CANADA EMISSIONS REDUCTION INNOVATION NETWORK (CERIN) PUBLIC REPORT

1. PROJECT INFORMATION:

Project Title:	**Arolytics Optimized Leak Detection Program for Tanks and Other Key Equipment Proposal**
Emissions Reduction Scope/Description:	Developing and predictive optimal technology screening strategies for efficiently detecting tank emissions.
Applicant (Organization):	Arolytics Inc.
Project Completion Date:	April 1, 2023

2. EXECUTIVE SUMMARY:

In collaboration with PTAC, Tourmaline, and CanERIC, storage tank emissions and flow monitoring data are being provided to inform model simulations to identify measurement technology and campaign structures (survey timing and frequency) that have the highest impact on methane reductions through earlier leak detection.

Arolytics has developed a research-based modelling platform to predict leaks from equipment and optimize leak inspection schedules using a variety of detection technologies. With the influx of new technology for higher frequency monitoring (fixed sensors, satellites, fixed wing, drones, vehicles), Arolytics will use the model and Emissions Testing Centre (ETC) data to research both an optimal inspection procedure and measurement technologies to simulate reductions tank emissions.

3. KEY WORDS

Natural Resources Canada Ressources Naturelles Canada

Canada

ALBERTA INNOVATES

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

Tanks, emissions, methane, model, detection

Natural Resources Canada / Ressources Naturelles Canada

Canada

ALBERTA INNOVATES

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

4. APPLICANT INFORMATION:

Applicant (Organization):	Arolytics Inc.
Address:	1401 1 St SE, Calgary, AB T2G 2J3
Applicant Representative Name:	Cam Rollins
Title:	Operations Manager
Applicant Contact Information:	Email: cam.rollins@arolytics.com Phone: 1.403.874.7313

5. LEAD CONTRIBUTING PARTNER INFORMATION:

Organization:	Emissions Testing Centre
Address:	University of Calgary Room 105B, 906 8 Ave SW Calgary, AB T2P 1H9
Representative Name:	Carter Bates
Title:	Innovation Engineer (EIT)

6. PROJECT PARTNERS

Arolytics would like to thank the NGIF Emissions Testing Centre and Tourmaline for provision of data to complete this project as an in-kind service.

A. INTRODUCTION

In 2018 the Canadian Federal and several Provincial governments announced new methane regulations that required industry to measure, reduce and report emissions data for the first time. In Alberta, these regulations came into effect in 2020 through Directive 060 (1) where facilities required either 1 or 3 surveys per year by an Optical Gas Imaging (OGI) technician to identify any fugitive methane emissions sources for repair in a Fugitive Emissions Managment Plan (FEMP). For this project's focus on storage tanks, we are considering controlled tanks only in these simulations, as controlled tanks require 3 OGI surveys annually where as uncontrolled do not. An explanation of controlled tanks is provided in the methods section. In Arolytics' experience working with industry, we have realized there is a knowledge gap and lack of available tools to effectively manage and predict emissions in addition to manage and learn from leak detection and repair data (LDAR) to be more efficient with repairs.

In response to regulatory survey frequency requirements, over 150 commercial methane detection and quantification technologies have recently entered the market, making the methane measurement and data landscape highly fragmented, difficult to action, and sensor specific. These technologies and providers are often referred to as alternative technologies that can provide operators an alternative approach to meeting the Directive 060 requirements through an alternative FEMP (alt-FEMP). The Arolytics field-based equivalency model (AroFEMP) simulates FEMP and alt-FEMP programs to compare emission reductions and predicts effective alternative technologies and campaign structures to reduce effort and save resources while reducing similar emissions to a FEMP program.

This project is a part of a multiphase Tourmaline funded project. This first phase (CanERIC funded portions) involves researching repair timelines for tank components and technology detection abilities for tank emissions to model scenarios with higher survey frequency (more than 3 fugitive emissions surveys a year) and their impact on emissions reductions. It is likely that opportunities to improve the model will arise from this project such as simulating multiple crews operating in tandem and component specific repair chances. This project will inform future phases of the project to understand what data is needed from service providers and important metrics for tracking repair timelines and identifying any potential opportunities for improved timelines. In addition, this project is predictive in identifying strategies that the industry can adopt to efficiently reduce methane emissions through more efficient repairs and often fewer site visits. Arolytics has worked with Tourmaline staff and the Emissions Testing Centre data sources to evaluate data inputs and desired business intelligence forms to reduce emissions from tanks.

Future phases to the project will include:

1) Expansion of Arolytics' existing data management platform to automatically ingest data from all six technology types (fixed / continuous sensor, handheld, drone, vehicle-based, aerial, and satellite),

2) Create operational insights and a reporting framework to support a wide variety of internal and external disclosure needs,

3) Commercial-scale demonstration with an industry partner from CanERIC by 2024.

At the completion of the full project, Arolytics will provide a detailed research report based on the ETC data showing opportunities for methane emissions reductions for tanks where multiple sensing technologies are deployed. The report will outline primary technology deployment types (fixed sensor, drone, aerial, satellite, OGI, vehicle), when to use them, how they interact, and a typical cost of inspection / m3 of methane reduced. This non-confidential report is released at this time to satisfy

NRCAN reporting requirements but is early in the evolution of this project. A further upload to the CERIN Data Portal is anticipated at project end.

B. METHODOLOGY

The following section describes the model and then walks through the 4 main building blocks of the model.

The Arolytics field-based equivalency model, AroFEMP, is written in R programming language. The model simulates methane leaks and repairs in regions that feature approximately uniform methods of upstream oil and gas production. The model incorporates attributes of real oil and gas production infrastructure, as well as region and company-specific information regarding methane leaks and repair practices. All historical field data provided to Arolytics has been used to populate input parameters throughout the model. In the few instances where project-specific data was not available, select parameters are derived from relevant Canadian methane measurement studies with data collected in similar regions.

Leak detection and Repair (LDAR) program features tested in the model include: using various measurement technology types, applying technologies at various frequencies, the order and timing in which technologies are implemented, and the follow-up criteria required for leak localization and repair. The model estimates methane emission reductions from hundreds of possible combinations of characteristics that form an alt-FEMP.

Given the fact that the model reports approximate average emissions applicable to an extensive time period while real world emissions data are collected over a very brief time period, it is likely there will be a discrepancy between any absolute emissions estimated by the model and real-world emission measurements collected during a FEMP. Arolytics recommends programs be compared on a relative basis, for example: *the model predicted the alt-FEMP would achieve X% greater total emission reductions than OGI.*

The model input parameters that required research for this project are an infrastructure list, past emissions data, and technology specifications. The processes for getting this information are described in the following sections.

1) Infrastructure

The infrastructure list is what the model uses to assign leaks and simulate surveys and repairs. For this project, a fictitious set of infrastructure that is not based on any company was created as the basis for running model simulations. For this project, we focused on simulating controlled tanks specifically as they require 3 OGI surveys a year (AER Directive 060). Storage tanks (ie. uncontrolled tanks) are designed to easily vent to atmosphere to prevent pressure build up and tank failure. Controlled tanks have devices added to them to gather potentially vented emissions and redirect them to a flare system or sell line instead of being vented to atmosphere. Since these systems are expected to be closed, any emissions from the tank are considered fugitive emissions.

Rough ranges of the number of tanks that could be present at various facility subtypes were estimated through general conversations with industry members. These tank estimates were not intended to be exact, but rather to show that certain facilities would generally have a different tank count than others (i.e. a gas processing plants versus a single well gas battery). The distribution of subtype codes across the site list was informed by the Petrinex facility list file, downloaded in March 2023. The percentage of sites that fall within each type grouping, (that is 300’s = batteries, 600s = compressor stations and custom treating facilities, etc.) of D060 facilities requiring surveys (Table 1) was calculated. These proportions were applied to the site (LSD) list and a random value from the range of potential tank counts (Table 1) was selected to establish the number of tanks at the site. For the screening technologies that conduct surveys, a site list of 150 sites with a total of 526 tanks across the sites was generated.

For the fixed sensor technology used in continuous monitoring, the site list focused on gas plants only and included 10 gas plants with a total of 113 tanks across the sites. This may be an inaccurate number of tanks but that does not impact the interpretation of the results. A deployment of fixed sensors would scale up or down, in terms of total number of sensors deployed, to have complete coverage of potential emission sources. For example, a battery facility would require fewer tanks to have the same coverage. This was done to make the modelling more efficient, as these require a different modelling approach, and takes longer to simulate.

Table 1 Percent of active sites under each subtype code group. Data is from Petrinex Facility list download for March 2023. Estimation of range of tanks per site based on each subtype code group.

Facility Sub-type	Sub-type Code	Number of Active Facilities	Potential Range of Tanks	Modeled Facility List Site Count	Modelled Facility (tank) List Count	Notes
Battery Facilities	300's	18026 (71%)	2-3	108	317	Batteries typically have a lower number of tanks
Gas Plants	400's	476 (2%)	7-15	3	36	Gas plants typically have the highest number of tanks
Injection Facilities	500's	1627 (6%)	2-4	9	24	Injection facilities were assumed to have a similar number of tanks to batteries
Compressor Stations and Custom Treatment Facilities	600's	5413 (21%)	2-8	7	141	Compressor stations typically have diverse tank counts

2) Emissions Data

The AroFEMP model requires fugitive emissions data representative of the facilities being modelled, in this case individual storage tanks. Several contacts in the methane research field were consulted for any public emissions data that had source labels (i.e. emissions from a tank). Two options were found, the Fugitive Emissions Management Program Effectiveness Assessment (FEMP EA) and the British Columbia Energy Regulator (BCER) Equivalency reports with public data sets. Both were reviewed for this project.

The FEMP EA data did not contain enough component specific measurements from controlled tanks and unfortunately was not used for this project, which we realize is a specific use case.

The BCER has conducted annual reports on emissions and provides a dataset with several quantitative OGI measurements that can be used for modelling controlled tanks. The 2020 and 2021 data sets were used and filtered for QOGI emissions data related to tankage (process block = tankage). The survey values are recorded as component level emissions with survey date, facility id and facility type information. As the modelling is simulating individual tanks, we are taking a conservative approach by using component level emission rates. These are the smallest emission rates and are not giving any advantage to the technologies by considering site aggregated emissions, a large emission source that the technolgoy would have a great chance of detecting. Below is the distribution curve of the actual fugitive emissions data (Figure 1 A). It has the characteristic heavy tailed curve common across fugitive emission data profiles.

The model uses a vent distribution profile and probability of venting to simulate site level venting that could potentially be flagged by technologies as fugitive emissions. If vents are flagged during fugitive emission surveys in the model this leads to a follow-up OGI survey that does not generate any repairs or reduce emissions. Tourmaline Oil petrinex venting data from the May 2022 to April 2023 was used to generate the vent distribution profile shown in Figure 1B. For this project we assume that Tourmlaine Oil as representative example of a larger company. Any results or recommendations from this report are highly likely to be effective for smaller companies when scaled down for aerial, drone, and vehicle based approaches, where as fixed sensors and satellite might have cost barriers. The average vent rate was calculated as 522 m^3/day and sites had a 71% probability of venting. This value is used in the model to simualate how some sites would be venting during screening campaigns and this could mask a technologies abaility to detect fugutive emissions.

Emissions distribution profiles for fugitives (left A) and vent (right B) sources. Fugitives have a lower over magnitude as expected. Both curves show a heavy tailed feature, where a small portion of the leaks make up the largest emission rates.

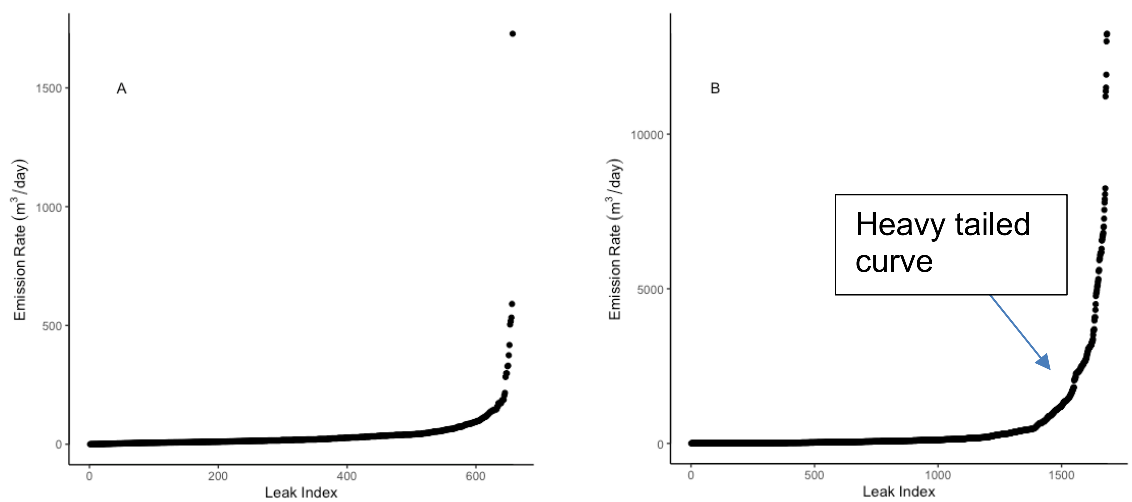

Figure 1: Emissions distribution profiles used to inform the model with fugitive emissions data in A and vent emissions data in B. The leak index is the ranking number of the data point when ordered from lowest to highest emission rate.

The fugitive emissions baseline represents the magnitude of leaks that are present on Day 0 of the model. The baseline was built using the fugitive emission data filtered from the BCER dataset. Fugitive measurements were summed to create an annual emissions rate for tankage, for each year of data. This summed value is an estimate of the total fugitive leakage in m^3 for each year. This value was then divided by 365 to get the average daily tankage emissions.

The model requires that an emissions frequency for tankage be specified to determine how many tanks are leaking on Day 0 of the simulation. However, since the survey information does not have total tank counts at each site surveyed, it is not possible to calculate this at the individual tank level. Instead, the

Cap-OP Study (3) was referenced that found 57% of facilities were emitting. This study selected approximately 260 sites randomly to undergo survey campaigns for fugitives and vents. These surveys are assumed to have been done on similar infrastructure as those present in the BCER data set and are therefor comparable. The BCER data shows that 49% of all facilities found leaking had tankage components leaking. An estimation can be made using the percent of facilities with tank emissions and the BC total % of facilities leaking to calculate that approximately 28% (57% * 49%) of facilities have tankage emissions. In the model, it was assumed that each site is a single facility, with a varying number of tanks, and the average daily tank emissions were applied across 28% of the sites. This was done by taking the average number of tanks per site in the simulated infrastructure list, multiplied by 28% of the total site count (150) to divide the emissions across those tanks.

Table 2 Break down of public data sets and tank related emissions.

	Data Set	
Stats	BC OGC	FEMP EA
Data Count	11817	3515
QOGI Data Count	3171	241
Tank QOGI data points	**657**	**9**
# of facilities	168	NA
# of facilities with tank leaks	82	NA
# of surveys	533	NA
# of surveys with tank leaks	177	NA

The average daily leak rates for all tankage – total leak rate for each year divided by 365 – was 30.6 m^3/day and 42.6 m^3/day for 2020 and 2021 respectively. The overall average across the two years was 36.6 m^3/day.

The fugitive emissions baseline value used in the emissions modeling with the controlled tanks was 5380 m^3/day, which is an estimate total emission rate from all 526 tanks simulated. The baseline fugitive emission frequency was calculated as 28%, meaning that 28% of tanks have fugitive emissions on Day 0 in the model. Separate baseline parameters were generated specifically for the tanks in gas plant facilities in the fixed sensor scenario. In this scenario, the fugitive emissions baseline value used in the emissions modelling was 1281 m^3/day. This value is 44 m^3 greater (3%) than intended due to a rounding error. We are confident that this error does not impact the interpretation of the model results and simply resulted in higher emissions overall. The baseline fugitive emission frequency for the gas plants was calculated as 30%, meaning that 30% of tanks have fugitive emissions on Day 0 in the model.

If the assumptions used in the baseline Day 0 are inaccurate, the impact on the model is limited to how many sites are emitting in day 0, the actual baseline emissions value is not affected. After Day 0 of the model, the model uses a random leak production rate of 0.21 and randomly assigns leaks from the leak distribution profile to non-leaking tanks. Having the initial Day 0 number of tanks emitting incorrect will impact the performance of the 1st campaign, whether screening or OGI survey.

3) Methane Detection Technologies

Service provider information was used to determine an industry representative value for survey time, cost, and detection thresholds. Emissions detection details were left out of the document, as often these are confidential and vary by survey approach. The industry estimates of survey time in units of sites per day and the estimated cost per site are provided in Table 3. In Arolytics' experience, costs for inspection have been extremely variable over the last year as this is an evolving space.

Survey times were adjusted for OGI surveys to allow for 10 tank assessments per day, where tank top access is gained to completely survey all tank components. This is an unsupported assumption that tries to account for the assessment tree suggested in the Clearstone Engineering report (2) that involves surveying failing upstream components. The amount of time it would take to diagnose the issue, across various facility types, would be useful to know to better estimate OGI survey time across different facility types.

Table 3 Approximated survey times and costs for each technology

Technology	Sites surveyed per day	Approximate Cost Per Site ($CAD)
Aerial	64	$300
Drone	8	$350
Vehicle	12	$250

Satellite	~5000	X**
Fixed Sensor	NA	$20000***
OGI	3*	$1000

**Surveys approximately 10 tanks a day, on average this amounts to 3 sites per day.*
*** Satellite costs are confidential and vary by site density. We could not provide an approximate value that would be misleading across common contexts.*
**** Approximate annual cost of fixed sensors with rental and service fees. This would vary greatly by site size.*

For each of the non-OGI technologies, depending on the service provider, the detections could be qualitative or quantitative. Qualitative detections are also called absence presence detections and use less sophisticated techniques to determine if evaluated levels of specific gas species are present and infer that fugitive emissions may be the source. Quantitative measurements will turn sensor detections into an accurate emission rate which can be used for emissions accounting purposes. Some quantitative technologies have similar detection and quantification capabilities as QOGI cameras.

The following descriptions of methane screening technologies are generalized, and new creative sensor combinations and applications are being developed so the exact methodology a platform uses is rapidly improving.

Satellite Technology:
Uses sensor payloads that orbit the earth to quickly scan many sites in a short time period, multiple times across orbits. These systems are excellent at detecting large emitters very quickly but have a very high detection limit.

Aerial Technology:
Uses piloted aircraft to fly either spectral imagine devices to scan the ground like LiDAR, or a spectrometer that measures atmospheric concentrations looking for elevated emissions. These benefit from very fast survey times, typically only a few days, but require additional passes over infrastructure to distinguish venting from fugitive emissions or may not be capable of distinguishing vents from fugitive emissions.

Drone Technology:
Uses remotely piloted aircraft carrying a small payload to quickly sample the airshed around a facility. These payloads can be spectrometer or chemical based sensors that measure the concentration of gas species. Post processing can be used to generate emission plumes from GPS information, and wind

speed and direction can determine the likely source of emissions. Another version is a drone that carries a quantitative OGI camera that allows for alternative OGI camera angles.

Vehicle Technology:
Uses a vehicle with a gas analyzer and wind anemometer to screen for emissions plumes. These technologies can provide immediate feedback and, in some cases, enable sources to be attributed in real time. Some versions can quantify emissions and provide detailed site level emissions. Other packages use the gas analyzer to find sites with elevated concentrations then conduct immediate OGI survey of the site.

Fixed Sensor Technology:
These can be thought of as weather stations for fugitive emissions. They are deployed around a site to continuously monitor the air to detect elevated emissions and with additional computational processing provide an emission rate estimate. The packages can also be programmed with a large leak response protocol where a sensed and sustained elevated emission rate triggers immediate contact to operations and can potentially trigger very fast repair of large emissions.

4) Campaign Designs

Two approaches that the AroFEMP model results could comment on for tanks are:

1) General survey times/ effort could be reduced and days to repair could be reduced.

Typical program comparison modelling with Aerial, Vehicle, Drone, and Satellite with follow-up % to make the OGI process more efficient. All compared to default OGI program with 3 surveys annually.

2) Fixed sensor monitoring of gas plants

Gas plant facilities made up about half of the emissions in the BC data. Fixed sensors are costly so the assumption was to focus these on a large facility where the impact could be the greatest: gas plants.

Table 4 Campaign design values used for number of surveys per year and follow-up percentage.

Technology	Campaigns per year	Follow-up Percentage	Total number of Programs Modelled
Aerial	3, 4, 6, 12	20, 40 , 60	12
Drone	3, 4, 6, 12	20, 40 , 60	12
Truck	3, 4, 6, 12	20, 40 , 60	12
Satellite	3, 4, 6, 12	20, 40 , 60	12
Fixed Sensor	3, 4, 6, 12	20, 40 , 60	12
OGI	3, 12	NA	2

Table 5 Campaign timings for each simulated survey frequency

Campaigns per year	Months they occur
3	May, mid-July, October
4	May, July, September, November
6	March, mid April, June, mid July, September, mid October
12	At the start of each month

In addition to fixed sensor modelling, we have anecdotal fixed sensor monitoring data of a gas plant provided by Tourmaline Oil. As the data is only coming from one site, it is unsuitable to use in the modelling process, but it does provide an opportunity to understand how fixed sensors detect tank vents and leaks, with processing notes and vent flow rates provided for the same time periods to determine if emissions line up. The data was filtered by VRU presence to determine if the fixed sensors saw fewer emissions at similar vent flow rates. The fixed sensor data was filtered for sensor location and wind direction that would directly line up the tankage with a sensor location. The wind directions were then given a 20˚ buffer and the data was filtered and joined with tank vent flow monitoring data by timestamp. Of all 13 sensors, 7 were found to be in a location that could receive tank only emissions plumes. This filtering process may have error and we expect emissions from the gas plant site to be in mixed with tank plumes, but for this analysis, the effect is expected to be minimal.

C. PROJECT RESULTS AND KEY LEARNINGS

Results:

We modelled 60 alt-tech campaigns across 5 technologies, 4 campaign frequencies, and 3 follow-up percentages. A higher follow-up percentage means more sites (LSDs) flagged with emissions will be surveyed by OGI after the screening technology campaign is completed. A higher percentage means a longer follow-up time and potentially longer time to fix leaks. Methane data management software and application program interfaces (APIs) can streamline the transfer of data from service providers to operators to greatly improve repair timelines.

Of these mobile alt-tech screening programs, only 12 were found to achieve greater reductions than the default OGI scenario (Table 6) and required 6 or 12 screening campaigns annually and a follow-up of 40 to 60%. All alt-Tech campaigns took longer than the default OGI campaign to complete. This is due to the time required for conducting QOGI surveys at the percentage of sites flagged by the screening technology.

Surveys with follow-up thresholds of 40 and 60 % showed equivalent or better emissions reductions. It is important to note that if a screening technology flagged a percentage of sites as emitting that is lower than the follow-up threshold, OGI follow-up surveys will still happen at the full follow-up threshold percentage with the excess percentage of sites being randomly selected. This allows for the potential to detect and repair leaks not found in the screening campaigns.

The majority of mobile alt-tech campaigns had more repairs than OGI, due to the more frequent campaigns and site visits. The vehicle and drone-based technologies performed similar to aerial and satellite in the 12x campaigns which is unexpected and likely due to the fact that the repairs in the last two campaigns were not repaired through the LDAR process and counted towards the emissions reductions because the full campaign length is almost 2-months and the model simulations end after 1 year; that is to say, these repairs would have occurred in the January or February of the following year. The campaign lengths are very long, in some cases over a year, as it is assumed that only one crew is deployed. The modelled alt-techs were also compared to a monthly (12x) default campaign, and no programs were found to be near equivalence.

Table 6 Comparisons of alt-Tech to OGI model results for the full facility type region.

Arolytics Rank	Technology	Screening Campaigns per Year	Follow Up Percentage for OGI	Alt-Tech Survey Length Total (Days)	Total Campaign Length (Days)	Difference between Alt-Tech and OGI campaign Lengths (Days)	Annual Methane Emissions (m3)	Alt-Tech Total Repairs	Methane Emissions Difference between Alt-Tech and OGI	Repair Difference between Alt-Tech and Default
1	Truck	6	60	78	265	109	1511197	336	-12%	10%
2	Aerial	6	60	18	205	49	1545537	323	-10%	6%
3	Satellite	6	60	6	193	37	1627977	330	-5%	8%
4	Satellite	12	40	12	262	106	1430548	342	-17%	12%
5	Aerial	12	40	36	286	130	1599557	263	-7%	-14%
6	Drone	6	60	114	301	145	1556034	319	-9%	5%
7	Satellite	12	60	12	386	230	1180745	376	-31%	23%
8	Aerial	12	60	36	410	254	1159383	362	-33%	19%
9	Drone	12	40	228	478	322	1597047	261	-7%	-14%
10	Truck	12	40	156	406	250	1484551	285	-14%	-7%
11	Truck	12	60	156	530	374	1105464	371	-36%	22%
12	Drone	12	60	228	602	446	1168558	357	-32%	17%
	Default - OGI	12	NA		624	468	926172	414	-46%	36%

These campaigns would have 900 to 1800 alt-tech site screenings based on the campaign screenings and our simulated facility list of 150 sites. The length of the full OGI campaign was 156 days. Table 7 shows the approximate cost of the different technologies.

Table 7 Approximate costs of alt-Tech programs and OGI. Satellite costs could not be calculated.

	Campaigns per Year	
Technology	**6**	**12**
Vehicle	$ 225,000	$ 450,000
Drone	$ 315,000	$ 630,000
Aerial	$ 270,000	$ 540,000
Satellite	NA	NA
40% Follow-up Cost	$ 180,000	$ 720,000
60% Follow-up Cost	$ 270,000	$ 1,080,000
OGI	NA	$ 1,800,000
*Default OGI with 3 surveys a year would approximately cost $450,000		

Fixed Sensor Campaigns:
The fixed sensor campaigns focused on a subset of 10 gas plant sites. Several combinations of annual follow-up frequency and percentage were found to reduce methane emissions relative to the default program. The top three campaigns have trade-offs between how often OGI is scheduled and how much OGI follow-up is conducted. Interestingly, the 6x and 12 x campaigns with more than 40% follow-up had more reductions than the monthly OGI campaign with fewer repairs likely due to focused efficiency.

Table 8 Results of the fixed sensor modelling at 10 simulated gas plant sites.

Arolytics Rank	Technology	Screening Campaigns per Year	Follow Up Percentage for OGI	Total Campaign Days	Difference between Alt-Tech and OGI campaign Days	Annual Methane Emissions	Alt-Tech Toal Repairs	Methane Emissions Difference Alt-Tech and OGI	Repair Difference between Alt-Tech and Default
1	FixedSensor	6	40	24	-6	286579	73	-21%	10%
2	FixedSensor	4	60	24	-6	348333	73	-4%	10%
3	FixedSensor	12	20	24	-6	342041	64	-6%	-4%
4	FixedSensor	3	60	18	-12	361297	66	-1%	-1%
5	FixedSensor	6	60	36	6	260519	79	-28%	19%
6	FixedSensor	12	40	48	18	246097	84	-32%	27%
7	FixedSensor	12	60	72	42	215682	91	-41%	37%
	Default - OGI	12	100	120	90	314376	93	-14%	40%

<u>Case Study: Fixed Sensor real world data example from one gas plant:</u>

Analyzing the Tourmaline gas plant fixed sensor data, we found they performed well at detecting emissions from the direction of the tank block but there are likely other sources mixing in with the emission plume. Using a year of vent flow rate and fixed sensor data, we can split the data into two groups around the date when the VRU was installed on the tankage block, figure 2 and figure 3 are pre and post VRU respectively. There was a large decline in the magnitude of detections from the fixed sensors when the VRU was installed. Figure 2 shows the recorded emission rate from the fixed sensor plotted against the recorded vent flow rate of the tanks before a VRU was installed on the tanks. Values to the right of the solid line indicate additional emissions not accounted for in the vent flow measurements meaning the tanks were leaking or there was another emissions source mixing with the vent plume. Figure 3 shows the same data sources but after a VRU was installed showing the reduction of tank vent detections as a result. Any fixed sensor values above zero would be either vents or leaks from the tankage or from another source. This highlighted the importance of fixed sensor placement and taking advantage of prominent wind directions to improve emissions attribution to a facility as without the sensor coverage at the site, there would not have been enough isolated wind directions being monitored to conduct this analysis.

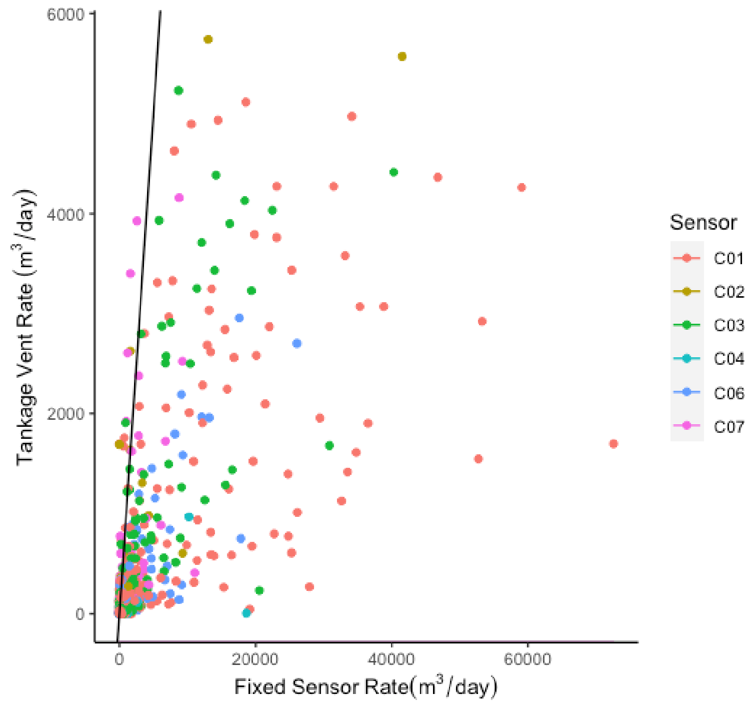

Figure 2 Fixed sensor emission detections plotted against tank vent flow meter measurements. The solid line represents a 1:1 relationship between the two measurements. Measurements to the right of the line indicate that the fixed sensors may have detected additional emissions above the reported vent flow rate.

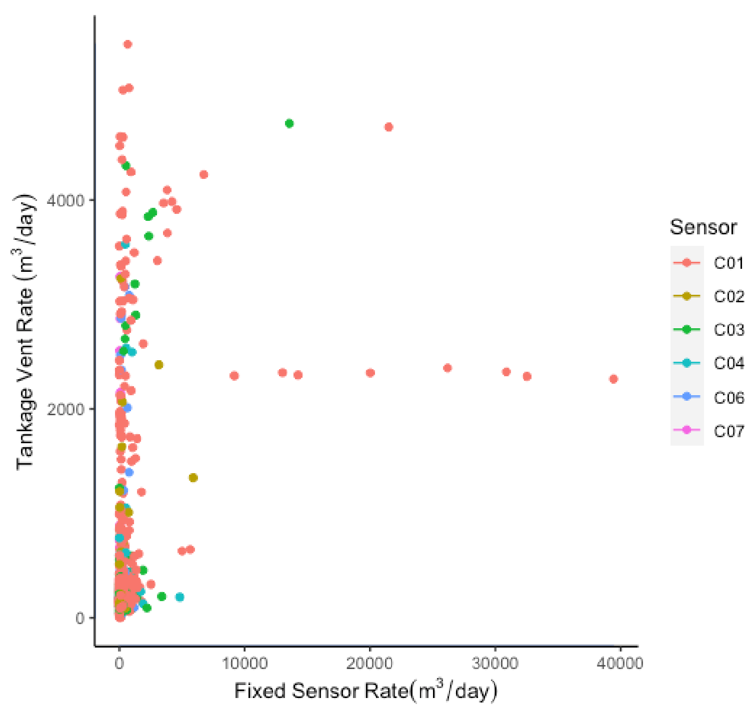

Figure 3 Emissions and vent data after a VRU was installed on the tanks.

If the remaining emissions to the right of the line in Figure 2 or anything greater than zero in Figure 3 are assumed to be leaks, the data can be further processed to generate a leak distribution profile, Figure 4. The data with the VRU absent had the vent flow rates subtracted from the fixed sensor emissions for the same time frame and were ranked and plotted. With the VRU present, we assume all detected emissions are leaks. This should be considered a very preliminary analysis, but it does show promise that some alt-Tech applications could help generate data sets to inform the AroFEMP model.

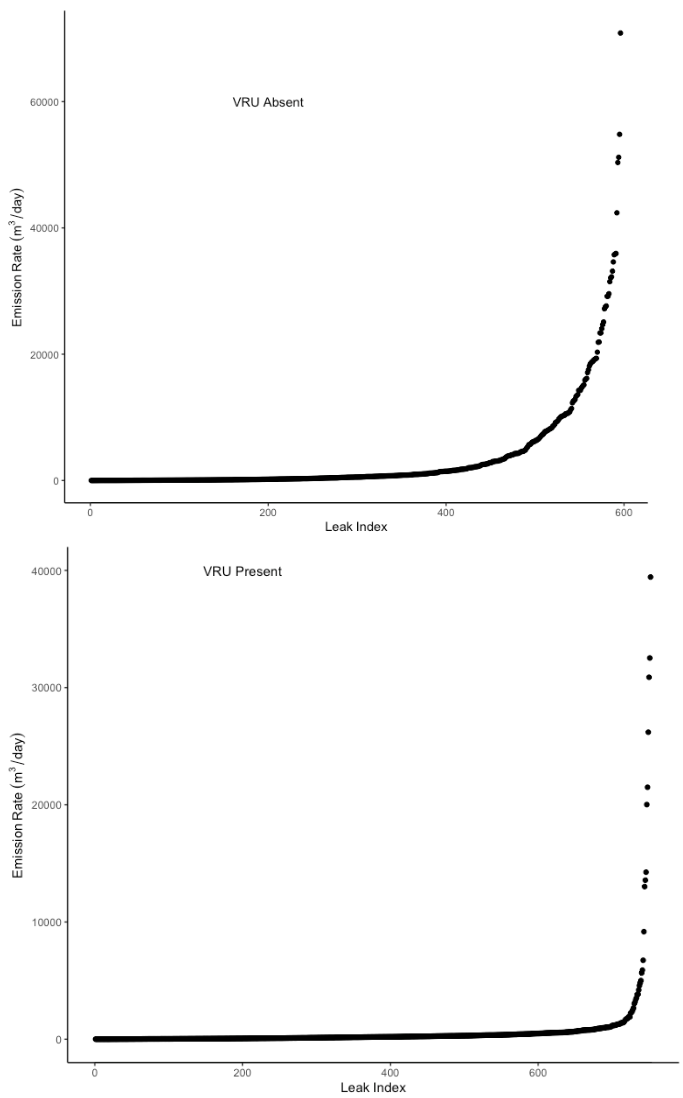

Figure 4 Leak distribution profiles derived from the fixed sensor data.

From the plots in Figure 4 it appears that the controlled tanks have fewer “medium” sized leaks (ranging in the thousands of m^3/day) and instead have a very sharp increase in the heavy tail to “large” leaks (ranging in the tens of thousands). This could indicate that controlled tanks are good candidates for frequent rapid, high-level screenings (such as satellite or aerial) that could catch any “large” leaks that would justify particularly rapid repair or that may warrant an earlier shutdown than planned (assuming shutdown is required for repair). However, due to the limited size of the data set a confident conclusion cannot be made at this time and this remains an area for further investigation when more data becomes available.

Aerial and OGI survey tank emissions were also provided by Tourmaline, and we analyzed the data to see if it aligns with the fixed sensor measurements. The aerial data lines up with fixed sensor detections, though the magnitudes are similar, the fixed sensor showed the temporal variability of the emissions in greater detail compared to the aerial flight data which is an average of multiple snap shots at different times. These values are very agreeable. An OGI survey also found tank emissions, however, these values did not line up with the tank specific sensor monitors, because the wind direction would have pushed the plume through the main plant. However, the sensors on the opposite side of the facility from the tanks still detected these emissions, and estimated a lower emission rate from the source. The rates aren't expected to match up since there could be other plumes mixing or infrastructure obstructing the full plume from reaching the fixed sensor.

Discussion:

In our experience, alt-FEMPs and AroFEMP modelling results are ideally suited for facility lists with high ratios of sites requiring annual surveys compared to triannuals. The alt-tech performs better because the annual sites can be visited more frequently with reduced cost and effort. This posed a challenge for this project, focused entirely on controlled tanks that require triannual surveys. Despite OGI's advantage given the high triannual count, the alt-Techs still performed well in terms of reductions.

The biggest challenge with these campaigns is total survey time for OGI follow-up. The model assumes one crew for any screening and surveys and results in the OGI follow-up accounting for 50% or more of the campaign days, and in some cases 80-90%. This could be overcome by having two or more follow-up OGI crews.

For vehicle and drone screening platforms, an OGI technician could travel along with the technology to conduct immediate OGI follow-up. There are some unknowns to this approach to accurately model the time efficiency gained, for example "does the whole site require a survey if the alt-tech can pinpoint the emissions source?". Efficiency would also be impacted if one or both crew members are certified OGI technicians. Another option to reduce OGI follow-up time would be to have an OGI follow-up for every other screening campaign that triages the leaks from both screening campaigns before it. The model does not have the ability to simulate these features, but it is our intention to develop them to compare campaigns more accurately for more dynamic higher frequency programs.

With the above taken into consideration, we believe the best options for alt-tech surveys of controlled tanks to be 6 campaigns a year program with vehicles, aerial, or satellite using a 60% follow-up threshold. These programs would cost at minimum $500,000.00 dollars for the simulate company of 150 sites, compared to the estimated OGI cost of $450,000.00. Although the alt-Tech is slightly more expensive, it could generate efficiencies and reductions that would make their performance better than OGI. There are also opportunities for the vehicle alt-Tech costs to be reduced further by having immediate OGI follow-up, so that technology could outperform OGI in methane reductions and be more cost effective depending on how the campaigns are executed.

Since these three technologies performed similarly, we are confident in saying that these could be combined into a hybrid program for similar performance. Drone technology is very close to making this list, but the longer survey time makes the total campaign length too long to be reasonable. However, this would likely change with the addition of an OGI technician to conduct immediate OGI follow-up after or during the drone screening.

The fixed sensors performed very well and from the analysis of the Tourmaline Oil data provided, there is a possibility that fixed sensors could help us understand tank related emissions more thoroughly to better design reduction strategies. Although the modelling was focused on simulating gas plants, we are confident these sensors would perform well at any facility type, provided they are installed with enough coverage considering wind directions that can help attribute emissions to specific infrastructure.

In researching the emissions data from the BCER study and reviewing literature, we found a common statement that controlled tanks are difficult to repair, as components often require shutdown to be serviced. We realized our model is not able to simulate the requirement of shutdowns to make repairs happen. This makes the assumption in the modelling of 30 days to repair, and that the LDAR process leads to repairs, potentially unreasonable and also supports the idea that different components or facilities would have different likelihoods of repair and repair timeframes. The table below shows tank components and the portion that were repaired along with days to repair statistics.

Table 9 Repair statistics for tankage components from the BCER public data set for 2020 and 2021 showing repair status and median and mean days leaking.

Leaking Component	Leak Repaired Indicator	Count of Leaks	Median Leak Days	Mean Leak Days	Total Emission Rate (m^3/day)
Control Valve	NO	1	172	172	88
Control Valve	YES	4	72	70	35
Connector	NO	73	226	259	2238

Connector	YES	149	64	91	3080
OLine	NO	16	401	400	159
OLine	YES	37	18	53	483
Other	NO	21	191	233	355
Other	YES	43	31	62	4033
PPump	YES	1	74	74	3
PRV/PSV	NO	65	177	189	2654
PRV/PSV	YES	59	29	62	4146
PSeal	YES	1	0	0	13
Thief Hatch	NO	39	211	265	1675
Thief Hatch	YES	109	61	89	7169
Valve	NO	1	392	392	13
Valve	YES	38	18	35	580

Additionally, there is a chance that repairing an emitting thief hatch will not solve the emissions source issue. There could be a control component upstream that continues to leak into the tank or a malfunction in the vent recovery system that simply causes the thief hatch vent to open and emit again.

We think this highlights an importance for increased survey frequency of tank systems and the collection of more data in the LDAR process. Improving the detail of LDAR surveys to include tank types and counts present would be very advantageous to understanding an individual tanks leak frequency and the ability for OGI to survey all components. More details on repairs to understand the probability of repair for different components where partial or full shutdowns are required compared to repairs made without shutdowns.

Currently AroFEMP models a list of facilities, but we are working towards upgrading this to model component level emissions and repairs. This feature in addition to the feature of chance of no repair, we could start to look into what facilities or tank systems are better able to be shut down or partially shut down for repair. This would significantly reduce the methane reductions the model simulates, as a portion of leaks would simply not get repaired, or the repair could be delayed by 30+ days due to required shutdown, but it would allow us to understand how some technologies have advantages of identifying repairable components faster, or can free up operations time to address those quick repairs faster and enable scheduling of shut downs for full repair.

It is also possible that alt-tech service could soon develop the ability to identify leaking components to the same standard as OGI and facilitate faster repair actions.

In conclusion, this modelling project has found that high frequency mobile alt-tech surveys deployed 6 or 12 times a year, can be equivalent to a default OGI program that conducts 3 surveys a year. We discussed how adjustments to the application of the technology can make it advantageous over OGI, and how there are ways to reduce the modelled total campaign lengths.

Future work:

An ideal dataset would have site level to component level alt-tech screening campaign information, OGI quantitative measurements, repairs statistics, number of tanks present on the site, distinction of controlled versus uncontrolled, and type of recovery unit if it is a controlled tank. This data set would inform the model to simulate component emissions and repair likelihood and timeline for repair for better comparison across technologies.

Uncontrolled tanks could be monitored regularly for high venting emissions via an aerial or satellite service provider. It would be interesting to explore possible methane abatement by VRU installation or processing adjustments that reduced tank venting.

Put references after Section E.

References:

1. Alberta Energy Regulator, Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting

2. Clearstone Engineering Ltd, " Study to Investigate Fugitive and Venting Emissions from Aboveground, Fixed-Roof Storage Tanks," Alberta Energy Regulator (AER), 2019.

3. Cap-Op Energy, “British Columbia Oil and Gas Methane Emissions Field Study,” Prepared for BC Energy Regulator and others, 2019. Available: [https://www.bcogc.ca/node/15509/download]

D. PROJECT AND TECHNOLOGY KEY PERFORMANCE INDICATORS

Organization:	**Current Study**	**Commercial Deployment Projection**
Project cash and in-kind cost ($)	Cash = $180,320 In-kind = $60,000	Total = $975,000

	Total = $240,320	
Technology Readiness Level (Start / End):	6 / 7	6 / 9
GHG Emissions Reduction (kt CH4/yr):	0	0
Estimated GHG abatement cost ($/kt CH4)	0	0
Jobs created or maintained:	2	10

E. RECOMMENDATIONS AND NEXT STEPS

The next key project milestones include:

a) Expansion of Arolytics' existing data management platform to ingest data from **all six** technology types (fixed / continuous sensor, handheld, UAV, vehicle-based, aerial, and satellite).
b) Link operational data to emissions data to understand and reconcile gaps between measured and inventoried emissions, and better understand the root cause of emissions.
c) Development of a flexible reporting framework that supports a variety of internal and external disclosure needs.
d) Commercial-scale demonstration with an industry partner.

In addition to finding and repairing methane leaks sooner, non-GHG environmental benefits as the Arolytics' products advance include:

- Decreased cost of leak detection and repair by utilizing the technology best suited to the producer company. These costs can be reduced up to >40% based on existing Arolytics clients.
- Improved understanding of detection technologies, inspection methods and regulations.
- Auditable performance of emissions programs to evaluate Environmental, Social, Governance (ESG) goals, especially ones tied to sustainability-linked financing. A digital tool to prove carbon competitiveness.
- Optimizing emissions programs to reduce potential safety incidents.
- Automation of otherwise manual tracking, reporting and management activities.
- Risk mitigation from an ESG and capital markets perspective if companies have strong oversight over their emissions.

This technology will empower CanERIC members to harness their measured methane data to better inform policy, and lead methane reduction programs in Canada and globally.