissions by eliminating otherwise vented natural gas. Both were deployed for extended periods of time which helped to understand mainteneance and reliability requirements of the devices.

Observations from the deployment of Multiphase Flow Meters:

- The potential market is very large. The multiphase flow meters would reduce the need for a 3-phase separator, thereby eliminating the need for the pneumatic devices associated with each separator.
- Weatherford and m-Flow each deployed a multiphase flow meter at an operating natural gas well site. The TRL levels have advanced for both technologies, and Weatherford currently market this as commercial products.
- The multiphase flow meters could be installed at both brownfield and greenfield sites.
- Widespread adoption for these types of meters in the Canadian natural gas industry will depend on the accuracy in maintained over time. Emphasising the need for long-term field deployments.

Observations from the deployment of technologies to reduce emissions from engines include:

- Natural gas is a lower GHG emission intensity fuel than diesel. By substituting some diesel used on drilling rigs with natural gas, not only is there a seen a decrease in emissions from direct combustion, but there is also a secondary benefit of reduced trucking needed for transporting loads of diesel. Precision's drilling rig upgrades included a new Dynamic Gas Blending (DGB) system, a new 1 MW Energy Storage System (ESS), and a new Smart Engine Management System (SEMS). TRL was 7 at the start of the NGIF ETC Program deployment. After field testing, the TRL increased to 9.
- Methane slip in natural gas co-blended diesel engines is a concern that hinders achieving the full environmental benefits of these systems. However, the NGIF ETC Program provides an avenue for this technology to evolve. The newly commissioned CEMS offers a pathway for optimizing these systems to fully realize their benefits.

Technologies Evaluated: Overview

Technologies Evaluated: Overview

The following sections detail the testing programs run through ETC during Fiscal 2021 and Fiscal 2022. Highlights of the tests and results are shown here, with more details provided in the individual project reports housed in the CERIN data portal (www.cerinprojects.ca).

1. Qube Technologies

Qube Technologies is a leading producer of artificial intelligence (AI)-based environmental surveillance technology for the upstream energy industry. Qube is Calgary-based, with 30 employees performing R&D, assembly, and testing of methane detection sensors being deployed in Western Canada, the U.S., the Middle East, and Australia.

Website: www.qubeiot.com

CERIN Report: Qube CERIN report

Technology Description

Qube has developed a low-cost environmental surveillance technology to continuously monitor for greenhouse gas emissions, including methane. Fixed sensors detect methane and other harmful gases in real-time to allow operators to effectively find and repair emission leaks. The fixed sensors are simple to install, are solar-powered, and transmit data directly to the cloud. Emission and environmental data are visualized on a web-based, user-friendly platform.

Technology Deployment February 1st, 2022, through present – West Wolf Lake Gas Plant

Qube deployed nine Axon-fixed sensors around the perimeter of the WWL Gas Plant. Qube continues to refine the cloud-based dashboard that provides real-time values for release rate (kg CH_4/hr), likely release location, cumulative methane releases over 1, 7, and 30 days, CH_4 concentration at each sensor, wind speed, and direction.

Comparison of metered releases with Qube's release location and site rate estimates is ongoing.

Technology Deployment February 16th, 2022, through November 2022 – Spirit River Controlled Release Wellsite

Qube deployed three Axon fixed sensors around the perimeter of the Spirit River Controlled Release Wellsite. Three sensors should allow Qube to triangulate and determine release locations. Figure 3 shows one of the Qube sensors in the foreground, set up around the Controlled Release

Figure 3: *Qube deployment at the 13-35 ETC Well Vent Site.*

Wellsite perimeter.

Observations, Conclusions, and Next Steps

Throughout the project, Qube has been able to successfully demonstrate the detection of known emission events at both the West Wolf Lake Gas Plant and the Spirit River Controlled Release Well site, under a variety of environmental conditions. Runtime was high for all devices throughout the project, even under winter conditions with temperatures as low as -30°C.

Qube's system captured the broad trend of emissions at the site, showing high emissions site rates in the periods prior to the installation of the VRU, with notable localization events occurring from the tanks on the sites. Following the installation of the VRU, Qube noted much lower emissions. Qube also showed the potential to capture fugitive emissions from tank thief hatches after the installation of the VRU.

Qube will continue to have devices deployed at the West Wolf Lake Gas Plant and the new South Edson Controlled Release Wellsite. Qube's hardware is currently commercial, and initial localization and quantification models are currently available, however, Qube continues to invest in R&D to further advance the model accuracy. The localization and quantification models will be further tested further at the ETC.

2. Kuva Systems

Kuva Systems is a methane monitoring technology company focused on making the invisible measurable and manageable. With offices in Calgary, Boston, Houston, and Midland, Kuva's patented infrared camera and cloud monitoring solution provide oil and gas companies with timely notification of methane leaks and the ability to investigate root causes of emissions.

Kuva's solution enables upstream and midstream oil and gas companies to improve their operations and meet ESG and methane intensity goals.

Website: www.kuvasystems.com

CERIN Report: Kuva CERIN Report

Technology Description

The Kuva camera uses non-thermal short-wave infrared light (SWIR) to detect emissions of hydrocarbon gases. Kuva's core technology includes the SWIR camera combined with a comprehensive end-to-end cloud solution for continuous leak detection and quantification of tank emissions. Kuva's solution will:

1. Automatically detect hydrocarbon gas, including methane.
2. Pinpoint emissions sources by visualizing detected gas as a colour overlay on an image of the environment (gas in color, environment in grayscale).
3. Automatically generate alarms (with human review to eliminate false alerts).
4. Continuously quantify emission rates, currently offline & batched, with integrated continuous solution in development.

Technology Deployment April 1st, 2022, through present - ETC WWL Gas Plant

The angle of the sun and camera, shadows, and the material and uniformity of backgrounds can all affect the detection performance of the Kuva camera. To study these effects, Kuva installed two Kuva cameras at the ETC. The cameras were commissioned on Friday, April 1st, and have been in continuous operation since.

Figure 6 plots the result of Kuva's emissions quantification algorithm at

Figure 4 shows the east camera installation. Figure 5 is an example of a methane leak detected by Kuva. In this image, leaks are seen both from the tank vent and from the thief hatch. Kuva highlighted the importance of being able to separate the emission plumes in these images to be able to properly locate and quantify single emission source points.

Figure 4: *Kuva Camera East Installation.*

Observations, Conclusions, and Next Steps

Kuva's cameras demonstrated an ability to continuously detect both persistent and intermittent releases from tanks during daylight hours. Detected releases include routine vents and fugitive emissions from thief hatches.

Kuva cameras can quantify and locate releases. Quantification accuracy is dependent on several factors, including windspeed, release size, distance between the camera and the release, and multiple releases overlapping as one. Detection sensitivity is dependent on a number of factors, including solar irradiance.

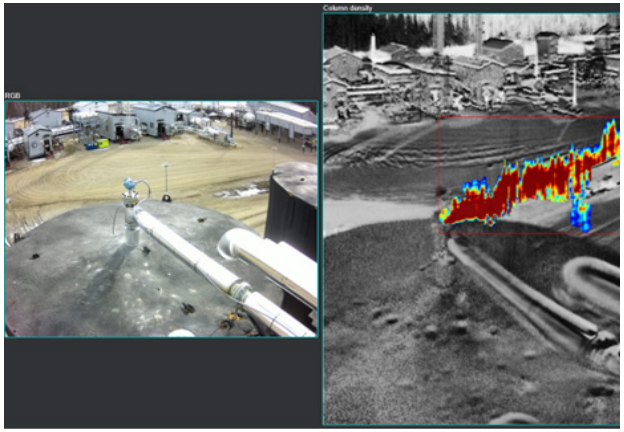


Figure 5: *Kuva Leak Detection at the West Wolf Lake Gas Plant.*

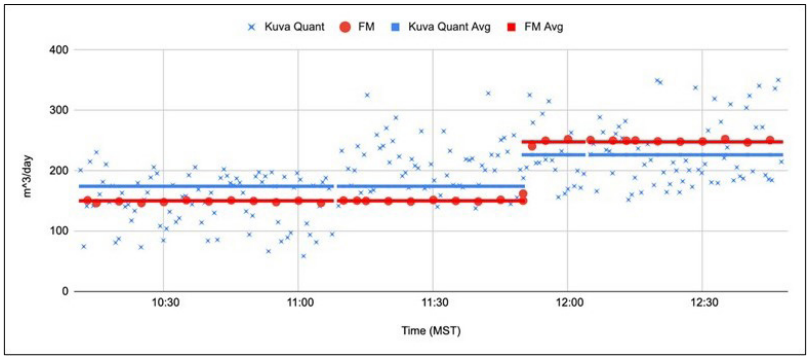


Figure 6: *Kuva Quantification Outputs at the ETC Spirit River Controlled Release Site.*

Figure 6 (*page: 32*) plots the result of Kuva's emissions quantification algorithm at the Sprit River CRS. While there can be variations in output rates for any given time, when taken as an average over an extended time, the Kuva predictions track closely with the measured flow meter (FM) values. Kuva continues to advance detection sensitivity and quantification accuracy. As detection sensitivity improves, so does quantification accuracy. Ongoing work will focus on low light conditions and the rapid 'validation' of detection data for quantification.

3. Project Canary

Project Canary is a science-based enterprise emissions data platform that helps energy leaders identify, measure, understand, and act on GHG and other harmful emissions. Project Canary provides software visualization tools, high-fidelity sensor solutions, and rigorous environmental assessments.

Website: www.projectcanary.com

CERIN Report: Project Canary CERIN Report

Technology Description

'Canary X' is Project Canary's most widely deployed methane monitoring system. Canary X uses a Tunable Diode Laser Absorption Spectroscopy (TDLAS) sensor, which can detect methane concentrations below ambient levels.

Technology Deployment

The ETC provides a unique opportunity to evaluate Canary X's detection and quantification effectiveness. Testing was run at the ETC Spirit River test location, which simulates methane releases at conventional oil and gas operations. Figure 7 shows the Canary X mehane monitoring device.

NGIF and Project Canary developed a test plan that included a consistent methane emission baseline and intermittent fugitive and operational emissions. Ideally, the testing would occur over two or more months. This was because Project Canary generally runs for around one month to generate the data used to tune their quantification algorithms, and after this time the predictions in their dashboard go "live" for use.

Observations, Conclusions, and Next Steps

Unfortunately, the Spirit River Controlled Release Wellsite experienced operational delays, and the window to deploy and test Canary X was shortened to less than a month during the winter season. This proved to be insufficient time to complete the test plan. Also, cold weather

Figure 7: *Project Canary's 'Canary X' Methane Monitor.*

impacted Canary X's operation. However, Project Canary gained valuable experience operating during a Canadian winter. Project Canary plans to complete the evaluation of Canary X and redeploy it at NGIF's new South Edson Controlled Release Wellsite in Q1 2024. Future testing will be run with a model that is specifically designed for cold weather operations, and testing at the South Edson CRS can be run continuously (i.e., not a single campaign like in late 2022), giving sufficient time for Project Canary to start to build quantitative outputs and prove the validity of their platform.

4. 4Blue Energy Services

4Blue Energy Services is a carbon footprint detection and quantification tech company. Their goal is to develop and provide 24/7 autonomous volumetric measurement, quantification, and compliance corroboration of methane emissions and emissions reduction solutions. They want to develop cost-effective, fit-for-purpose, nonintrusive hardware for measuring emissions, coupled with an AI interface to identify and quantify emissions.

CERIN Report: 4Blue CERIN Report

Technology Description

4Blue is developing an AI-powered, cloud-based platform that will be coupled with inexpensive gas imaging cameras installed at the perimeter of an oil and gas facility to monitor, detect, quantify, analyze, and monetize GHG emissions. Their proposed solution couples both hardware (stripped down, inexpensive OGI) and software (AI-based quantification algorithms).

Technology Deployment

The ETC lab performed a series of tests with air, smoke, and metered methane releases. Initial tests were run first with air, smoke and a visual camera to see what an emission plume would look like. The following test was run with CH_4 at the same rates and with the OGI camera. The OGI images were compared against the visual air/smoke images to adjust image parameters so that 4Blue was sure that methane was seen in their stripped-down OGI camera. This was the technology proof of concept stage of testing.

In the second test stage, the ETC lab ran CH_4 releases at different rates, and 4Blue's camera recorded images of these varying rates. Data generated from each test was provided to 4Blue. 4Blue is developing algorithms that will estimate release rates based on plume size and shape.

Figure 8 shows 4Blue set up in the ETC lab Controlled Release Chamber.

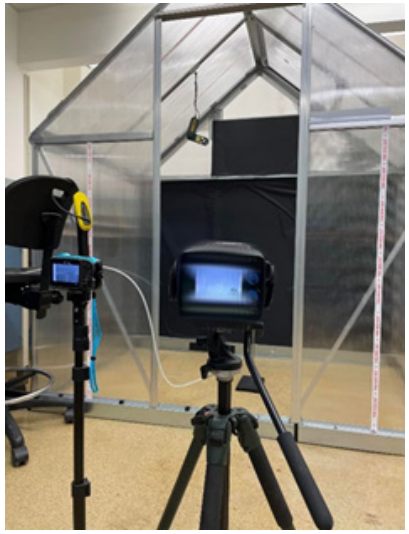


Figure 8: *4Blue System Setup at the ETC lab Controlled Release Chamber.*

Observations, Conclusions and Next Steps

4Blue collected and analyzed multiple data sets and has since been working on developing an AI model for locating and quantifying methane releases. Future work will include blind releases to compare AI-modeled release rates versus actual release rates.

5. TransRail Innovation Group (TRIG)

TRIG specializes in building rail tank cars and terminal solutions for both transloaders and shippers. TRIG's expertise in terminal design, commodity visibility, digital sensor technology, and process re-engineering enables TRIG to deliver enhanced safety, compliance, throughput, and efficiency.

Website: www.transrailinnovation.com

CERIN Report: TRIG CERIN Report

Technology Description

TRIG is developing low-power, small (localized) methane sensors for detecting larger emissions at the source (e.g., wellhead, pressure release valve, storage tank vent line). When these sensors are properly rated for safety and site access, TRIG will propose different mounting positions that will allow the detection of a significant process or equipment failure. Within the scope of the ETC, TRIG wanted to perform methane detection tests in the lab that best represent the placement of the sensor in relation to the fugitive emission source.

Technology Deployment

Test protocols were developed using one commercially available methane sensor. Pure methane was released at a constant rate, and the sensor was placed at various positions and distances from the release point. The ability of the sensor to detect methane was recorded. This was Phase 1 of testing – the methane detection proof of concept stage. Figure 9 below shows the laboratory setup. The mass flow meter is on the left, and the fixed sensor is clamped to the right.

Stage 2 of testing was focused on sensor data quantification. Methane rates were fixed, and the sensor was moved to different positions to identify what range of output CH_4 concentrations would be recorded. Then, emission rates were changed, and this process was repeated. The ETC lab fed all of this data back to TRIG to use in the validation of the sensor and for the development of a quantification algorithm.

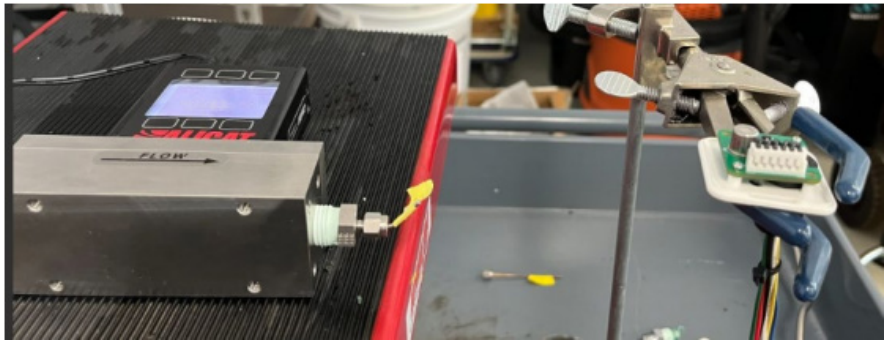


Figure 9: *ETC Lab setup Mass Flow Meter and Fixed Sensor.*

Observations, Conclusions, and Next Steps

TRIG's sensor was able to detect methane when their device was exposed directly to the path of the leak source. However, it is not sensitive enough to quantify it as soon as their device is moved away from the leak. TRIG will continue to evaluate various methane sensors to understand accuracy, sensitivity, and positioning.

6. LiDAR Services International Inc.

LiDAR Services International Inc. (LSI) is a Canadian, Calgary, Alberta-based airborne LiDAR service provider that has been in business since 2002. LSI's business focus is to provide high-quality airborne LiDAR data collection and processing services. In 2021, LSI added aerial surveys for

methane detection and quantification to their service portfolio.

Website: www.lidarservices.com

CERIN Report: LSI CERIN Report

Technology Description

LSI deploys a thermal infrared hyperspectral imaging system designed for use on a wide variety of manned and unmanned aerial platforms. The system produces orthorectified, geo-referenced infrared gas detection images to quickly identify and quantify a gas leak. The system has been field-tested over natural gas facilities in France (for GRTgaz) and is ready to be further tested over existing oil and gas facilities in Western Canada.

Based on previous field work, LSI anticipates a lower detection limit of 0.5 g/s (85 m^3/day).

Technology Deployment

LSI installed the infrared hyperspectral imaging system on a Bell 206 helicopter. In November 2021, the helicopter performed multiple aerial surveys at the Spirit River Controlled Release Site and the West Wolf Lake Gas Plant.

LSI purchased a twin-engine airplane and installed the infrared hyperspectral imaging system. In April 2022, LSI flew both the West Wolf Lake Gas Plant and the Temporary Controlled Release Site. The controlled releases were varied in rate, allowing LSI to confirm the lower detection limit, probability of detection, and accuracy of quantification.

Observations, Conclusions, and Next Steps

LSI successfully detected methane in a variety of weather conditions, including snow on the ground. An important finding is that the sensor requires a difference in temperature between the ground surface near the scene of the leak and the target methane plume. With adequate ground/plume temperature differential (>5°C), the sensor performs well with background conditions of either snow or dry ground. Figure 10 is an example of observed methane plumes coming from the liquid storage tanks at the WWL gas plant.

Also, LSI calculates the Lower Detection Limit for each aerial scan. The probability of detection is 85% when the actual release rate is greater than the calculated lower detection limit. This is shown in Figure 11.

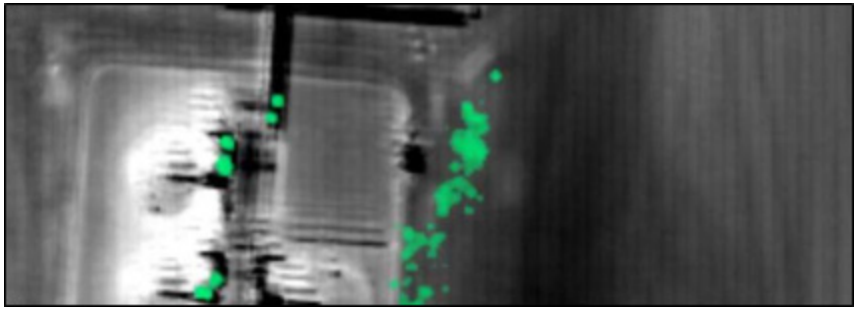


Figure 10: *WWL Gas Plant Liquid Storage Tanks Methane Detection.*

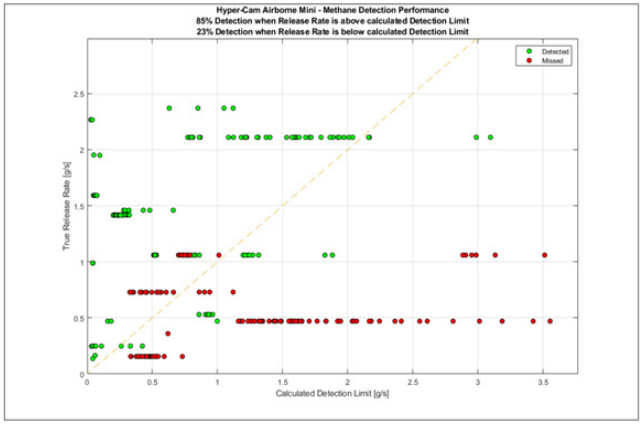


Figure 11: *LSI Methane Detection Performance Outputs.*

7. AltoMaxx Technologies

AltoMaxx Technologies is a drone service provider offering inspection services, integrated solutions, and capacity building within the power utility, public safety, and oil and gas industries. Headquartered in St. John's, Newfoundland and Labrador, with five offices throughout Canada and the United States – AltoMaxx serves an international client base, deploying drone technologies in projects around the world.

Website: www.altomaxx.com

CERIN Report: AltoMaxx CERIN Report

Technology Description

AltoMaxx drone expertise has been combined with a Tunable Diode Laser Absorption Spectroscopy (TDLAS) methane detector. The Lower Detection Limits (LDL) is 5 ppm-m. This allows users to fly over a site and determine the exact location of methane releases. AltoMaxx is developing capabilities to quantify methane releases with drone surveys using both TDLAS and OGI technologies.

Technology Deployment

Altomaxx deployed to the West Wolf Lake Gas Plant and the Temporary Controlled Release Site from April 25th through to 30th, 2022. At the gas plant, AltoMaxx focused on tank vents, compressor seals, and methane slip in engine exhaust. The goal of testing at the gas plant was to demonstrate the ability to detect methane emissions; AltoMaxx planned to fly drones, identify emission source points and follow up with a handheld OGI camera for emissions quantification.

In a second test, AltoMaxx ran multiple surveys over multiple days at the Temporary CRS, where emissions were fixed at different values, and AltoMaxx would fly repeat patterns over these continuous emissions. The goal was to acquire the data needed to evaluate the impact of flight speed, flight altitude, release rate, and weather on methane detection and quantification.

Observations, Conclusions, and Next Steps

AltoMaxx was able to determine that an ideal flight speed for low flow rate emissions (less than 200 m^3/day) was 1.5 meters per second at an altitude of 20 meters. This gave reliable detection of leaks as low as 15 m^3/day. The quantification piece (i.e., converting the measured ppm-m from the drone into different rates) is still ongoing.

At the WWL Gas plant, AltoMaxx was also able to evaluate a multi-gas sensor for the measurement of flare stack emissions. Since flare stack emissions are not controlled or measured, it is difficult to determine the accuracy of the AltoMaxx sensor.

AltoMaxx also utilized the methane sensor to confirm methane slips in each of the four compressor engine exhaust vents at the gas plant. By comparison, OGI cameras cannot detect the presence of hydrocarbons in engine exhaust due to high temperatures, but the AltoMaxx drone technology was able to see these emissions, similar to what was observed in the flare stack. Future testing to compare drone measurements with CEMS will be valuable.

8. GHGSat

GHGSat is the global leader in high-resolution remote-sensing of greenhouse gas from space – an approach it pioneered – and provides unique emissions data and intelligence to businesses, governments, regulators, and investors worldwide to optimize their performance and uphold environmental standards.

Website: www.ghgsat.com

CERIN Report: GHGSat CERIN Report

Technology Description

GHGSat launched its first methane detection satellite in 2016 and now has 12 satellites in orbit, including its first carbon dioxide detection satellite, launched in November 2023. Each satellite uses patented infrared detection technology. Detection thresholds have improved 10-fold since 2016 and are currently reported as being ~ 4,000 m^3/day or 100 kg CH_4/hr.

Technology Deployment April 25th through April 30th, 2022 - Temporary Controlled Release Site.

While the range of emission rates required for satellite imagery far exceeds what is present at the ETC operating facilities, the Temporary Controlled Release Site is ideal for evaluating GHGSat's lower detection limits because the natural gas trailer can be used for high-rate releases over a short period of time (i.e., as the satellite passed overhead).

GHGSat's satellite passed over the Temporary CRS at 11:55 a.m. on April 28th and again at 11:44 a.m. on April 29th. Methane was released at a rate of 8,000 m^3/day and 6,000 m^3/day for the two days, respectively, starting 30 minutes prior to the expected scan to allow for good plume formation.

Observations, Conclusions, and Next Steps

Unfortunately, cloud cover limited the ability of GHGSat's satellite to detect methane releases. See Figure 12 for the satellite image of the Temporary Controlled Release Site. The high rate of CH_4 release is not visible in this image because clouds have completely obscured the view.

The perimeter of the plant and further focus on possible emission source points.

High-rate releases are relatively uncommon in Canada, but they can possibly occur, and from a global standpoint, high-rate releases can always happen. GHGSat continues to support controlled release data collection initiatives to further understand the performance of the system. Further testing could potentially happen at the ETC, if desired. GHGSat, NGIF, and Tourmaline would have to coordinate controlled releases based on the satellite orbit schedule and forecasted weather conditions.

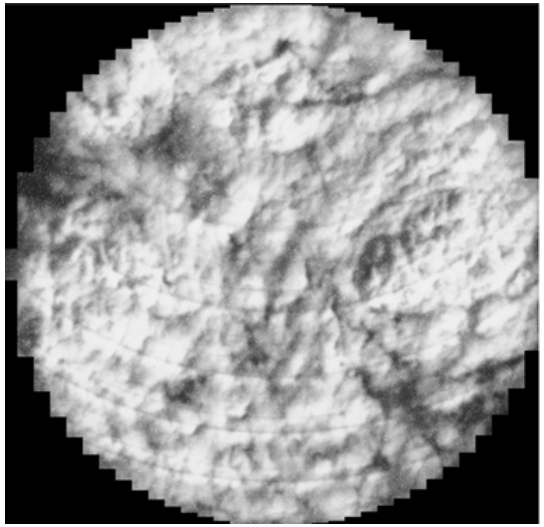


***Figure 12:** Clouded Satellite Image of the Temporary Controlled Release Site on April 28th, 2022*

9. Eosense

Eosense is a Canadian company that develops gas monitoring instruments that enable scientists and engineers to measure environmental gas flux and concentration.

Website: www.eosense.com

CERIN Report: Eosense CERIN Report

Technology Description

The Vertex-Eosense Truck-Mounted Methane Emissions Monitoring Project is an innovative approach to emissions monitoring. The concept is that the Eosense eosEM methane monitoring system would be mounted on a Vertex-operated liquids hauling transport truck. The eosEM sensor passively collects methane emissions data, while the Vertex truck routinely hauls liquids for Oil and Gas operators, including Tourmaline. In this fashion, site-level emissions monitoring would be run in the background during routine trucking operations, and site operators would be notified if the emissions level were to change significantly from the baseline.

Technology Deployment

Two phases of deployment were run at the ETC. Phase 1 involved an installed eosEM on a Tourmaline pickup truck. The pickup truck would routinely drive around the perimeter of the WWL Gas Plant and record emissions on the Eosense system. The associated emissions levels from fixed perimeter sensors were also taken at these same times and fed back as input data to Eosense. Figure 13 shows the methane detected by the truck-mounted sensor compared to the methane measured at the fence line by fixed sensors.

When fixed sensor emissions are high (red colour in Figure 13), the Eosense sensor also records higher emissions, so there is a reasonable qualitative match between the two independent data sets.

In Phase 2 of testing, the eosEM sensor was installed on a Vertex liquids transport truck. The sensor that was on the ETC Tourmaline pickup truck followed the heavy haul liquids transport truck out to a site while tanks were being unloaded, and data was acquired from both sensors at the same time. The objective of Phase 2 of testing was to understand if the facility operations altered the numbers measured in the heavy haul truck compared to what was measured in the pickup truck.

Observations, Conclusions, and Next Steps

Good agreement has been seen between vehicle-mounted sensors and fixed-site sensors. The transport truck-mounted sensor can estimate relative methane levels and highlight areas at the site that might need further investigation. To date, a great deal has been learned from the operator about how to integrate this sensor into a future operational alt-FEMP technology. The next steps will include a larger deployment of instruments across additional routes, seasons, and geographic areas.

Figure 13: Eosense Survey Route and Results from the West Wolf Lake Gas Plant.

10. mCloud

mCloud is a high-growth software company solving some of the world's most challenging energy problems. mCloud's AssetCare® helps operators reduce fugitive emissions through an integrated suite of Leak Detection and Repair (LDAR) capabilities.

Website: www.mcloudcorp.com

CERIN Report #1: mCloud Phase 1 CERIN Report

CERIN Report# 2: mCloud Phase 2 CERIN Report

Technology Description

mCLoud AssetCare® integrates an operator's existing data infrastructure to optimize assets including methane emissions. The concept is that mCLoud builds/integrates a site's digital twin with leak detection tools to estimate methane emissions – when emissions are found, the source points are identified through AI algorithms and linked back to the digital twin of the facility, so site operators are given information about a potential emission linked to a specific location. From the hardware side, mCloud's approach is to identify leaks is using the Prosaris Ultrasonic Leak Detector, which is designed to be a wearable device for operators to hold or wear as they move around the facility. The leak detector tool is equipped with the ultrasonic leak detection piece and a GPS locator to tie measurements back to the digital twin. The Prosaris Ultrasonic Leak Detector has been validated using air releases. mCloud requires the Prosaris Ultrasonic Leak Detector to be validated for methane and other gases.

Technology Deployment

The ETC Lab worked with mCloud to jointly develop a test plan to evaluate the performance of the Prosaris Ultrasonic Leak Detector at different temperatures, leak sizes, and gas types, including methane. Phase 1 of testing was a proof of concept of the tool using methane: Effect of distance between leak and detector, and impact of emission rate were also evaluated to determine false negative and false positives, if any, under the impact of other noise interference. Once the sensor was validated from Phase 2, Phase 2 testing involved development of parameters needed to quantify the observed emissions – tuning of gas constants for reliable quantification results and varying the orifice size and angle of the gas release to identify predictable relationships of emission relative to sound frequency.

Observations, Conclusions, and Next Steps

False negative and false positive detections were less than 20% of the total tests performed. The ideal detection distance was found to be 0.5 to 2 meters. The type of gas released had no apparent effect on the ultrasonic leak detector. Temperatures of -20°C and +50°C had no effect on the sensor or battery. Sound interference from a compressor, drill, and fan had little impact on the ultrasonic detector's performance. The ultrasonic leak detector can quantify within ±30% compared to the

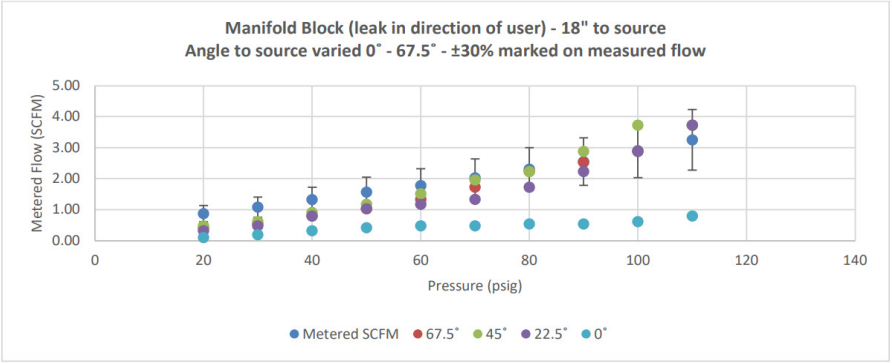


Figure 14: *mCloud: Ultrasonic Sensor Test Results for Detection Sensitivity to Angle from Leak vs. Gas Pressure vs. Leak Rate Showing Sensitivity to Nearby Leaks.*

metered release rate. This requires determining both the gas type and gas temperature.

The next steps include lab testing at lower flow rates and variable humidity. Field deployment will be necessary to confirm the lab findings. Prior to field deployment, the sensor and tablet must be intrinsically safe.

11. Convrg Innovations, formerly Westgen Technologies

Convrg Innovations offers energy solutions to reduce emissions, boost performance, and maximize efficiency at oil and gas facilities. EPOD empowers companies to pressurize on-site pneumatic systems and achieve over 95% emissions reductions.

Website: www.convrginnovations.com

CERIN Report: Convrg Innovations, former Westgen, CERIN Report

Technology Description

To provide instrument air for pneumatic devices, Convrg introduced EPOD solutions, an instrument air and power generation system with an optional solar hybrid and battery array for an uninterrupted power supply (UPS). The power generation systems of the EPOD adopt 6kW to 35kW industrial-grade generators with a custom-sized capacity of up to 150 kW of power and heat. The optional solar panels and advanced UPS battery array reduce fuel consumption and extend maintenance intervals. The EPOD air and power systems can reduce emissions from fuel gas-driven pneumatic devices by up to 99.5%.

Technology Deployment

Tourmaline identified two wellsites near Edson, Alberta, to evaluate Convrg's EPOD technology. The EPOD Mini and EPOD 20kW were installed in November 2021. Both are still in operation. Reliability, emission reduction potential, and ability to operate using unprocessed fuel gas under field operating conditions were evaluated. Figure 15 plots the baseline emissions for the ETC Tourmaline site #1 before implementation of the EPOD (i.e., with CH_4 venting) compared to after. Similar results were also observed for site #2, demonstrating the significance of this technology in wellsite pneumatic venting emissions reduction.

Observations, Conclusions, and Next Steps:

Over more than twelve months of operations, from November 2021 to January 2023, a total volume of 188,044 m^3 of air was generated by the two units and used to operate pneumatic instruments. During this field trial, the air compressors eliminated 3,657 tonnes of carbon dioxide equivalent emissions.

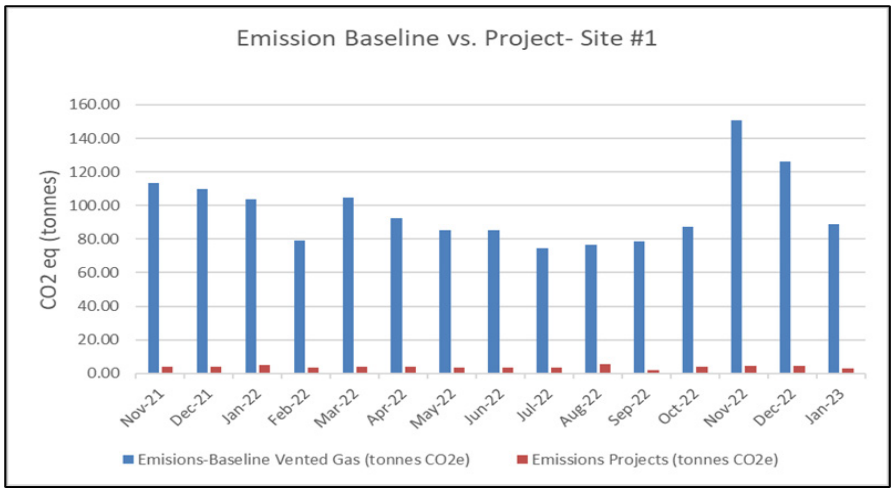


Figure 15: *Convrg's EPOD System - Reduction in Emissions (Tourmaline ETC Site #1).*

12. Marathon Compression

Marathon Compression provides trusted compression solutions that include VRU's to eliminate methane venting from tanks and KL8 Air-Power Units to power site pneumatics, instrumentation, and controls. Marathon provides creative solutions that deliver comprehensive design and engineering services, working collaboratively with clients to supply compression equipment to the oil and gas industry.

Website: www.marathoncompression.com

CERIN Report: Marathon CERIN Report

Technology Description

To provide instrument air for pneumatic devices, Marathon's KL-8 Air-Power unit adopts a unique 5kW natural gas internal combustion (IC) engine that is designed and used for micro-combined heat and power (CHP) systems. This CHP system is capable of over 40,000 hours of continuous service with 4,000-hour service intervals.

Technology Deployment

The KL8 was installed on a Tourmaline six well pad located near Edson, Alberta. The six wells are on timers, flowing for less than 12 hours a day. The goal of the study was to evaluate the KL8's reliability, emission reduction potential, and ability to operate using unprocessed fuel gas under typical environmental extremes experienced in west-central Alberta.

Observations, Conclusions, and Next Steps

Over the eight months of operation from April to November 2022, a total volume of 23,555 m^3 of air was generated and used to operate pneumatic instruments. Figure 16 shows the baseline CH_4 venting emissions and the final site reduced emissions after installation of the Marathon air compressor. The engine has achieved a 99.1% runtime by running for over 5800 hours with no major mechanical failures.

Tourmaline will continue to operate the KL8 unit in the field, with the ETC. continuously gathering data on the performance of the unit – to determine how it operates under severe winter conditions and confirm reliability over time.

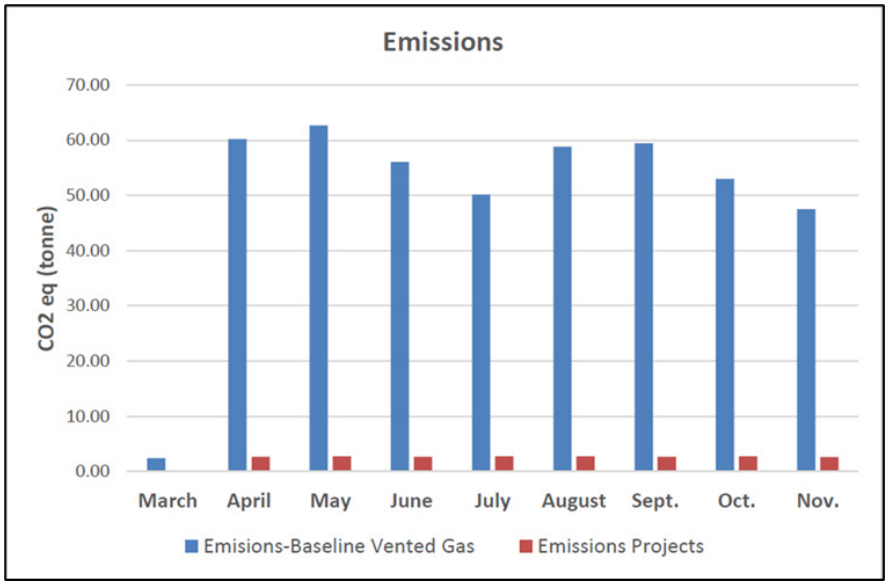


Figure 16: *Marathon System - Baseline and Project Emissions.*

13. Packair Industries Inc.

Packair was founded with the goal of solving common issues with compressed gas compressors, particularly compressor inefficiency and lack of true portability. Packair developed a small-scale compressor that is light and portable (while retaining the ability to perform material work) and one that they feel is more efficient than other commercial compressors targeting constrained power operations.

CERIN Report: Packair CERIN Report

Technology Description

Packair has developed a portable multi-cylinder, battery-powered, efficient compressor that runs cooler than traditional units. This system is designed to be cost-effective, requires low power to operate, and is suitable for hazardous environments when matched with an appropriate motor. Compressed air can replace natural gas in pneumatic devices, thus eliminating methane venting. Figure 17 is an image of the small Packair compressor, connected to a motor and air filter.

Technology Deployment

The ETC Lab evaluation included the ability to control compressed air release rates accurately and repeatably and to understand compressor power requirements. Two systems were tested at the ETC Lab – a 5-piston compressor (lower air flow rates) and a 10-piston compressor (higher air flow rates).

For each test, the ETC lab measured the power required to produce the desired air-flow rate at a desired pressure. Each test also recorded sufficient variables to calculate flow rates at standard pressure and temperature conditions.

Observations, Conclusions, and Next Steps

The Packair 5-Piston Compressor unit operating at 1667 rpm produced 6.3 SCFM of air at 40 psig using 329W power. The Packair 10-Piston Compressor unit operating at 1556 rpm was producing 11.9 SCFM of air at 40 psig using 570 W power. The testing at the ETC successfully proved the technical viability of their technology, and discussions with Tourmaline and other stakeholders helped Packair to reach an informed decision about their market size moving forward. Despite the lab success, Packair has decided not to continue product development, leading to the commercialization of their compressor. In Packair's assessment, the market for small, efficient compressors in the oil patch is declining, given the shift to drilling larger multiwell pads.

Figure 17: *Packair Compressor Connected to a Motor and Air Filter.*

14. Kinitics Automation Ltd.

Kinitics Automation is a Vancouver-based cleantech startup that has its roots in the automotive and power generation industries. They have developed a Bundled Wire technology that utilizes shape memory alloys (SMA) to control the motion of products, including control valves in the case of production wellsite facilities, replacing existing methane-venting pneumatic actuators.

Website: www.kiniticsautomation.com

CERIN Report: Kinitics CERIN Report

Technology Description

Kinitics is developing a valve actuator that uses shape memory alloy (SMA) to produce force and displacement. SMAs are materials that change shape with changes in temperature. In wire form, SMAs will contract when heated and return to its original length when cooled. The SMA wire can be heated by simply passing an electric current through it. The process is fully reversible, making the wire an ideal choice for high-cycle applications.

Kinitics Automation is proposing to introduce its electric valve actuator, or KVA, as a direct replacement for methane-venting pneumatic devices currently deployed at production wellsites in Alberta.

Technology Deployment

Kinitics has available funding to build multiple KVA systems and install them in field service. Prior to field deployment, the ETC Lab generated performance data in a controlled environment and demonstrated reliability and robustness (Figure 18).

Kinitics and the team at the ETC lab (UCalgary) jointly developed a test plan to evaluate the performance of the KVA. Positional accuracy, response time, and power consumption were monitored at various valve positions and operating temperatures ranging from -40°C to +40°C. Phase 1 of testing involved demonstrating that the valve could remain closed against a very high differential pressure, and Phase 2 of testing demonstrated the precision control of the valve actuator. Figure 19 (*page: 45*) shows the key output from Phase 2 testing at ambient temperature, and similar plots were generated at +46°C and -43°C in the CERIN report.

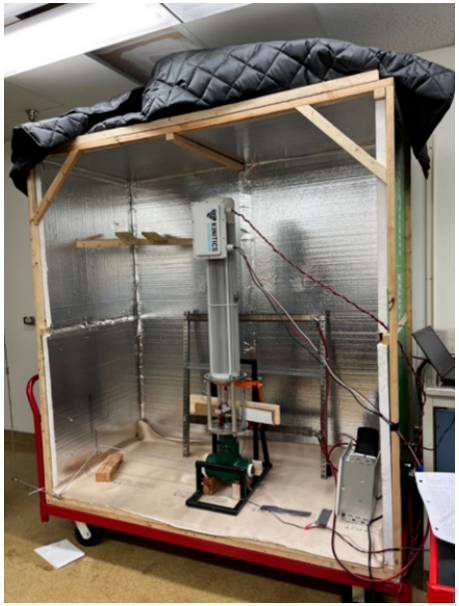


Figure 18: *Kinitics Actuator Controlling a Pneumatic Valve in the ETC Lab Controlled Temperature Chamber.*

Observations, Conclusions, and Next Steps

In lab testing, the deadband is <0.25%, positional accuracy within 0.1%

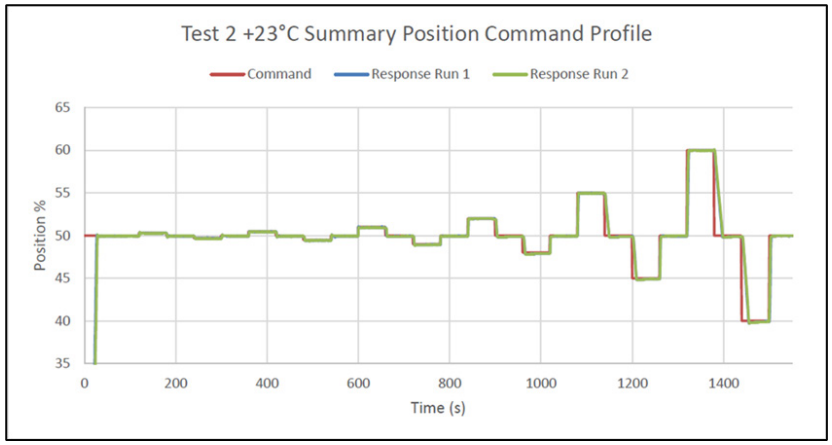


Figure 19: *Kinitics Valve Actuator Response to Precision Location Commands (ambient temperature.)*

of the setpoint, and settling time showed a minor decreasing trend with increasing ambient temperature. Future testing will include long-term operations over 3 months in the lab and field testing. Data generated at the ETC lab and field will optimize the KVA, including improved response rates and reduced power consumption. On the basis of lab and field testing results, Kinitics Automation will build version 2.0 of their valve actuator, which will be the final commercial prototype available for sale.

15. CH4NGEnergy

CH4NGEnergy was formed and funded through the Avatar Innovations Program. CH4NGEnergy's proposed technology captures vented methane gas in a transportable vessel filled with adsorbent or activated carbon.

CERIN Report: CH4NGEnergy CERIN Report

Technology Description

CH4NGEnergy's proposed technology is focused on capturing vented gas and re-routing what would have been vented natural gas into a transportable vessel that is filled with adsorbent or activated carbon. Natural gas will be held in this state, and periodically these capture vessels will be transported offsite, where gas will be desorbed out of the tank and provided to a natural gas market.

Technology Deployment

The ETC Lab evaluated various adsorbents and activated carbon under proposed process conditions. This allowed CH4NGEnergy to determine the technical and economic viability of its methane emissions reduction solution.

Observations, Conclusions, and Next Steps

ETC Lab evaluated pore size distribution and adsorption/desorption isotherms for various adsorbent materials:

- Activated charcoal
- Off-the-shelf activated carbon
- Activated carbon generated from 0.8 mm pellets
- Activated carbon generated from asphaltenes

All tests were performed using nitrogen gas. Activated carbon from asphaltenes has promise in terms of unit pore volume, and pore surface area, and potential use for bitumen beyond combustion. Additional testing is necessary to 1) confirm material interaction under pressure and 2) performance with methane.

16. Weatherford

Weatherford delivers innovative energy services that integrate proven technologies with advanced digitalization to create sustainable offerings for maximized value and return on investment.

Website: www.weatherford.com

CERIN Report: Weatherford CERIN Report

Technology Description

Weatherford's Foresite Flow multiphase flow meter will meter oil, gas, and water simultaneously, eliminating the need for 2 and 3-phase separators at oil and gas well sites and batteries. Separators typically have pneumatic devices for pressure and level control, and these devices can be a significant source of methane venting. Replacing separators with multiphase flow meters will significantly reduce methane emissions.

The Weatherford Foresite Flow Meter consists of 3 instruments: Venturi, Sonar, and Red Eye, as shown in Figure 20. The Venturi nozzle measures the total liquid fraction (oil + water). The Sonar Array measures the mixed phase's velocity, which is converted to a volumetric flow rate knowing the cross-sectional area. The Red Eye meter measures the water content of the liquid phase based on infrared light absorption.

Technology Deployment

Field deployment at a Tourmaline wellsite occurred between December 2020 and January 2022.

The initial trial of the Weatherford ForeSite Flow meter was on a system designed for high flow rates. Wells were commingled to get these higher rates. A second blind trial was then run using low-flow rate individual wells, comparing multiphase flow performance between the test separator and ForeSite Flow. Figure 21 (page: 47) shows the results of the meter for predicting gas, oil, and water rates during this blind trial period.

Observations, Conclusions, and Next Steps

The field trial yielded significant insights into the performance of diverse flow measurement techniques. The Foresite Flow Meter metered volumes were consistently within 3% of the individually metered volumes from the separator.

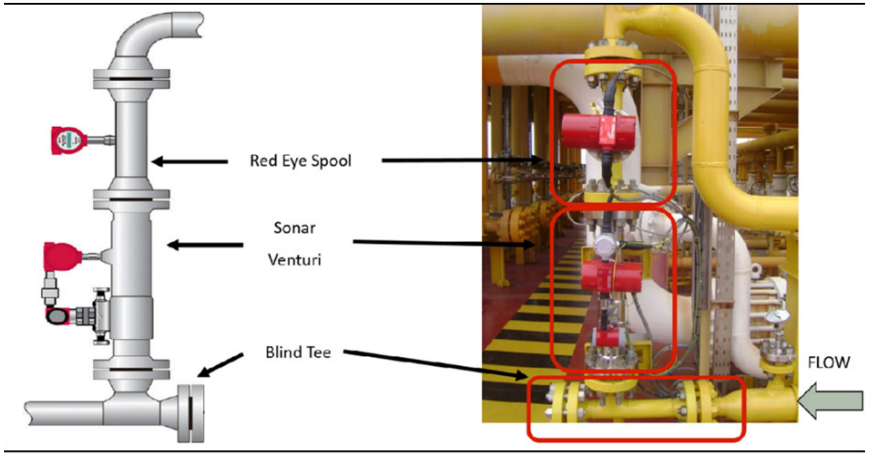


Figure 20: *Weatherford Multiphase Flow Meter Schematic Diagram.*

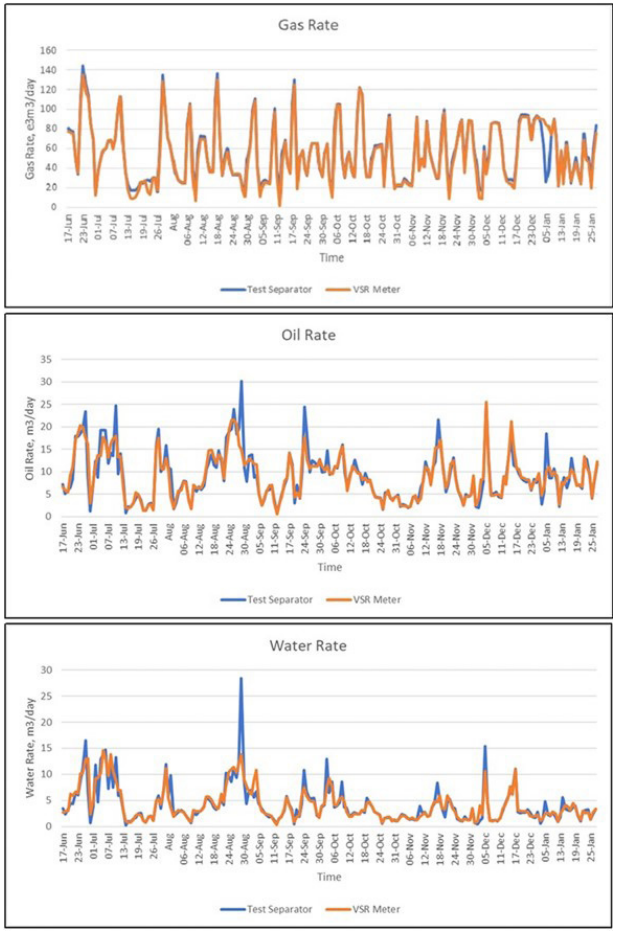


Figure 21: *Weatherford Foresite Flow Meter Predictions of Gas, Oil and Water Rates.*

17. Northern Alberta Institute of Technology (NAIT)

The Northern Alberta Institute of Technology is a polytechnic and applied research and sciences institute in Edmonton, Alberta, Canada. NAIT approached the Technology and Innovation team at Tourmaline to do a capstone project looking at possible solutions for battery warming at field wellsite facilities, and this data was eventually compiled and summarized as an ETC report as part of the HQP training portion of the program.

Website: www.nait.ca

CERIN Report: NAIT CERIN Report

Technology Description

Electrically powered devices have been adopted as a replacement for gas-powered (pneumatic) devices at wellsites to reduce associated emissions. However, the batteries used to power these devices face challenges such as decreased efficiency in harsh, cold weather conditions.

The NAIT capstone study was focused on finding a solution to keep the batteries within a suitable temperature range to maintain their efficiency and lifespan.

Technology Deployment

NAIT proposed solutions to maintain a consistent power supply during the cold winter months and reduce replacement costs. The proposed solutions were to increase insulation, add a heat source, or switch to self-heating batteries. See Figure 22 (*page: 48*), which shows an insulated battery box at the Tourmaline wellsite and a close up of the heat tracing.

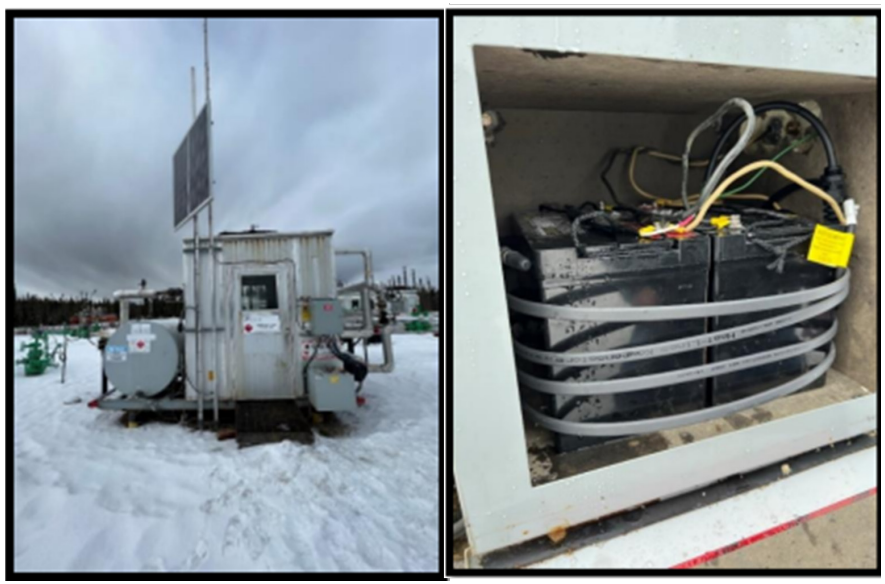


Figure 22: *Battery Box at Wellsite, and Heat Tracing of a Battery.*

Observations, Conclusions, and Next Steps

After conducting two field trials at a Tourmaline well site south of Edson, it was found that using a low-voltage heat trace system with a thermostat and low-voltage shut-off was the most effective and cost-efficient solution. It is recommended for further testing to determine the minimum length of heat trace needed and the optimal insulation for each wellsite.

18. Precision Drilling

Precision is a leading provider of safe and high performance, high-value services to the oil and gas industry. Precision Drilling offers an extensive fleet of highly efficient Super Series drilling rigs. Precision has partnered with several industry leaders to develop its full technology suite, which delivers efficient, predictable, and repeatable results through enhanced drilling performance.

Website: www.precisiondrilling.com

CERIN Report: Precision CERIN Report

Technology Description

Two of Precision Drilling's rigs were upgraded in two phases, with phase 01 comprising an upgrade from conventional bi-fuel systems on three generators to the latest Dynamic Gas Blending® (DGB) systems. The DGB system was then paired with a Smart Engine Management System (SEMS), allowing automatic start and stop generators. Phase 02 included the addition of three Caterpillar lean burn 100% natural gas G3512 engines for power generation and a 1 MW Energy Storage System (ESS) to manage the transient power demands of the rig efficiently. The natural gas generators and ESS were combined to make a mobile natural gas power unit controlled by the SEMS software. See Figure 23 below for the Natural Gas Power Generation and ESS.

Figure 23: *Natural Gas Power Generation and ESS Container and Trailer.*

Technology Deployment

The natural gas power unit, ESS, and SEMS were successfully integrated into both upgraded drilling rigs and deployed and studied at Tourmaline well sites for approximately one year. 27 wells were drilled with the new natural gas mobile power system. Performance was compared to 36 wells that were drilled with engines equipped with conventional first-generation (non-dynamic blending) bi-fuel systems.

Observations, Conclusions, and Next Steps

Initial performance targets were met or exceeded. The backup DGB generator was utilized only 4% of the time. Improved energy management reduced engine run hours by 30%. Figure 24 shows a key output from this study – the decrease in diesel consumption on the project rig compared to a baseline drilling rig. With natural gas having a lower GHG emission factor than diesel, reduced diesel usage translates to overall lower GHG emissions. Within this project, GHG emissions were reduced by 39%, or 3,650 tonnes/year/rig, based on 343 operating days per year.

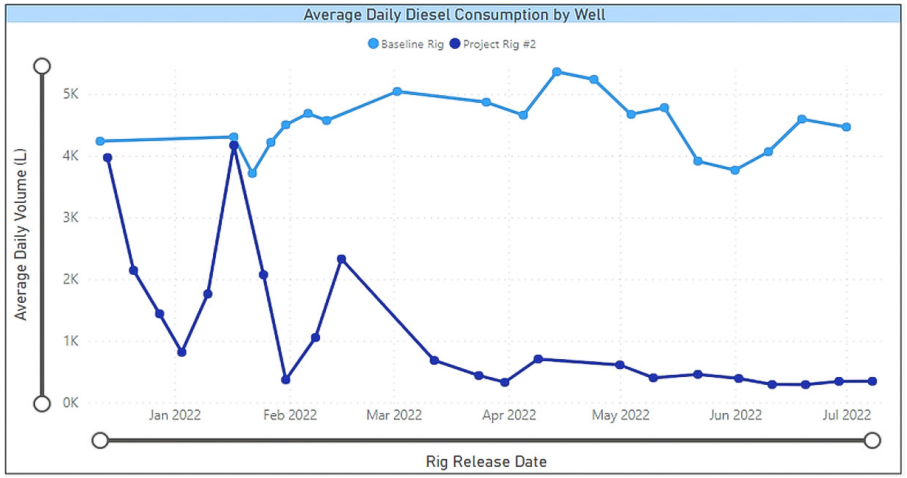


Figure 24: *Average Daily Diesel Consumption - Precision Baseline Rig vs. Project Rig.*

The next steps will focus on improving system reliability and battery efficiency, followed by full-scale commercialization. A key to understanding this technology's total GHG mitigation aspect is to have a better measurement of methane slip in the engine exhaust, which can be accommodated in future testing at the ETC.

19. Trican

Trican is a leading energy service company headquartered in Calgary, AB. Trican provides a comprehensive array of specialized services, including fracturing, cementing, and coiled tubing.

Website: www.tricanwellservice.com

CERIN Report: Trican CERIN Report

Technology Description

Field comparison of Caterpillar 3512C Tier 2 to Caterpillar 3512E Tier 4 engines in well fracking applications. Both engines are fueled by a combination of diesel and natural gas. The Tier 2 engine blends natural gas into the intake air and direct injection of diesel. Tier 4 engines inject natural gas directly into the intake port and direct injection of diesel, with the desire to maximize the displacement of diesel with natural gas to reduce costs and emissions.

Technology Deployment

The project was executed in the Gundy field north of Fort St. John, British Columbia, in January 2022 on an 8 well pad. Fuel and emissions measurements were completed at various engine operating points to map a range of fuel consumption and emissions profiles for both engine types. The goal of the study was to evaluate the Tier 4 engine (more efficient

gas substitution design) against the previous Tier 2 model.

Observations, Conclusions, and Next Steps

Tier 4 engines achieved consistently higher natural gas substitution with less variability across different engine loads compared to Tier 2 engines. Figure 25 shows that diesel consumption is lower for the Tier 4 engine (i.e., cleaner burning fuel with more CH_4 substitution), and Figure 26 shows that the methane slip also appears to be lower for the Tier 4 engine as well. These methane slip numbers were measured using discrete samples, and better measurements of methane slip can be made in the future with the integration of the ETC - CEMS unit.

Overall, the improvement that was observed for the Tier 4 engine consisted of an additional 14-18% natural gas consumption and an average 60% reduction in diesel consumption when comparing the highest-substitution scenarios. Tier 4 engines reduced methane slip by an average of 46%. Tier 4 engines reduced overall GHGs by about 20% over the operating points evaluated. Tier 4 engines also showed an average fuel efficiency improvement of 21% over Tier 2 engines.

In terms of the Tier 4 engine, an improvement was observed that involved an additional 14-18% substitution of diesel with natural gas. Furthermore, in comparing the highest substitution scenarios, there was an average reduction of 60% in diesel consumption.

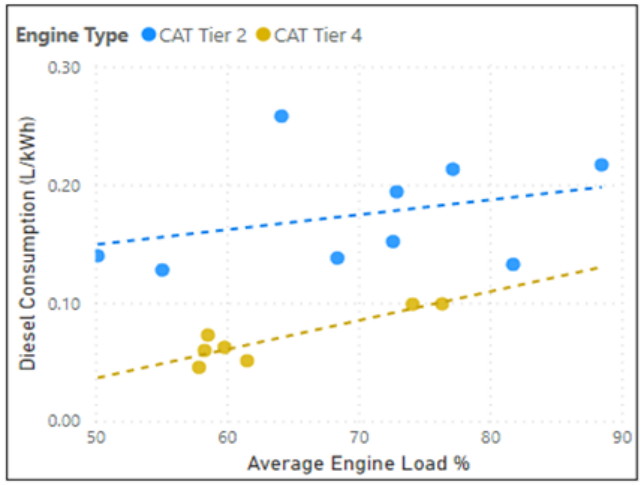


Figure 25: *Normalized Diesel Consumption as a Function of Engine Load (Tier 2 vs. Tier 4 engines.)*

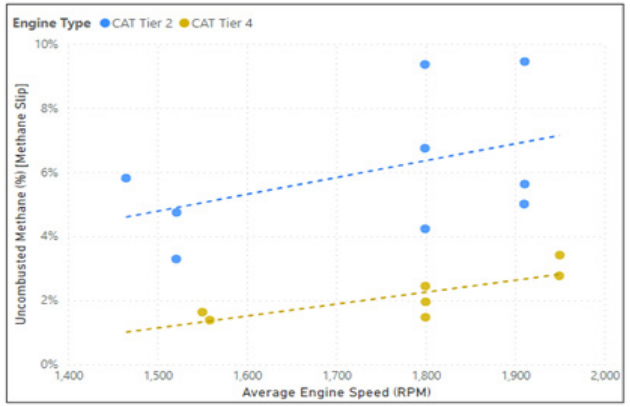


Figure 26: *Calculated Un-Combusted CH_4 as a Function of Engine Speed (Tier 2 vs. Tier 4 engines.)*

Impact : Methane Emissions Reduction

Impact: Methane Emissions Reduction

The Government of Canada has established ambitious targets for methane emissions reduction, with plans to enhance these targets in the coming years. Modern West Advisory, a consortium partner, independently conducted an assessment of the current landscape and generated the table presented in Table 4.

Table 4 shows the 2021 methane emissions by source category, estimated by Modern West Advisory (MWA)[1].

Emissions Source Category	2014 AB Methane Emissions (Mt CO_2e)	2021 AB Methane Emissions (Mt CO_2e)
Pneumatics	9.6	5.5
Routine Venting	7.0	2.8
Methane Slip – Fuel Combustion	3.0	2.7
Fugitives	3.1	1.6
Surface Casing Vent Flow/ Gas Migration	1.2	0.9
Methane Slip – Flaring	0.8	0.8
Compressor Seals	0.6	0.4
Spills & Ruptures	0.9	0.3
Glycol Dehydrators	0.9	0.2
Total	27.1	15.3

Table 4: *Alberta's 2021 Methane Emissions by Source Category*

1 MWA, "Methane Mitigation Pathways Part II: Future Drive to 75". Prepared for Alberta Innovates, June 20, 2023.

The table illustrates a substantial reduction in routine venting, pneumatics, and fugitive emissions. This reduction is chiefly attributed to technological advancements in these areas over the past few years. High-bleed devices have been replaced with low-bleed devices, and Government grants for tank Vapour Recovery Units (VRUs) have made their implementation more cost-effective, leading to a significant decrease in venting. Additionally, improved emissions detection of fugitive sources has empowered operators to identify and rectify issues at an unprecedented rate. The NGIF ETC Program exists as a platform for de-risking these technologies and providing a pathway to commercialization and widespread adoption that will be needed to reach these targets.

1. Pneumatic Venting Emissions Reduction

Opportunity: The largest methane source in 2021 is from natural gas-driven pneumatic equipment. The NGIF ETC Program has done significant work in advancing technology towards no-bleed devices. A significant focus of the NGIF ETC program from 2021 to March 2023 has been on testing technologies for reducing pneumatic venting at remote well site facilities. As previously discussed, the NGIF ETC Program trialled three instrument air compressor packages, one non-emitting electric actuator, and two multiphase flow meters. Technology reliability is key and needs long-term deployment for testing, ideally at multiple locations. The NGIF ETC Program provides this capability and the sharing of test results, which is valuable for the rollout of successful technologies to other potential customers.

Gap: Moving forward, it should also be emphasized that although

advances have been made, technology trials of pneumatic vent elimination in live operations require further testing. These devices serve a critical role in operations and, as such, must meet rigorous safety and reliability standards to promote widespread adoption.

2. Tank Venting Emissions Reduction

Opportunity: Source identification and technology barriers may prevent routine venting from being completely eliminated. Vapour Recovery Units (VRU) are used to capture and compress associated gas in the tank's headspace. The focus currently is on cheaper and better vapour recovery systems and thief hatches.

Gap: VRUs can be prone to leakage and require regular maintenance. VRUs may not be economical solutions for single tanks with low associated gas production[2]. In situations with low vent gas volumes, current VRU systems can paradoxically increase emissions, as the energy required to operate the compressor may exceed the environmental benefits of capturing the small volume of gas.

Consequently, the development of position monitors for thief hatches is crucial. Progress has been made in improving thief hatch technology, with ongoing deployment showing promising results. Self-sealing thief hatches and position monitoring eliminate the need for operators to work at heights (improved safety), lower emissions, and lower costs. Further testing is required to maintain the safety function of the hatches. More work is needed to bring these technologies to commercial viability.

3. Methane Destruction

Opportunity: Incinerators and enclosed combustors destroy captured vent gas, with destruction efficiencies greater than 99%. These technologies are smaller and more compact than a flare stack.

2 *Sentio Engineering, 2015*

Also, where flares must be at least 25m from processing equipment and storage tanks[3], enclosed combustors can be as close as 10m from processing equipment and storage tanks. Combined, enclosed combustors could be a cost-effective option for flares and are considered a good option when gas conservation options are not available.

Gap: The efficiency and performance of these systems are critically dependent on gas flow rates. A significant challenge lies in broadening the applications for this technology. The NGIF ETC Program is actively inviting companies to explore and develop technologies geared towards mobile gas destruction, especially for scenarios like blowdowns, showcasing a commitment to fostering innovative, versatile, and efficient solutions for emission management.

4. Methane Slip Emissions Measurement and Reduction

Opportunity: Methane slip, a source of emissions from reciprocating engines, results from a balance between NOx and CH_4 in engine exhaust. Leaner burn engines, with excess O_2, emit less NOx but more methane compared to oxygen-starved, rich burn engines. Newly designed engines meeting US EPA Tier IV standards exhibit significantly lower methane emissions, e.g., The proof-of-concept tests with Trican-operated Tier II and Tier IV engines demonstrated a nearly 50% reduction in methane slip and a 20% overall GHG reduction using the newer Tier IV engines.

Gap: Understanding methane slip is still in its early stages, lacking baseline assessments, long-term detection techniques, and commercially available mitigation technology. The factors contributing to increased methane slip from a daily maintenance perspective remain relatively unknown. In response, the NGIF ETC Program has commissioned a mobile CEMS trailer to investigate and quantify this phenomenon.

3 *Alberta Energy Regulator, 2022a*

This initiative aims to rapidly advance the reduction of methane slip in current and future engine models.

Furthermore, the NGIF ETC Program is exploring early TRL post-combustion catalysts to assess their potential in reducing methane slip from existing engine exhausts.

5. Fugitive Emissions Reduction

Opportunity: Fugitive emissions often arise from faulty seals, equipment leaks, or infrastructure ill-suited for the use case. The primary solution approach for most producers is a leak detection and repair program. However, current technologies require investment to enhance response time and better quantify the location, volume, and quantity of emissions. The NGIF ETC Program has made significant strides by exploring aerial and continuous monitoring solutions.

Gap: Although detection capabilities have improved, increased testing will enhance both the localization and quantification of sources. The new CREEW is designed to release known gas quantities from single or multiple points to evaluate the efficacy of detection and quantification technologies.

Path Forward

Path Forward

For this reporting period (March 2020 – March 2023), 21 site users (19 reported) conducted technology testing and validation projects, with 37 individual projects completed under the NGIF ETC Program. The development and deployment of these technologies, among others, have supported the 45% federal methane emissions reduction targets. Many of the near-term opportunities are being implemented: running efficient production systems, operating pneumatics with air or electricity versus methane, capturing methane as a valuable product rather than venting it, reducing tank venting, and starting to quantify and reduce methane slip from natural gas combustion engines.

These tests have achieved significant Key Performance Indicators (KPIs), such as enhanced detection accuracy, emission reduction effectiveness, job creation, and revenue growth. As an example, two companies participating in the NGIF ETC Program have already created more than 100 new jobs and achieved revenue growth exceeding $38 MM CAD from 2021 to 2023.

With the foundation of this success, the NGIF ETC Program path forward will build its capacity as a centre of excellence by addressing key areas below and offering:

- **New technologies are required to meet stringent emissions targets:** Technology will be critical to meet increasingly stringent environmental standards. The challenges in achieving even further reductions (e.g., the 75% reduction target) will be great, as many of the required technologies are yet to be developed. Accelerating the pace of technology testing and driving towards scientifically rigorous outcomes will be key to rapid commercial adaptation. The bias will be towards new versus incremental technologies.
- **Rigorous multi-season testing is required to derisk technologies for commercial deployment:** The devices tested would serve critical roles in operations and, as such, must meet rigorous safety and reliability standards to promote widespread adoption across the oil and gas industry. While advances have been made to technologies in the key opportunity areas indicated above, further testing and technology assessment in live operations is required.
- **Deploy methane management technologies at scale across the gas value chain to achieve material emissions reductions:** To date, the NGIF ETC Program has focused on de-risking individual technologies. However, to achieve material emissions reductions, technologies must be adopted at scale across the natural gas value chain and at multiple operator sites. The NGIF Accelerator is uniquely positioned to foster the collaboration required to disseminate information from the test programs and provide access to the broader gas industry.
- **Support the development and sharing of certification best practices and standards:** The NGIF ETC Program is administered by the NGIF Accelerator. As an independent not-for-profit organization, NGIF Accelerator can work across national and international jurisdictions to share best practices and support the development of standards and protocols for the detection, measurement, and mitigation of methane emissions.
- **Collaborate to expedite commercial deployment:** The early

successes achieved under the NGIF ETC Program must continue to broaden adoption to deliver benefits at scale. Collaboration is key for these companies to build trust across government, industry, or academic partners.

- **Train highly qualified personnel to provide safe, reliable, low-emissions energy into the future:** The development and deployment of advanced methane management technologies will require collaboration between skilled personnel trained across multiple disciplines.
- **Digital technologies will help accelerate technology development and deployment:** Methane management technologies rely on a wide array of digital technologies to calibrate, quantify, predict, and scale technological solutions. Digital technologies continue to transform gas operations with new opportunities. The academic personnel in the NGIF ETC Program are at the forefront of applying digital tools to help accelerate commercialization.

The ambitious goal of a 75% reduction in emissions by 2030 presents a formidable challenge for the energy sector. Central to overcoming this hurdle is rapid technological innovation and adoption, at a pace without precedent. For context, consider the telephone's evolution: transitioning from landlines to cellular phones took nearly 90 years, and even then, not all U.S. households adopted landlines. In stark contrast, current regulations require the immediate, industry-wide adoption of nascent technologies, effectively skipping over the gradual development stages typical of oil and gas technology. This scenario is akin to developing a smartphone before the invention of the landline phone.

The NGIF ETC Program plays an indispensable role in addressing this challenge. It offers an unparalleled platform for the rapid development of technology, enabling small and medium-sized enterprises to innovate, test, and refine their solutions through the "free-to-user" model. This unique approach has significantly contributed to achieving a 45% methane reduction target and positions the NGIF ETC Program as a crucial player in the industry's effort to meet the new 75% reduction target by 2030. The NGIF ETC Program facilitates the development of innovative, safe, reliable, and accurate technologies, ensuring their widespread adoption across the industry.

The federal and provincial governments' long-term vision and funding has been instrumental in the early success of the NGIF ETC Program as a "free-to-user" test platform spanning lab to live operating environments. The continued operation and support of the NGIF ETC Program are critical for meeting the upcoming, more stringent federal and provincial methane reduction targets. The path forward is characterized by an urgent need for swift and effective technological advancement and deployment at scale. By ensuring the NGIF ETC Program continues to receive the necessary backing, we create an ecosystem where emerging methane reduction technologies can be cultivated, verified, and implemented on a scale that aligns with both environmental objectives and the sustainable advancement of the industry.

Appendix A

Contributors and Acknowledgements

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Appendix B

Description of the NGIF ETC Program Tourmaline Field Testing Sites Measurement Category: Engine Exhaust

Engine exhaust can contain unburnt fuel, often referred to as “methane slip.” This can be difficult to detect and quantify since the concentration of methane is relatively low and the exhaust gas plume is elevated, hot, and at high velocity. To accurately quantify methane slip in each engine, a mobile Continuous Emission Monitoring System (CEMS) was constructed and delivered to Tourmaline in November 2022, field-tested and debugged over the next year, and finally commissioned in September 2023.

The CEMS is installed in a mobile trailer, which allows it to test all four engines at the Hub as well as other engines at Tourmaline sites. Figure 27, shows the mobile CEMS trailer installed by two engine exhausts at the Hub.

CREEW

CREEW is a gas multiwell battery with engineered venting. Sweet-produced gas from one well is vented through a series of gas-driven pneumatic pumps that circulate methanol in a closed loop. The release rate is controlled by turning on and off the number of pneumatic pumps. This allows for a venting rate variation between 5 – 300 m^3/day.

This site contributes to the advancement of the NGIF ETC Program in enhancing emissions detection technologies by offering known emissions from single or multiple sources. These tests enable technology providers to refine their solutions, ensuring accurate quantification and localization of emissions under operational conditions with background noise generated by the combustor.

Figure 28 is an image of the CREEW. The site has up to four vent release points, so technologies trialed at the site can be tested for their ability to quantify total release rates along with localized emission rate detection. The individual vent locations are metered but not controlled, so the split between vent locations can be recorded but not set as part of the test.

Figure 27: *CEMS Mobile Trailer at the Hub.*

Figure 28: *CREEW: Aerial Shot of the Facility.*

Appendix C

GLOSSARY OF TERMS:

altFEMP – Alternative Fugitive Emissions Management Program

CEMS – Continuous Emissions Monitoring System

CREEW – Controll Release East Edson Wellsite

CRS – Controlled Release Site

D&C – Drilling & Completions

DGB – Dynamic Gas Blending (partial replacement of diesel with natural gas in D&C engines)

EPOD – Engineered Power On Demand (product of Convrg Innovations)

ESS – Energy Storage System (a component of the Precision Drilling engine design)

GoA – Government of Alberta

IC – Internal Combustion

SEMS – Smart Engine Management System (a component of the Precision Drilling engine design)

SMA – Shape Memory Alloy (the basis for Kinitics Automation electric valve actuator)

SRCRS – Spirit River-Controlled Release Site

TDLAS – Tunable Diode Laser Absorption Spectroscopy

TRL – Technology Readiness Level (i.e., a measure of where technology sits in its development from concept to commerciality)

UPS – Uninterrupted Power Supply

VRU – Vapour Recovery Unit (installed to control venting emissions from liquid storage tanks)

WWL – West Wolf Lake Gas Plant (i.e., the main NGIF ETC Program live testing centre for emissions monitoring technology)

Questions?

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