Emissions Testing Centre Program

PERFORMANCE REPORT 2022 – PART I

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Special acknowledgement

NGIF Capital would like to gratefully 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).

NGIF Capital would also like to acknowledge the in-kind contribution and assistance provided by the University of Calgary, Tourmaline Oil Corp. (Tourmaline) and Perpetual Energy (Perpetual). Each has provided host sites, resources, and valuable insight respectively into the program's laboratory validation and live site testing of clean-tech startups and their methane solutions for the gaseous energy industry.

John Adams
President and CEO
NGF Capital

Message from the CEO

I am pleased to share our NGIF Emissions Testing Centre Program 2022 Performance Report. This report will be one of two reports that outlines our key achievements under the funding we received from Natural Resource Canada.

NGIF Emissions Testing Centre Program is one of two programs operated by NGIF Capital. NGIF Capital is a Canadian venture capital firm offering grant and equity financing for cleantech startups that deliver clean technological solutions to the environmental challenges and other types of challenges facing the natural gas sector. NGIF Capital operates the Industry Grants Program, the Emissions Testing Centre Program, and a venture capital fund, Cleantech Ventures Fund I.

The NGIF Emissions Testing Centre Program is a $28MM industry-led methane emissions testing platform for multiple startups to validate their solutions in a simulated and live gas operations environment. With financial support from Natural Resources Canada provided by CERIN and in-kind support provided by our partners, the University of Calgary and Tourmaline/ Perpetual, we have been able to bring the NGIF ETC to life.

The NGIF ETC Program is one-of-a-kind and truly unique. This plug-and-play instrumented platform for both simulated emissions testing and live testing at an operating gas facility will allow clean-tech startups to validate their technology to detect, quantify, and control methane emissions. The simulation host site at the

University of Calgary lab provides controlled testing and HQP support in data analytics and reporting, while the live field host sites operated by Tourmaline/ Perpetual provide an avenue for cleantech startups to validate their technology in a real-world setting.

An operational team came together from a syndicate of stakeholders to plan and design this first-of-kind initiative. This started from the time funding was approved in January 2021 until the program became fully operational in November 2021. It involved the engineering, construction, installation, and commissioning of equipment to continuously measure methane releases from tanks, compressor vents, engine exhaust, and flare systems. Over twenty cleantech projects are currently ongoing at the simulation site and live sites of the NGIF ETC, with a minimum of 20 to 30 startups in the pipeline for 2023 and beyond. The main activity in the fiscal years 2020-21 and 2021-22 was the design, construction, and commissioning of the ETC testing sites and the ETC program. The current report focuses on the development of the ETC.

We thank NRCan for the financial funding and commitment. We are also appreciative of the in-kind support from Tourmaline, Perpetual, and the University of Calgary, without which the NGIF ETC would not be brought to life. We are excited about the future of the NGIF ETC, one where cleantech solutions that have been validated at our controlled and live sites go on to commercialization and reduce methane emissions.

John Adams
President and CEO
NGIF Capital

About NGIF Capital

Who is NGIF Capital?

- NGIF Capital is a subsidiary of CGA Enterprises, a wholly-owned subsidiary of the Canadian Gas Association.
- We have offices in Ottawa, Calgary, and Montreal.
- We offer both grant and equity financing for startups with environmental performance solutions for natural gas, renewable natural gas, and hydrogen.
- We connect energy leaders with innovators in the space, scaling startups from concept to commercialization.
- We focus on technology validation, industrial demonstration, and customer creation.

NGIF Capital is an early-stage venture capital firm for the gaseous energy sector

NGIF Capital operates:

Industry Grants Program

$22MM

Emissions Testing Centre Program

$28MM

Cleantech Ventures Fund I

$55MM

Our Team

BRING TOGETHER BEST-IN-CLASS TALENT

NGIF Capital has built a team of 15 professionals speaking 14 languages with subject matter expertise in natural gas operations, venture capital, engineering, law, finance, communications and technology development.

BACK ROW

Jonathan Bryan
Technical Director, NGIF Emissions Testing Center

Ashutosh Pohary
Senior Manager, Contracts

Milan Karan
Lead, Systems Architect & Administrator, NGIF Capital Corp.

Ali Ali
Lead, Contracts and Partnerships, NGIF Industry Grants

Saad Sarfraz
Manager, Technology and Evaluations, NGIF Industry Grants

Akhil Abat
Venture Partner

Isaac Da Silva Aboo
Principal and Director, Legal Affairs

Michael Hebert
Principal, Venture Capital, NGIF Cleantech Ventures

Abdul Qadir
Director, Finance, NGIF Capital Corp.

FRONT ROW

Ayoola Ajibare
Communications Coordinator, NGIF Capital Corp.

Rosalby Guerrero-Mesia
Coordinator, Investment Process, NGIF Industry Grants

John Adams
Managing Partner, NGIF Cleantech Ventures

Daniely Molero
Executive Assistant to the President and CEO & Board Secretary

Glory Haruna
Accounting & Office Management Coordinator, NGIF Capital Corp.

BY THE NUMBERS

15
Full time employees

38
Average age

14
Languages

15
Team members with university degrees

Meet our People: CEO and Managing Partner

John, President and CEO of NGIF Capital and Managing Partner of Cleantech Ventures, brings 30 years of experience in cleantech, management, venture capital, and finance.

He has led the development of NGIF Capital's integrated investment platform growing startup companies from concept to commercialization. In addition, John holds several board positions including:

- Board and Audit and Finance Committee Member of the Clean Resource Innovation Network (CRIN).
- Board and Audit Committee Member for Tidewater Renewables (TSX: LCFS).
- Board and Observer seats on several Cleantech Ventures portfolio companies.

John earned his bachelor's degree from the University of Toronto in Environmental Science, is a graduate of the Berkley Venture Capital Executive Program, and was awarded several distinctions such as World Biz Magazine's 2021 Global Top 100 Innovation CEOs (#2) and Canada's 2022 Clean50.

John Adams

President & CEO, NGIF Capital
Managing Partner, Cleantech Ventures
Ottawa, ON and Calgary, AB

"At NGIF Capital, we are leading a new way to think about venture capital. We've taken on early stage cleantech investing and re-imagined how strategic energy investors can work together as a group.

We have created a successful startup model that has broken new ground on validation, customer creation and product-market fit.

By putting our investors at the center of what we do, we can increase the performance of an entire sector that will benefit society."

Meet our People: Investment Team

Our investment team across North America is made up of **hand-picked, dedicated investment professionals**.

Collectively, they have decades of experience in cleantech, natural gas operations, venture capital, investment banking, engineering, law, and technology.

Akhil Abat
Venture Partner
Calgary, AB

Michael Hebert
Principal
Calgary, AB

Isaac da Silva Aboo
Principal and Director,
Legal Affairs
Montreal, QC

New Hire
Analyst
Calgary, AB

New Hire
Analyst
Location TBD

New Hire
Associate
Location TBD

Meet our People: Grants Team

Our grants team oversees the full Industry Grants management lifecycle and Emissions Testing Centre program. Collectively, the team is comprised of technical experts in mechanical and chemical engineering, greenhouse gas qualification, technology evaluation, and project management.

New Hire
Director,
Industry Grants
Calgary, AB

Jonathan Bryan
Technical Director
Calgary, AB

Saad Sarfraz
Manager, Technology
Intake & Evaluation
Calgary, AB

Ashutosh Pohary
Senior Manager,
Contracts
Calgary, AB

Ali Ali
Lead, Contracts &
Partnerships
Calgary, AB

Samaneh Ashoori
Senior Analyst,
Technology Evaluation
Calgary, AB

Meet our People: Operations Team

Our operations team members represent the corporate, administrative, systems, and communications function of the organization.

Collectively they have experience in communications, finance, accounting, social media, executive assistance, and administrative matters.

Abdul Qadir
Director, Corporate Finance & Accounting
Calgary, AB

Milan Karan
Lead, Systems Architect & Administrator
Calgary, AB

Rosalby Guerrero Messia
Coordinator, Investment Process
Ottawa, ON

Ayoola Ajibare
Communications Coordinator
Calgary, AB

Daniely Molero
Executive Assistant to the President and CEO and Board Secretary
Ottawa, ON

Glory Haruna
Accounting & Office Management Coordinator
Calgary, AB

Dini Philip
Communications Coordinator
Calgary, AB

New Hire
Social Media Coordinator
Calgary, AB

Ali Tarar
Manager, Finance and Accounting
Calgary, AB

NGIF Capital
Industry Leadership

NGIF Capital is unique as it brings energy industry leadership and industrial validation to its cleantech investments.

INDUSTRY GRANTS PARTICIPANTS

- Mitsubishi Corporation
- PNG Pacific Northern Gas
- Perpetual Energy
- Petronas
- SaskEnergy
- Shell
- Tidewater Midstream and Infrastructure Ltd
- Tourmaline
- APEX Utilities Inc
- ATCO
- Birchcliff Energy
- Canadian Natural
- Enbridge Life Takes Energy
- FortisBC

EMISSIONS TESTING CENTRE CONSORTIUM

- Alberta Innovates
- CERIN Canadian Emissions Reduction Innovation Network
- CCGA Canadian Gas Association / Association canadienne du gaz
- University of Calgary
- Natural Resources Canada / Ressources naturelles Canada
- Perpetual Energy
- Tourmaline

CLEANTECH VENTURES FUND I LIMITED PARTNERS

- ARC Resources Ltd.
- Birchcliff Energy
- Canadian Utilities Limited An ATCO Company
- FortisBC
- TC Energy
- Tidewater Midstream and Infrastructure Ltd.
- Tourmaline
- TriSummit Utilities

Cleantech Categories

NGIF Capital creates environmental performance with cleantech solutions that will reduce GHG emissions, criteria air contaminants, freshwater use, and land disturbance.

Our specific cleantech categories include:

- Hydrogen Production
- Renewable Natural Gas
- Carbon Capture, Utilization, and Storage
- Methane Mitigation
- Emissions Monitoring
- Energy Efficiency
- Heat and Power Generation
- Fuel Switching
- Natural Gas Production and Recovery
- Digital Transformation
- Transportation Mobility
- Value-Added Products
- Waste Heat Utilization
- Water Management
- Land Reclamation

NGIF Emissions Testing Centre Program

Testimonials

Scott Volk
Tourmaline Oil Corp.

"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 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 provides a unique opportunity to test and develop the best, emerging technologies while collaborating with our peers and elevating our industry as a whole."

Ian Gates
University of Calgary

"The NGIF ETC lab at the University of Calgary 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."

Bryan Cawthorn
Bluestar

"It has been a tremendous opportunity to participate in the design, construction, and commissioning of the NGIF ETC – a first for Canada and the natural gas production industry."

Jackson Hegland
Modern West Advisory

"The NGIF ETC is a unique initiative that brings together industry, cleantech service providers, and academia. It is critical to ongoing and future emissions management activities. And the NGIF ETC supports Canada's leadership with respect to methane management. Working with NGIF has been a pleasure, and we look forward to the continued growth of the ETC initiative."

Our Roots – The Canadian Gas Association and NGIF Capital

The funding agreement contract is between Natural Resources Canada and the Canadian Gas Association under its subsidiary company NGIF Capital hereafter referred to as NGIF.

The Canadian Gas Association (“CGA”) and its member companies have been front and center in driving the innovation agenda for decades, while they ensure the delivery of reliable, affordable, clean energy services. In September 2016, the CGA created the in-house Natural Gas Innovation Fund to focus its innovation agenda and targeting support for cleantech innovation in natural gas. In 2020, CGA created CGA Enterprises. Subsequently, under CGA Enterprises, a new corporate entity called NGIF Capital Corporation (“NGIF Capital”) was established in 2021.

NGIF Capital is a Canadian venture capital firm offering grant and equity financing for cleantech startups with solutions for the natural gas sector.

NGIF Capital is unique as it brings Canada’s energy industry leadership to every investment taking startups and their ideas from concept to commercialization. Unlike other VCs, NGIF Capital has strong connections to every part of the gas value chain offering it a means to test, develop, and accelerate customer creation. NGIF Capital operates NGIF Industry Grants (the original Natural Gas Innovation Fund), the NGIF Emissions Testing Centre, and the NGIF Cleantech Ventures.

Executive Summary

The NGIF Emissions Testing Centre is a program to de-risk and validate new, pre-commercial technologies that detect, quantify, and control methane emissions. NGIF ETC was formed under the Canadian Emissions Reduction Innovation Network (CERIN), which was established by Natural Resources Canada (NRCan) and Alberta Innovates (AI). NRCan has provided $8.25MM in funding till March 31 st, 2022.

Depending on the Technology Readiness Level (TRL), de-risking and validation of a new technology can be done in the controlled environment of a laboratory or at an operating natural gas production facility. The NGIF ETC includes both the laboratory facility hosted by the University of Calgary (UCalgary), and operating field sites hosted by Tourmaline Oil Corp. (Tourmaline).

NRCan funding is directed to the Canadian Gas Association (CGA), and NGIF runs the program on behalf of CGA. The program is also carried out by the two main funding Ultimate Recipients, University of Calgary, and Tourmaline. The NGIF ETC program covers the following activities:

- Instrumentation for emission measurement and quantification at Tourmaline's field sites, including the main test site at the West Wolf Lake (WWL) gas processing plant that is jointly owned by Tourmaline and Perpetual, and operated by Tourmaline.
- Development of NGIF ETC Laboratory at the University of Calgary, including a custom Controlled Release Chamber and custom Controlled Temperature Chamber.
- Testing and evaluating pre-commercial technologies to detect, quantify, or control methane emissions.
- Data management, staff, and support services.

The NGIF ETC focuses on five Emission Source Areas. New technologies must align with one or more:

Area 1 – Fugitive leaks
Area 2 – Emissions from flare systems
Area 3 – Vents from liquid storage tanks and compressors
Area 4 – Wellsite facility vent emissions
Area 5 – Well Drilling and Completions (D&C) emissions

NGIF ETC has developed a stage-gated process to intake pre-commercial technologies, provide them access to testing and validation at either the UCalgary's controlled laboratory or Tourmaline's operating sites, and record and report on the results. Technologies are first identified through NGIF Industry Grants, NGIF Cleantech Ventures, NGIF Trusted Partners, Tourmaline's in-kind contributions, and through communications with subject matter experts.

In fiscal year 2021-22 projects have been initiated with 11 technology providers. In all cases, the work is ongoing and will continue through 2022. The technology providers, their technology focus area, and NGIF ETC Location are summarized in Table 1 below:

Technology Provider	Technology	ETC Location
Luxmux	Fixed perimeter sensor	Gas plant
Qube	Fixed perimeter sensor	Gas plant, wellsite vent
Kuva	Fixed sensor – tanks	Gas plant, wellsite vent
AltoMaxx	Drone sensor	Gas plant
LSI	Fixed wing aircraft sensor	Gas plant, wellsite vent
4Blue	OGI fixed perimeter sensor	Laboratory
Kinitics	Electric valve actuator	Laboratory
Packair	Instrument air compressor	Laboratory
Trican	CAT Tier 4 Engine	Wellsite D&C
Precision Drilling	Hybrid/Dual fuel engine	Wellsite D&C
Ensign Energy Services	Dual fuel engines	Wellsite D&C

***Table 1:** 2021-22 Technology providers running tests at the NGIF ETC*

Overview of the NGIF ETC

The NGIF Emissions Testing Centre is a 4-stage program to de-risk precommercial technologies that detect, quantify, and control methane emissions. The NGIF ETC was formed under the Canadian Emissions Reduction Innovation Network (CERIN), which was established by Natural Resources Canada (NRCan) and Alberta Innovates (AI).

In 2018, CERIN hosted a series of workshops to identify actions to improve the commercial development and adoption of new technologies for methane control in upstream oil and gas operations. A key finding from CERIN's work was that cleantech start-ups often faced challenges in getting their prototypes de-risked and validated in field applications. Furthermore, results from any field work were often siloed, preventing collaboration.

The NGIF ETC addresses both of these issues identified by CERIN. The NGIF ETC is a network of laboratory and field sites for technology evaluation and provides a data portal for public sharing of results. This technology testing program consists of the following steps:

- User intake into the NGIF ETC – understanding the emission driver for a given technology, determination of testing needs, work plans and KPI's, allocation to an appropriate testing site within the ETC.
- Technology testing either in the ETC Laboratory, one of the ETC field sites, or both.
- Reporting of results and data sharing.

4.1 The Five Focus Areas

In the fall of 2019, CERIN awarded NGIF $5.1M to develop the Emissions Testing Centre program. On January 13th, 2021, NRCan and the Canadian Gas Association (CGA) executed an Initial Recipient Agreement (CGA is the parent company of NGIF). CGA also signed an Ultimate Recipient Agreement with the UCalgary and with Tourmaline, the laboratory and field site hosts respectfully.

The Ultimate Recipient Agreements codify the eligible activities and scope of work, including Three Emission Source Areas as:

Area 1 – Fugitive leaks

Area 2 – Emissions from flare systems

Area 3 – Vents from liquid storage tanks and compressors

In March 2021, following extensive discussions with NGIF, Tourmaline and NRCan, the NGIF ETC program was expanded with an additional $3.15 million from NRCan, bringing the total funding to $8.25MM. Tourmaline also supplied commercial and precommercial technologies as 'in-kind' contribution. The new funding was to be used for two additional Emission Source Areas:

Area 4 – Wellsite vent emission quantification and control

Area 5 – Well Drilling and Completions (D&C) emission quantification and control

Approved eligible funded activities within the ETC program include:

- Instrumentation for emissions measurement and quantification at the West Wolf Lake (WWL) Gas Plant, which is jointly owned by Tourmaline and Perpetual, and operated by Tourmaline.
- Costs associated with the testing of emission detection, quantification, and control technologies at the NGIF ETC field sites.
- Development of the NGIF ETC Laboratory for controlled environment testing, and highly qualified personnel (HQP) provided by the University of Calgary's Global Research Initiative in Sustainable Low Carbon Unconventional Resources.
- Development of a data portal, to be used by all CERIN members (NGIF and PTAC) for uploading and sharing of results openly with engaged stakeholders.
- Support from key contractors/consultants and NGIF key staff salaries/ benefits and travel required to operate the NGIF ETC program.

Significant effort was required to complete the NGIF ETC engineering, procurement, and construction by November 1st, 2021. The WWL Gas Plant began technology evaluations in November 2021. The ETC Lab at the UCalgary was operational on July 1, 2021.

4.2 ETC Operational Model

The NGIF ETC is run through an Operations Committee, which consists of the following:

- NGIF ETC technical director – management of ETC program and cleantech company intakes.
- NGIF ETC Lab Coordinator and UCalgary HQP team lead – lab testing coordination and coordination of HQP team with ETC activities.
- NGIF ETC Field Site Host Operator (Tourmaline) – Innovation team at Tourmaline is responsible for coordinating all field testing and field data management.
- Modern West Advisory – Subject Matter Expert (SME) responsible for assisting with technology test planning, data analysis, and reporting of results.

The role of the Operations Committee is to review technology intake planning, coordinate the execution of tests, and have overall responsibility for managing reporting and data sharing from the ETC.

NGIF ETC has developed a stage-gated process designed to intake technologies, identify appropriate sites for technology testing, and generate reports specific to each technology.

This process is shown schematically in Figure 1

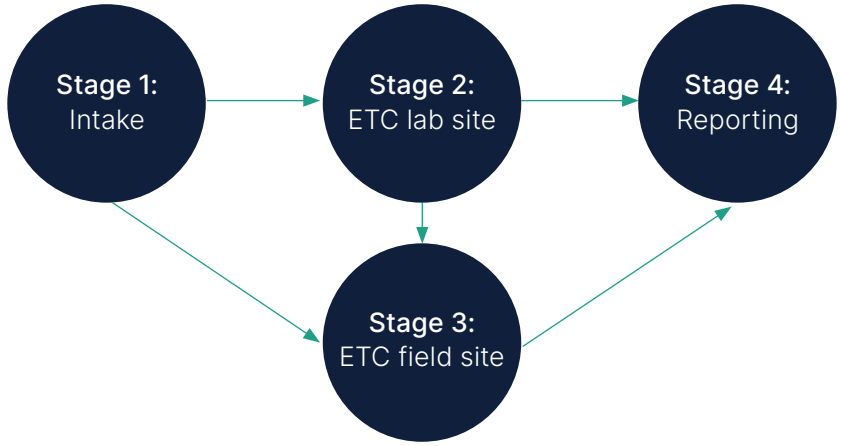

Figure 1: *NGIF ETC Program – Operational model*

Stage 1: Intake

Emerging technologies are identified as possible candidates for NGIF ETC deployment in several ways, summarized in Table 2.

Identification Methods	Technology
NGIF Industry Grants (NGIF IG)	NGIF IG hosts 2 cleantech funding competitions/ year; proposals for technologies that relate to methane detection, quantification or control may be steered to the NGIF ETC.
NGIF Cleantech Ventures (NGIF CV)	NGIF CV attracts and scouts for ventures with innovative clean technologies for natural gas on rolling basis. Technologies relating to methane detection, quantification or control may be steered to the NGIF ETC.
NGIF Trusted Partners	Trusted partners include NRCan, AI, ERA, BC ICE Fund, Geoscience BC, Innovation Saskatchewan, and OCI. Each Partner has ongoing funding programs that may include technologies that are within the scope for the NGIF ETC.
Other Deal Flow Channels	Cleantech companies can reach out directly to NGIF or its members in the NGIF ETC Operations Committee.

Table 2: *Technology identification methods*

It should be emphasized that the ETC program is a pathway for technology testing, where the actual tests are run at no charge to the site users. Any additional costs associated with technology development are not covered by ETC, hence cleantech companies generally get their funding through respective channels under the various intake pathways or would have to be self-funded.

Once a technology is identified, the company submits an NGIF Intake Form. See Appendix B. The Intake Form requires only non-confidential information. Each intake form is reviewed by the ETC Operations Committee (see Appendix C for current membership). The Operations Committee evaluates each technology on:

- The applicability for methane detection, quantification, and/or control in one or more Emission Source Areas, i.e., if the proposed technology test is within the mandate of the ETC.
- The Technology Readiness Level (TRL), to identify to which site the technology will be evaluated.
- Hazardous Area Classification and safe work practices.

The evaluation may benefit from one or more meetings between members of the NGIF ETC Operations Committee and each technology proponent.

If successfully screened, the Operations Committee will recommend the technology advance to either Stage 2 NGIF ETC Laboratory Evaluation (UCalgary), or directly to Stage 3 NGIF ETC Field Operating Site (Tourmaline). At this time, acceptance into ETC is formalized through a signed contribution agreement with CGA. This agreement includes a jointly negotiated test plan and the test performance criteria that need to be measured. Site access agreements are also signed with the cleantech site user and the NGIF ETC site hosts, which specify rules around requirements for site access and data ownership and sharing.

Stage 2: ETC UCalgary laboratory evaluation

Low TRL technologies can benefit from bench-scale testing performed at the University of Calgary. Examples of bench-scale testing planned or underway includes:

- Methane detection thresholds for new optical imaging cameras.
- Methane detection thresholds for new acoustic sensors.
- Reliability of control equipment at extreme temperatures or extended run times in a controlled environment, to prove prototype safety before expensive field trials.

See Section 5 and Appendix D for a fulsome description of UCalgary's laboratory.

As part of the intake process, the full testing goals and objectives are identified. The ETC lab works with the cleantech company site user to finalize a work plan and executes this testing plan. Upon completion of the testing, the technology may advance to Stage 3 and be deployed at one or more operating sites hosted by Tourmaline. Alternatively, the technology may bypass Stage 3 and advance to Stage 4 Results and Reporting.

Stage 3: Deployment at operating site(s) hosted by Tourmaline

Technologies that have successfully passed Stage 1, and sometimes Stage 2 as required, can be deployed for evaluation at one or more live field-testing sites hosted by Tourmaline. As with Stage 2 testing, the contribution agreement signed between the technology proponent and CGA will have laid out the test objectives, including a jointly negotiated test plan and the test performance criteria that need to be measured. The field site host (Tourmaline) will work with the site user on the development of a formal testing plan and will manage testing in the field, including providing field-based emissions numbers back to the site user.

Most technologies that detect, quantify, or control methane emissions will be evaluated over multiple trials or an extended period of time to capture performance during multiple seasons.

See Section 6 for a full description of the operating sites hosted by Tourmaline.

Stage 4: Results and reporting

A key attribute of the NGIF ETC is the sharing of data and results through documentation and reporting. The test plans developed in Stage 2 and Stage 3 will generate data that will be shared with the technology proponents. Stage 2 performance reports are typically written by UCalgary. Stage 3 performance reports are typically written by the technology providers themselves or by UCalgary HQP, with input and review by the ETC Operations Committee.

Reports may be for internal or external audiences. Internal reports contain all the testing details and results. Internal reports are shared between the site user, site host, and any funding stakeholders involved in the technology development. Internal reports are deemed confidential.

External reports are meant for a broader audience, provide a high-level overview, are free of proprietary information, and are deemed non-confidential. A public data portal was created (www.cerinprojects.ca) to share the reports.

4.3 Site hosts

4.3.1 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.

4.3.2 Tourmaline/ Perpetual

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.

Perpetual is a Canadian oil and natural gas exploration, production, and marketing company. Perpetual operates a diversified asset portfolio, including liquids-rich natural gas assets in the deep basin of West Central Alberta, heavy oil and shallow natural gas assets in Eastern Alberta, and longer-term opportunities through undeveloped oil sands leases in northern Alberta.

Tourmaline/ Perpetual as the host site is committed to supporting the ETC project by providing multiple sites for technology testing as well as personnel for coordinating safe and effective tests in the field.

Tourmaline believes the project is critical for evolving new technology and methodologies to continue materially reducing methane and other emissions over the entire EP business.

4.4 Support organizations

4.4.1 Bluestar Engineering Ltd.

Bluestar Engineering is a mid-sized EPCM firm based in Calgary, Alberta. As a long-time consultant to Tourmaline in the upstream Western Canadian gas industry, Bluestar was a natural fit to assist NGIF ETC in the construction of the industry-first Emissions Testing Centre, tied into Tourmaline's WWL gas plant.

In cooperation with NGIF and industry stakeholders, Bluestar was instrumental in the conceptual design, detailed engineering, and construction of the testing facilities. Throughout the design life cycle, Bluestar guided the technical feasibility and suitability of various measurement equipment and instrumentation. During the procurement and construction phase, with critical support from the NGIF ETC live host site partner Tourmaline, Bluestar worked closely with all contractors to safely complete all construction activities. Upon completion of construction, with the support of the Operations and Engineering teams from Tourmaline, Bluestar worked with critical contractors to successfully commission the NGIF Emissions Testing Centre.

4.4.2 Modern West Advisory, Inc.

Modern West Advisory (MWA) is a strategic consulting firm working with corporations across the energy, transportation, infrastructure, and mining sectors, government, industry associations, and clean technology providers on developing a low-carbon economy through carbon accounting and corporate ESG performance services. MWA is one of Canada's leading advisory service providers, with unique expertise in ESG strategy and reporting, greenhouse gas quantification and compliance analysis, global carbon markets, life-cycle analysis, scenario analysis, and cleantech R&D.

MWA provides technical advisory services to NGIF Capital and Tourmaline relating to methane detection, quantification, and control technologies. MWA has identified technologies for Stage 1 Intake, and has assisted in the development of Stage 3 test plans and field deployment, and reporting requirements in Stage 4.

4.5 2020-21 and 2021-22 ETC road map

The ETC project was formally awarded to CGA in May 2020. Initial discussions had been between CGA (through NGIF) and Perpetual, who were co-owners of the WWL gas plant, and at that time operated the plant. However, in the summer of 2020, plant operatorship transferred to Tourmaline, and the rest of 2020 was spent on detailed planning discussions around how the mandates of the ETC could be implemented safely in this live operating environment. As expected, adding pre-commercial technology testing capabilities to a live operation comes with a high degree of risk, and it was imperative for project partners (CGA and Tourmaline) and NRCan to all be clear about what could be done and what were the goals of the ETC.

The Contribution Agreement (CA) was signed between CGA and NRCan in January 2021, and work on the program began in earnest. During January 2021, CGA signed Ultimate Recipient agreements with the two ETC site hosts: University of Calgary and Tourmaline. The ETC consortium then identified two main contractors SME's to assist with the program: Bluestar Engineering as the EPC company, and Modern West Advisory as our emissions control technology advisor. The ETC also hired lab and field site coordinators to manage the flow of testing in both test centres. With all key people in place, the detailed design of the ETC began. The fiscal year 2020-21 ended with all agreements

in place and the planning of instrumentation within the ETC main testing centre (Tourmaline West Wolf gas plant) was completed to the level where detailed costing could be completed and budget allocated to start purchasing equipment.

Figure 2 shows the high-level timeline of the development of the ETC program. There was an unprecedented effort to plan, design, procure equipment and construct the main field test site (the WWL gas plant) all during 2021. This was made even more challenging due to delays in equipment fabrication and shipping, due to ongoing COVID constraints. The main ETC field site was not commissioned until the end of October 2021, and field technology testing could not begin until November 2021. The intake of technologies for the field started earlier, and it quickly became apparent that the field users had long-term usage needs, meaning that most field projects would have to run through 2022.

Commissioning of the ETC lab was completed by June 30, 2021, and tests at the lab commenced in July 2021. As with the field, technology intake discussions quickly showed that most lab users required multiple projects to be run, to properly advance their technologies. While individual lab projects are designed to be relatively short in time (i.e., 1 – 2 weeks running time), the ETC lab is designed to be customizable to each user, so set-up and preparation often takes much longer than the actual time spent testing the technologies with the site users.

In parallel, the development of the ETC program was ongoing throughout the fiscal year 2021-22. The ETC is not simply a lab and field test site, but the entire process of bringing in site users, building and executing test plans, and reporting results. Longevity discussions, and different models of operating the ETC as a long-term free testing platform, were also started towards the end of 2021 and are ongoing.

The work done in 2020-21 and 2021-22 was mainly focused on the development of the ETC program and the testing sites. The centre is now fully operational, so ongoing work is now related to the operations of the ETC – testing and reporting with current site users and bringing in new site users for 2022-23.

NGIF Emissions Testing Centre

PROJECT SCHEDULE

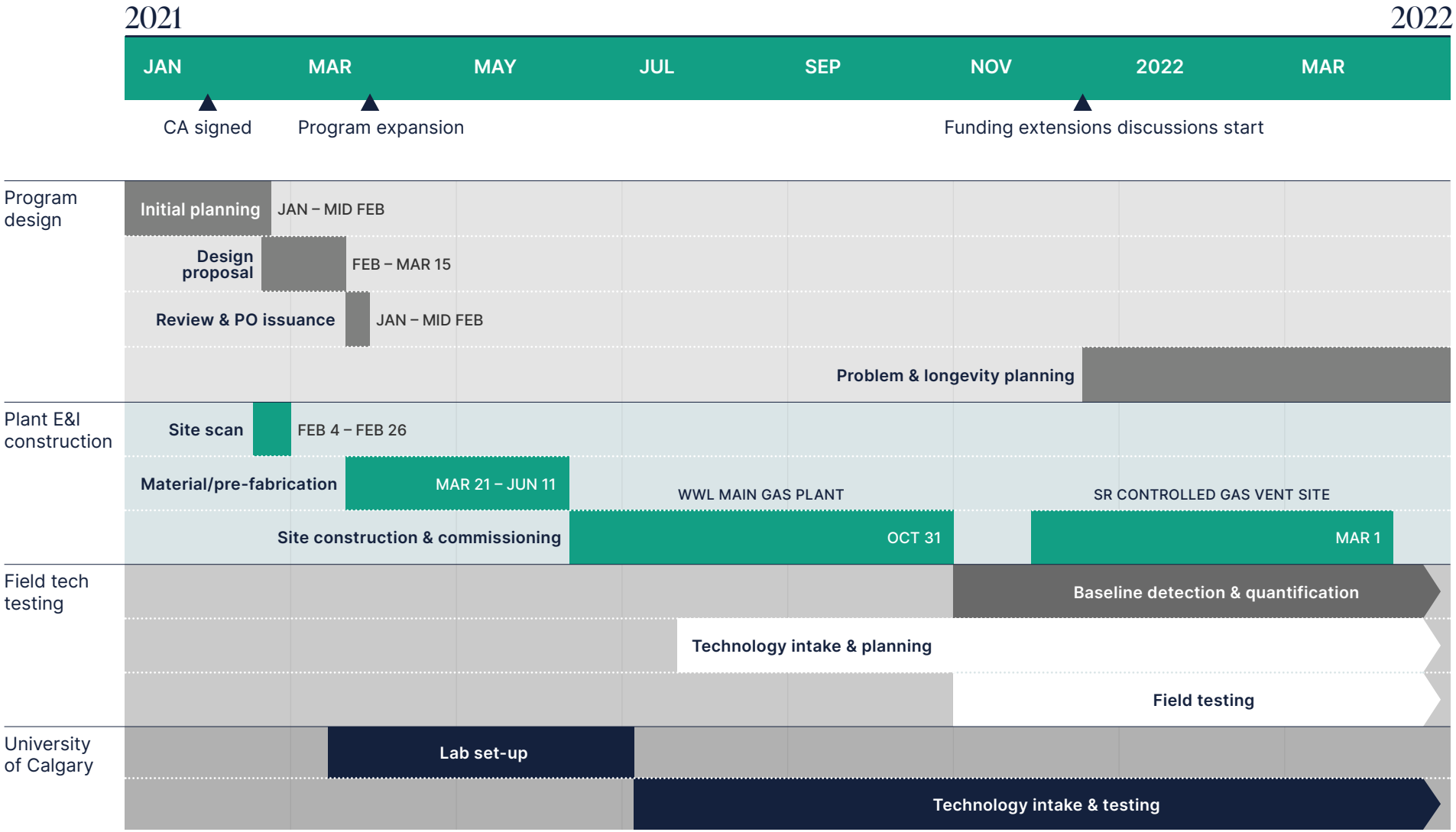

Figure 2: *ETC Program timeline up to March 2022*

ETC Laboratory

UCalgary Host Site Laboratory

Bench-scale testing and applied research will benefit cleantech startups that are in an early stage or with low TRL technologies. The University of Calgary has world-class capabilities in testing and research and is an integral partner in the NGIF ETC.

The NGIF ETC Laboratory is located at the University of Calgary's Research Park. It is run by Dr. Ian Gates, Professor, Department of Chemical and Petroleum Engineering at the Schulich School of Engineering. Assisting Dr. Gates are Nicole Calma, NGIF ETC Lab coordinator and main liaison between the ETC and external site users, and Dr. Jacky Wang – senior research engineer. Dr. Wang is also the key liaison between the ETC and the Highly Qualified Personnel, or HQP, a team of graduate students and post-doctoral fellows assisting the cleantech companies with test design, analysis, and reporting of results.

The NGIF ETC Laboratory consists of two laboratories the Analytical Laboratory and the Testing Laboratory. More details are provided in the following sections:

5.1 Analytical Laboratory

The Analytical Laboratory contains state-of-the-art lab equipment valued at approximately $2.2 MM and selected for the specific needs of the oil and gas sector. See Appendix D for a list of equipment available. The Testing Laboratory was recently constructed for the specific needs of the NGIF ETC, and several pieces of equipment were purchased directly for use in the ETC (Appendix D). See Figure 3 on the right for images of the Analytical Laboratory. Also, Appendix D lists computer hardware and modelling applications available to the NGIF ETC.

Figure 3: *ETC Analytical Laboratory*

5.2 Testing Laboratory

The Testing Laboratory has a custom Controlled Release Chamber (Figure 4) and a custom Controlled Temperature Chamber (Figure 5).

The Controlled Release Chamber allows for the safe release of methane at various rates. This is ideal for new sensors that detect and quantify methane. The sensors can be evaluated safely, quickly, and cost-effectively. The sensor's lower detection thresholds and confidence in quantification can readily be determined. Additionally, it is important to determine a sensor's ability to detect methane in the presence of other compounds, including various VOCs (ethane, propane, and butane) and water vapour.

The Controlled Temperature Chamber (Figure 5) is designed to test methane control technologies under the extreme temperatures that Alberta oil and gas operations must face. The chamber will control temperatures from -40°C to +40°C. The chamber's size is large enough to accommodate zero-emitting controllers, a small instrument air packages, and free-standing fixed sensors for methane detection and quantification.

5.3 ETC Controlled Environment Tech Testing Protocols

While the eventual goal of technology testing at the ETC is to run tests under live field conditions, the risks of lower TRL technologies make it challenging to bring them immediately to the field. Tests run in the controlled environment provided by the ETC lab can never really mimic the full range of conditions that can be present in a live operation, but they can help to de-risk the technology and answer issues around safety, power requirements, and prototype reliability under variable conditions. Tests can also be run to help companies acquire data for calibration or further development, to enhance their chance of success in a future field trial.

The ETC lab exists to take in any methane control technology that fits within the mandate of the ETC, and which is not yet ready for the field. Tests at the ETC lab are customized to each technology being tested. Testing protocols are determined on a case-by-case basis, in collaboration with lab host site users. This flexibility was found to be of value to site users; protocols with this flexibility in mind, and certain high-level lab testing protocols are followed as a general practice.

Methane Measurement Technology Tests. Tests involving devices to monitor methane releases are generally focused on the ability to see releases and, ideally, quantify them. The ETC lab runs tests in the

Figure 4: *ETC Laboratory Controlled Release Chamber*

controlled release chamber (Figure 4). The system can release gas at various rates, up to a maximum of 6000 scm^3/min (i.e. 0.36 sm^3/hr or 8.84 sm^3/day). While specifics of tests were decided upon with each end user, testing would generally involve:

- Setting up a constant low rate (<1000 scm^3/min) and venting to confirm that the methane measurement test prototype can see methane releases.

- Increasing the CH4 vent rate stepwise from low rates to high rates, to provide data to the lab site user for quantification of emission rate vs. tool output.
- Varying the CH4 venting rate once again, but now from multiple emission sources. This allows site users to attempt to distinguish between different source points and quantify either individual sources or total system emissions.
- Run a constant rate CH4 vent from a single source, but now with an air blower in the system, lab site users can acquire data for how their prototypes can measure emissions in still air vs. flowing air.

The lab would generally provide some of the emission rates to the users as a learning data set, and some data would be collected as blind, so the user can test their quantification algorithms.

Methane Vent Source Elimination Technology Tests. These are tests involving devices (air or electric controls) to eliminate venting of methane venting at well site facilities. Once again, specifics for each test are customized for each site user, but general test protocols would involve:

- Evaluation of system base response (e.g. air flow rate, ability to open or close a vent, etc) at ambient conditions.
- Evaluation of the system response at cold temperatures (-40°C).
- Evaluation of the system response at high temperatures (+40°C).

Tests would be run multiple times to determine reproducibility of the lab vent emissions control prototype and to demonstrate system reliability at high and low temperatures. The goal of this lab testing is to troubleshoot issues to be resolved, or to demonstrate that system performance works well to reduce the risk of any subsequent field testing.

Figure 5: *ETC Laboratory Controlled Temperature Chamber*

In general, ETC lab site users require independent validation of their prototypes, so reports from the ETC lab are usually written by the ETC lab coordinator and/or UCalgary HQP.

ETC Field Host Sites

Tourmaline Operated Live Host Site

Testing methane detection, quantification, and control technologies in a live and operating environment is one of the main objectives of the NGIF ETC. The NGIF ETC consists of several field sites, all operated by Tourmaline:

- The main testing centre is at the West Wolf Lake gas plant just south of Edson, Alberta. This gas plant is jointly owned by Perpetual and Tourmaline, and operated by Tourmaline, and access to this site was made possible by approval from both site owners.
- A suspended Tourmaline well site north of Grand Prairie is continuously metered for 24/7 evaluation of detection and quantification technologies.
- A Tourmaline well site in West Wolf Lake was a temporary controlled release site specifically for aerial detection and quantification in April 2022.
- Tourmaline's network of upstream well sites provide the opportunity to evaluate various methane control technologies.
- Tourmaline's fleet of drilling rigs provides the opportunity to evaluate emissions reductions at drilling and completion (D&C) operations.

The following sections provide details of each NGIF ETC Field Site.

6.1 West Wolf Lake Gas Plant

The West Wolf Lake Gas Plant, jointly owned by Perpetual and Tourmaline and operated by Tourmaline, is the main Emission Test Centre, located 15 kilometers south of Edson at 10-03-052-17W5. It is a shallow cut plant processing 60 MMSCFPD of sweet gas from the surrounding area. Products include natural gas, stabilized condensate, liquified petroleum gas (LPG), and produced water.

Figure 6 is an aerial image of the gas plant.

The previous Section 4.1 described the five areas of focus for the Emission Testing Centres. The first three areas apply explicitly to the West Wolf Lake Gas Plant

Area 1 – Fugitive leaks

Area 2 – Emissions from flare systems

Area 3 – Vents from liquid storage tanks and compressors

A comprehensive understanding of baseline emissions is necessary to best support cleantech startups. Meters and analysers are required to continuously quantify methane emissions. Capital allocated for instrumentation at the WWL Gas Plant totaled approximately $3.21MM. Table 3 below is a high-level summary of the capital spend by emission category.

In total, there were over 66 flow, pressure and fluid property

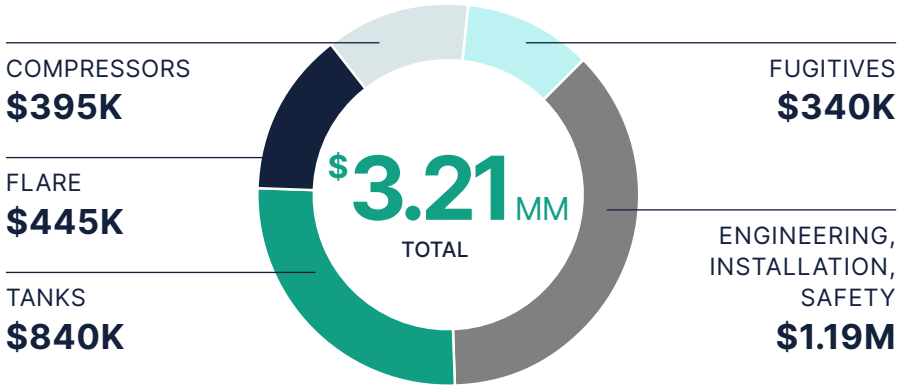

Table 3: *Capital allocated to Bluestar and used on instrumentation at WWL gas plant.*

Figure 6: *Aerial image of Tourmaline's West Wolf Lake Gas Plant*

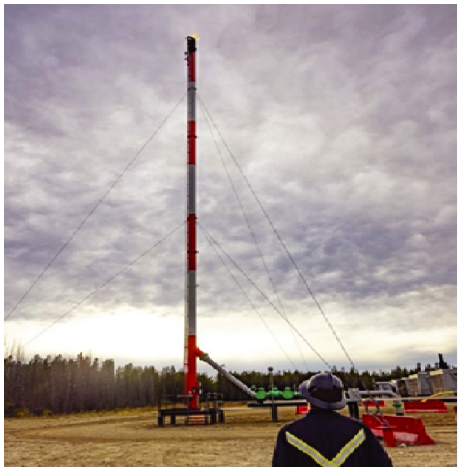

Figure 7: *Emergency flare*

measurement devices installed at the gas plant, capable of generating over 130 unique pieces of data. This is supplemented by regular optical gas imaging (OGI) surveys, vent gas sampling and analysis by AGAT Laboratories, and aerial screening.

The following sections detail the instrumentation by emission category:

Flare system

The Gas Plant's Emergency Flare System allows for the safe depressuring of process units in the event of an upset or emergency. The Flare System was modified to include a flare gas meter, a continuous online analyser to measure the oxygen content of the flare gas, and a meter on the fuel gas purge. As well, bypass flanges were added to allow for the temporary installation of new flare gas meter technology while the plant remains operational.

Figure 7 shows the Emergency Flare System. Figure 8 shows the bypass flanges and Fluenta flare gas meter local flow indicator.

Tank vent emissions

Methane releases from storage tanks are traditionally very difficult to detect and quantify. The WWL Gas Plant has condensate, slop, and water tanks that were originally venting to the atmosphere. Each tank is 30 ft tall. The height makes it a challenge to detect and quantify vent releases
from the ground.

A manway was installed to provide ready access to the tank tops. The manway enables the monitoring by OGI cameras – crews can now climb up to see the top of each tank and directly measure emissions from vents and thief hatches. Each tank vent is individually metered

Figure 8: *Flare System Bypass Flanges and Fluenta Flow Indicator*

Figure 9: *Tank Manway Module including vent lines & instrumentation*

and individually vented and includes a sample point for individual gas analysis. Each tank vent is connected to a common manifold, such that any combination of tanks can be combined if desired and metered as a single release. See Figure 9 for an image of the tank manway, vent lines, and instrumentation.

Later in the summer of 2022, Tourmaline installed a Vapour Recovery Unit (VRU) to the tank system. The integration of the VRU with tank testing will be further described in Section 6.6.

Fugitive emissions

Fugitives are defined as unintended releases of hydrocarbons into the atmosphere. Fugitives are typically detected manually with Optical Gas Imaging (OGI) cameras.

To baseline methane emissions, including fugitives, two commercially available fixed sensors supplied by Baker Hughes and Scientific Aviation were installed around the perimeter of the Gas Plant (Figure 10). The sensors can detect methane concentrations as low as 1ppm in the air that passes through them. The sensors also include measurement of wind speed and direction, which enables the calculation of release rate from the measured methane concentrations. Multiple sensors theoretically can be used to pinpoint the release location. Baker Hughes sensor is intrinsically safe and can be installed within process units.

Figure 10 also shows the location of site user prototype sensors, which are co-located with the commercial sensors to ensure that all systems are recording similar levels of methane concentration in the air at similar locations.

Figure 10: *Locations of Scientific Aviation and Baker Hughes Commercial Methane Sensors*

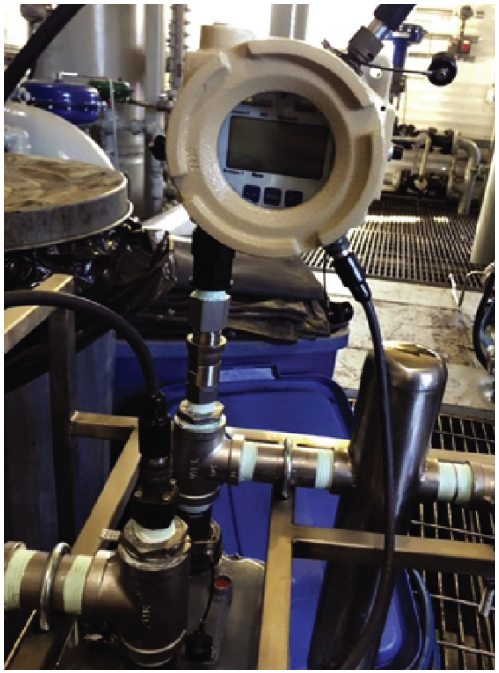

Figure 11: *Compressor Packing Seal Vent Gas Meters*

Compressor vents

The Gas Plant has three Aerial compressors and one GE compressor for inlet and sales gas compression. Each is driven by a large Waukesha engine. There are two common sources of methane releases from compressors: compressor rod packing seals and methane in engine exhaust.

All seals used in rotating equipment will pass gas. For sweet gas compressors, this gas is collected and vented to atmosphere. Positive displacement meters are installed on each compressor to accurately record the volume of vented gas. See Figure 11.

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) with methane capabilities is under construction and will be delivered in October 2022.

6.2 Well Controlled Release Vent Site

The NGIF ETC includes a suspended well located one hour North of Grand Prairie at 13-35-076-07W6. The well has a known continuous surface gas vent flow. The vent rate was confirmed by Bridger Photonics aerial survey in June 2021. The site has a wellhead, separator building, and hydrocarbon storage tank, all of which are out of service. The continuous surface casing vent flow makes this ideal to use as a controlled release site.

Figure 12: *ETC Vent Site with different emission points and On-Site Combustor*

A new metering manifold was design and installed at the site in January 2022. The manifold includes control valves that can be operated remotely. The surface casing vent is routed to 4 locations: the wellhead, top of the separator building, the top of the storage tank, and to a newly installed enclosed combustor supplied by ClearRush. The enclosed combustor is designed to combust some or all the casing gas. Combined, the metering manifold, control valves and enclosed combustor allows the ETC to send any amount of casing gas to any vent location or eliminate venting by combusting.

Two fixed sensors provided by Scientific Aviation provide baseline monitoring. Qube and Kuva have also deployed sensors for evaluation.

See Figure 12 for an aerial image of the well site showing the location of the process equipment and methane sensors.

6.3 Temporary Controlled Release Site (Spring 2022)

A Temporary Controlled Release Site was established at an operating well site for testing that was run in the spring of 2022. The Site featured a custom trailer supplied by Nitrogen Technologies containing 16 high pressure laminated bullets of compressed natural gas. The on-board control panel monitored pressure and temperature, and metered the gas rate. The gas flowed through flexible lines to a 2" vent stack 15 ft tall, temporarily located in the middle of the well site. See Figure 13.

Gas rates were accurately metered from 40m3/day to 8,000 m3/day. This is an ideal range to evaluate aerial detection and quantification technologies, including unmanned aerial vehicles (UAV's), fixed wing planes, and satellites.

The Temporary Controlled Release Site was operated during the week of April 24th, 2022. Altomaxx, LSI, and GHGSat each surveyed the facility.

6.4 Field Host Upstream Well Site Facilities

In addition to hosting the gas plant and controlled release sites, Tourmaline has also committed to contributing over 100 different well sites in Alberta and British Columbia to be available for testing and validating methane emissions monitoring, quantification, and mitigation technologies. Wellsites of different sizes are available for use in both baselining venting emissions and testing of wellsite emissions control technology, as they are brought into the NGIF ETC.

Various technologies are scheduled to investigate power solutions for remote wellsites, compressed air solutions for existing pneumatics, and electric wellsites. These tests will be run as part of the 2022-23 fiscal year program. All of the wellsite facility methane venting tech will come funded through NGIF Industry Grants, or provided in-kind

through Tourmaline. The role of the ETC is to provide supplementary measurements to quantify emissions reduction, and support the analyses of these various technology solutions.

The primary source of wellsite GHG emissions are methane emissions from pneumatic devices such as level controllers, pressures controllers, and pumps. While these sites are always open to methane emissions measurement tech users, the site users to date have generally been focused on technologies on venting emissions mitigation.

Wellsites with 1 to 24 wells are available to validate emissions reduction technology including remote power generation and alternative forms of hydrocarbon component separation controls and flow measurement (e.g. multi-phase metering as a proposed alternative to venting associated with wellsite separators).

Various wellsite facilities have been made available for technology testing at the NGIF ETC, including sites with the following fluid separation controls:

- Low bleed methane pneumatic control separator sites (current industry standard)
- Electric control separator sites (electric actuated valves and pumps)
- Electric effluent metering sites (no physical separation)
- Sites with combinations of the above

The technologies currently scheduled for testing as part of the 2020-22 ETC intake process are:

- Instrument air to replace gas pneumatics
  - Marathon Compression's instrument air system (03-12-51-20W5)
- Westgen Technologies' Engineered Power on Demand (EPOD) system
  - EPOD (12-03-60-02W6)
  - EPOD Mini (15-07-50-20W5)

  Global Power Technologies' instrument air system (02-30-50-19W5)
- Electric actuators for control valves on separators
  - Kinitics Automation (04-17-52-15W5)
- Multiphase flow meters for replacing physical separation
  - M-Flow multiphase flow meter (05-03-76-08W6) Weatherford Foresite flow meter (a-32-I/94-B-09)

Figure 13: *Spring 2022 Temporary Controlled Release Site*

6.5 Field Host Drilling & Completions Sites

Tourmaline has also made several drilling rigs and frac fleets available for technology testing across Alberta and BC. Nine rigs and one frac fleet are equipped with diesel and natural gas flow measurement. Exhaust stack emissions are measured as required for technology testing.

The primary source of emissions on drilling and completion sites results from combustion of hydrocarbon fuels, typically a combination of diesel and natural gas. Similar to compressors at gas plants, engines on D&C sites may contain unburnt natural gas (methane slip). Quantification of these emissions will be made using a mobile Continuous Emission Monitoring System (CEMS) with methane capabilities, which has been purchased and will be utilized for supporting data on rigs and frac fleets. The goal of testing in this emission source area is to test different engine technologies in their ability to generate power, reduce fuel usage (i.e. lower life cycle GHG emissions) and limit the presence of methane slip in exhaust streams.

Drilling Rig types and equipment include:

- Bi-fuel natural gas and diesel-powered drilling rigs (baseline)
- 100% natural gas/battery powered hybrid rig
- 100% electric highline powered rig
- CAT Advanced DGB 4.4 Bi-fuel kits
- CAT Smart engine management system

Frac fleets and equipment include:

- Tier 4 CAT natural gas bi-fuel pumpers
- Tier 2 CAT natural gas bi-fuel pumpers
- Natural gas power generation (generators, portable turbines)
- Natural gas superheaters

Figure 14 is an example of a Tourmaline Drilling Rig Operation.

Figure 15 is an example of Tourmaline's Fracing Operation.

6.6 Field Tech Testing Protocols

Similar to the ETC lab, the ETC field test site exists to help methane control tech providers accelerate the development of their field prototypes (TRL 6 – 7 to get to the field). The challenge to a field environment is that the complete emission profile may not be as easy to measure and quantify, compared to a controlled environment. The ETC took steps to meter and baseline these live environment emissions as completely as possible, so that tech testing in the field can be run quantitatively and methane control can be proven from these various prototypes. Specific protocols for testing are customized to each technology trial, again following the needs of individual users. This document lists general test protocols and information that is available to site users, but the work plans and data inputs and outputs are actually identified with each site user on a case-by-case basis, as part of their intake process.

Gas Plant Emissions Testing Protocols

At the gas plant, ETC field site users have been generally focused on methane emissions measurement. Site users have been technologies such as fixed sensors or perhaps mobile sensors or flyover tech (drones and fixed wing aircraft). The goal of coming to the ETC gas plant test site is to try to measure emissions in a real operating facility, where there will be multiple emission sources, at variable rates, all interfering with one another. The value statement that the ETC brings, compared to testing at any other facility, is the ability to measure the plant baseline emissions, i.e., metering of all known emission sources and quantification of site total emissions at the plant perimeter. The goal was to independently measure the site emissions and provide this data back to site users to validate their findings. The test protocol for baselining emissions is as follows:

Figure 14: *Tourmaline Drilling Rig Operation*

Figure 15: *Tourmaline Fracking Operation*

- During the time of testing, the ETC is recording venting emissions from all known vent sources. This data can be provided, either spatially or in aggregate, to the site users. This includes metered vents from all compressors and tanks at the ETC. This metered release information is valuable for providing data for flyover technology (drones and fixed wing aircraft).
- The ETC also has commercial fixed sensors located around the gas plant and throughout the gas plant. Methane (CH4) concentration measured at these sensors can also be provided in aggregate to site users, along with temperature and windspeed measured data collected at the same time. In general, the ETC will aggregate sensor CH4 concentrations, so that site users will not be given any commercially sensitive information for a single competitor product. Likewise, the conversion of measured emission concentrations to emission rates is also obtained through proprietary algorithms for each sensor, so these numbers would generally not be given to site users.
- The emissions from tank venting are metered for each independent tank, or the tank outlets can also be amalgamated into a single large release point, if preferred. NOTE: since the start of the ETC gas plant, the field site host has since installed a vapour recovery unit (VRU) onto the tank system, so venting emissions off the tanks would be reduced accordingly. However, if required for testing, individual tanks can still be disconnected from the VRU, so venting emissions can still be generated and metered, as inputs for tank venting emissions measurement tech.
- Once the Vapour Recovery Unit (VRU) was installed into the tanks, the metered releases were now all collected through the VRU, but un-metered fugitive releases are still present. Existing site users had the previous metered release data to tune their quantification algorithms, and for future site users tanks can be temporarily disconnected from the VRU to generate venting emissions for quantification. The idea would be for any tank monitoring technology to be able to show that they can see and quantify the metered releases, and then with the tanks connected to the VRU, the un-metered release rates could now be trusted based on this prior quantification step.
- The pilot gas and fuel gas to the main plant flare are also metered and recorded, so the normal plant operating constant flare rate is metered and can be provided to any flare monitoring tech that may come to the field site. During times of plant upset, where flare rates increase, the ETC monitors which lines are contributing to the flaring events, so information about elevated flare rates can also be backed out for any site users who need this information.
- What is not metered from the gas plant is fugitive emissions (e.g. leaks in lines and equipment) and emissions from tank thief hatches. Thus, operations records and estimates these emissions volumes which are provided back to site users. For this reason, measurements at the gas plant are often coupled with quantification studies at the controlled release vent site (discussed next). In addition, the ETC gas plant runs periodic OGI and commercial fixed wing to identify these unmetered CH4 releases.
- The other CH4 release point that was identified at the ETC gas plant is methane slip out of compressors. The ETC has procured a Continuous Emissions Measurement System (CEMS) unit, which will be used to quantify this methane slip, and provide this information

back to perimeter sensor site users.

Well controlled release vent site testing protocols

- While methane monitoring at the gas plant is the true live environment test, the emissions are difficult to quantify completely even with all the attempts made to capture the system baseline. Thus, additional quantification of technology can also be achieved at the well Controlled Release Vent Site. At the site, the ETC can release metered (known) releases from a select number of emission points, and site users can test their ability to measure and quantify releases still in the field, but in a simpler system than the gas plant. The goal of this controlled release site is to provide a place where known (metered) emissions can be released, and data provided back to site users. The Controlled Release Vent Site is located on a suspended well with metered surface casing vent flow, so the actual emissions from this site are well known, and this can therefore be used to test site user technology ability to quantify emissions, as well just as see them. The general testing protocols for the Controlled Release Vent Site are:

- The site runs a fixed low emission rate (15 – 20 m 3 /day) from a single vent source. This is run over time, with changing wind conditions and day/night operation so with temperature changes. Starting with a single release point and fixed rate allows site users to see how their numbers change for this constant actual emission rate.

- The site then runs higher emission rates (e.g. 30 m 3 /day up to 80 – 100 m 3 /day) from multiple emission source points. This allows users to see if they can differentiate and quantify different emission sources, as well as quantify the total site emissions. Once again, at each test condition, emissions are fixed for several days, so site users can see how variable their numbers are for these fixed actual emissions.

- Finally, the site would run a test program with some baseline low emission rate (15 – 30m 3 /day) with periodic high emission rates (80 – 120 m 3 /day) turned on and off. This allows site users to see and quantify these periodic, non-standard release rates, and evaluates their ability to see both high and low emissions without intermediate calibration. Data can be either provided to site users or run as blind tests for them, or some combination of the two, depending on what the site users need.

Temporary controlled release site (Spring 2022) testing protocols

- The temporary controlled release site was set up for the Spring 2022 measurement campaign, which was focused on providing data to overhead emissions measurement technology (drones and fixed wing aircraft). As discussed previously, this release site was set up just for this testing campaign, as the surface casing vent flow from the primary Controlled Release Vent Site was very low. The testing protocol followed at the Temporary Controlled Release Site was:

- A fixed methane release was set using the controlled release natural gas trailer (60 – 100 m 3 /day). At this constant rate, the testing tech (drones or aircraft) would fly over the release point multiple times, investing the effect of changing speed and elevation on measurement of emissions. At each speed or elevation they would also fly over the fixed release point numerous times, to get a statistical representation of how stable their numbers were.

- The fixed release would then be switched to a different value, and the test site user would repeat their test program, i.e., measuring repeatability of data at different speeds and elevations of passing over the release point. This was repeated for several different rates, to get site users data for stability of their numbers and ability to

quantify emissions over a range of different values.

- Finally, the temporary release site was used to provide data to GHGSat's satellite technology. The ETC communicated with GHGSat to determine the intervals during the testing week where their satellite would be overhead. Then, for the time before the satellite passed by until just after it had passed, the on-site methane trailer released very high rates of methane (6000 – 8000 m 3 /day) and provided this release rate back to GHGSat.
- This temporary site no longer exists, but in future overhead emissions measurement tech campaigns, a similar program could also be run at the primary Controlled Vent Release Site. Reports from the these studies will be written by the site users, with support from NGIF. The final publication of public reports will be signed off by both the site user and site host.

Upstream well site facilities testing protocols

The goal of technology testing at wellsite facilities has generally been focused on technologies that eliminate venting emissions from pneumatic instruments at the wellsite. Depending on the tech test type, the data collected and provided back to site users will be different. However, the general protocol for testing is as follows:

- For pneumatic venting devices (level and pressure controllers, and pumps) baseline data is collected off the sites before technology implementation, or off similar sites, showing the rate of gas releases. This allows for quantification of what are the methane release rates and volumes, and the GHG savings, from switching over to instrument air or electrification solutions.
- For remote power solutions, the power output (W) is measured, along with fuel gas requirements for the site before the technology implementation, or from comparable baseline well sites.
- For all devices in the field, one of the other major KPI's that always must be answered is the stability of devices in the field – how well do they work over multiple seasons and temperatures, with minimal downtime or repair/maintenance costs. So simply logging the operational time and reporting on stability under field conditions is also a measurement parameter from field testing.
- For many of the technologies brought into ETC within this emission source area, these were in-kind through Tourmaline or NGIF Industry Grants projects. As such, the technology developers may not necessarily be directly involved in the interpretation of emissions reduction from their technology. These reports will be written through the NGIF ETC, but will still be reviewed with the site users and site host for sign off before sharing of public reports.

Drilling & completions sites testing protocols

D&C operations are very high fuel consumers, as detailed previously in Section 6.5. Tourmaline provided access to these rigs in-kind, and took the responsibility for managing data collection on site. The general testing protocols followed were:

- Tourmaline would acquire data on power requirements and outputs for the drilling rigs and/or frac fleets, along with metered data on fuel usage.
- Tourmaline would also take samples of produced gases to measure methane slip in the outlet of combustion sources. In the future, the ETC mobile CEMS unit will be utilized to take these measurements more effectively.
- The final assessment of performance of the various rigs will be based on a total assessment of fuel used (total GHG emitted) and methane slip volumes that are present in the exhaust gases.
- As the primary driver of this program, Tourmaline will be the main author of this work, with support from NGIF as required. The final public reports will be signed off by both the site host and technology providers.

CERIN Data Portal

The CERIN program had two overarching goals: (1) to make field testing more accessible for methane control cleantech companies, and (2) to provide a means for sharing of data to accelerate deployment and give cleantech companies the ability to share results with multiple stakeholders. Thus, one of the goals of CERIN was to develop a knowledge-sharing data portal, which would house results from all testing run under both CERIN-sponsored programs: the NGIF ETC and the PTAC CanERIC program. The ETC was tasked with developing this data portal on behalf of both programs. This development was run through the University of Calgary, with continuous input from PTAC, AI and NRCan.

A data portal has been developed (www.cerinprojects.ca), which houses all test results from the CERIN initiative. This portal has several capabilities:

- **Private data:** Confidential test data can be uploaded and shared with a small number of stakeholders: the cleantech company site user, the site host, and any direct funders. This information can be securely stored in the data portal, and can only be accessed by members who, once logged in, have been given read or write rights to these folders.
- **Public reports and/or data:** can be accessed by anyone who visits the website. The public reports can be downloaded by anyone Figure 16 shows this definition of users and access to information schematically. Public users will only see the public-facing reports, while users given log-in access will see both the public reports and any additional folders they have been given access. While the website has the capability to house a large amount of private data securely, it is not a mandate for site users to upload data to the portal. What is a requirement for any project run through the NGIF ETC or PTAC CanERIC is that there must be a publicly available report.

Figure 17 shows the cerinprojects.ca home page. Site visitors can click on “About Us” to learn about CERIN, and see information on the various CERIN members (NGIF, PTAC, AI, and NRCan). The projects page will display all uploaded projects – public and any private folders to which the users may have been given access. While there is a requirement to enter a valid email address to download a report, this is simply for tracking purposes, i.e. to develop an understanding of who is using the website over time.

	See all public facing projects	See projects they’re given access too	Post projects	Approve projects posted by any user logged in	Change the entire website (Fix bugs, re-designing)
Public user, not logged in	✓	×	×	×	×
User, Logged in	✓	✓	✓	×	×
Admin	✓	✓	✓	✓	✓

Figure 16: *Schematic of Data Portal users and access to information*

The requirement for public sharing of results is specified in the contribution agreements signed between CGA and any ETC site user. The actual definition of what will be shared is determined as part of the subsequent site access agreements, signed between the site users and site hosts. These access agreements detail what data is collected and shared, and with whom, and stipulate that agreement needs to be obtained by both parties before any information is publicly shared.

The CERIN data portal runs under Amazon Web Services, and some of the ETC funds from NRCan were used to ensure that this portal will be paid to remain active for, at minimum, five years. The long-term management of the data portal is part of the longevity planning for ETC, and this longevity planning will also eventually need collaboration with PTAC.

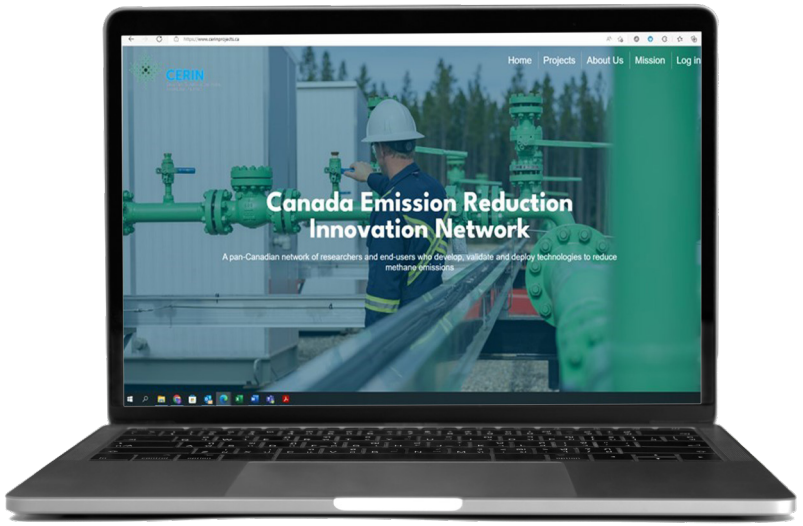

Figure 17: *CERIN Data Portal landing page*

Updates – 2021-22 Fiscal Year

Stage 1: Intake – 2021-22 Fiscal year

Table 4 below shows the summary of tests that have been started at the ETC in Fiscal Year 2021. Many of these are long term studies, so operations are still ongoing. Furthermore, many technologies require several different types of tests, with each type of test appearing as a project in the table. Further details of the various site users are provided below.

Project no.	Tech Provider	ETC Location	Test Description
1	Luxmux	Gas plant	Perimeter sensors – long term monitoring
2	Qube	Gas plant	Perimeter sensors – long term monitoring
3	Qube	Vent site	Perimeter sensors – controlled release calibration
4	Kuva	Gas plant	Continuous OGI for tank vent monitoring and quantification development
5	Kuva	Vent site	Continuous OGI for tank vent monitoring and quantification development
6	AltoMaxx	Vent site	Drone methane sensor
7	LSI	Gas plant & metered well	Fixed wing sensor – Phase 1 detection testing
8	LSI	Vent site	Fixed wing sensor – Phase 2 detection testing
9	4Blue	ETC Laboratory	Cheap OGI cameras and AI – Phase 1
10	4Blue	ETC Laboratory	Cheap OGI cameras and AI – Phase 2
11	4Blue	ETC Laboratory	Cheap OGI cameras and AI – Phase 3
12	Kinitics	ETC Laboratory	Data on rate of valve response, pressure, response to hot/cold conditions, power
13	Kinitics	ETC Laboratory	Data on positional accuracy of system to different valve positions, hot/cold conditions
14	Packair	ETC Laboratory	Compressor response at various rates/volumes (low/medium/high rate ranges)
15	Packair	ETC Laboratory	Compressor response at ambient vs. cold temperatures
16	Trican	Wellsite completions	CAT Tier 2 diesel displacement performance and measurement of emissions and methane slip
17	Trican	Wellsite completions	CAT Tier 4 diesel displacement performance and measurement of emissions and methane slip
18	Trican	Wellsite completions	Cummings Tier 2 diesel displacement performance and measurement of emissions and methane slip
19	PD	Wellsite drilling	Hybrid rigs fuel performance and methane emissions detection
20	PD	Wellsite drilling	Advance Smart engine management fuel performance and methane emissions detection
21	PD	Wellsite drilling	DGI fuel performance and methane emissions detection
22	Ensign	Wellsite drilling	Step blend fuel performance and methane emissions detection
23	Ensign	Wellsite drilling	Gas blending system fuel performance and methane emissions detection

Table 4: *Summary of ETC testing for fiscal year 2021-22*

Blue 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.

4blueenergy.com

Luxmux

Luxmux is a privately held corporation founded in 2011 in Calgary, Alberta that designs and manufactures rugged, compact, narrow line width lasers and broadband light sources for scientific research and industrial markets, including biomedical imaging, energy, environment, material characterization, metrology, optical device characterization and remote sensing.

luxmux.com

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.

lidarservices.ca

Qube Technologies

Qube is a leading provider of environmental surveillance technology with a mission of helping primary industries, such as oil and gas, cost-effectively detect, quantify, and reduce methane and other greenhouse gas emissions. They combine reliable hardware, advanced science, and intuitive analytics, into an affordable, reliable alternative for emissions monitoring. Qube works with leading operators throughout the world and has support from a wide range of investors and government bodies.

qubeiot.com

Kinitics Automation Ltd.

Kinitics Automation is a Vancouver-based company that produces motion control products using shape memory alloy materials. Kinitics manufactures its own line of actuators and piston pumps based on the company's Bundled Wire technology, which generates precise linear motion in an electrically operated, compact package that requires little infrastructure to implement. The company is developing a valve actuator in response to the natural gas industries need for a zero-bleed actuator that can fail closed in the event of a power or signal interruption.

kiniticsautomation.com

Altomaxx

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.

altomaxx.com

Kuva Systems

Kuva Systems is a methane monitoring technology company focused on making the invisible measurable and manageable. With offices in Boston, Houston, and Calgary, Kuva's patented infrared camera and cloud monitoring solution provide oil and gas companies with timely notification of methane emissions and the ability to investigate root causes of emissions while delivering zero false positive detection alerts. Kuva's solution enables upstream and midstream oil and gas companies to improve their operations and meet ESG and methane intensity goals.

kuvasystems.com

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.

ghgsat.com

Packair Industries Inc.

"Packair was formed to design and deliver a patented air compressor that is

- designed for efficiency. It can produce unusual air flow at pressure from a minimal power supply
- oil-free, to enable extreme weather operation, with reduced maintenance
- constructed with materials suited to consistent product operation
- truly portable

The first three characteristics make the compressor particularly well-suited for off-grid use which requires consistent work performance, such as remote well sites. Higher air flow at pressure can replace methane actuation of instrumentation, by providing the air volume at pressure needed to control site operations."

packairindustries.com

Stage 2: ETC Laboratory evaluation

The following technologies are being tested at UCalgary's NGIF ETC Laboratory:

9.1 4Blue Energy

Technology description

4Blue is developing an AI-powered, cloud-based platform, which will be coupled with purpose-built hardware, for the purpose of monitoring, detecting, quantifying, analyzing, and monetizing GHG emissions and footprint. To achieve their objectives, they stripped down an OGI camera to simplify it and make it much cheaper than a traditional OGI camera. 4Blue plans to use these scaled-down OGI systems as inexpensive perimeter sensors, which could be placed around emission sources in live operations, and which would image emissions directly. They will then layer in their AI-based interpretations of converting images to emission rates and volumes and provide this back to site users.

Testing deployment:

4Blue is currently at a relatively low TRL. They have obtained an OGI camera and want to test it in a controlled environment and evaluate its ability to detect emissions. Then the lab ran metered emissions and provided them with this data, for them to start to develop their interpretation software.

Initial tests at the ETC were run using air and smoke at known metered rates. The camera's visual images related different plume sizes to different release rates. With the successful generation of images completed, a second test was performed with methane to (a) prove that their simple camera can in fact see a methane plume and (b) evaluate different lenses to see how to optimize the visualization of the plume. The third testing program focused on quantification. The lab ran a suite of metered fixed-release rates in the Controlled Release Chamber, under various artificial light conditions. Data generated from each campaign has been provided back to 4Blue, who are working on their algorithm to relate plumes images back to these metered release rates.

Figure 18 below shows 4Blue set up in the Controlled Release Chamber

9.2 Kinitics Automation Ltd.

Technology description

Kinitics is developing a valve actuator using their 'Bundled Wire' technology, which uses shape memory alloys (SMAs) to produce force and displacement. SMAs are materials that can respond to temperature changes by changing shape.In wire form the wires will contract when heated and stretch when cooled. Heating of the SMA wire is readily achieved by passing electric current through it. The process is fully reversible making the wire an ideal choice for high-cycle precision applications.

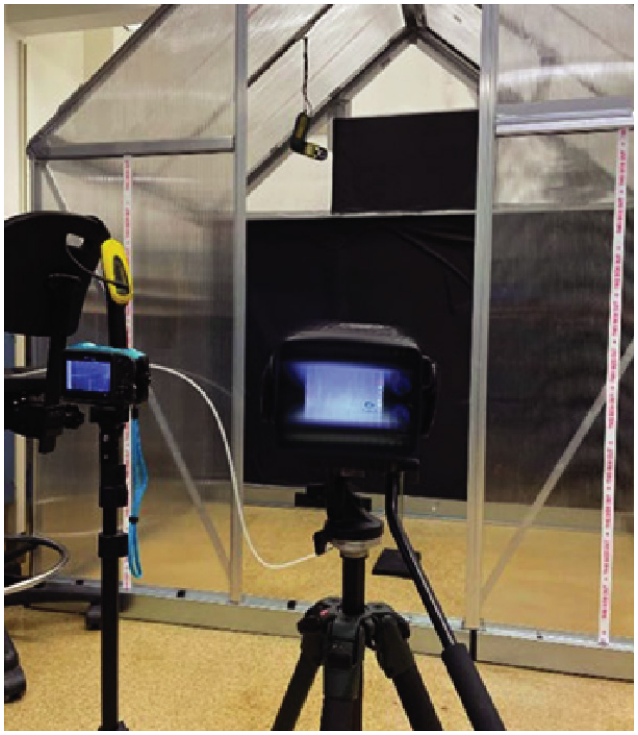

Figure 18: *4Blue System Setup at the ETC Lab Controlled Release Chamber*

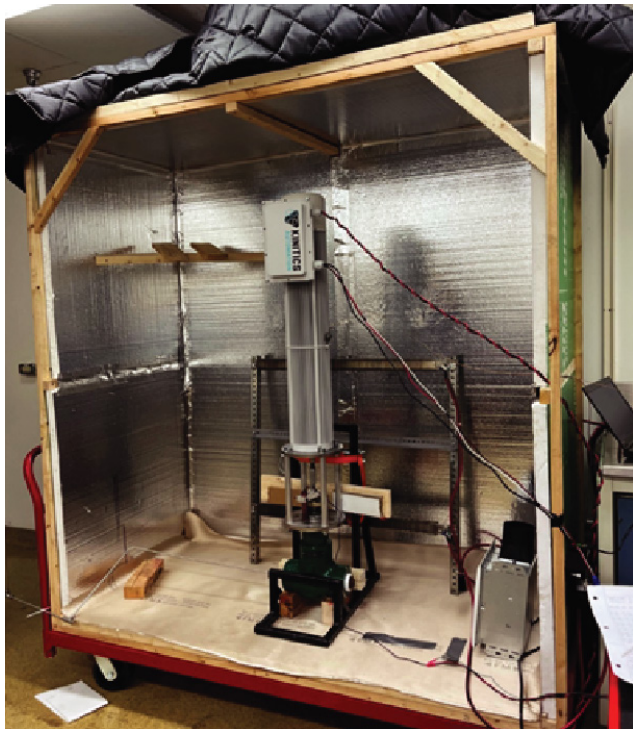

Figure 19: *Kinitics Actuator Controlling a Pneumatic Valve in the ETC Lab Controlled Temperature Chamber*

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

Testing deployment

Kinitics has available funding to build multiple electric actuator 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 19).

In the first set of tests, the Kinitics Valve Actuator (KVA) was alternated between a 50% valve position and a 0% (closed) position. Positional accuracy, speed of the valve position change, and power consumption were monitored and measured. Tests were performed in the Controlled Temperature Chamber at ambient temperature as -40°C and +40°C

In the second set of tests, the KVA was once again set at the 50% position and then stroked up or down in various increments. Response to positional commands, and power consumption were measured and monitored. Tests were run in ambient conditions and at -40°C.

9.3 Packair Industries Inc.

Technology description

Packair has developed a portable multi-cylinder, battery powered, efficient compressor that runs cooler than traditional units, and hence is made of plastic. The compressor can deliver compressed air at 130 psig and up to 10 cfm. This system is designed to be cost-effective, require low power to operate, and suitable for hazardous environments. Compressed air can replace natural gas in pneumatic devices, thus eliminating methane venting.

Testing deployment

The ETC Lab evaluation included the ability to control different compressed air release rates accurately and repeatably, and to understand the power requirements. Figure 20 shows the Packair unit in the lab – the compressor is small, housed within the air filter, and connected to a motor. Testing was performed at high, medium, and low demand, and at ambient and cold temperatures, for up to 90 minutes.

Figure 20: *Packair System Setup at the ETC Lab Controlled Release Chamber*

Stage 3: ETC Live Field Site Evaluation

Technology testing at the WWL Gas Plant began in November 2021. Many of the technologies require evaluation in all four seasons and will be deployed through the end of 2022 or beyond. Analysis from these technologies is still pending.

The following sections introduce the various companies that are currently deployed at the ETC Gas Plant and Well Site. As each project is completed, results will be published on the CERIN data portal (cerinprojects.ca).

10.1 Lidar Services International Inc

Technology description

The methane detection and quantification technology are developed by a Quebec-based Canadian company who has been in operation for more than 20 years delivering numerous high-performance spectral imaging systems, mostly to the military sector.

The thermal infrared hyperspectral imaging system is 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 fieldwork LSI anticipates a lower detection limit of 0.5 g/sec (85 m3/day).

Technology deployment November 2nd to 5th, 2021

LSI installed the infrared hyperspectral imaging system on a Bell 206 helicopter (Figure 21). On November 2nd, the helicopter performed multiple aerial surveys of the 13-35 well site north of Grand Prairie. The well's surface casing gas vent was metered continuously with a Hawk 9000 2" turbine meter. Unfortunately, the surface casing vent flow rate was very low (<5m3/day) due to unseasonably cold weather, and LSI was unable to detect methane.

On November 8th, the helicopter performed multiple aerial surveys above the West Wolf Lake gas plant. LSI was able to detect methane releases from Compressor engines and seals, and the atmospheric storage tanks. Images from this trial are shown in Figure 22 and Figure 23. The data was very helpful to LSI to calibrate their instruments and assess the impact of flight speed and elevation

Figure 21: *LSI's Infrared Hyperspectral Imaging System installed in a Bell 206 Helicopter*

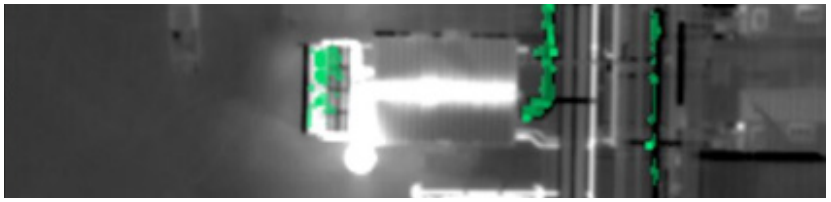

Figure 22: *WWL Gas Plant compressor Building Methane Detections*

on detection capabilities.

Technology deployment April 29th and 30th, 2022

LSI purchased a twin-engine airplane, installed the infrared hyperspectral imaging system, and received Transport Canada approval to fly on Thursday April 28th (Figure 24)

LSI flew both the 10-03 West Wolf Lake Gas Plant and the 04-28 Controlled Release Site. Results from this campaign are still pending.

10.2 Kuva Systems

Technology description

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

1. Automatically detects hydrocarbon gases including methane.
2. Pinpoints emissions sources by visualizing detected gas as a colour overlay on an image of the environment (gas in colour, environment in greyscale).
4. Automatically generates alarms (with human review to eliminate false alerts and so the customer receives no false positive detections).
5. Will 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 Kuva camera uses sunlight to detect methane and VOCs, of which intensity changes throughout the day and year. 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.

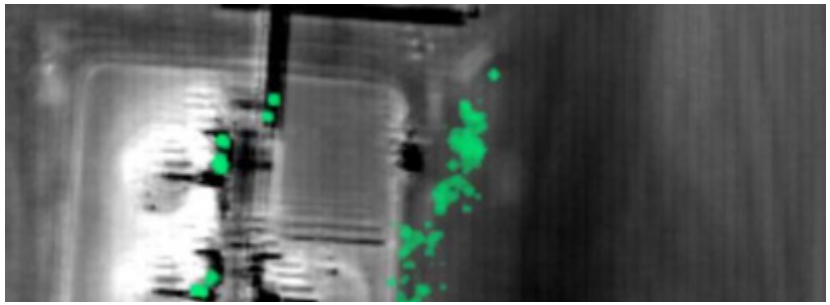

Figure 23: *WWL Gas Plant Liquid Storage Tanks Methane Detection*

Figure 24: *LSI's new [make and model] twin engine aeroplane parked at YET Edson, AB.*

Figure 25 and Figure 26 show images of the east camera installation and the view from the camera. The west camera install and view of the tank farms from this camera are shown in Figure 27 and Figure 28.

Comparison of metered releases with Kuva's detection and quantification is ongoing.

Figure 25: *Kuva Camera East Installation*

Figure 26: *View of tank farm from East Kuva Camera*

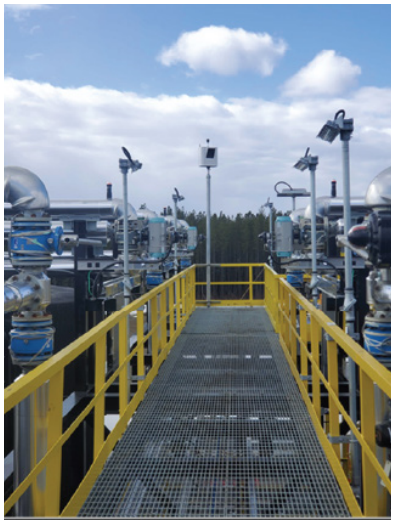

Figure 27: *Kuva Camera West Installation*

Figure 28: *View of Tank Farm from West Kuva Camera*

Technology deployment March 15th, 2022 through present – ETC 13-35 well site

A single Kuva camera system was deployed at the 13-35 well site, focused on the controlled releases from the storage tank. Figure 29 and Figure 30 show the installation and the onsite storage tank from the camera, respectively.

The well site was expected to return to typical release rates in the summer of 2022, and releases from the tank would be remotely controlled from 0 to 200 m3/day. Unfortunately, the surface casing vent flow from the 13-35 well appears to have dropped off to under 20 m3/day. The ETC is looking for new permanent solutions for a vent site, but since instrumentation and site users like Kuva are already present on site, a natural gas trailer will be brought in for a controlled release campaign in the fall of 2022 (i.e. 2022-23 fiscal year).

Figure 29: *Kuva Camera Installation ETC 13-35 Well Site*

10.3 Qube technologies

Technology description

Qube develops low-cost environmental surveillance technology to continuously monitor greenhouse gas emissions. Fixed sensors located around a site automatically detect methane and other harmful gases in real time, allowing operators to quickly find and repair leaks. Operators can install Qube sensors in less than 20 minutes. They are solar-powered and can operate continuously for over two weeks without sunlight. Qube sensors send data to the cloud, where advanced machine learning algorithms quickly locate, quantify, and classify the detected emissions. Emissions and environmental data are visualized on Qube's Emissions Dashboard, providing operators with real time notifications of leaks, and a complete picture of live and historical GHG emissions across their organization.

Figure 30: *Camera view of ETC 13-35 Well Site*

Technology deployment February 1st, 2022, through present – ETC 10-03 gas plant

Qube continuously updates its cloud dashboard to provide operators with real time data on emissions and environmental conditions at their site. This data includes release rates (kg/hr), inferred release locations, gas concentrations, wind vectors, temperature, humidity, and pressure.

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

Technology deployment February 16th, 2022, through present – ETC 13-35 well site

Qube deployed three Axon devices around the perimeter of the 13-35 Well Site, which should provide Qube algorithms with sufficient data to infer the release locations. Figure 31 shows one of the Qube sensors in the foreground.

As discussed previously, the expected surface casing vent flow rates at the 13-35 well site did not return to the expected levels. The ETC ran several programs to shut in the well and build up pressure, followed by a pressure relief step that was associated with a fast, higher rate of methane release. Qube participated in data collection from these releases, and will participate in the fall 2022 controlled release program with a natural gas trailer brought to the 13-35 site.

10.4 Luxmux

Technology description

Luxmux ARMS Smartpole™ is a multiple gas monitoring system specifically engineered to be a continuous emissions monitoring solution. The ARMS SmartER is a data consolidation system that allows 24/7 access to emissions information.

Smartpole sensors placed around oil or gas sites can detect up to four elements from a list of CH4, CO2, CO, O2, NH3, H2S, NO2, HF, SO2, CL2, O3, VOC, and dust. Detected information includes the concentration of element, wind speeds, wind direction, relative humidity, air temperature, air pressure, and GPS location with elevation. All information is compiled into a report that can be remotely accessed at any time through a MODBUS RS232 over USB/RJ45 connection or the Cloud. Luxmux's photonic technology can also be mounted on UAV's or drones. While fixed perimeter sensors are currently the primary focus of the ETC, Luxmux has also indicated a desire to test their technology in a drone configuration, to help augment the measurements taken at the perimeter of the plant and further focus in on possible emission source points.

Technology deployment February 1st, 2022, through present – ETC 10-03 gas plant

The initial testing plan called for six perimeter sensors to be installed at the ETC gas plant testing site, and an additional three sensors to be located at the ETC well vent site. Luxmux installed their first set of three Smartpole sensors at the ETC gas plant in the first week of February 2022. Figure 32 shows an image of one of these installed units. The sensors are placed on vertical roads with cement bases and each unit was individually powered by solar panels at the top of the pole.

During the initial equipment installation, the devices ran into cellular communication issues. Luxmux made the decision to re-design their sensors to work on radios, with all units communicating via radio to a central node that would have a good cell connection. The switch to radio communication required a re-build of some components of their circuit boards. Unfortunately, they have been adversely affected by the

world-wide part shortage. Currently, Luxmux has still not yet completed the installation process for all nine planned sensors at the ETC gas plant and secondary vent site.

10.5 AltoMaxx

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 April 25th through April 30th, 2022 – ETC WWL gas plant

AltoMaxx surveyed the ETC Gas Plant daily during the week of April 25th, focusing on tank vents, compressor seals, and methane slip in engine exhaust.

Multiple surveys over multiple days allowed AltoMaxx to evaluate the impact of flight speed and flight altitude on methane detection and quantification at an operating facility. Comparison of AltoMaxx results verses metered releases and composition is ongoing.

Technology deployment April 25th through April 30th, 2022 – ETC temporary controlled release site

AltoMaxx surveyed the Temporary Controlled Release site daily during the week of April 25th, 2022. Controlled releases are an ideal way to evaluate the impact of release rate on detection and quantification, at various flight speeds and latitudes and weather conditions.

Comparison of AltoMaxx results verses the controlled releases is pending.

10.6 GHGSat

Technology description

GHGSat launched its first satellite in 2016, its second and third satellites in 2021, and 3 additional satellites in May 2022. Each satellite uses patented infrared detection technology. Detection thresholds have improved 10-fold since 2016, and is currently ~ 4,000 m3/day.

Technology deployment April 25th through April 30th, 2022 – ETC 04-28 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 Controlled Release sites at 11:55 am on April 28th and again at 11:44 am on April 29th. Methane was released at a rate of 4,000 m3/day starting 30 minutes prior to the expected scan to allow for good plume formation.

Unfortunately, cloud cover limited the ability of GHGSat's satellite to detect methane releases. For satellite technology to work, the emission plume needs to be visible, and in both timed release periods, clouds interfered with the plume image and prevented a quantification of the plume size.

See Figure 33 for the satellite image of the Temporary Controlled Release Site.

10.7 Miscellaneous D&C technologies

Reciprocating engines are the primary source of emissions in drilling and completion operations. Caterpillar has a large market share of the engines used for drilling rig power generation and frac pumper power, so they are the primary technology provider for this area of the ETC. Caterpillar is the largest manufacturer of industrial diesel and natural gas engines used by several different industries. Their engines are used worldwide, specifically in the Canadian upstream oil and gas industry for drilling and completing wells.

The key users of such technology are the service companies that drill and complete the wells. For this project, these companies are Precision Drilling, Ensign Energy Services, and Trican Well Services, which are all contracted by Tourmaline.

Technology description

Drilling rigs

Modern drilling rigs use AC power to enable high-tech integrated controls and automation. To power this system, typical rigs use diesel generators that have been modified to run as bi-fuel (a combination of both diesel and natural gas). The partial natural gas substitution helps to reduce GHG emissions from combustion, but since the engines were

Figure 31: *Qube deployment at the 13-35 ETC Well Vent Site*

Figure 32: *Luxmux Smartpole setup at the ETC Gas Plant Testing Site*

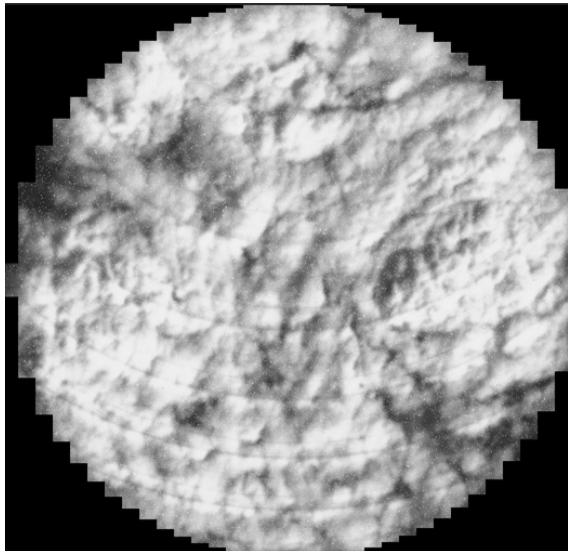

Figure 33: *Satellite image of the Temporary Controlled Release Site on April 28th, 2022*

not specifically designed to run on natural gas, some of the natural gas "slips" through the engine uncombusted. This "methane slip" negates the positive effect natural gas has on GHG emissions as a lower carbon fuel.

New technologies currently being tested aim to further reduce diesel consumption and reduce or eliminate methane slip. One example system is the natural gas engine/battery hybrid system. This system includes three 1 MW generators driven by Caterpillar G3512 100% natural gas engines as well as a 1.2 MW battery pack, referred to as an Energy Storage System (ESS). The natural gas engines are equipped with a Smart Engine Management System (SEMS), which integrates the ESS and the natural gas generators to act as one combined system. The SEMS automatically turns engines on and off as power demand changes and keeps engine runtime similar. Some rigs have incumbent bi-fuel engines with a SEMS which helps reduce fuel consumption by reducing redundant engine runtime. There are also serval types of gas blending systems for the bi-fuel engines deployed on the instrumented rigs, allowing for comparison across the typical drilling rig fleet.

Frac fleets

In Hydraulic fracturing operations, a series of high horsepower pumps are used to deliver a water and sand slurry down the wellbore at high rates and pressures to fracture the formation rock. Today, several frac fleets utilize pump units that use bi-fuel engine add-on kits to partially displace diesel with natural gas. Similar to drilling rig engines, traditional diesel engines are not designed to run on methane gas, resulting in lower efficiency and incomplete combustion.

The primary technology being tested at the ETC is the 3512E Tier 4 engine, which was developed by Caterpillar to meet US EPA Non-road mobile Tier 4 Final emission standards. The 3512E engine uses a fuel injection system that precisely times gas injection with engine strokes in each cylinder, resulting in more complete combustion and better diesel displacement percentages compared to previous systems that blend natural gas with diesel prior to injection. In-cylinder pressure sensors provide control over the combustion, blend, and air ratios which further contributes to efficient and complete combustion. Based on lab data applied to operating conditions, the Tier 4 engine can achieve displacement rates of 85% natural gas, a higher natural gas combustion efficiency, and a more consistent performance across varying altitudes and temperatures.

Figure 34: Exhaust sample line connected to a Tier 4 engine

Technology deployment

Drilling rig fuel and power instrumentation were installed in Q2 2022 on four Precision Drilling rigs and 5 Ensign Energy Services drilling rigs. Data collection is ongoing, and emissions testing will be performed in 2022 and/or 2023.

The Tier 4 frac fleet was phased into operation from Q3 2021 to Q1 2022. Emissions testing was performed on the Tier 4 engines compared to the incumbent Tier 2 engines In January 2022 on a BC completion site.

Path Forward

Path Forward for 2022-23

Although over 20 projects are ongoing at the ETC, there is generally a need for long-term site usage, so most of the companies that have already gone through the intake process are still currently in Stage 2 (laboratory testing) or Stage 3 (field live site testing). NRCan has approved additional funding of $1MM for the fiscal year 2022-23, which is crucial to completing the ongoing projects and bringing on a minimum of an additional 10 projects within the current fiscal year, bringing the total site usage by March 31, 2023 to be at minimum 30 projects run through the ETC.

NRCan has also expressed that in the 2022-23 year end technical report, there should be not only a summary of test results for each site user, but also an impact assessment made showing the potential for methane emissions reduction under different levels of uptake from the various companies that have gone through ETC. This report, along with individual technical reports, will be the main output from the ETC for 2022-23.

NGIF and its site host partners (Tourmaline/ Perpetual and UCalgary) are actively pursuing different funding opportunities and reviewing longevity operating models for the NGIF ETC, under different levels of funding. It is our goal to keep this as a free test centre for methane emissions control technology testing, as this is a critical need for the energy industry during these times of changing methane regulations. We are proud to say that the NGIF ETC plays an important role in this space, helping methane cleantech companies to accelerate their path to commercialization and, along with this, helping to provide future commercial solutions for methane emissions reduction to the upstream oil and gas industry.

Appendix A

Contributors and Acknowledgements

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Appendix B

NGIF ETC INTAKE FORM

GENERAL NGIF ETC INTAKE FORM

The Natural Gas Innovation Fund (NGIF) Emission Testing Centre (ETC) is a platform to de-risk emission reduction technology in a laboratory and in an Oil and Gas operator environment.

All information provided by the Technology Company shall be non-proprietary and deemed to be non-confidential and must be truthful, legal and not violate the rights of others. Should confidential information be required or requested by the NGIF-ETC members, at any time during the process, appropriate confidentiality measures will be put in place.

All information will be shared with the NGIF-ETC Technology Review Committee for review and alignment with the current or future ETC program.

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1. Please specify your interested testing environment (check one box):
   a. ☐Lab: University of Calgary laboratory
   b. ☐Field: Tourmaline gas plant, wellsite facilities, and/or D&C operations
   c. ☐Laboratory and field facilities

2. Company Name: Click or tap here to enter text.

3. Primary company Contact Information: Click or tap here to enter text.

4. Website URL: Click or tap here to enter text.

5. Technology Readiness Level (TRL 4 to 9): Click or tap here to enter text.
   Please refer to the following link https://www.ic.gc.ca/eic/site/080.nsf/eng/00002.html

6. Provide a 1-2 paragraph description of your company, your tech and your proposed testing at the NGIF ETC. This is information that can be publicly released in press statements of public-facing progress reports.

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7. Briefly describe the technology – background, description and and value proposition (max 500 words):

8. Indicate any other government and/or non-government organizational funding granted to the proposed technology:

9. Indicate the technology product readiness timeline for lab and/or field installation:

10. Describe how you think NGIF-ETC can assist your technology roadmap (lab and/or field):
    a. *Describe what type of testing would be of interest to you for your technology de-risking.*
    b. *Describe what are the testing requirements you will need at the ETC –what are your testing install and data needs, what you need the ETC to provide to you.*
    c. *Describe the projected timeline needed for any product/prototype tests.*
    d. *If the testing requires any special install requirements with costs associated, please highlight them for planning/budgeting purposes*

11. Attach any additional information that you feel the NGIF-ETC intake committee should know about your technology and/or company.

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Appendix C

ETC operations committee participants

NGIF management:

- Jonathan Bryan (ETC technical director)

Tourmaline innovation team:

- Scott Volk (team lead)
- Carter Bates (EIT, main field support)
- Dylan Morrow (EIT)
- Brandon Dewar (EIT)

University of Calgary:

- Ian Gates (professor, head of ETC lab and HQP program)
- Nicole Calma (ETC lab coordinator)

Modern West associates:

- Wayne Hillier (Subject matter expert advisor to the ETC)

Appendix D

University of Calgary ETC lab equipment and modeling abilities

University of Calgary's analytical laboratory equipment:

- Mass Spectrometry Detector (GC-MSD),
- Sulfur Chemiluminescence detector (GC-SCD),
- Flame Ionization Detector (GC-FID),
- *Simulated Distillation Micro-GC with four channels (natural gas, refinery gas, and permanent gas analysis)
- Lifesizer 500 for particle size analysis, Optical PSD with Image Capture
- DHR-2 rheometer, Brookfield Rheometer (2.8 McP max, <220C), Anton-Paar Viscometer (viscosity, density)
- Uniaxial Mechanical Tester (for compressibility and Young's modulus)
- Tensiometer for IFT (up to 220C), Dynamic Foam Analyzer
- Zeta/Streaming Potential Analyzer for emulsion studies
- UV-VIS split beam spectrophotometer
- Surface Roughness apparatus (3D profilometer)
- *Anton Paar autosorb system for chemi- and physisorption analysis of catalyst metal area, mico or mesopore size and surface area
- Moisture Analyzer (sand and bulk samples, T controlled)
- Helium gas membrane test (flux/leak) apparatus, hydrogen separation
- Vacuum Pumps, Vacuum Oven, High T Furnace (1100C)
- Confocal Microscope with High Pressure (~5MPa) Stage for observing Pore Scale Dynamics
- Custom-designed core flood apparatus, high temp. reactors, flow cells

Analytical laboratory equipment was supplied by the Professor Ian Gates through his research group as a 'in-kind' contribution.

Equipment identified with * was partially funded by Natural Resources Canada.

Computer hardware

- six 80-core workstations
- six 8-core dual and eight 16-core quad processors workstations
- 40-core quad processor workstations, 1
- 6-core +2 and 4 GPU (128 core each) workstations
- 96-core cluster
- access to Westgrid supercomputing capabilities as needed.
- Modelling Applications
- DFT and molecular simulation: Gaussian, Material Studio, VASP
- Computational Fluid Dynamics: COMSOL (flow, electromagnetic, chemical reaction, heat transport, multiphase, porous media modules), Ansys Fluent (computational fluid dynamics)
- Reservoir Simulation: Petrel (Geomodelling), Eclipse & Intersect (Reservoir Simulation), CMG IMEX, GEM, STARS (Reservoir Simulation)
- Process Simulation: Aspen HYSYS, DWSIM
- Mechanical Modelling: Abaqus (mechanics for hydraulic fracturing)
- Codes developed within Gates Research Group (C, C++, Python, Matlab): Steam scheduling for CSS, SAGD, SF (for field scale modelling using type curves, Discrete Fracture Model ode, Optimization Codes, Air pollution LSTM modelling and forecasting, Multiphase/multi-regime flow models.

Questions?

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