FINAL OUTCOMES REPORT

UCalgary-Canadian Natural Fugitive Emissions Pilot Study: Field Scale Deployment and Acceleration of Made-In-Alberta Technology for Fugitive Emissions Detection and Reduction

ERA Project ID: F0160797

Title of project: UCalgary-Canadian Natural Fugitive Emissions Pilot Study: Field Scale Deployment and Acceleration of Made-In-Alberta Technology for Fugitive Emissions Detection and Reduction

Name and information of recipient contact: Chris Hugenholtz, chhugenh@ucalgary.ca

Name of ERA project advisor: Bruce Duong, Senior Manager, Recovery Technologies

Start date of project: September 15, 2020

Completion date of project: October 31, 2023

Technology readiness level at project initiation:
PoMELO Padmapper: 8
PoMELO Passive: 6

Technology readiness level at project completion:
PoMELO Padmapper: 9
PoMELO Passive: 9

Total actual ERA funds received:
$1,422,587

Total actual project costs:
$2,845,446
Final outcomes report submission date:
October 27, 2023

Short project description: The primary objective of this project was to pilot and advance commercial deployment of a new vehicle-based technology for regulatory leak detection and repair (LDAR) at upstream oil and gas facilities in Alberta. The secondary objectives were to: (i) evaluate the technology's operational performance at scale, both on and off facilities, in order to define the market fit and opportunity; and (ii) extend the technology's software functionality by consolidating data and reporting. To achieve these objectives, the University of Calgary partnered with Canadian Natural to scale-up deployment of its rapid vehicle-based methane emissions mapping system at thousands of O&G facilities across Alberta.

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4. Executive summary

This Final Outcomes Report meets the requirements set by the Contribution Agreement between The University of Calgary and Emissions Reductions Alberta (ERA). ERA provided grant funding to The University of Calgary for the project entitled UCalgary-Canadian Natural Fugitive Emissions Pilot Study: Field-Scale Deployment and Acceleration of Made-In-Alberta Technology for Fugitive Emissions Detection and Reduction. The project goals were to complete a full-scale field pilot of a new vehicle-based technology for regulatory leak detection and repair (LDAR) and simultaneously develop the world's first mobile sensing system for monitoring site-level emissions measurements of upstream oil and gas wells and facilities.

The technology, called PoMELO, is an emissions management system developed at the University of Calgary that incorporates a scientific-grade multi-sensor hardware unit, advanced software to automate data processing and guide decision making, and a work practice to accelerate actions to reduce methane emissions. PoMELO has two deployment modes with the same hardware. The on-pad mode (on facilities, on private roads and property) is for LDAR surveys and uses proprietary software called PoMELO Padmapper. The off-pad mode is for site-level emissions monitoring and uses proprietary software called PoMELO Passive. The ERA project entailed pilot deployment of the hard unit and Padmapper software to advance the technology readiness level (TRL) from 8 to 9, and maturation of the Passive software from TRL 6 to 9.

All key performance indicators were achieved or exceeded, including the following:

- A median on-pad survey time of 3.58 minutes using Padmapper. This entails the time it took to collect, process, map, and generate a report of the measurement data.
- The average number of sites surveyed per day was 11.24, which includes follow-up inspection with an OGI camera where necessary.
- Operator-reported efficiency gains for on-pad LDAR surveys compared to conventional LDAR methods up to 50%.
- Quantified and attributed seven site-level methane plumes from off-pad surveys per 100 km of driving.
- Facility driveability, which refers to the ability to drive around all the equipment on site, was 50-75%.
- The uptime for the systems was 5291.8 hours based on off-pad data, but the uptime is much greater if on-pad data are included. The average hardware uptime between interventions was 661.5 hours, and the average software uptime between interventions was 132.3 hours.
- Operators intervened with the hardware 2-4 times per year to tighten and replace worn components.
- Operators identified approximately 20 software issues per year, mostly related to bugs. Bugs decreased substantially with the second-generation quantification model and were negligible towards the end of the project.
- User satisfaction increased as software improvements were made and was high by the end of the project.

In addition to the foregoing performance metrics, PoMELO was successful in finding and informing repairs of fugitive methane emissions sources from oil and gas equipment. During the pilot deployment in Canadian Natural's LDAR program, PoMELO completed 4,998 on-pad surveys of 1,564 unique oil and gas sites.

A key accomplishment of this project is that Canadian Natural continues to use the technology post project for regulatory LDAR surveys. This is evidence that the project succeeded in commercializing the technology for full-scale industrial deployment. PoMELO continues to be the most widely used advanced measurement technology for regulator approved LDAR surveys in Canada and has established the largest, vehicle-based monitoring program of site-level methane emissions in the world.

5. Project description

5.1. Introduction

The goal of this project is to execute an intensive field trial of the PoMELO vehicle-based methane emissions detection and quantification system. The project involved a partnership between the University of Calgary and Canadian Natural. Canadian Natural used the PoMELO system to achieve regulatory compliance for their leak detection and repair (LDAR) program, while simultaneously collecting data and advancing the PoMELO system for general use.

The project was designed to advance two deployment modes of PoMELO: (i) Padmapper provides on-pad equipment-scale emissions detections, attributions, and quantifications, and (ii) Passive uses the data collected between sites to build a mobile sensor web of site-scale emissions detections, attributions, and quantifications. The data produced by PoMELO enable emissions reductions by generating information from which repairs and retrofits can be made.

The PoMELO system consists of (i) hardware, (ii) onboard firmware and software, and (iii) cloud-based software. Each component works together synergistically. The hardware consists of three high performance sensors that are mounted on the roof of regular field trucks. These trucks are driven by operators to oil and gas sites and collect data continuously onboard a local computer. The local computer runs customized firmware and onboard software that collects data from the sensors, logs internally the data, and serves the Padmapper software suite. The Padmapper software takes the sensor data and presents a user interface to operators in the cab that shows which equipment on a site is emitting and provides a triage grade emissions rate. Off-pad data are packaged for transmission to the cloud, where the cloud-based software processes raw data with the Passive project.

5.2. Background of the Project

Finding, locating, and quantifying anomalous methane emissions from upstream oil & gas (O&G) facilities safely and cost-effectively is a cornerstone enabler of methane emissions reductions. One of the key challenges facing industry is that there are millions of components at upstream O&G facilities globally that require routine inspection to find leaks. Research has shown that a very small percentage of components are leaking and require repair. Use of conventional close-range inspection methods is inefficient and costly as all components need to be inspected to find the small percent that are leaking. This has driven innovation in new technologies and methods to find leaks faster and at a lower cost than existing methods.

Simultaneously, the need for measurement of methane emissions has greatly increased. First, measurements are now under proposal for being written into regulations for methane emissions management. For example, the U.S. Environmental Protection Agency has proposed regulations up for comment that have an explicit measurement-based methane fee, applicable across the U.S. Fees cannot be levied without measurement, opening up a considerable market for accurate and rapid methane measurement. Second, oil and gas producers now face considerable pressure from the investment community to reduce methane emissions. Credible and auditable performance showing effective methane management is an important enabler of investment for projects such as LNG facilities and major production expansions. To demonstrate progress and performance, producers require measurements. And third, a wide variety of voluntary gas differentiation schemes are being developed to sell gas produced with demonstrable low emissions at a premium. Some of these schemes require measurements.

To address these issues, the University of Calgary developed a vehicle-based emissions measurement system called PoMELO. The technology was developed in Q4 2017 with funding from Natural Resources Canada and the Petroleum Technology Alliance of Canada. Within months, the system was selected to compete in the Stanford/EDF Mobile Monitoring Challenge (MMC). Subsequent funding from Alberta Innovates Climate Change Innovation and Technology Framework (CCITF) Clean Technology Development (CTD) brought the technology to TRL8 and enabled development of a second deployment mode (PoMELO Passive).

PoMELO has been strategically positioned to move to a commercial operations mode as a commercial partner would be better suited to provide commercial services to the oil and gas sector. The project has undergone considerable commercialization activities through the University of Calgary technology transfer office Innovate Calgary in an effort to commercialize the technology.

Canadian Natural is a large producer of oil and gas across Alberta and was interested in deploying PoMELO to improve the cost-effectiveness of its LDAR programs. Canadian Natural obtained approval from the Alberta Energy Regulator to deploy a PoMELO based LDAR program in place of their standard AER Directive 060 LDAR requirements. To advance PoMELO, Canadian Natural and the University of Calgary entered a partnership whereby University of Calgary would subcontract Canadian Natural to perform field testing of PoMELO as part of their regulatory LDAR program, fulfilling their requirements to the AER while simultaneously executing a rigorous field program advancing PoMELO.

5.3. Project objectives

The primary objective is to pilot and advance commercial deployment of made-in-Alberta technology for fugitive emissions management of upstream O&G facilities. The secondary objectives are:

1) To evaluate PoMELO’s operational performance at scale, both on (Padmapper) and off facilities (Passive), to define the market fit and opportunity.
2) To extend PoMELO’s software functionality by consolidating data and reporting from Padmapper and OGI.

5.4. Performance/success metrics identified in the Contribution Agreement

5.4.1. Survey time on pad

Commercialization target: 5 minutes on average.
Project target: 6-10 minutes on average.
Pre-project achievements: 5 minutes on average at METEC; 6-22 minutes in AMFC (June & Nov 2019).
Project achievement: Across the entire project, the median survey time for PoMELO was 3.58 minutes. To bring this number into context, a site survey with PoMELO and the Canadian Natural work practice involves first using PoMELO to measure emissions across the site by driving around the site, then using the software to quantify emissions, and prepare reports. After this, crews would conduct follow-up investigation with an OGI camera, complete documentation and other reporting, then proceed to the next site.

This metric only measures the survey time. Other times such as reporting, follow-up, investigation, or other on-site data collection is not quantified. Additionally, these data are not a good metric of PoMELO performance as the time relates closely to the number of leaks found (and reporting required), any other data collected, and the general efficiency of Canadian Natural on-pad processes. While we worked with crews to improve the speed of PoMELO related reporting and data entry, the other components of a site visit have limited meaning for PoMELO performance.

To put the metric into context, we show in an upcoming peer-reviewed journal article (in press at the time of writing) that reducing survey time on pad with vehicle-based screening can substantially streamline LDAR surveys and reduce program cost.

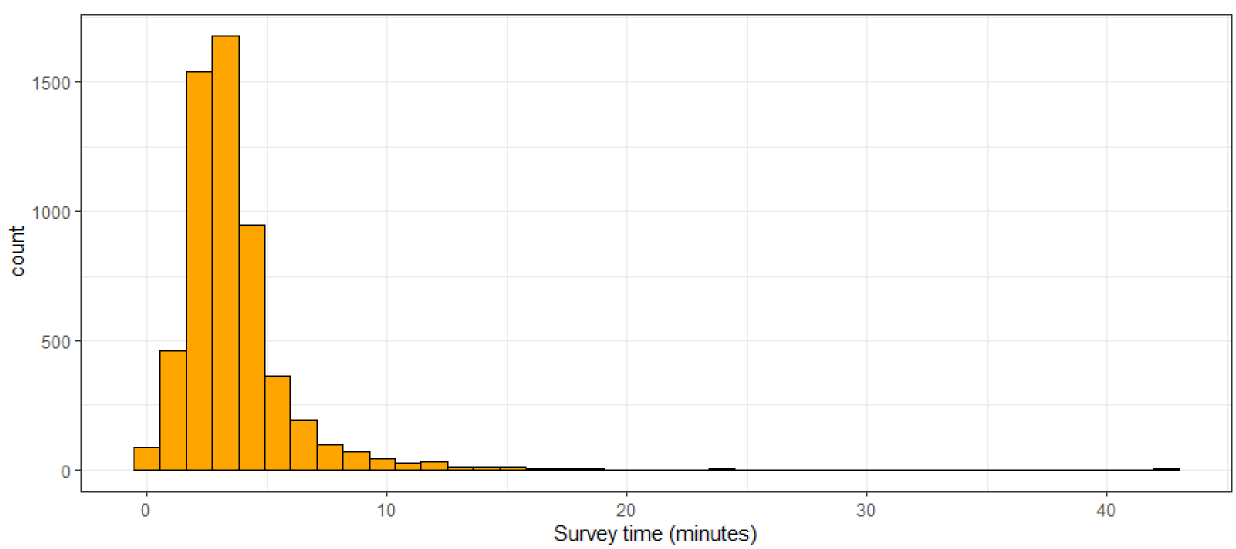

***Figure 1**: Survey time across all sites.*

5.4.2. Facilities surveyed per day (in combined OGI work practice)

Commercialization target: 7-10 on average.
Project target: 7 on average.
Pre-project achievements: 5-8 facilities/day in AMFC.

Project achievement: The project average was 11.24 sites per day. This result is modulated by the total time on pad, which is a result of number of leaks, the work practice, and many other factors which are not explicitly related to PoMELO. Additionally, it is important to note that the number of sites surveyed in a day is closely related to the drive time between sites. Canadian Natural sites for this pilot project were often located far away from each other and it is likely that operations where all sites in an area are surveyed and drive time could be minimized would have much faster results.

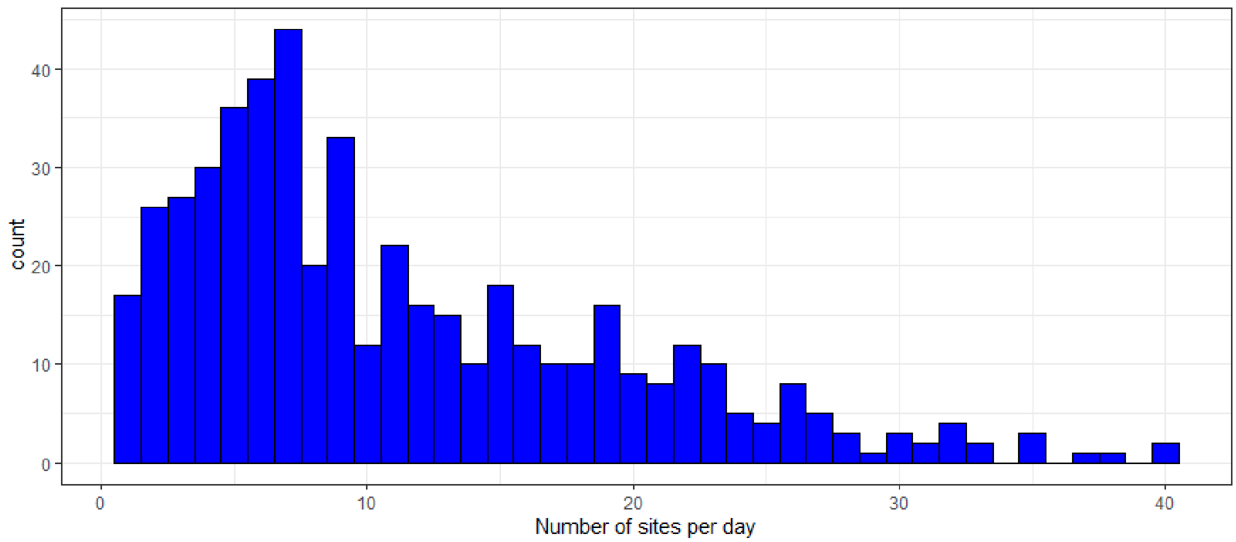

Figure 2: *Total number of sites per day across the project, among all systems.*

5.4.3. Operator-interpreted efficiency gains

Commercialization target: 20-50%.

Project target: 10-30%.

Pre-project achievements: N/A.

Project achievement: Following the release of the major software update at the end of year 1, crews reported significant efficiency gains in most situations. All operators saw major gains at medium to large facilities that had few fugitive and vent sources to start with. Crews reported efficiency gains of up to a 50% reduction in the time spent on-site at large facilities. Operators mentioned minor efficiency improvements of around 25% at small sites as an OGI survey of the facility can be completed quickly. Crews reported minor efficiency gains at sites that had a large quantity of vents or fugitive sources. No operator reported a decrease in efficiency even in the most unfavorable conditions.

5.4.4. Quantified and attributed plume intersections on public roads per 100 km

Commercialization target: 5-20 on average

Project target: 5-10 on average

Pre-project achievements: 8 on average from 20-day field campaign in 2018

Project achievement: There were approximately 6.96 successfully attributed plumes per 100 kms of public road Passive data. See Section 6.4.6 for further details and additional details.

5.4.5. Facility drivability

Commercialization target: 50-75%

Project target: 50%

Pre-project achievements: 50% of facilities in PTAC's Alt-FEMP and AMFC were drivable (i.e., PoMELO could circle all equipment on-pad).

Project achievement: Canadian Natural crews did not provide reliable data to assess this quantitatively, but qualitative results suggest that 50-75% of equipment could be easily surveyed with PoMELO. This varied considerably across the province with much higher facility drivability in the Lloydminster region where sites had truck tank-loading turn-arounds – and lower in other parts of the province that had more topographic constraints on site construction and production was primarily through pipeline.

5.4.6. Hardware performance

Commercialization target: 3,000 hours

Project target: 300 hours

Pre-project achievements: Replacement of 2 temperature sensors due to damage by student operator between 2017-2020.

Project achievement: The systems were collectively up for 5291.8 hours from our data collected from off-pad. The systems were up for more than this value if including data on pads. With approximately 4 interventions required per year, the hardware had an average uptime between interventions of 661.5 hours. It is likely there were additional interventions that were not reported to us that could be fixed without help from University of Calgary staff.

5.4.7. Software performance

Commercialization target: 3,000 hours.

Project target: 300 hours.

Pre-project achievements: Not measured to date.

Project achievement: The systems were collectively up for 5291.8 hours from our data collected from off-pad. The systems were up for more than this value if including data on pads. With approximately 20 interventions per year, we estimate an average uptime of 132.3 hours between interventions. We expect this number is lower as there were issues that did not yield bug reports or definable issues.

5.4.8. Operator hardware interventions

Commercialization target: 10 per year.

Project target: 20 per year.

Pre-project achievements: N/A.

Project achievement: Operators did not intervene with the hardware for the purposes of correcting hardware failures, all operations maintenance and repairs were conducted by University of Calgary staff. Canadian Natural operators did regularly inspect, maintain, and clean the systems. Operators intervened with the hardware 2-4 times per year to perform self-induced upgrades. For example, some crews purchased and installed aero-bar roof racks and performed the retrofit installation themselves. As well, one crew added a handle to their system. One crew also added noise reduction materials. These interventions tapered off throughout the project as crews tailored their installations to their likings and operational habits.

5.4.9. Operator identified issues / bugs

Commercialization target: 2 per year on average.

Project target: 4 per year on average.

Pre-project achievements: N/A.

Project achievement: Operators identified approximately 20 issues with the software per year. This related closely to the maturity of the software. As noted in Section 6.2.6, software underwent considerable evolution throughout the project, meaning the software was operated with a lower level of maturity as we rolled out changes to improve quantification for the Canadian Natural work practice. Identified bugs decreased as software matured with the second-generation quantification model near the end of the project.

5.4.10. Environmental blackouts (weather limitations)

Commercialization target: 20 days per year.

Project target: 30 days per year.

Pre-project achievements: Successful operation in light precipitation; mapping algorithms do not work well when there is no wind.

Project achievement: We estimate 30 days per year were unsuitable for PoMELO use due to weather issues. This metric is extremely susceptible to the deployment zone and the operational management of the operators of PoMELO. We could not use 'off-days' as a good proxy of weather limitations as hoped as Canadian Natural did not utilize PoMELO at full operational scale, with many days off due to other operational management issues (see Section 5.5.2). While weather certainly limited some PoMELO operations, weather limitations often were related to dangerous driving conditions and other factors that cannot be meaningfully addressed in the design of PoMELO.

5.4.11. User satisfaction

Commercialization target: High.

Project target: High.

Pre-project achievements: N/A.

Project achievement: Surveys suggested high user satisfaction. This noted, user satisfaction changed through the project, improving with the release of the second-generation quantification engine and maturation of the software. User satisfaction also related to the clarity of work practices, once crews had a better understanding of what PoMELO could do for them and the mechanics of the Canadian Natural work practice, satisfaction increased.

Canadian Natural continues to use the systems post project.

5.5. Discussion on any changes in the Project during the lifecycle of the ERA funded Project scope

5.5.1. Canadian Natural on-pad operations

To provide background information and context on this topic, there are two general categories of work practices that can be implemented with PoMELO.

Detection-based work practice: this work practice is based on using PoMELO to detect emitting equipment on sites. From this, all equipment that is emitting is inspected using standard component scale leak detection technologies such as OGI. This work practice is mature and well validated with straightforwardly understood emissions reductions efficacy (Barchyn and Hugenholtz, 2020).

Quantification-based work practice: this work practice uses the PoMELO system to quantify equipment. Equipment that exceeds a certain emissions rate is then flagged for follow-up with standard component scale leak detection technologies such as OGI. This work practice depends on quantification accuracy to be efficient and effective.

Canadian Natural implemented a quantification-based work practice, instead of the detection-based work practice.

5.5.2. Canadian Natural operations management

We had a target operational uptime expectation of approximately 30-40 hours per week, depending on season. Canadian Natural operations used the systems at a much lower operational efficiency than this.

5 Project Work Scope

5.6 Deployment

Deployment of the PoMELO systems proceeded in multiple phases:

System construction: three systems were built with metalwork, electronics assembly, software configuration, and initial testing completed prior to sensor integration. The systems were tested around Calgary prior to deployment to ensure systems performed to specification, complete commissioning tasks, and prepare for deployment.

Canadian Natural vehicle installation: vehicles from Canadian Natural were delivered to the University of Calgary and installation and calibration was performed in Calgary.

Training and vehicle handover: training occurred in two parts. First, Canadian Natural field crews conducted the online component of the training modules. Second, some field crews performed in person training at the University of Calgary, which was performed also at a nearby Canadian Natural field site. Some Canadian Natural crews were trained by other crews in an effort to minimize gatherings as part of COVID restrictions.

Vehicle delivery: vehicles were delivered with the PoMELO systems to the field offices where Canadian Natural field crews were based and survey programs commenced shortly thereafter.

Figure 3: *Canadian Natural vehicles with PoMELO systems prior to the field deployment.*

5.7 Operations

Canadian Natural operated PoMELO through March 2021-December 2022 as part of this project.

5.7.2 Shadow campaigns

Figure 4: *Shadow campaigns involved University of Calgary staff shadowing Canadian Natural operators to help improve PoMELO operations and learn about PoMELO performance in the field.*

Shadow campaigns were very effective to advance PoMELO on-pad operations. The shadow campaigns helped advance PoMELO in several manners:

1) Enhanced training: shadow campaigns allowed us to fill in any missing training gaps and help educate the field crews on new features. In particular, it greatly helped with training for the new quantification engine, helping field crews understand new results and interpret quality control data.
2) System inspection: shadow campaigns allowed us to conduct inspections of the systems and understand how the system was wearing. These inspections were valuable additions to the servicing schedules.
3) Feedback: we obtained very high-quality feedback from operators as we were able to spend some time with them and listen to their notes on using the system. Operators were much more likely to provide quality feedback in the field than through surveys. However, surveys were still valuable to provide synoptic information. Some small changes to the software and hardware that had major implications for crew satisfaction were identified through these sessions.
4) Understanding of problem / product-market fit research: we were able to deeply understand the problem that Canadian Natural staff were approaching and the nature of emissions on their sites. This was valuable to help us tailor the system to the needs of LDAR operators.

Shadow campaigns were completed following the Milestone schedules.

Lloydminster: April 2021

A field visit to Lloydminster crews occurred shortly after deployment. The field visit helped provide supplementary training for field crews in Lloydminster whom were unable to attend the initial project training. Additionally we gained valuable feedback from the field crews and better understood the type of production in Lloydminster and their goals for surveys.

Rocky Mountain House: June 2021

The system was in good shape during this shadow campaign and did not require any interventions.

Edson: October 2021

The operator reported PoMELO was a time saver at newer sites that run off instrument air.

Lloydminster: October 2021

Most facilities in the Lloydminster region use old, retrofitted engines to power sites and compress hydrocarbons. These engines are inefficient and release a significant amount of unburnt methane fuel in the exhaust, also known as fuel slip. Methane in the fuel slip often covered and contaminated entire sites resulting in false positives for non-emitting equipment.

Turner Valley: May 2022

The operator mentioned they were pleased with the updated software. Specifically, they were impressed with the user interface and quantification improvements.

Lloydminster: July 2022

Both operators mentioned since the major software update their confidence in the system increased and efficiency gains had improved.

Grande Prairie: August 2022

The operator shared their high level of confidence in the system to detect methane emissions.

5.7.3 Servicing events

Servicing events were conducted on a yearly basis (2 events per system over the project), with interim servicing and system inspections conducted during shadow campaigns. Servicing events were very effective at cataloging the wear on the systems. Additionally, servicing events allowed for predictable system downtime where we had an opportunity to update software and apply operating system patches on our firmware computers. As with all computer systems, PoMELO requires occasional planned downtime to update key operating system components.

We completed the following servicing events: in-house servicing events were completed in December 2021, and December 2022. The in-house servicing events were more granular than servicing during shadow campaigns and allowed for in depth documentation of wear and tear.

5.7.4 Quantification engine improvements

The University of Calgary conducted work to improve the quantification engine of PoMELO Padmapper. Note that these changes only affected the on-pad part of PoMELO.

Improvements to the emissions quantification engine in PoMELO Padmapper required significant research and development effort at the University of Calgary, and was undertaken in several phases, in several major software design-develop-test-deploy cycles. This project was a significant scope change to the ERA project. This noted, these changes to improve PoMELO are beneficial and will net much wider benefits outside of the ERA project.

User-interface preparation: First, the user interface part of PoMELO was modified.

An extensive testing program at the University of Calgary, prior to deployment, was utilized to mature the interface prior to deployment. Canadian Natural crews and managers were engaged as part of this process to obtain feedback on ease of use and optimize the level of detail that would effectively balance crew operations and accuracy.

Quantification engine development: The quantification engine was developed with previously collected controlled release data. The new algorithms included major changes to anomaly calculations, wind modeling, equipment specific plume modeling, and significant modifications to the emissions rate calculations. The new engine actively de-convolved the methane contributions from closely positioned emissions sources to provide emissions rate estimates in mixed plumes.

The new quantification engine also included a transition to probability-based emissions modeling and included significant self-monitoring capabilities to understand the accuracy and precision of each emissions measurement. Emissions quantifications from all stand-off technologies tend to vary in accuracy and precision based on the weather conditions. The PoMELO quantification engine actively measures the conditions to effectively modulate the error curves so users have an accurate understanding of the uncertainty of each measurement.

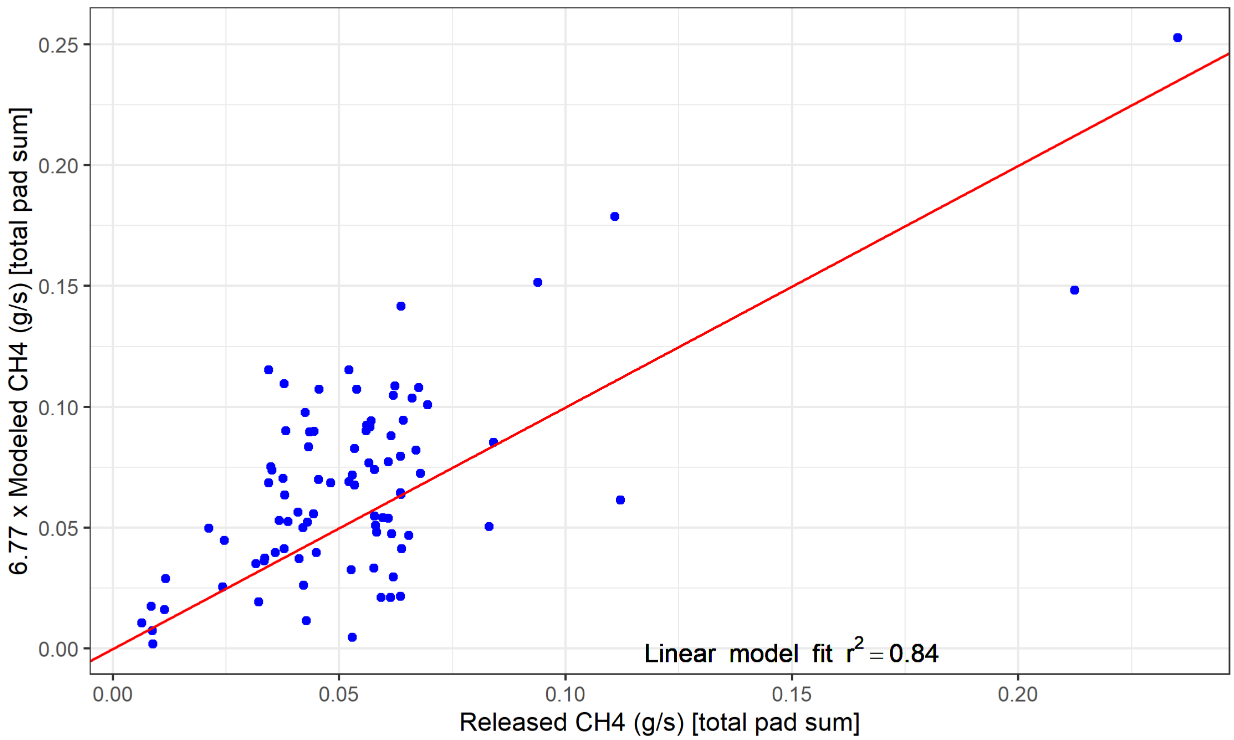

***Figure 5**: Total pad emissions rate measured with PoMELO against controlled releases with the new updated quantification engine. See Barchyn and Hugenholtz (2020) for full details and context on this plot.*

Quantification engine performance report: To communicate the general performance of the emissions quantification engine and help users understand the performance of the PoMELO emissions quantification engine, we wrote a comprehensive quantification performance report (Barchyn and Hugenholtz, 2022). This report provides sufficient information for users of PoMELO to carefully understand and model the emissions measurement characteristics. It is now industry standard to transparently share emissions measurement capabilities and required to help with regulatory approval, so this report was a vital addition to enhance the commercial potential of PoMELO with an enhanced quantification engine.

Barchyn TE, Hugenholtz CH, 2022. Complex multi-source emissions quantification results for the PoMELO vehicle measurement system, test results from the CSU METEC facility. EarthArXiv. DOI: https://doi.org/10.31223/X5XP7B

Post-measurement analysis and measurement enhancement workflow tool: To better enable the use of probabilistic emissions management tools we built out a system for integrating different measurements. The benefit of this is enhanced accuracy and several new measurement modes that allow enhanced accuracy with multiple measurements and a comprehensive approach to risk-based modeling of emissions measured from Padmapper. This toolbox was tested as a web-based tool – but subsequently installed on PoMELO systems and linked with the PoMELO data. The web-based version was left as a system for office staff to work with emissions quantifications. The toolset was introduced in a subsequent update and was referred to as the 'UCalgary Emissions Explorer'.

Training, consultation, and feedback: As the new quantification engine rolled out, feedback was gathered from Canadian Natural crews. An extensive training package was provided to help crews understand what they were looking at and how to manage probabilities. While the Canadian Natural work practice was not modified in any way to shift to a managed risk or probability-based format – the concept was introduced to crews and managers. Shadow campaigns helped drive home the concepts and introduced some 'on the ground' training for crews on how quantification worked with PoMELO.

The general feedback from crews was very positive. Crews were pleased with the increased accuracy of the results and the velocity of operations increased as less OGI follow-up was required.

5.7.5 PoMELO sensor performance

PoMELO sensors are a major capital component of PoMELO – we discuss sensor performance prior to discussing performance of the rest of the hardware package. The PoMELO sensors performed very well across all conditions. There were no major issues identified with the sensors and inspections through the servicing program did not provide any indications that the sensors were close to end of life or isolate any durability concerns.

The fact that no long-term issues were identified is an extremely positive outcome from the ERA project.

Proven long-term field performance helps both commercial partners of PoMELO as they can confidently promise long term operations for clients, and for potential PoMELO clients as they can feel confident purchasing equipment. Longevity in value also raises a prospect of a resale market and suggests that initial capital expenses could be recouped in some cases through resale. Generally, we believe PoMELO systems have a long lifespan and with semi-annual servicing and care systems should last many years with little depreciation.

5.7.6 Hardware performance and improvements

Beyond the three sensors, PoMELO has a considerable amount of mounting hardware, electronics equipment, and accessories. This hardware is essential to the PoMELO design and effectively mounting the fragile sensors on the roof of a vehicle in a useful and durable configuration is one of the core enablers of the PoMELO system. Long term durability was an important question prior to the ERA project as it deeply affects the long-term commercial viability of the PoMELO system in commercial operations.

In general, the hardware performed exemplary. The system encountered all types of roads and crews did not take any special care with the system, so it was subject to extensive vibration and all-weather conditions. The hardware and electronics components were reliable and could be trusted to support PoMELO operations. Very few hardware related issues were encountered.

The excellent hardware performance provides strong validation of the hardware design and greatly de-risks long-term future operations.

5.7.7 Software performance and improvements

The software performance throughout the ERA project was generally excellent, with very few critical failures identified over many thousands of hours of operations. The initial focus of the ERA project was maturation within the detection-based work practice; however, changes to the operational work practice by Canadian Natural required the software to evolve more than initially considered within the original ERA application. Changes to software meant that the software was undergoing active development of new functionality and features instead of maturing the existing stack.

***Table 1**: Synopsis of major software version deployments.*

Software phase	Final update deployment date
Initial deployment	March 2021
Directed operations update	June 2021
Quantification engine update #1 (user interface)	September 2021
Quantification engine update #2 (engine)	February 2022
Post-measurement analysis and measurement enhancement with OGI tool	August 2022

Initial deployment: The initial version of the software was designed and developed prior to the start of the ERA project, including key localization and detection algorithms (Barchyn and Hugenholtz, 2020). The user interface included extensive functionality for managing sites and projects, and included the first-generation quantification engine. The initial deployment had some minor bugs that were progressively repaired throughout the first couple months of deployment.

Directed operations update: To help Canadian Natural operators, we modified the Padmapper user interface so it could only be operated in one operations trajectory. This modification greatly reduced the options available for Canadian Natural operators and improved operations habits as the software guided the user through onsite quantification and reporting.

Quantification engine update #1 (user interface): As part of the transition to a new quantification engine, we rolled out a change to the user interface first – running the first-generation quantification algorithms in the background. This change created substantial visual changes to the user interface and introduced a web-based map which users interacted with. An extensive system for pre-cached imagery was developed. Similarly, this change was accompanied with an extensive training package and consultation with Canadian Natural crews to help adaptation.

Quantification engine update #2 (engine): The second major update to the software involved the quantification engine itself. This involved major changes to the algorithms that changed how emissions quantification worked and resulted in fewer changes to the user interface. This change was accompanied with extensive training, support, and consultation with Canadian Natural crews. This introduced QC notes and a system to interpret emissions rates in terms of probabilities.

Post-measurement analysis and measurement enhancement with OGI tool: The final major update of the ERA project deployed the post-measurement analysis and OGI tool on Canadian Natural systems. This update enabled the full capabilities of probabilistic emissions reconciliation and management to Canadian Natural crews.

Throughout the ERA project significant enhancements to the software were made. These enhancements will improve the commercial viability of the PoMELO system. While the need for major changes to the quantification engine demanded by Canadian Natural crews operating with a non-standard work practice delayed software maturation – the final version of the software at the end of the ERA project was quite mature and included extensive practical functionality.

5.8 PoMELO Padmapper

5.8.2 General results

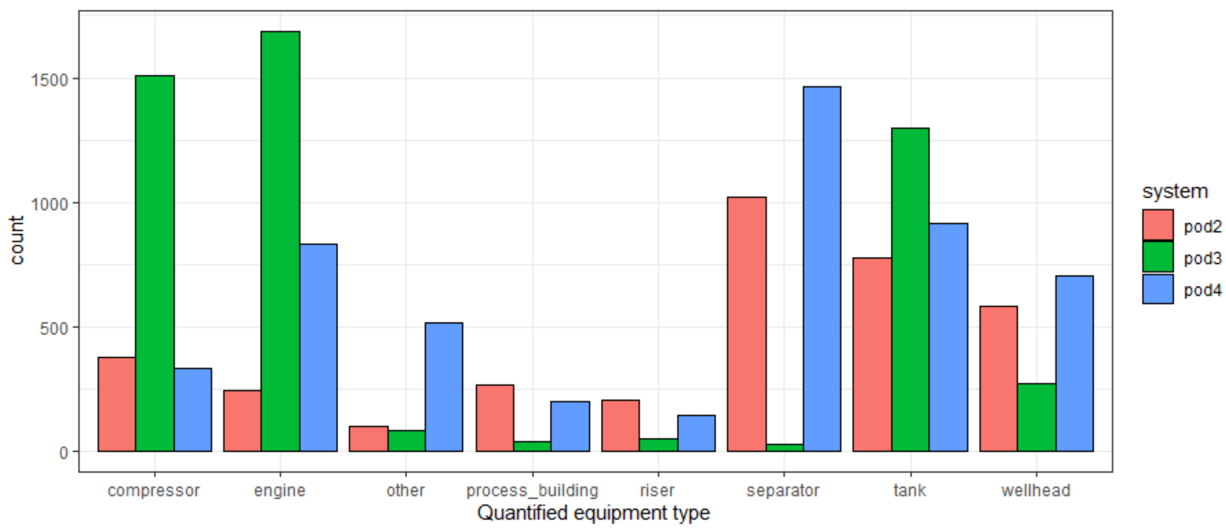

Figure 6: *Types of equipment quantified with Padmapper equipment scale quantification across the systems: pod2 (Stettler), pod3 (Lloydminster), pod4 (Edson / Grande Prairie).*

Coverage provides a unitless measurement of site access. Low 'coverage' means that it was difficult to drive the vehicle in the best location to make measurements. It also proxies the time that was spent in the core areas for quality data. Higher coverage can also indicate many laps and a focus on quantification quality.

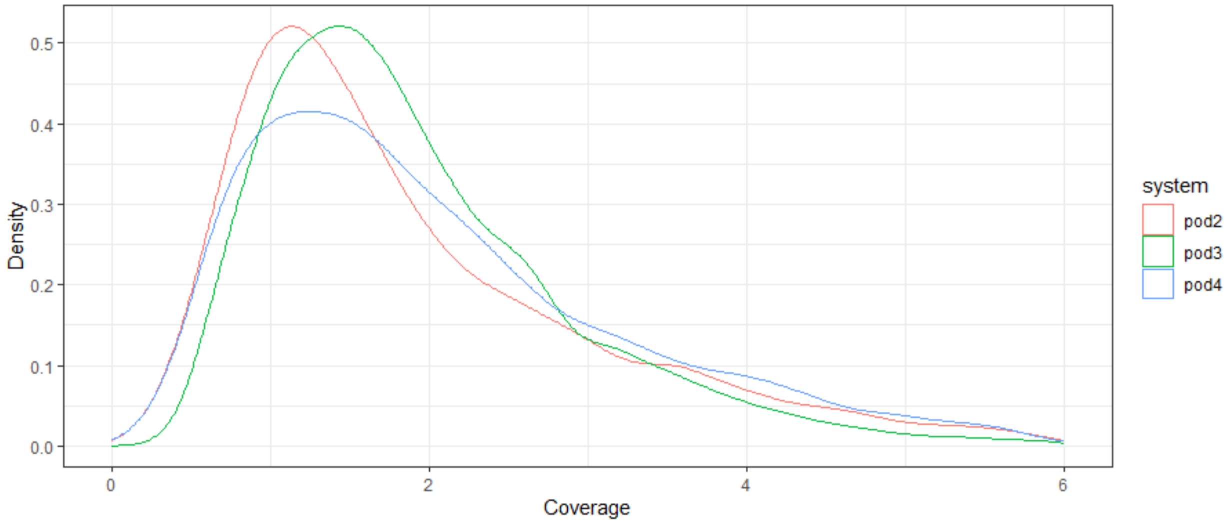

***Figure 7**: General coverage for Padmapper equipment scale quantifications across the systems: pod2 (Stettler), pod3 (Lloydminster), pod4 (Edson / Grande Prairie). Higher coverage indicates better vehicle access or more time spent surveying the core areas that yield high quality emissions quantifications.*

5.9 PoMELO Passive

5.9.2 Data collection

Part of the ERA project was to collect a large dataset to scale up the Passive modality of PoMELO. This was successfully achieved, with large quantities of data collected from Canadian Natural field operations.

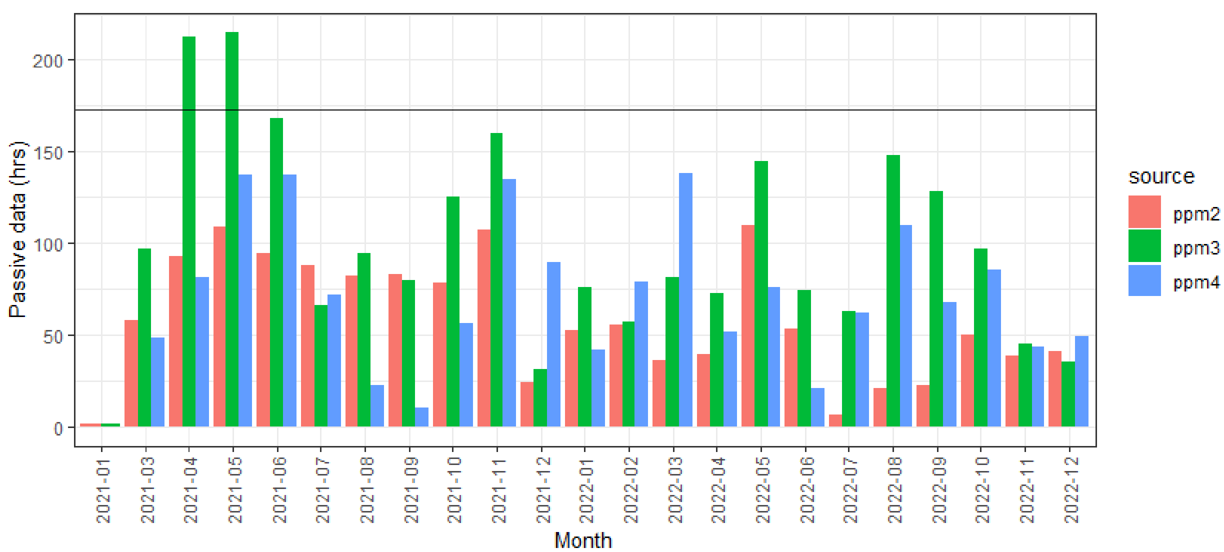

***Figure 8:** Passive data collected across the project, expressed as number of hours per month, stratified among different systems: ppm2 (Stettler), ppm3 (Lloydminster), ppm4 (Edson / Grande Prairie). Note the variability on a month-to-month basis and particularly the sharp gaps in uptime. The black line at 173 hours represents a standard 40 hours per week work week. These data are generally less than expected, but nonetheless provided a large dataset.*

Software systems for managing and transmitting data to the University of Calgary worked well throughout the project with only a few minor enhancements from start to finish of the project. The on-vehicle data system effectively split data between confidential and non-confidential data licenses following the agreement between the University of Calgary and Canadian Natural, only transmitting non-confidential data off the vehicle systems.

5.9.3 Operations monitoring

To enable monitoring of Passive data collection and help understand the areas of the province where data was being collected a live operations monitoring dashboard was created. This provided University of Calgary staff the ability to monitor the data collection by displaying the location of LDAR sites targeted by Canadian Natural as well as the live location of PoMELO vehicles.

5.9.4 Passive data serving

Within the University of Calgary, there was a need to serve PoMELO data out for internal uses and ad hoc research. Various research requirements involved queries by temporal extent, spatial extent (with custom polygon masks), system status, system id, and key data such as methane concentration. The volume of data and necessity to perform spatial queries required a specific tool. Spatial queries could involve data from any system, at any time and required the use of a high-performance query system.

To meet this requirement a PoMELO Application Programming Interface (hereafter PoMELO API) system was developed.

Throughout the project, the volume of data in the Passive serving database increased, necessitating changes to the query architecture to improve the query performance. The web-based front end was revised to improve the query performance and facilitate multi-stage queries.

To facilitate straightforward data viewing the database was exposed to research use with a mechanism for custom table connections, which allowed research use at the University of Calgary whereby researchers could connect their desktop Geographic Information System (GIS) software to their custom queried table and effectively navigate, view, and style the data.

5.9.5 Passive processing toolchain

Development of the passive processing toolchain was successfully achieved throughout the ERA project. This toolchain is a system to process the off-pad data in a scalable manner to produce useful information from off-pad data. While a large quantity of the processing toolchain was developed prior to the ERA project or parallel to the ERA project – it was necessary to deploy the algorithms in a scalable and high-performance system to automatically process the data.

The data from the ERA project was diverse, across many different environments, and across all seasons. The primary challenge with Passive calculations involve: (i) the volume of data and requirement for specialized systems to manage and process the data with sufficient velocity, and (ii) effectively evaluating the quality of the plume crosses and resulting attributions to find the best and most reliable plume cross data.

Not surprisingly, data were overwhelmingly biased to locations close to roads where the PoMELO systems drove. This is not likely to statistically skew the data as a tool for inventory of methane emissions.

The toolchain was effective at processing the large volumes of data collected by PoMELO systems and was scalable to allow research and development.

5.9.6 Results

The Passive project yielded a considerable volume of data for processing from each of the 3 systems (PoMELO 2, 3, 4).

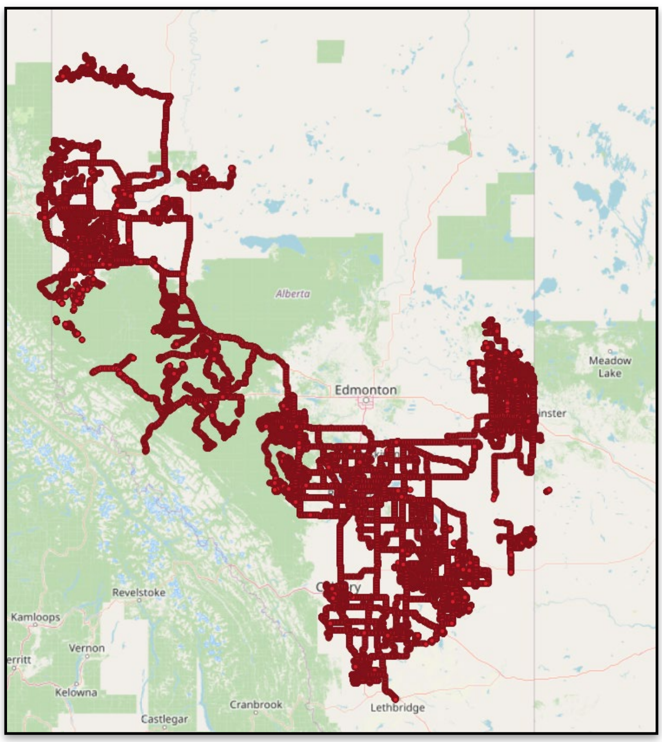

***Figure 9**: General data coverage across the Passive project.*

Figure 10: *An example of an emissions measurement, attribution and quantification from the Passive modality. In this example, the vehicle path is shown with barbs pointing to the direction of the wind. The red colors indicate higher methane concentration anomalies. This peak was segmented out, and the white dots show the flowtrace (where air was suspected to travel). The attributed site is shown with a blue dot. This estimate was taken passively without the knowledge of the field crews, just as they were driving to another site. The estimated emissions rate was approximately 601 cubic m / day of methane. This site could be prioritized for abatement as this is a relatively large emissions rate from a relatively small site.*

6 Commercialization

6.6 Commercial advancement

The PoMELO system deployed in the ERA project has made major strides towards commercialization and market adoption. At present, PoMELO is not commercially available; however, the ERA project has effectively positioned the PoMELO system as one of the most commercial-ready technologies available from the University of Calgary.

The PoMELO system was deployed with an additional operator parallel to the ERA project. Additionally, Canadian Natural has elected to continue using their PoMELO systems beyond the end of the project and have secured a licensing agreement from Innovate Calgary. These are strong votes of confidence in the PoMELO system for future commercial utility.

The PoMELO system is presently available for non-exclusive licencing by any producer. There is a route for oil and gas producers to obtain hardware, software, and support directly from the University of Calgary. While the University of Calgary is not a commercial business – we have made the technology available – and are ready to help oil and gas producers deploy to reduce emissions. There are no barriers to access for the technology.

The ERA project contributed to this positioning through several routes:

1) The PoMELO hardware and sensor package is now field proven in real oilfield conditions. This greatly de-risks commercialization as a commercial provider of PoMELO does not have to be concerned with long term field performance.
2) The PoMELO hardware and sensor package wear is well understood and there is effective documentation on required maintenance and servicing – this greatly decreases the risk of client dissatisfaction as we have encountered most problems that are likely to go wrong with PoMELO, and figured out how to mitigate them.
3) The PoMELO software is greatly matured and is much more sophisticated than it was previously. In particular, the quantification engine is class-leading among competitors and includes effective test data to support that performance. These software advances mean PoMELO is the most promising new equipment scale measurement technology that is available for commercialization – and demonstrated to be among the most promising available globally (Barchyn and Hugenholtz, 2022).
4) The ERA project facilitated extensive market engagement – and this engagement means that many industry players are familiar with the technology and a commercial partner would be able to harness that familiarity.
5) The ERA project also facilitated expansion of market adoption. This means that PoMELO is being used by industry and they are keen to see a long-term commercial partner take over PoMELO operations. The agreements with these industry players are designed to explicitly help a commercial provider and are structured such that a commercial partner would be in a straightforward position to adopt these existing deployments. This type of positioning is immensely valuable for a commercial provider as they could adopt these deployments and (possibly profitably) bootstrap initial phases of company development.

As noted, market adoption of PoMELO is expanding:

1) Within the ERA Project an additional oil and gas producer in Alberta purchased and deployed a PoMELO system. This deployment represents a major vote of confidence for the system.
2) Canadian Natural has voluntarily elected to continue using their 3 PoMELO systems beyond the ERA project. This is a major win for market adoption as it signals Canadian Natural wishes to continue with their PoMELO operations beyond the ERA project. Canadian Natural is an influential company in Alberta.

Beyond this, there are regular inquiries from industry who are interested in deploying PoMELO. Some of these inquiries could lead to additional deployments in the near future.

6.7 Commercialization partner engagement

Through the University of Calgary technology transfer office (Innovate Calgary) we have engaged with many potential commercial partners in a focused effort to facilitate commercial adoption of PoMELO. These efforts have gained traction, but at present, PoMELO is not commercially available.

We remain fully committed to commercialization of PoMELO within an Alberta-based business and while PoMELO is not commercialized presently, the market for methane emissions measurement and reduction tools is maturing and evolving rapidly, meaning the case for commercialization of PoMELO is becoming more and more commercially attractive.

6.8 Barriers to commercialization

The ERA project allowed us to understand the main barriers to commercialization of PoMELO, which provides helpful insight into continued efforts:

1) Technical personnel: As a hardware and software system deployed within a highly technical industry, technical personnel are required to repair, service, build, and manage PoMELO in field operations. While there are many entrepreneurs whom see the commercial case of PoMELO and are keen to explore 'cleantech' opportunities, often there are issues with sufficient practical expertise to perform PoMELO operations or perform the necessary product management. This underscores the real need for entrepreneurs with technical skills or consortiums of co-founders who have the necessary range of skills. Efforts to teach entrepreneurship need to extend across all backgrounds.
2) Methane market understanding and volatility: The market for methane measurement and detection technologies is large and nascent. The difficulties associated with understanding the market, various regulations and competitor weaknesses have created risk for commercial providers of methane measurement technologies. Regulatory drivers vary considerably and while it is very likely that the long-term trajectory for market potential for PoMELO will be robust – there will be many short-term bumps along the way. This volatility must be managed in a startup business. Additionally, oil and gas companies can lack internal motivation to achieve largescale emissions reductions.
3) Hardware: The PoMELO system cannot be a pure software company. The need for managing real hardware can pose a barrier to commercialization. First, the supply chain delays and costs of the sensors are a barrier to rollout. Second, the need for this hardware component reduces scalability and there are limits to the speed of upscaling. These challenges are real and while the ERA project successfully de-risked the hardware component of PoMELO for long term operations, it is not straightforward to eliminate the hardware barrier. While the hardware barrier limits the capacity for extreme growth – it does also successfully limit competition.

6.9 Technology advancement

Refer to Section 5.4 for outline of technology development accomplished in ERA project.

6.10 Future commercial prospectus

The market for methane measurement technology is rapidly expanding. Throughout the ERA project we saw expansion of market in the two market drivers of PoMELO adoption:

1) Regulatory forcing: methane mitigation is often forced through LDAR regulations, or requirements to manage methane emissions from upstream sites in various venting or total emissions regulations.
2) Voluntary emissions management: some oil and gas operators wish to voluntarily reduce their emissions to increase profitability, manage stakeholder relationships, or attract investment. Similar to this, some operators wish to show their work on emissions management through

measurement. Voluntary initiatives to achieve better-than-regulations emissions reductions are abound (MiQ, Veritas, etc.) and consumer demand for low emissions intensity gas is increasing.

Regulatory forcing is changing quickly. In Canada, Environment and Climate Change Canada (ECCC) has outlined the scope of their new regulations and it appears to be a dramatic change for the oil and gas industry – with extremely aggressive mitigation targets and large-scale ramp-up of LDAR activities to achieve the results. These changes signal major market expansions for PoMELO.

Similarly, in the United States, the U.S. Environmental Protection Agency is formalizing a new set of rules that will strongly increase the LDAR requirements for oil and gas operators. These regulations, even if implemented in a weaker form will produce substantial new action for LDAR activities. In drafts of the regulations, there is well defined path for widespread regulatory approval of tools like PoMELO. Furthermore, there will be monetary penalties issued to producers based on how much methane they emit (the so-called 'methane fee'). Measurement technology will be required to evaluate risk of fees and manage methane profitably.

Voluntary emissions management is an expanding market for PoMELO, but the business value paths for enhanced methane performance are now well established:

1) Improved access to capital: oil and gas becomes a more attractive investment with better ESG performance as investors are more likely to see long term profitability from their investment. Securities regulators are beginning to actively regulate ESG claims as ESG focused investment funds begin to demand more robust reporting.
2) Increased product retention: Single to (in some cases) double digit percentages of produced gas are lost through leaks and poor methane management, representing lost and salable product.
3) Increased product value: there are a variety of markets for 'certified gas' that is produced with low methane intensity. This gas can be sold for a premium, in addition to providing a certification for companies to show their methane performance.
4) Increased access to markets: Europe is importing large amounts of gas and has moved effectively towards deliberately not importing gas that does not meet its standards for methane performance.
5) Strategic asset management: it is widely understood that some assets will be unprofitable with ifuture methane mitigation activities – there are companies who are keen to move in certain strategic directions and profit from the information asymmetry that self-measurement of methane can provide.

Broadscale trends in methane management are overwhelmingly shifting to a measurement-based approach. Methane emissions from the oil and gas sector have been widely underestimated and it is becoming increasingly apparent that measurement-based approaches are a very critical path forward for oil and gas producers. As the pace of measurement programs increase and new data emerge, there is a clear trend that is showing that the scope of the methane emissions problem is much larger than initially figured. This scope increase translates to increased market potential for PoMELO.

Sector-wide methane surveillance is increasing in intensity and efficacy. A non-profit led satellite (MethaneSat) is nearing completion and launch – which if successfully deployed will provide methane surveillance data globally free of charge. MethaneSat doesn't compete directly with PoMELO data – but will likely validate the need for measurements and help PoMELO Passive monetize data in the future. Many science campaigns have conducted very large monitoring programs across both the US and Canada. While these data mostly end up in science papers – they also are disseminated publicly and has generated significant publicity for the oil and gas sector. Further to this, as part of the proposed US EPA rule there are regulatory mechanisms where monitoring data (by third parties) can be used to trigger obligations for oil and gas operators to inspect their sites. This demonstrates that the US EPA sees sufficient benefit in these third-party surveillance efforts to consider writing them into regulations. PoMELO Passive (as a surveillance style modality of PoMELO) is positioned to effectively meet this new need for widespread methane monitoring.

7 Environmental benefits

7.6 Emissions reduction impact

7.6.2 Emissions reductions overview

PoMELO reduces methane emissions by providing high quality emissions data on upstream oil and gas sites (enabled emissions reductions). With these data, operators can perform regulatory leak inspections (LDAR), and direct repair and retrofit operations. Subsequent repair and retrofit operations result in the actual emissions reductions. In most cases, PoMELO is unable to reduce emissions on its own, but forms a key component of emissions reductions processes.

Methane itself is colorless and odorless, meaning many emissions sources are unknown on upstream sites. Specialized equipment such as PoMELO are required to enable emissions reductions. Without information, repairs and retrofits to address methane emissions sources are either impossible or inefficient. As this information gathering is a major expense and modulator of emissions reductions – the measurement technologies such as PoMELO have a large effect on resultant emissions reductions and are an essential component of modern emissions management programs.

As an upstream producer in Alberta, Canadian Natural must complete LDAR at its upstream production sites following the AER Directive 060. Directive 060 has provisions that allow for custom LDAR technology deployments. Canadian Natural applied for a custom LDAR program (known as an Alt-FEMP) with PoMELO and thus had a suite of sites identified for surveys to meet their regulatory requirements. Canadian Natural used PoMELO for other non-regulatory purposes in addition to regulatory surveys.

We first review the project emissions reductions that were calculated in the initial application to ERA. Note that two aspects of the project affected the actual achieved emissions reductions. First, as detailed in Section 5.5, we applied to complete the ERA project with a detection-based work practice for PoMELO, whereas Canadian Natural elected to perform a quantification-based work practice. Second, Canadian Natural operated with lower-than-expected operational efficiency (see Section 5.5.2), resulting in a reduction in the number of sites surveyed as part of their regulatory program.

7.6.3 Projected emissions reductions

The projected emissions reductions in the original application to ERA assumed Canadian Natural would apply a detection-based work practice and achieve surveys of all sites originally planned (see Section 5.1). The proposed deployment with Canadian Natural targeted 2,593 facilities across Alberta, with annual surveys at 1,042 facilities and biannual surveys at 1,551 facilities. This translated to 4,144 facility surveys annually. Projected emissions reductions were calculated with the assumptions that Canadian Natural would survey all sites in the program with required intervals and conduct no extra surveys or use PoMELO for any other purposes.

With a detection-based work practice the emissions reductions occur through a process where (i) PoMELO detects emitting components, (ii) OGI triage is triggered to investigate, and finally (iii) leaks are repaired, reducing emissions. PoMELO is used as a tool to target more detailed and time consuming OGI surveys. As PoMELO has a detection limit lower than OGI, we assumed that all emissions that would have been found with OGI would be first detected by PoMELO (see further in Barchyn and Hugenholtz, 2020). From this, PoMELO and OGI surveys see the same leak sources and we can extend emissions reductions estimates from OGI-only surveys to PoMELO + OGI in a detection-based work practice. This simplifies predictions of emissions reductions as there is no additional modeling required (as can be common in more complex multi-technology LDAR deployments). We summarize our estimation method from the original application to ERA below, reproduced here for completeness.

To estimate the number of leaks present at the target sites, we used the following estimation method. In Alberta, Johnson and Tyner (2020) catalogued 19,607 sites that are now subject to 1x/year LDAR (70.5% of total leak rate), and 2,308 sites are subject to 3x/year LDAR (15.0% of total leak rate). Simulations suggest regulatory OGI-only LDAR will reduce emissions rate by 45.2 kt CH_4 (equivalent to 1,130 kt CO_2e_{100} over 100 years at a GWP of 25, or 3,797 kt CO_2e_{20} over 20 years at a GWP of 84) (Johnson and Tyner, 2020). To achieve AER approval an LDAR program using PoMELO Padmapper must reduce at least this volume of emissions. We estimate that in full commercial deployment 75% of LDAR crews will use PoMELO systems. Not all facilities are suitable for PoMELO application. We estimate 75% of fugitive emissions at upstream facilities are suited to PoMELO. Thus, in full commercial deployment we estimate PoMELO Padmapper will be responsible for emissions rate reductions of 25.3 kt CH_4 (636 kt CO_2e_{100} or 2,125 kt CO_2e_{20}) in Alberta. This is equivalent to 56% of fugitives targeted by LDAR in Alberta under AER regulations. We project that reductions attributed to the combination of PoMELO Padmapper and Passive will greatly exceed 60%. It is important to note that projected GHG reductions attributed to LDAR in Alberta are much lower than reductions from the implementation of control technologies (e.g., solar and electric conversions, low bleed pneumatics, vent gas capture, etc.) (Johnson and Tyner, 2020). This is reflected in our estimates from the application of PoMELO Padmapper. However, a key value proposition of PoMELO is that it collects considerable amounts of emissions data that are useful beyond LDAR and will contribute to strategic emissions reductions plans across the suite of different emissions sources at upstream sites.

For project specific emissions reductions the proposed deployment with Canadian Natural targets 2,593 facilities across Alberta, with annual surveys at 1,042 facilities and biannual surveys at 1,551 facilities (4,144 facility surveys annually). To determine fugitive emissions reductions, we took the 2018 fugitive emissions inventory from Johnson and Tyner (2020) and calculated the average site-level fugitive emissions with facility counts on an AER subtype code basis from the Alberta production reporting system Petrinex. Joining the target sites by location and description to the master facility data allowed us to bring forward facility by facility fugitive emissions estimates. Ravikumar and Brandt (2017) predict emissions reductions from application of annual and biannual OGI at typical upstream facilities are approximately 42% and 59%, respectively, using a numerical model. From this inventory, application of the full program and relaxation to a new baseline is predicted to reduce emissions rate by 1,872 t CH_4 (46.8 kt CO_2e_{100} or 157.2 kt CO_2e_{20}). Note that these reductions are calculated as the emissions relax to the new baseline. The majority of which will occur during the 2-year LDAR program but will require continuation of the program past 2 years to fully realize. We predict that PoMELO will detect 75% of these fugitive emissions and thus can be attributed to 1,404 t CH_4 (35.1 kt CO_2e_{100} or 117.9 kt CO_2e_{20}) of emissions rate reductions from the original emissions rate at commencement of the new program.

As the project scope changed (see Section 5.5) and the number of site surveys was different than predicted, we can scale our projected emissions reductions by the number of sites that were part of the program. This is a basic approximation of the efficacy of PoMELO as the averaged value depends on the mix of sites under survey. With these caveats, the average per site emissions rate reductions are projected to be 541 kg CH4 (13.5 t CO_2e_{100} or 45.5 t CO_2e_{20}) per site (under a scenario with 59.8% bi-annual site visits and 40.2% annual site visits).

Projected emissions reductions from the Passive component of the PoMELO system were estimated to be negligible or difficult to quantify precisely. This was due to the early-stage nature of Passive and the fact that Passive produces larger scale and less direct information. The primary route for emissions reductions from Passive involves producing data that help in large scale planning of emissions reductions activities or occasional identification of extremely anomalous situations ('super-' or 'ultra-emitters'). Identification of extremely large emitters through regular surveillance is an emerging and productive approach to methane emissions reductions. It is normal that only a few locations emit a sizable fraction of basin emissions (Cusworth et al., 2022) and regular surveillance has proven its worth as a viable strategy. This noted, it is difficult to project reductions from isolated and extremely rare (but large magnitude) events.

7.6.4 Backgrounder on emissions reductions in LDAR programs

Emissions reduction from LDAR operations requires a conceptual outline to context the measurements we have reported and to ensure maximum clarity with respect to emissions reductions values reported as part of this project. LDAR programs reduce leaks in upstream oil and gas equipment. Leaks occur through inevitable degradation of equipment and are produced continuously. LDAR programs find, and eventually fix these leaks, reducing emissions. Thus, there is both an input and output to the pool of emissions sources, simultaneously affecting the total number of emitters (and broader scale emissions rate).

LDAR surveys in this program are periodic, once or twice a year. The LDAR crews arrive, identify sources for repair, which eventually are abated, then leave. Not all leaks are detected in any given survey. This is inevitable as the detection limit of OGI (the limiting tool in leak detection) is not perfect (see further in Zimmerle et al., 2020). Typically, larger leaks are more likely to be detected and smaller leaks are more likely to be missed.

Considering one site, the trajectory of emissions rate will drop sharply after an LDAR survey and subsequent repairs, then progressively increase with new leaks until the next survey and repairs. The longer the interval, the greater the number of leaks – explaining the well understood generality that more frequent LDAR surveys will reduce the site emissions rate (Ravikumar and Brandt, 2017).

Related to this, there is a continuous reduction of emissions associated with non-LDAR maintenance activities, or any identification of leaks outside of a formal LDAR program. This is known as the 'natural repair rate' and is closely related to the operational practices of any given operator (Fox et al., 2021). For example, extremely large leaks can be identified without special methane detection technologies or affect production in some identifiable way – and can be repaired outside of a formal LDAR program. To add further complexity, the rate of this non-LDAR abatement almost certainly has some non-linear relationship with the number of leaks and volume of lost methane. When the sum loss rates become noticeable through production metering for example, the rate of abatement is likely to increase as those known leaks are fixed to improve production. There is likely some relationship between the age of facilities and the number of leaks – whereby old facilities likely have higher leak numbers and rates. Older facilities are inherently more likely to be retrofitted. Additionally, odor complaints (from co-emitted species) are more likely in sites with many leaks. Operators are incentivized to voluntarily repair known leaks and reduce emissions to keep odor complaints down, but this incentive doesn't kick in until emissions reach some threshold rate. Further, loss rates that pose a safety risk are usually addressed. These are complex mechanisms – but the end result is likely a situation whereby non-LDAR abatement rates increase with number of leaks and volume of leaks. This is a non-linearity in non-LDAR emissions that will keep leaks from increasing infinitely.

As sum emissions rates from a pool of leaks distributed across many sites are affected by both inputs (new leaks), and outputs (LDAR triggered repairs and non-LDAR maintenance) – changes in the sum emissions rate require much higher abatement rates than would be initially expected. Consider an example where abatement is equal to production of new leaks. In this example, there are substantial emissions rates reductions occurring (equal to the production of new leaks) – but the total sum emissions rate is not going down – it is holding steady.

Regulators around the world are moving to increase the frequency and stringency of LDAR operations to bring the sum emissions rate from leaks downwards. All evidence suggests that this will occur – but it is important to emphasize two points: (i) LDAR will find and fix more emissions than the sum emissions rate reduction because new leaks produced continuously must also be abated, (ii) LDAR emissions reductions must continue to hold steady at the new sum emissions rate.

The broader purpose of this section is to accurately context our measurements. In this program we cannot feasibly measure changes in sum emissions rate from leaks. However, we can estimate the total reductions attributable to PoMELO from records of leak abatement. There is a critical difference between these two measurements in that the sum of all emissions rates from leaks abated cannot conceptually equal a change in sum emissions rates (see Figure 11).

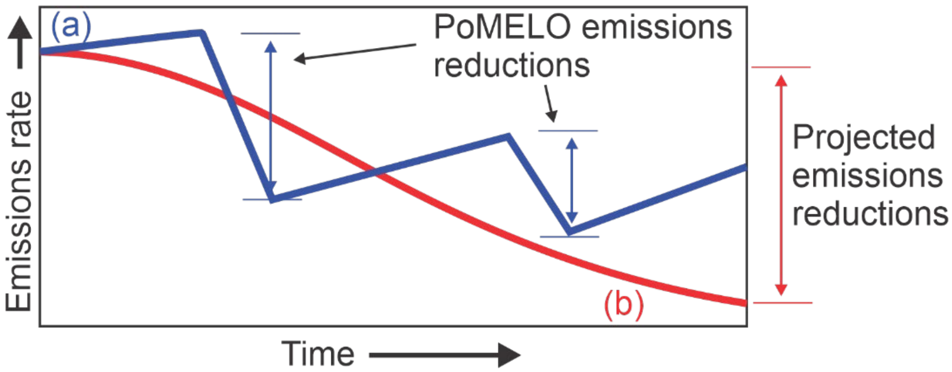

Figure 11: *A cartoon depiction of the difference between projected emissions reductions and the reported emissions.The blue line (a) shows the actual emissions rates from sites. After each survey visit the emissions rate drop as leaks are repaired, but then begin rising again as new leaks accumulate. The total emissions reductions reported here partially offset new leaks generated in the survey. The red line (b) shows the sum emissions rate for a large number of sites, similar to the projections used in the project application. This slow drop and relaxation to a new baseline actually requires substantially more emissions reductions than pictured to offset the continuous production of new leaks.*

An important caveat here is that our projected emissions reductions are reported as a change of a sum emissions rate (an inaccessible parameter presently) and cannot be directly compared to the project results. Such a comparison is not defensible as it requires estimation of the leak production rate and leak magnitude curves. Presently we do not have sufficient data to perform the modeling required to isolate these variables (Fox et al., 2021).

7.6.5 Baseline

We use a baseline of pre-project emissions rate. This baseline is used as we provide direct emissions reductions estimates, rather than a measurement of the state of leak emissions rates at project end (which would necessitate a difference against an assumed baseline). Note that we are unable to measure the sum emissions rate of either the pre-project or post-project state and instead report total emissions reductions (see Section 9.1.3).

7.6.6 Project emissions reductions

Several important differences occurred in the project plan which had effects on the emissions reductions:

1) Canadian Natural elected to use a quantification-based work practice (see Section 5.5). This method changes the follow-up pathway from detected emissions as low-emitting equipment are omitted from further surveys (and potential for emissions reductions). We expect this method would reduce less emissions than a detection-based work practice by design – but we cannot be certain. See Section 5.51, and 9.1.2 for a more detailed discussion.
2) Canadian Natural reduced the scope of their AER approved site list used for this project. This scope reduction reduced the number of surveys that were explicitly required to meet AER compliance.
3) Canadian Natural increased the scope of surveys by using the PoMELO system on sites which were not explicitly part of the AER approved LDAR program, or used PoMELO at higher frequencies on sites that were part of the AER LDAR program. These additional surveys were

welcome additions to the program, but introduced some uncertainty to emissions reductions calculations based on the initially supplied site list.

4) Canadian Natural also found methods to use PoMELO for operations that were not explicitly regulatory LDAR (e.g., measuring changes to emissions profiles with process changes, or distribution pipeline leak surveys). Similarly, this experimentation is welcome and important, but the contributions of PoMELO in these new contexts to emissions reductions is not straightforward and remains un-captured in this assessment.

These changes had three broadscale effects on quantifiable emissions reductions in the ERA project. First, we expected the changes to operational aspects of the program by Canadian Natural resulted in net fewer emissions reductions than would have occurred if the program operated following the initial program design. Second, many activities undertaken by Canadian Natural were out of the initial scope and additional to expected AER approved LDAR operations (thus increasing the PoMELO attributable emissions reductions). Third, many activities that Canadian Natural used PoMELO for helped considerably with producing information used in decision making. Information that eventually is used to strategically reduce emissions is very difficult to directly attribute to PoMELO. Anecdotally, crews were much more attuned to the emissions coming from their sites after using PoMELO, which allows them to make much better decisions and effectively manage emissions. This latter effect was particularly important in the Lloydminster region, an area of particular note with respect to methane emissions in Canada.

The value of this indirect data to emissions reductions strategy requires emphasis. We believe that the ability for crews to autonomously target sites, and directly and quickly learn how to improve production practices to reduce emissions in the heavy oil belt of Canada is one of the key drivers of Canadian Natural's ongoing interest in using PoMELO into the future. This advantage of PoMELO is not particularly quantifiable or attributable unfortunately.

Results from the project are listed in Table 2. Please review Section 9.1.2 to understand the conceptual context of these results and how they relate to projections.

***Table 2**: Emissions rate reductions across the project. The 2021 and 2022 columns detail results from the project as reported by Canadian Natural. These cannot be meaningfully compared with projections. Please review Section 9.1.2 to review the conceptual context of these results.*

Metric	**2021**	**2022**	**Total**
# of site surveys	2,270	2,728	4,998
# bi-annual sites[1]	850	1,021	936
# annual sites[1]	571	686	629
# sites surveyed total[2]	1,421	1,707	1,564
# sources identified and directly attributed to PoMELO data	1,874	1,668	3,542
Emissions reductions total (CH_4)[3]	658.0 t	359.0 t	1017.0 t
Emissions reductions total (CO_2e_{100})[3,4]	16.5 kt	9.0 kt	25.4 kt
Emissions reductions total (CO_2e_{20})[3,5]	55.3 kt	30.2 kt	85.4 kt

Incurred emissions (CO_2)[6]	21.9 t	26.3 t	48.2 t
Emissions reductions total (net) (CO_2e_{100})[4]	16.4 kt	8.9 kt	25.4 kt
Emissions reductions total (net) (CO_2e_{20})[5]	55.3 kt	30.1 kt	85.4 kt
Emissions reductions per site (CH_4)	463.1 kg	210.3 kg	336.7 kg
Emissions reductions per site (CO_2e_{100})[4]	11.6 t	5.3 t	8.4 t
Emissions reductions per site (CO_2e_{20})[5]	38.9 t	17.7 t	28.3 t

[1]For 2021 and 2022 columns, this is assumed to be equivalent to the initially proposed site visit mix (59.8% bi-annual site visits and 40.2% annual site visits). Note this is an approximation as PoMELO was used in ad hoc emissions management operations at sites that were non-regulatory.

[2]The number of sites surveyed is an approximation as some site surveys were completed outside of the regulatory program as part of non-regulatory emissions reductions efforts.

[3]Emissions reductions were calculated by Canadian Natural using AER Manual 015 (AER, 2020b) and take into account the types of sources that were detected and mitigated.

[4]Emissions reductions for the 100-year horizon are calculated with a GWP of 25 following the values typically used by regulatory authorities at time of project commencement. Estimates in more recent scientific literature are different and the value used for any application must be considered.

[5]Emissions reductions for the 20-year horizon are calculated with a GWP of 84 following the values typically used by regulatory authorities at time of project commencement. Estimates in more recent scientific literature are different and the value used for any application must be considered.

Several important notes must be emphasized with these results:

1) Emissions reductions as reported to the AER from Canadian Natural or disseminated by Canadian Natural through other means may differ from these values. This is expected as Canadian Natural used PoMELO for non-regulatory uses as part of its internal processes to improve operational practices and reduce methane emissions. Reporting to the AER from Canadian Natural should be considered separate from these results reported to the ERA which encompasses a broader suite of work.
2) Emissions reductions only quantify directly attributable emissions reductions and do not quantify the emissions reductions that occur from general improvements to Canadian Natural's operations management of methane.
3) Application of LDAR technologies in a mode-shift tends to result in a situation where emissions reductions slow as the emissions profile approaches a new equilibrium. Most sites in Alberta have undergone a mode-shift with deployment of new LDAR regulations and increased frequency and stringency (AER, 2020a). For example, the first survey after a long time without formal LDAR will likely find many leaks, which will be repaired. Subsequent surveys will find fewer sources on average as the leaks found will be new leaks (e.g., since the first survey), or leaks that were missed on the first survey. This relaxation of efficacy is normal with LDAR technologies.
4) Emissions reductions reporting requires very careful consideration of baseline from which to measure reductions.

Several points of discussion can be pulled out from the results in Table 4.

In general, project emissions reductions were less than projected changes to sum emissions rate. Project emissions rate should exceed projections to account for new leaks generated mid-program (see Section 9.1.2). This was likely due to the lower operational uptime (see Section 5.5.2) of Canadian Natural surveys, combined with differences in the work practice (see Section 5.5.1).

Project emissions rate were reported using AER Manual 015 (AER, 2020b). Future research could closely examine these differences, but a much more productive exercise would be to measure the individual sources instead of comparing various emissions factor schemes. Such regulations exist outside of AB as other jurisdictions have prioritized closing this information gap (e.g., BC). Measurements of actual emissions reductions from leaks by measuring the actual leak rates would greatly reduce the emissions reductions uncertainty and make comparisons between projections and values reported with AER Manual 015 (AER, 2020b) more meaningful.

Although PoMELO quantifies emissions rates on these sites, there are many different categories of emissions on upstream sites – many of which are not targeted by PoMELO (yet are measured). PoMELO measures emissions at the equipment scale. It is common that a piece of equipment (e.g., separator) would have known vents (e.g., pneumatic instruments), as well as potentially one or two leaks. A measurement of the emissions rate at the equipment scale cannot quantify the individual leaks (in many situations) as the emissions from the leak are mixed with other, non-target emissions sources.

We expected lower emissions rate reductions in 2022 compared to 2021. The first year of the program coincided with a major step change in LDAR regulations across AB. It is not surprising that more emissions were abated in the first year of the project. As is common in step changes of LDAR operations, the emissions reductions slowly approach a new baseline that represents an equilibrium of leak production and abatement (Fox et al., 2021). The new, lower baseline represents the impact of more frequent surveys and better LDAR detection techniques, such as PoMELO trialed in this project (Ravikumar and Brandt, 2017; Fox et al., 2021).

PoMELO Passive, as expected could not quantifiably contribute to emissions reductions in the project. This noted, Passive is providing considerable information that will help with emissions management operations soon (see Section 6.4 for further discussion).

7.6.7 Incurred emissions

The main source of emissions resulting from the program relate to vehicle use. Following NRCan estimates of emissions incurred (NRCan, 2023), the emissions incurred are 271 g / km (for Ford F150 4x4). For approximately 177,905 km of travel over the course of the project, this suggests vehicle use incurred approximately 24.1 t CO_2 per year. This is likely an underestimate as we likely have not captured all vehicle use associated with the surveys. Crews drove their trucks without PoMELO on and we lack information on the kilometers driven while on sites. Additionally, PoMELO likely reduces mileage compared to measurements due to greater electricity draw and air resistance. Nevertheless, emissions incurred from vehicle use are very low compared to emissions reductions benefits of PoMELO (see Table 4).

There are other emissions incurred as part of the project related to computer and electricity use in office settings. We have considered these emissions as negligible but acknowledge their existence.

7.6.8 Future emissions reductions

Our expectations of future emissions reductions remain similar to the values predicted in the initial application. In contrast to the ERA project, we propose commercial rollout to proceed with the originally applied for detection-based work practice. This work practice is simple, defensible, and efficient. Although some efficiencies may be found in work practices similar to the one deployed by Canadian Natural – we expect that future regulations will demand that crews follow-up on all emissions detected (rather than just those that exceed a certain threshold amount). Regulatory signals suggest increased stringency and a much tighter situation with respect to allowable emissions.

This noted, the quantification capabilities of PoMELO are best-in-class (Barchyn and Hugenholtz, 2022), and these data are of abundant strategic value for methane management. We expect future deployments will operate with a detection-based work practice – but collect ancillary quantifications that provide an important value-add above meeting regulatory requirements. We expect Passive to provide additional value-add in synoptic methane data. We have considerable difficulty quantifying the emission reductions associated with synoptic data – but all indications are that such data is essential to future emissions management programs and key to future methane performance of the oil and gas sector.

We follow the future projections detailed in Section 9.1.2, and summarized from the original ERA application.

Table 3: *Projected metrics of deployment following scenarios in Section 9.1.2.* This provides an approximation of expected future PoMELO operations in LDAR.

Metric	**Future projected**
# of site surveys	19,898
# tri-annual sites	1,731
# bi-annual sites	0
# annual sites	14,705
# sites surveyed total	16,436
Emissions reductions total (CH_4)	25.3 kt
Emissions reductions total (CO_2e_{100})[1]	632.5 kt
Emissions reductions total (CO_2e_{20})[2]	2125.2 kt
Incurred emissions (CO2)[3]	158.5 t
Emissions reductions total (net) (CO_2e_{100})[1]	632.3 kt
Emissions reductions total (net) (CO_2e_{20})[2]	2125.0 kt
Emissions reductions per site (CH_4)	1539.3 kg
Emissions reductions per site (CO_2e_{100})[1]	38.5 t
Emissions reductions per site (CO_2e_{20})[2]	129.3 t

[1]Emissions reductions for the 100-year horizon are calculated with a GWP of 25 following the values typically used by regulatory authorities at time of project commencement. Estimates in more recent scientific literature are different and the value used for any application must be considered.

[2]Emissions reductions for the 20-year horizon are calculated with a GWP of 84 following the values typically used by regulatory authorities at time of project commencement. Estimates in more recent scientific literature are different and the value used for any application must be considered.

[3]Calculations incurred emissions are taken using the average incurred emissions per site associated with vehicle use (measured in this project at approximately 9.64 kg CO_2 per site), and scaling to total survey sites.

7.7 Other environmental impacts

Reducing methane emissions has very large impacts on human health adjacent to oil and gas facilities. Most oil and gas emissions contain considerable fractions of other hydrocarbons and chemical species in addition to methane (Cardoso-Soldaña et al., 2021; Lee et al., 2022). When methane emissions are reduced (primarily for purposes of addressing climate change impacts) – the emissions of these other species are also reduced.

Ozone is a serious health issue in some parts of the world with intensive oil and gas production and certain weather conditions (e.g., Colorado front range, Pfister et al., 2019). Emissions of volatile organic compounds from upstream oil and gas production contribute as a pre-cursor for ozone formation. In areas like the Colorado front range, many regulations for reducing methane emissions are targeted more generally at reducing emissions of the ozone pre-cursors (Pfister et al., 2019). Comprehensive studies of ozone production and the role of emissions from the upstream oil and gas sector have not been completed in Alberta – but there is strong evidence from other jurisdictions that reducing emissions from upstream sites will also benefit general air quality across Alberta.

Nearby to oil and gas sites, the direct inhalation of emissions has a number of widely studied health impacts. These health impacts vary based on the precise composition of emitted gas and concentrations of the proximate humans. From Table 2 in Lee et al. (2022), the following impacts are known to be directly caused by emissions (beyond the climate change effects of methane and regional issues associated with ozone):

1) **Benzene and Ethylbenzene:** leukemia (various types), anemia, immunological effects, neurol tube defects, congenital heart defects.
2) **Toluene:** endocrine disruption, birth complications and defects, nervous system damage.
3) **Acrolein:** eye, nose, and throat irritation, respiratory difficulties.
4) **Xylenes:** respiratory distress, chest pain, palpitations, nausea, nervous system impairment.
5) **Formaldehyde / acetaldehyde:** cancer, lung damage.
6) **Sulfur dioxide:** cardiac arrhythmias, reduced lung function, premature death.

These health effects are dominantly negative and could affect other non-human species. Non-human health effects (e.g., nearby grazing cattle) may be similar to human health effects (with possible economic implications associated with reduced cattle productivity) – but further research is required to constrain the magnitude of this impact.

Broadly, reducing methane emissions from the upstream oil and gas sector has a large number of associated benefits. These benefits vary considerably based on the proximity of receptors (humans, etc.), and precise compositions of emitted gas.

8 Economic and social impacts

This project created four full-time equivalent jobs at the University of Calgary and supported four field staff and two managers at Canadian Natural. The project also contributed to training activities and skill development for two Master's students, one PhD, and one postdoctoral fellow at the University of Calgary. Collectively, these individuals have helped grow Alberta's low carbon workforce.

The project helped demonstrate and operationalize innovation capacity within Alberta for supporting methane reduction from the oil and gas sector. In establishing PoMELO as class leading technology through this project, there is potential to increase the number of units deployed in Canada and other markets as new regulations come into force. The technology has matured to a stage where it is ready for transfer to a commercial entity that can scale and provide support services. The dual deployment model expands the commercial opportunity and end users to include oil and gas companies, government agencies, oilfield service providers, NGOs, and climate investors.

9 Scientific achievements

As part of the project, we actively disseminated results through many channels.

9.6 Net-zero Conference and Expo (October 25-27, 2022, Calgary, AB)

This conference was a key opportunity to promote the PoMELO system to key stakeholders within the Alberta methane ecosystem.

PoMELO / Centre for Smart Emissions Sensing Technologies Exhibition (SENST) Booth. We secured an exhibition booth to have a location where stakeholders could directly engage with the system and we could both promote the system and directly demonstrate and educate stakeholders on the scientific aspects of the system.

We had a live, running PoMELO system available in the booth to show attendees how the system worked directly. This was very educational for attendees as they could directly see the response speed of the system. We reprogrammed the system in a demonstration mode, so the display was realistic (even though there was no GPS reception). Numerous attendees had detailed questions on the engineering and design of the system and the engagement was effective at disseminating the science involved in PoMELO as well as understanding the product market fit.

We also included a large screen display with an interactive demonstration reel of various projects related to PoMELO. This form of dissemination was effective at showing the science in an engaging and accurate method that effectively served as a catalyst for more detailed conversations.

Figure 12: *Net-Zero Conference and Expo exhibition booth with University of Calgary students and employees as part of the larger Centre for Smart Emissions Sensing Technologies at the University of Calgary. This booth allowed us to directly show attendees the PoMELO system (on the table), and was an effective demonstration of the science capabilities of the system as attendees could closely inspect and directly understand how the PoMELO system works.*

The following presentations were presented at the NetZero Conference and Expo that were relevant to the ERA project:

University of Calgary PoMELO – Vehicle based methane measurement system technology overview. Thomas Barchyn. This 'tech talk' presentation was delivered to help disseminate science developed as part of the ERA project, and to promote the system to interested stakeholders.

When a Drone and an Old Map Collide: Challenges of Methane Emissions Screening with the Alberta Township System. Tyler Gough, Thomas Barchyn, Chris Hugenholtz, Coleman Vollrath, Mozhou Gao, Michelle Clements. This poster presentation helped disseminate scientific research into development of new methodologies for locating emitting oil and gas sites in Alberta. Locating oil and gas sites, and attaching relevant data, remains an important challenge with the PoMELO Passive project.

9.7 Internal reports

As part of scientific development, we also prepared internal reports to internally disseminate scientific findings within lab members in the University.

Alberta Methane Priors Dataset 2022. Thomas Barchyn. (12 pp.) This internal report details the data analysis procedures and considerations surrounding our in-house curated emissions point dataset. The dataset is an essential feedstock for PoMELO Passive and is developed by mixing many different location datasets together, taking advantage of their complementary capabilities.

Passive Data Overview. Thomas Barchyn. (70 pp.) This internal report details the calculations and data use considerations for the Passive project. The report also provides detailed description for use cases of Passive data and required caveats and data keys.

9.8 External reports

To disseminate results outside of the project we published the following external reports.

Complex multi-source emissions quantification results for the PoMELO vehicle measurement system, test results from the CSU METEC facility. Thomas Barchyn, Chris Hugenholtz. This report provided detailed information on the performance of the emissions quantification engine aboard PoMELO Padmapper.

The report is available externally here, and as an appendix to this report:

Barchyn TE, Hugenholtz CH, 2022. Complex multi-source emissions quantification results for the PoMELO vehicle measurement system, test results from the CSU METEC facility. EarthArXiv. DOI: https://doi.org/10.31223/X5XP7B

10 Overall conclusions

This project achieved its key performance metrics, helped reduce methane emissions, and advanced made-in-Alberta technology that is ready for deployment at scale. The technology has matured to commercial readiness and is used by several oil and gas companies in Alberta today, outside the ERA project. This demonstrates that we have successfully transferred university technology to industry. The potential to scale-up the technology has been established through the ERA project but depends on details in forthcoming regulations and a suitable and capable commercialization partner.

11 Next steps

11.6 Future projects with PoMELO

The ERA project has helped advance the PoMELO system in many ways. There are several follow-up projects with PoMELO presently underway:

1) Canadian Natural has elected to utilize PoMELO beyond the end of the ERA project.
2) Another producer has purchased and deployed a PoMELO system during the ERA project.

We are heavily using PoMELO in research operations across the domains of urban emissions management in Calgary, plume modeling, and methane emissions inventory work across Alberta.

11.7 Long-term commercialization plan

PoMELO is available for oil and gas producers to acquire and use to reduce emissions through the University of Calgary. The University of Calgary offers support, construction, and customization technical services to ensure the IP is open and available for use.

12 Communications plan

12.6 Website

To communicate directly to stakeholders we built a comprehensive website. This was launched September 2022, and has been online since then (with a few minor gaps due to server reconfigurations).

https://pomelo-methane.ca

This website is also available at https://pomelo-methane.ca. We actively promoted the website during the NetZero Conference and Expo, with dedicated business cards guiding stakeholders and interested parties directly to the site as the first point of contact to obtain info rmation on the system.

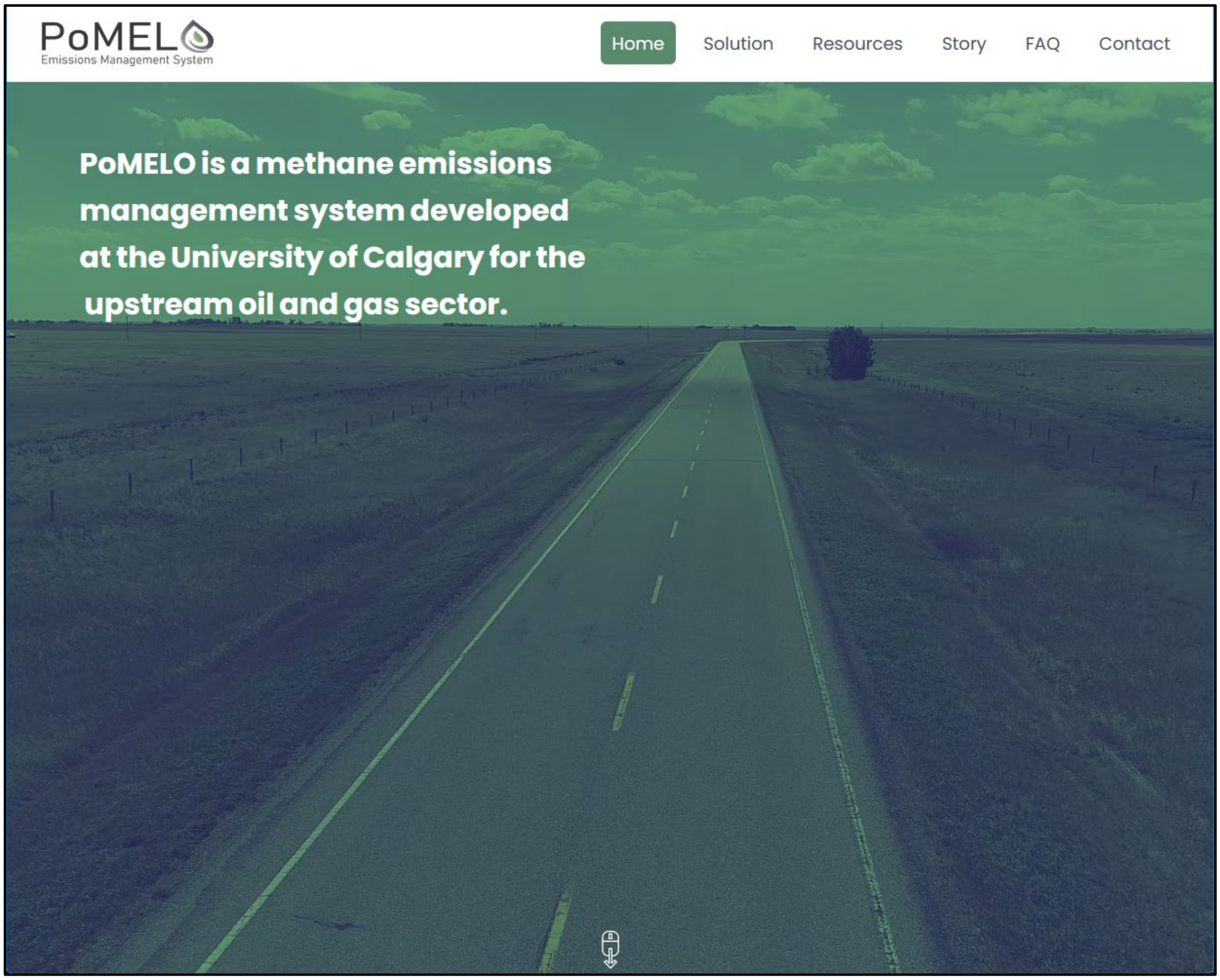

Figure 13: *The splash page of the PoMELO website, available at https://pomelo-methane.ca.*

The website features the following pages:
Home: A splash video helps to explain the general concept of PoMELO to users, with a scroll-down to an infographic style explanation of the general workflows involved with using PoMELO. This helps readers gain an immediate understanding within the first minute of visiting – which helps users quickly engage with the system. The rest of the page cascades into key details about the system, with small paragraph briefs on data collection hardware, efficiency, trusted results, and data management.

Solution: This page provides much more detailed information on the hardware and scientific capabilities of the system. We included detailed information on the hardware and sensors, the key value proposition of producing information on site, and the ability to produce custom data products with the UCalgary Emissions Explorer components of PoMELO.

Resources: The resources page provides links to the key documents that prospective PoMELO users require, including the detailed performance assessments and explainer documents that provide easier to access '2-pager' summaries of the larger reports.

Story: This page provides background information on the PoMELO system and how it was developed at the University of Calgary.

FAQ: Here we collated key questions about the system that we frequently get. This may be updated in the future to answer new questions as they arise.

Contact: The contact page has a contact form to get in touch with us.

12.7 Net-zero Conference and Expo

In addition to the scientific outcomes from attendance in the Net-zero Conference and Expo (October 25-27, 2022, Calgary, AB), we extensively communicated to stakeholders the PoMELO project. We secured an exhibition space, and had the PoMELO system running live to communicate how the system works in real life. This direct communication method was helpful and effective and was directly focused at industry and regulators.

12.8 United States Environmental Protection Agency

We presented directly to the United States Environmental Protection Agency on August 23, 2021 as part of their Methane Detection Technology Workshop. This workshop was part of their regulation development process and they were very interested in learning more about the PoMELO system and its benefits for emissions reductions. The presentation was entitled 'Work Practice Development, Evaluation, and Lessons from Deployment of Vehicle-Based Technology for Emissions Measurement'. This presentation was directly focused at the regulator to help them develop effective regulations to enable further advanced monitoring technologies.

12.9 Alberta Energy Regulator

We presented directly to the Alberta Energy Regulator on June 28, 2022 as part of their regulatory development processes. As the PoMELO system is deployed in Alberta in regulatory approved LDAR programs, this presentation was a good opportunity to engage directly with the regulator and ensure any questions they had were adequately addressed.

12.10 Demonstrations

We completed approximately one field demonstration per 3 months on a continuous basis. These demonstrations were predominantly within Calgary, but also included some driving outside of Calgary. The demonstrations were critical to help various stakeholders get a feel for the system. The demonstrations typically involved the stakeholder coming in our vehicle for a 'ride-along'. As the PoMELO system is a vehicle system – it is very easy for anyone to experience and quickly learn how PoMELO works from within the vehicle. As well, the demonstrations often ended up being quite flexible. If a stakeholder wanted to investigate something that we noted in the data, we were more than happy to oblige. These presentations were aimed at anyone who was interested in the system and ranged from possible collaborators to regulators to industry.

12.11 Post-project communications

We are focused on leveraging the success of this project for future PoMELO development and ensuring we use the results from the project to communicate the benefits of the PoMELO system:

Demonstrations: we are focused on continuing demonstrations of the system. PoMELO is easy to demonstrate and this has proved one of the more effective one-on-one communication methods available.

Conference presentations: we are focused on presenting PoMELO success in industry conferences to help communicate the success of the project.

Conference exhibitions: we are exhibiting the PoMELO system at the CH4 Connections conference in Fort Collins, Colorado (USA) on October 4-5, 2023. This conference is the pre-eminent methane measurement technology conference globally and we hope to share the successes of this project.

Scientific papers: we are preparing several scientific papers to communicate some results of the project in a peer-reviewed venue. The purpose of writing scientific papers is to help share the technical innovations of the project.

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