Methods for Estimating Emissions from Tanks

Prepared For:

Petroleum Technology Alliance Canada (PTAC)

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Submitted by: Modern West Advisory, Inc.

Primary Contact: Wayne Hillier

whillier@modernwestadvisory.com

Suite 600, 505 2nd St. SW

Calgary, AB T2P 1N8

Canada


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Calscan and Vertex were exemplary in their practical and professional approach to field work. They are respected and trusted by oil and gas operators because of their experience and their commitment to safety and communications.

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DISCLAIMER

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EXECUTIVE SUMMARY

The magnitude of tank vent rates, the temporal nature of tank vents, the root cause of tank venting, the difference between actual vent rates and reported vent rates, and the viability of emerging technologies to detect and quantify tank vent rates, are not widely understood or known. Efforts to-date to close these knowledge and technology gaps have been with a relatively small sample size of facilities and tanks.

Jointly funded by CanERIC, CRIN, and PTAC AUPRF, ***Methods for Estimating Emissions from Tanks*** answered many of these questions. The study focused on uncontrolled oil production storage tanks at conventional oil and gas batteries in Central Alberta, noting that gas plants, oil sands, and heavy oil operations are out of scope.

Three (3) field campaigns over 18 months deployed 4 different methane detection and quantification technologies

:

- Temporary installation of meters directly on the tank vents, complete with gas sampling and analysis
- Use of FLIR's Optical Gas Imaging (OGI) and Quantification hand-held devices
- Bridger Photonics' Gas Mapping LiDAR (GML) aerial screening technology
- Kuva's GCI362 continuous OGI Camera mounted on relocatable 30 ft towers.

Major findings and recommendations include the following:

The estimated inventory of production tanks at conventional oil and gas batteries in Alberta is approximately 12,000. 88% of the tanks are at oil batteries, split almost equally between single-well and multiwell facilities. 12% of the tanks are at gas batteries.

We estimate that 1,200 to 1,500 of the 5,400 Crude Oil Single-well Batteries do not have separators.

Oil Single-well Batteries *without* Separators will vent persistently at 50 to 500 m^3/day. Direct measurement with temporary meters confirmed the persistent nature. These sites can be identified by reviewing Petrinex Volumetric reports for gas production, disposition, fuel, flare and vent volumes. Despite being only 10% of the total tank inventory, Oil Single-well Batteries without Separators represent 64% of the tank vent emissions in the study.

Batteries with Separators, either Oil or Gas, Single or Multiwell, will vent intermittently with an average vent rate typically between 5 m^3/day and 50 m^3/day. Direct measurement with temporary meters has identified short–duration spikes in vent rates, often 500 m^3/day or higher. Duration may range from a few seconds to a few minutes. Short–duration spikes in vent rate are typically related to normal separator operation and the discharge of oil from the separator to the tank.

Batteries with Separators, either Oil or Gas, Single or Multiwell, can indeed vent persistently at rates up to or exceeding 500 m^3/day, but this is indicative of mechanical issues at the separator, design issues with the separator, or upstream well issues. Operators are generally aware of mechanical and design issues associated with separators and are aware of upstream well issues that can affect separator performance and tank venting. However, the frequency of the issues, the impact of the issues on tank venting, and the reporting obligations of vent volumes to Petrinex may not be broadly understood or shared. As a first step, PTAC's AUPRF committee could evaluate this relative to other priorities and consider hosting a workshop with subject matter experts to identify root causes and to identify monitoring, mitigation, and reporting best practices.

Area–based Aerial Detection and Quantification Surveys are a valuable and effective way of establishing a methane inventory of persistent and intermittent releases by facility type and process block, including tanks. Area–based means simply drawing a boundary that incorporates many operating facilities and surveying all the facilities within the boundary. It may be as large as 50 km by 50 km, contain 500 facilities, and 20 or more operators. The entire area can be surveyed by plane in less than a week. Process Blocks are a grouping of equipment by purpose or function.

Area–based Aerial Detection and Quantification Surveys can also support valuable research studies while establishing a methane inventory for the area. Examples of concurrent studies include:

- Confirm persistent tank venting at Oil Single–well Batteries without Separators
- Deploy ground–based meteorological stations for wind measurement to improve aerial quantification of methane and to improve wind models.
- Determine the optimal number of flights over a facility to accurately estimate intermittent release rates.
- Reconcile or integrate with other detection technologies into an accurate estimate of site–wide emissions. Other technologies could include continuous ground–based fixed sensors, mobile sensors and OGI cameras, and satellite–based sensors.
- Repeat surveys annually to identify any trends in methane emissions.

Campaign 1 included an area-based aerial detection and quantification survey of 500 operating facilities and concluded that venting from uncontrolled tanks contributed only 13% of areas total emissions. Of note, fugitives from controlled tanks were 12% of total area's emissions:

Process Block	% of Total Emissions
Compression	25%
Separation	24%
Tanks – Uncontrolled	13%
Tanks – Controlled	12%
Dehydration	6%
Well Head	3%
Miscellaneous <2% each	13%

Note that emissions from compressor buildings and separator buildings make up almost half of the area's total emissions. Emissions from the Compressor building could include methane slip in engine exhaust, compressor seal venting, or fugitives in the fuel system. Emissions from a Separator building could include venting from pneumatic controllers and chemical pumps, venting from the pop tank, or fugitive emissions.

Campaign 3 included an area-based aerial detection and quantification survey of 209 batteries with tanks. This campaign confirmed that Oil Single-well Batteries without Separators are a major source of tank vent emissions. This campaign also confirmed that the sum of aerial detections from 130 oil batteries *with* separators aligns well with the sum of vent volumes reported to Petrinex. This directionally indicates that Petrinex vent volumes, at least for oil batteries with separators, is reasonably accurate.

Oil Single-well Batteries *without* Separators (OSWBwoS) should be investigated further to identify vent reduction opportunities: The recommended investigation strategy includes:

- Identify OSWBwoS from Petrinex Volumetric Reporting
- Screen all OSWBwoS using Bridger GML aerial surveillance, or similar.
- For sites with large, persistent tank releases, confirm vent rate with a temporary meter installation of the tank vent for 4 hours, or with a temporary installation of a portable test separator for 24 hours.
- Confirmation of vent rate is important to assess mitigation options and economics. Typically, gas pipelines are not close by. This limits opportunities to conserve. Combustion as fuel, or combustion with a flare or enclosed combustors are the most likely vent mitigation options.

The following section, **Overview of Project and Results** further elaborates on each of the key findings and recommendations. Further details can be found in the body of the report.

OVERVIEW OF PROJECT AND RESULTS

The magnitude of tank vent rates, the temporal nature of tank vents, the root cause of tank venting, the difference between actual vent rates and reported vent rates, and the viability of emerging technologies to detect and quantify tank vent rates, are not widely understood or known. Efforts to-date to close these knowledge and technology gaps have been with a relatively small sample size of facilities and tanks.

Jointly funded by CanERIC, CRIN, and PTAC AUPRF, ***Methods for Estimating Emissions from Tanks*** objectives included:

1. Deploy relevant measurement and monitoring techniques for methane vents from uncontrolled fixed-roof liquid storage tanks in Alberta.
2. Understand the magnitude of tank emissions and the reasons for variability in emission rates.
3. Recommend alternate methods, techniques, and technologies to estimate tank emissions.

Four (4) detection and quantification technologies were deployed:

- Calscan's Hawk 9000 Data Logger and gas turbine meter. Portable, battery operated, intrinsically safe, ideal for temporary direct measurement of tank vents.
- Vertex's use of FLIR's QFx320 Optical Gas Imagining (OGI) camera to identify emission sources, and a FLIR-Providence Photonics QL320 QOGI system to quantify emissions.
- Bridger Photonics' Gas Mapping LiDAR (GML), an aerial screening technology deployed commercially in Canada since 2020, which can survey 100 sites or more in a day, detecting and quantifying methane releases and locating the release within 2 metres of source.
- Kuva Canada's newly commercial GCI362 continuous OGI camera with a passive shortwave infrared sensor. Self contained, cloud connected, and autonomous, the camera is installed on relocatable 30 ft towers.

Field work began in September 2021. Three (3) separate and distinct field campaigns were launched across central Alberta, focusing on oil storage tanks at conventional oil and gas batteries in Alberta, noting that gas plants, oil sands facilities, and heavy oil facilities are out of scope. Learnings from each campaign informed both the schedule and the scope of subsequent campaigns.

The following is a brief description of each campaign:

- Campaign 1: Fall 2021, Sundre area, 500 sites screened with Bridger, 8 sites direct measurements with Calscan/Vertex, and 10 sites with Kuva's continuous OGI Camera.
- Campaign 2: Spring 2022, central Alberta, 12 Oil Single-well Batteries *without* Separators, all direct measurement with Calscan/Vertex
- Campaign 3: Fall 2022, west of Sylvan Lake, 209 sites screened by Bridger, 3 sites with direct measurement, and 1 Kuva deployment.

The following is a summary of key findings:

Tank Population

Previous equipment inventory work in 2018 by Clearstone Engineering[1] estimated the number of tanks per facility type in Alberta. Updating Clearstone's methodology with 2022 Battery counts, we estimate the number of tanks at conventional and gas batteries in Alberta to be:

Subtype	Battery Description	# Batteries	# Tanks per Battery	Total Tanks
311	Crude Oil Single-well	4,164	1.302	5,422
321	Crude Oil Multiwell	390	1.302	508
322	Crude Oil Multiwell Proration	1,873	2.508	4,697
351	Gas Single-well	3,586	.213	764
361	Gas Multiwell	2,054	.275	567
362	Gas Multiwell Effluent	363	.415	151
			Estimated Total	12,108

Most batteries have separators, which by design separate produced gas from produced oil upstream of any oil storage tanks. However, we estimate there are 1,200 to 1,500 Crude Oil Single-well Batteries *without* Separators in Alberta. Roughly, 1 in 4 single-well oil batteries do not have a separator. Batteries *without* separators are very likely to have persistent tank vents.

[1] Update of Equipment, Component and Fugitive Emission Factors for AB UO&G. Clearstone Engineering June 2018

Controlled tanks are included in the tank inventory in the above table. However, the study of controlled tanks is not included in the scope of this project. Regardless, controlled tanks are found to be a recurring source of methane emissions. The total population of controlled tanks is not known, and therefore the percentage of controlled tanks with methane leaks is unknown as well.

Description of Tank Vents

Tank vents can be described both in terms of their magnitude (ie m^3/day or 10^3m^3/month) and in terms of their temporal nature, meaning, how does the vent magnitude change with time. Magnitude is important from a corporate reporting and emissions inventory perspective. Temporal nature must be understood when evaluating detection and quantification technologies. Temporal nature will also impact control strategies.

Bridger Photonics addressed the temporal nature by categorizing releases as persistent or intermittent releases. This project builds on this categorization and has expanded the types of persistent releases based on field observations. Working definitions used in this report are summarized in the following table. Examples of each appear on the next page, where the vent rate was determined by direct metering.

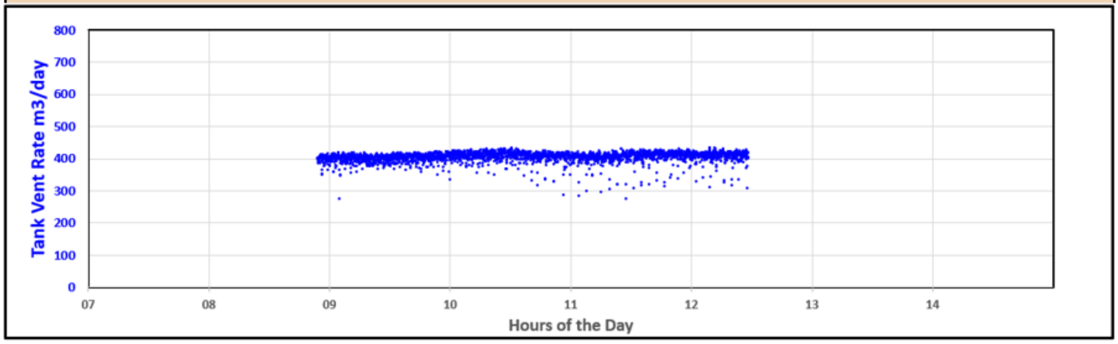
Temporal Category	Description
Persistent and Constant	Continuous vents at constant rate, relatively little fluctuation from the mean
Persistent and Fluctuating	Continuous vents, with large rapid fluctuations from the mean
Persistent, Fluctuating, and Cyclic	Continuous vents with large fluctuations, but cyclic in nature, typically 5 to 90 minutes
Intermittent	Non – continuous, where spikes in vent rates are followed by periods of zero or no detection.

Intermittent releases are typically associated with batteries with separators. A properly designed and well operated facility with separators may have a tank vent that averages less than 10 m^3/day but could see short-duration spikes of 500 m^3/day or higher.

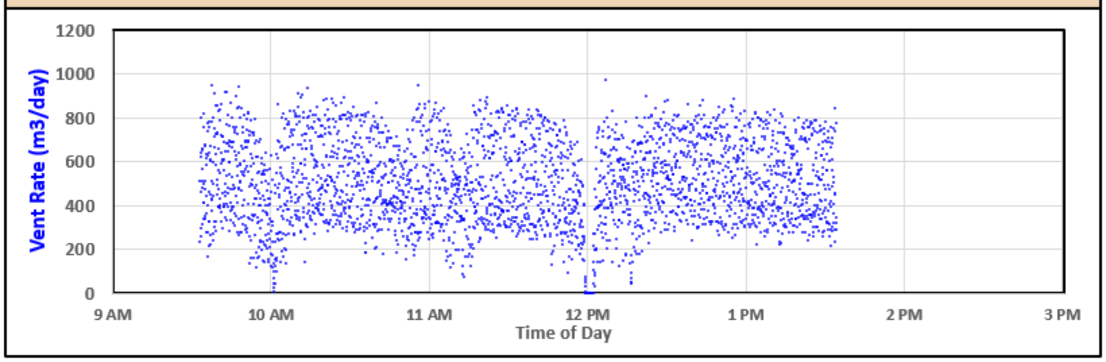
The ability to detect and accurately quantify intermittent tank vents is a challenge for all technologies. Fixed sensors that monitor tanks continuously may best be suited for detecting and quantifying intermittent releases. For example, Kuva's continuous OGI camera was able to detect intermittent releases during daytime operation.

Examples of the Temporal Nature of Tank Vents

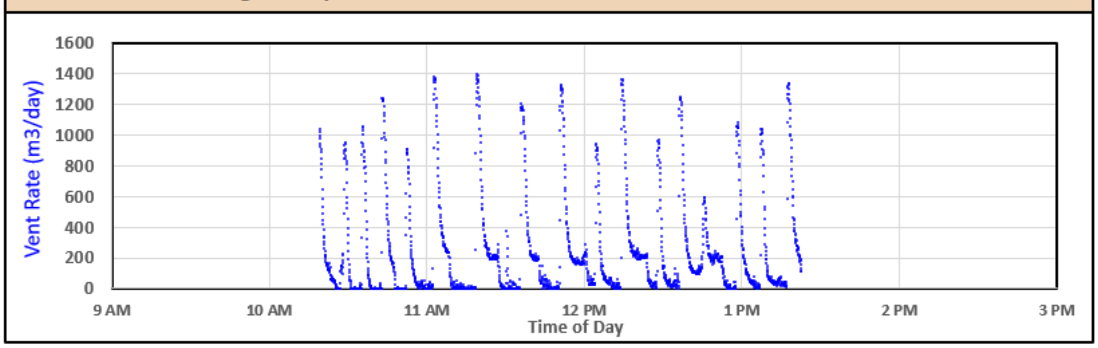
Persistent and Constant Tank Vent



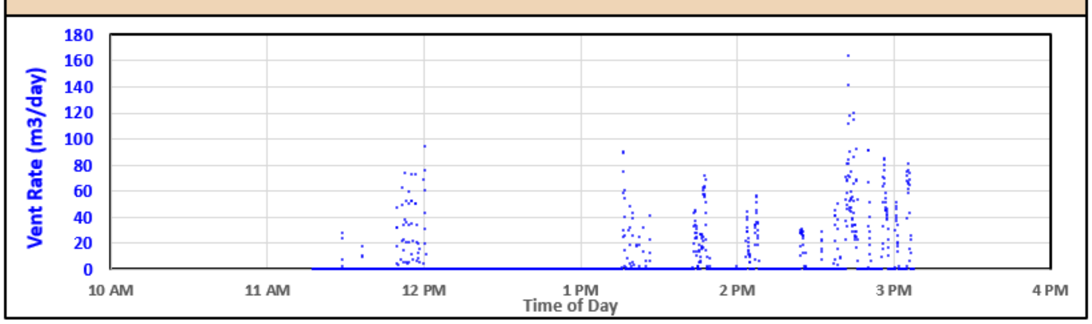
Persistent and Fluctuating Tank Vent



Persistent, Fluctuating, and Cyclic Tank Vent



Intermittent Tank Vent



Contribution of Tank Emissions to the Overall Methane Emission Inventory

Campaign 1 allowed the project team to assess the relative contribution of tank emissions to the overall area emissions. Bridger surveyed over 500 sites and 35 operators. All Bridger releases were overlayed on aerial images of each site, and each release assigned a 'Process Block'.

A Process Block is a grouping of equipment by purpose or function. For example, Separation is a process block that includes all equipment in and around the Separator Building. This would include the separator vessel itself, the attached pop tank, and pneumatic controllers, pneumatic pumps, and heaters inside the building. An aerial detection of methane from a Separation Process Block could be fugitive emissions, or vents from the pop tank or pneumatic devices. Aerial detection of methane at a Compression Process Block could include methane vents from compressor seals, methane slip in engine exhaust, and fugitive emissions from the fuel system.

Aerial surveillance normally cannot differentiate between a fugitive or a vent, and normally cannot attribute releases to specific pieces of equipment. Regardless, there is value in distinguishing releases from Separator Buildings, Compressor Buildings, Flare Systems and Stacks, Production Tanks, Dehydration Buildings, and Pump Jacks. Aerial imaging can also help to identify controlled tanks, which typically have visible piping on top of the tank.

From Campaign 1, Bridger's GML detected a total of 32,760 m3/day of methane. This was assigned to the following process blocks.

Process Block	% of Total Emissions
Compression	25%
Separation	24%
Tanks – Uncontrolled	13%
Tanks – Controlled	12%
Dehydration	6%
Well Head	3%
Miscellaneous <2% each	13%

In 2021, releases from Compressor Buildings and Separator Buildings contribute to almost 50% of the area emissions, based on Bridger's detections.

Uncontrolled tanks contributed only 13% of the area's total emissions.

Notably, controlled tanks almost equaled uncontrolled tanks. Emissions from controlled tanks are deemed to be fugitive emissions rather than vents. Pressure–vacuum valves that are designed to maintain a slight positive pressure are a common source of leaks on controlled tanks.

It is also important to note that the table above does not reflect the total process blocks surveyed in Campaign 1. The majority of sites surveyed by Bridger for Campaign 1 did *not* have Bridger detections. And a complete inventory of process blocks surveyed in Campaign 1 was not established, so we cannot definitively say what percentage of the process block population had Bridger detections.

Tank Emissions by Facility Type

Both Campaign 1 and Campaign 3 are considered 'area-based' aerial studies with a representative mix of assets. The sample size is large enough to draw reasonable conclusions on the distribution of emissions. Despite the different locations in the province, and despite the 16 months between campaigns, the two campaigns are very similar in the distribution of tank emissions, as listed below.

In both Campaign 1 and 3, most tank emissions came from Oil Single-well Batteries *without* separators.

Facility Type	% of Total Tank Emissions
Oil Single-well Battery *without* Separator	64%
Oil Single-well Battery (with Separator)	12%
Oil Multiwell Batteries	21%
Gas Single-well Batteries	2%
Gas Multiwell Batteries	1%

The Many Benefits of Area-based Aerial Detection and Quantification Surveys

Campaign 1 and 3 described above demonstrate that Area-based Aerial Detection and Quantification surveys are a valuable and effective way of establishing a methane inventory of persistent and intermittent releases by facility type and process block, including tanks.

Importantly, other valuable studies can be readily layered into an area-based aerial survey. Examples of layered studies include:

- Simultaneously deploying ground-based meteorological stations to study any improvement in aerial quantification accuracy, or to improve wind models.
- Installation of meters on the tank top to improve our collective understanding of the intermittent nature of tank venting and the required frequency of aerial detection to calculate an average release rate.

- Integrate aerial surveillance with other detection technologies, including OGI cameras, fixed sensors, truck-based sensors, and satellite-based sensors.
- Survey Oil Single-well Batteries *without* Separators to confirm persistent tank venting and to identify conservation opportunities.
- Aerial surveys repeated annually or semi-annually over the same area will identify trends in methane emissions.

An Area-based Aerial Detection and Quantification Survey could have the following elements:

- Draw an informed but random boundary that incorporates a large number of operating facilities and wells. Consider 50 km by 50 km, 500 facilities, 50 different operators.
- Consider 5 different areas of the province, or more, depending on funding and available resources.
- Survey the entire area with Bridger's GML technology, or equivalent. Each site has 2 or more aerial passes the first day, consistent with Bridger's commercial deployment. The survey is repeated on a subsequent day. Sites without detections on day 1 are surveyed again regardless.
- Sites are identified as gas or oil well sites, single-well or multiwell gas or oil batteries, compressor stations, gas gathering systems, and gas plants, using publicly available Petrinex data.
- Releases are classified as persistent or intermittent, where persistent is defined as always detected with each pass of the plane, and intermittent is defined as at least one detection and at least one non-detect when flown more than once.
- Detection locations and release rates are overlaid on high-definition geospatially- accurate aerial images of the site.
- The location of each methane release is assigned a 'process block', based on the aerial image and any plot plan and process flow diagram in the public domain. A process block is a grouping of equipment based on purpose or function.
- Prior to the aerial survey, at selected batteries consider the temporary installation of meteorological stations and meters on the tank vents. This will improve our understanding of intermittent venting and the probability of detecting intermittent vents. Quantification accuracy may improve by using direct wind measurement rather than wind models.
- Consider including in the survey Oil Singe-well Batteries *without* Separators, to confirm the persistent nature of venting and to identify conservation opportunities.

- Consider working closing with OGI Service providers and other detection technologies, to compare inventories and to understand the strengths and limitations of OGI Cameras, aerial surveillance, and other technologies, with the goal to develop an integrated approach to methane detection, quantification, and reporting.

Confirmation of Tank Venting at Oil Single–well Batteries *without* Separators

Campaign 1 identified Oil Single–well Batteries *without* separators as a potential source of persistent tank vents. This was confirmed in Campaign 2. Batteries without separators were identified from Petrinex Volumetric reports, public pipeline data and satellite images. Twelve (12) sites between Drayton Valley and Calgary were selected for Direct Measurement.

Campaign 2 confirmed that Oil Single–well Batteries *without* Separators will very likely have persistent tank vents between 50 m^3/day and 500 m^3/day.

Oil Single–well Batteries *without* Separators should be investigated further to identify vent reduction opportunities and improve vent rate estimation methodologies.

Oil Single–well Batteries *without* Separators have persistent tank vents that present opportunities for conservation. Also, new vent estimation methodologies are required since existing methodologies do not apply to batteries without separators. For example, the AER's 'rule–of–thumb' is for stabilized oil. Also, pressurized oil sampling for GOR or GIS testing will not include casing gas that is routed directly to the tank.

The recommended investigation strategy can include the following elements:

- Identify OSWBwoS from Petrinex Volumetric Reporting
- Screen all OSWBwoS using Bridger GML aerial surveillance, or similar.
- For sites with large, persistent tank releases, confirm vent rate with a temporary meter installation of the tank vent for 4 hours, or with a temporary installation of a portable test separator for 24 hours.
- Confirmation of vent rate is important to assess mitigation options and economics.

Petrinex Volumetric Reporting Verses Direct Measurement

It has been widely assumed that tank venting is under reported in Petrinex. This assumption was evaluated as part of Campaign 2.

Directive 60 was updated January 1st, 2020, to include new vent gas limits and fugitive emission management requirements. New reporting requirements to both Petrinex and AER's OneStop also came into effect.

Only 2 of the 12 sites in Campaign 2 reported vent volumes prior to 2020.

By the end of 2022, all 12 sites were reporting vent volumes. All sites displayed step-change increases in reported vent volumes after 2020, likely in response to the new requirements. And the reported vent volumes closely align with the direct measurement volumes recorded in the spring of 2022.

We can conclude from Campaign 2 that sites were indeed underreporting tank vents prior to 2020 but reporting has improved since 2020.

Petrinex Volumetric Reporting Verses Aerial Detection and Quantification

Campaign 3 included aerial surveillance of 209 sites with hydrocarbon storage tanks. The total sum of Bridger releases for each site was compared to the reported Petrinex volumes for the month of the Campaign.

- The sum of Bridger's releases from Oil Single-well Batteries *without* Separators exceeded that reported to Petrinex by a factor of 4. This may not be a surprise, given that Oil Single Well Batteries *without* Separators have been shown to have persistent releases, and that existing production accounting estimation methods are not applicable to sites *without* separators.
- The sum of Bridger releases from Oil Single-well Batteries *with* Separators exceeded that reported to Petrinex by a factor of only 1.25.
- The sum of Bridger releases at Oil Multiwell Batteries exceeded that reported to Petrinex by a factor of only 1.17.

This is encouraging. The sum of Bridger detections at 130 oil batteries with separators are within 25% of the total vent volumes reported to Petrinex. And the Bridger sum would be conservatively high since it includes intermittent releases.

Comparison between Bridger detections and reported Petrinex volumes can readily be part of future aera-based Aerial Detection and Quantification surveys.

To directly compare Bridger detections to vent volumes reported to Petrinex going forward, an understanding of intermittent vents and options for incorporating intermittent vents into an inventory need to be understood.

Quantification with Direct Measurements

Calscan's deployment of light weight meter runs provided the necessary data to understand tank venting. The meter runs included turbine meters, intrinsically safe battery-powered data loggers, and a gas sample point. The turbine meters are accurate over a flow rate of 20 m^3/day to 2000 m^3/day. Installation directly on top of the tank allowed for the evaluation of other technologies to detect and quantify tank vents.

Further investigation of tank vents would benefit from direct measurement using this setup. However, possible improvements could include:

- Installation of a second flow meter in series. This meter would be accurate from 0 to 50 m^3/day, to compliment the turbine meters inaccuracies below 20 m^3/day. Ideally, the new meter is 2" in diameter to avoid pressure drop issues, and battery powered to simplify installation.
- The use of a portable methane analyser will reduce sampling error and provide real–time results.

Quantifying with QOGI

The use of FLIR's GFx320 OGI camera has become standard equipment for the detection of methane releases. However, quantification of methane releases with the FLIR/Providence Q320 has not been widely embraced by many service providers.

During Campaign 2, Vertex developed confidence in the ability to quantify tank vents and to assess the temporal nature of the vents using the GFx320 camera. Three key components to their methodology are:

- Line of sight from the camera to the vent
- Measurement of local wind speed, ambient temperature, and distance from the OGI camera to the vent
- Up to four hours may be required to quantify fluctuating and intermittent releases.

Further work is recommended to refine and document this methodology and to provide a data set of sufficient quantity and quality to be statistically significant. Suggested improvements including blinding the direct measurement from the OGI camera operator, the use of an independent 3rd party to compare data sources, and soliciting help from FLIR experts for the protocol development.

Detection and Quantification with Bridger Photonics Gas Mapping LiDAR (GML)

Bridger's Gas Mapping Lidar (GML) is commercial technology that has been widely used in Canada since 2020. A benefit of Bridger's technology, and aerial surveillance in general, is the large number of facilities that can be surveyed in a short period of time. Bridger's data products include good plume visualization, locating the release point to within 2 metres or better, high-definition aerial images, an assessment of the temporal nature of the release, and an estimation of the release rate.

Wind speed is necessary for Bridger to calculate release rates. Since local wind speed is rarely measured, Bridger relies on wind models. These models may not be accurate at the site level or could be improved if local wind data is available. Also, controlled release studies indicate that Bridger has a high bias at low wind speeds.[2]

Bridger's GML can be a very effective technology for area-based studies as noted above. Area-based surveys in selected regions of Alberta will help develop an inventory of persistent and intermittent methane releases by facility type and process block, including tanks.

Further investigation of Bridger's detection and quantification capabilities should also be investigated. Direct measurement of tank vents, incorporating local wind speed, and increasing the number of scans per day may help to improve the probability of detection and the quantification confidence of intermittent releases. This can be readily incorporated into future area-based studies.

Detection and Quantification with Kuva's Continuous OGI Camera

Kuva has a growing data set of controlled releases and field trials that demonstrates detection thresholds and quantification confidence. Kuva's unique benefits include continuous non-contact emission measurements, monitoring multiple sources and multiple tanks with one camera, quick deployment, and relocatable installations.

Kuva's current limitations include daylight operation only, and the minimum detection limit is dependent upon distance from source, weather, and wind speed. Winter operation may be limited due to low or insufficient solar illumination.

Kuva has promise to be a relocatable quantification solution for tank monitoring in Alberta, particularly for intermittent releases.

Kuva also has promise as a continuous monitor for fugitive emissions from controlled tanks.

[2] Bell, C. et al. Single-blind determination of methane detection limits and quantification accuracy using aircraft-based LiDAR. Elementa: Science of the Anthropocene 10, (2022).

Background

Project Description

The magnitude of tank vent rates, the temporal nature of tank vents, the root cause of tank venting, the difference between actual vent rates and reported vent rates, and the viability of emerging technologies to detect and quantify tank vent rates, are not widely understood or known. Efforts to-date have been with a relatively small sample size of facilities and tanks.

This project, titled ***Methods for Estimating Emissions from Tanks*** was designed to answer the many outstanding questions with respect to tank venting. PTAC's AUPRF and CanERIC, as well as CRIN, funded the project. In-kind contributions came from the Sundre Petroleum Operators Group (SPOG) and Kuva Canada through existing Emission Reduction Alberta (ERA) funding.

The Project Team consisted of the following organizations:

- Modern West Advisory
- Calscan Solutions
- Vertex Professional Services
- Kuva Canada

Three (3) main objectives of ***Methods for Estimating Emissions from Tanks*** *are:*

1. Deploy relevant measurement and monitoring techniques for methane vents from uncontrolled fixed-roof liquid storage tanks in Alberta.
2. Understand the magnitude of tank emissions and the reasons for variability in emission rates.
3. Recommend alternate methods, techniques, and technologies to estimate tank emissions.

Field work began in September 2021. Three (3) separate and distinct field campaigns were launched across central Alberta. Learnings from each campaign informed both the schedule and the scope of work. The following is a brief description of each campaign:

Campaign 1: Fall 2021. Focus on the Sundre area, use June 2021 Bridger surveys of SPOG to identify uncontrolled hydrocarbons storage tanks with vents. Install temporary meters on top of each tank and install Kuva cameras.

Campaign 2: Spring 2022. Validate findings of Campaign 1 that Oil Single-well Batteries *without* Separators are a source of persistent tank vents. Install temporary meters on top of 12 batteries without separators.

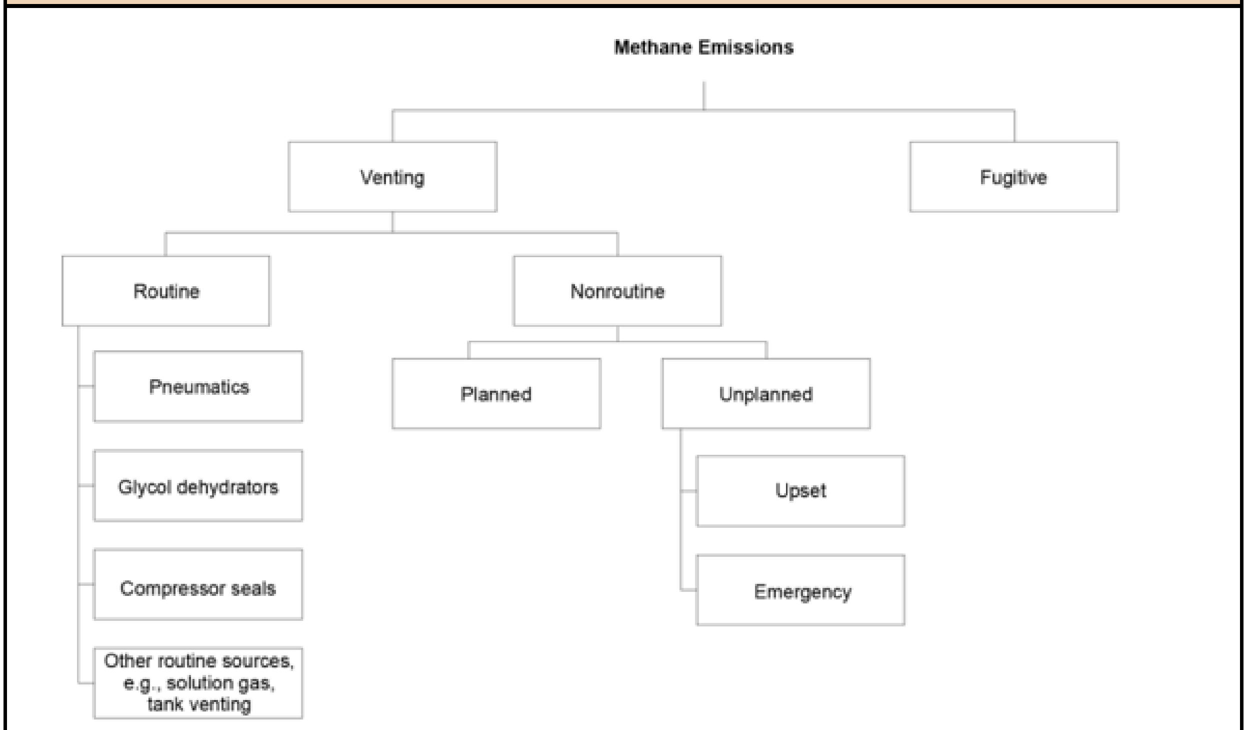
Campaign 3: Fall 2022. Bridger survey of 209 sites in west central Alberta. Sites elected to be a representative mix of oil and gas batteries, single and multiwell. Install temporary meters and Kuva camera prior to Bridger deployment.

The following subsections provide the necessary background for the project. Results of each campaign are then reviewed in detail in the next section.

Directive 60 Overview

Directive 60: Upstream Petroleum Industry Flaring, Incinerating, and Venting, published by the Alberta Energy Regulator (AER), establishes requirements for Oil and Gas operators to reduce methane emissions and meet the provincial target of 45% reduction by 2025 from 2014 levels. Figure B–1, below, illustrates how the methane emissions sources subject to Directive 60's requirements have been categorized. Note that tank venting is characterized as 'Other Routine Sources'

Figure B-1: Directive 60 Section 8 - Methane Emissions Sources



The following discussion on vent gas limits is specific to conventional oil and gas, and is not applicable to crude bitumen batteries, wells or batteries in the Peace River area, or Oil Sands operations including in situ schemes. See Directive 60, Section 8 for further details.

Effective January 1st, 2020, thru to Dec 31st, 2022, Directive 60 sets an Overall Vent Gas (OVG) limit of 15 10^3 m^3 per month for Routine and Nonroutine vent sources excluding pneumatic devices, compressor seals and glycol dehydrators. Effective January 1st, 2023, the OVG applies to all Routine and Nonroutine vents sources, including pneumatic devices, compressor seals and glycol dehydrators. See Table B–1 below:

Table B-1: Directive 60 Overall Vent Gas Limit and Defined Vent Gas Limit

		OVG	OVG	DVG - New Facilites[1]
	Effective Dates	Jan 1 2020 thru Dec 31 2022	Jan 1 2023	Jan 1 2022
	Limits	15 10^3 m^3 per month	15 10^3 m^3 per month	3 10^3 m^3 per month
Routine	Pneumatics		✓	
	Glycol Dehydrators		✓	
	Compressor Seals		✓	
	Other, including Tank Venting	✓	✓	✓
Nonroutine	Planned	✓	✓	✓
	Unplaned Upsets	✓	✓	✓
	Unplanned Emergency	✓	✓	✓

[1] Directive Section 60 8.4, pg 73: DVG applies to "...sites with first receipt or production on or after January 1,2022"

Table B–1 above does not reflect the restrictions on routine vents from pneumatics, glycol dehydrators, or compressor seals. For completeness, Directive 60's equipment–specific requirements are summarized in Table B–2 below. The reader is encouraged to review Directive 60 section 8.6 Equipment–Specific Vent Gas Limits for further details.

Table B-2: Summary of Directive 60 Equipment-Specific Vent Gas Limits

		Installed before Jan 1, 2022	Installed on or after Jan 1 2022
Pneumatic	Level controllers	controlled, or actuation frequency > 15 minutes[1]	controlled (ie zero emitting)
	Pumps	included in OVG limit	controlled (ie zero emitting)[2]
	Other Pneumatic Instruments	controlled, or vent rate < 0.17 m^3/hr [(3)]	controlled (ie zero emitting)
Compressor Seals [4]	≥ 4 Throws	include in RCS[5] fleet average[6] & repair requirments[7]	controlled (ie zero emitting)
	< 4 Throws		include in RCS[5] fleet average[6] & repair requirments[7]
Glycol Dehydrators[8]		< 109 kg/day	<68 kg/day methane

[1] Effective Jan 1 2023

[2] applies to pumps that operate > 750 hours per calendar year

[(3)] manufactuerer-specified steady state vent gas rate of < 0.17 m^3/hr

[4] reciprocating compressors rated for ≥ 75kW and pressurizd for ≥ 450 hours per year

[5] Reciprocating Compressor Seal (RCS). Fleet averagw < 0.35 m3/hr/throw. Any RCS vent > 5 m3/hr/throw repaired within 30days

[6] RCS fleet average < 0.35 m3/hr/throw.

[7] Any RCS vent > 5 m^3/hr/throw must be reduced to < 5 m3/hr/throw within 30days

[8] Includes relocated Deydrators

Battery Description

This section describes the various oil and gas batteries investigated in this study.

AER's ***Directive 017: Measurement Requirements for Oil and Gas Operations,*** and ***Manual 11: How to Submit Volumetric Data to the AER*** are useful resources to understand the various oil and gas facilities operating in Alberta, and the measurement and reporting requirements for each facility type.

From Manual 11, Table 2:

General Definition of a Battery:

A system or arrangement of tanks or other surface equipment receiving flow-lined production from one or more wells. Batteries must provide for measurement and disposition of production and may:

- include equipment for separating production into oil, gas, and water,
- include storage equipment for produced liquids before disposition, and
- receive product from other facilities.

Crude Oil Single-well Battery (subtype 311)

A production facility for a single flow-lined crude oil well.

Figure B-2, below, is a photo of an Oil Single-well Battery that was visited as part of this study. The photo shows a common setup for well head, pump jack and separator building.

Produced gas, often called Casing Gas, is a co-product at oil batteries. The casing gas from the well head is typically tied back to the oil line, and oil and gas flow co-mingled to the separator. This is difficult to see in Figure B-2. It is best explained schematically in Figure B-3, also below.

Directive 17 provides useful schematics to explain various types of batteries and their measurement requirements. Figure B-4 below uses the schematic templates in Directive 17 but modified to show casing gas production at an Oil Single-well Battery. Also included in the schematic is the hydrocarbon storage tank.

Figure B-2: Oil Single-well Battery with Separator

Figure B-3: Typical Oil Well with Casing Gas

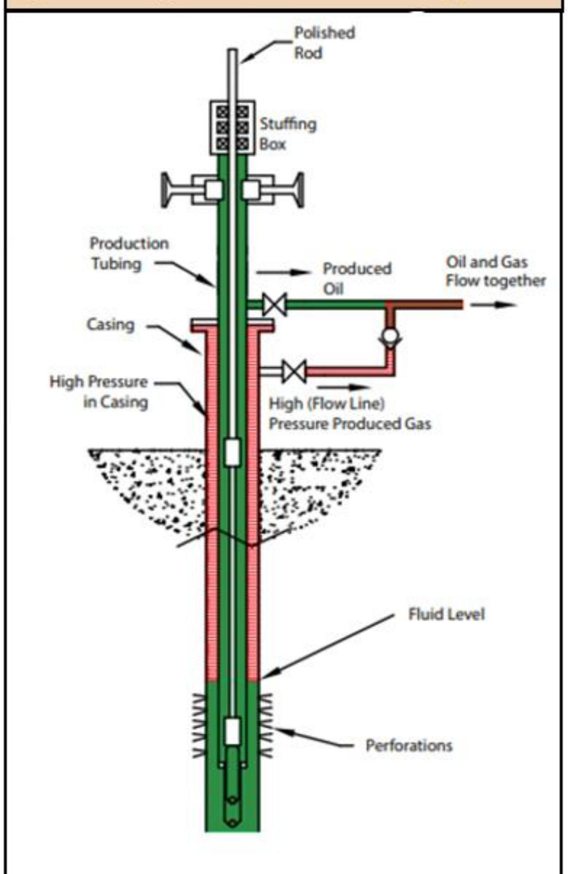
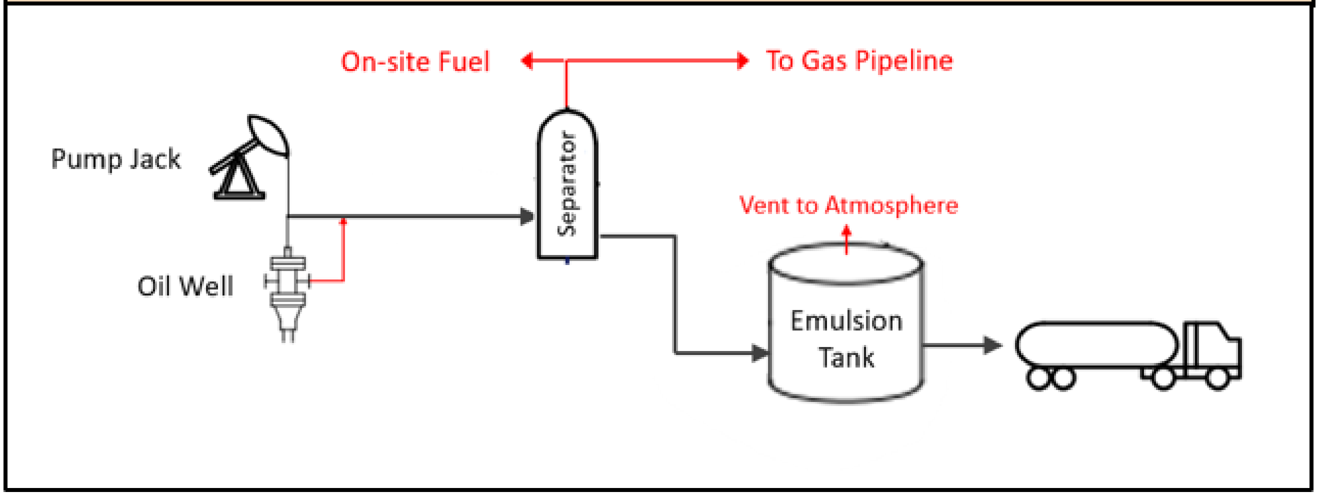
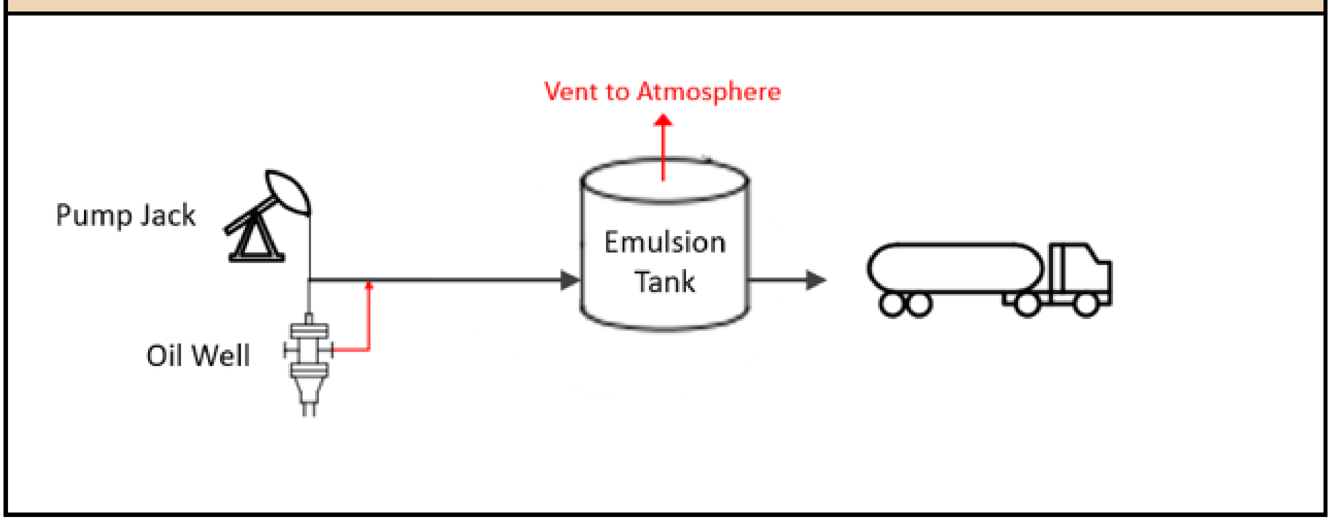


Figure B-4: Oil Single-well Battery with Separator



An important modification of the common Oil Single–well Battery with Separator shown in Figure B–2 (above) is the Oil Single–well Battery ***without*** a Separator. This is shown schematically in Figure B–5 below. Oil Single–well Batteries ***without*** Separators may represent only 10% of the battery population in Alberta but can have persistent tank venting due to the lack of gas separation. A common characteristic of Oil Single–well Batteries ***without*** Separators is the lack of gas pipeline infrastructure close by.

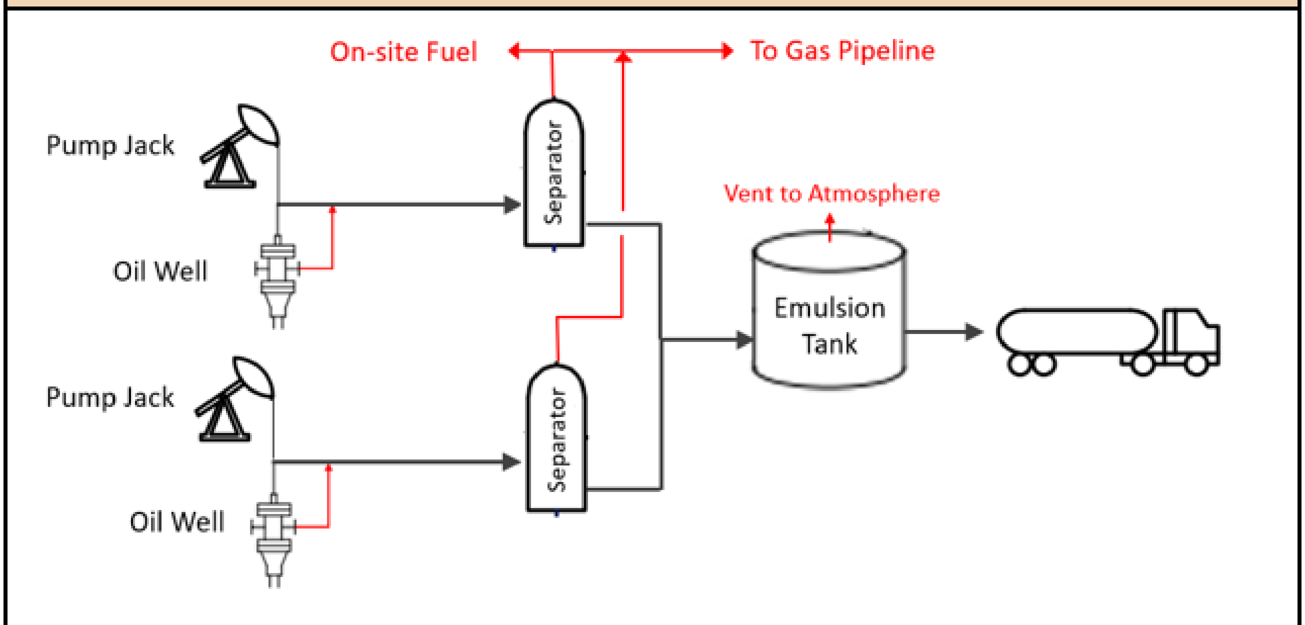
Figure B-5: Oil Single-well Battery without Separator



Crude oil multiwell group battery (subtype 321)

A production facility for two or more flow-lined crude oil wells where each well has its own dedicated separation and measurement equipment and all equipment shares a common surface lease location. See Figure B-6 below.

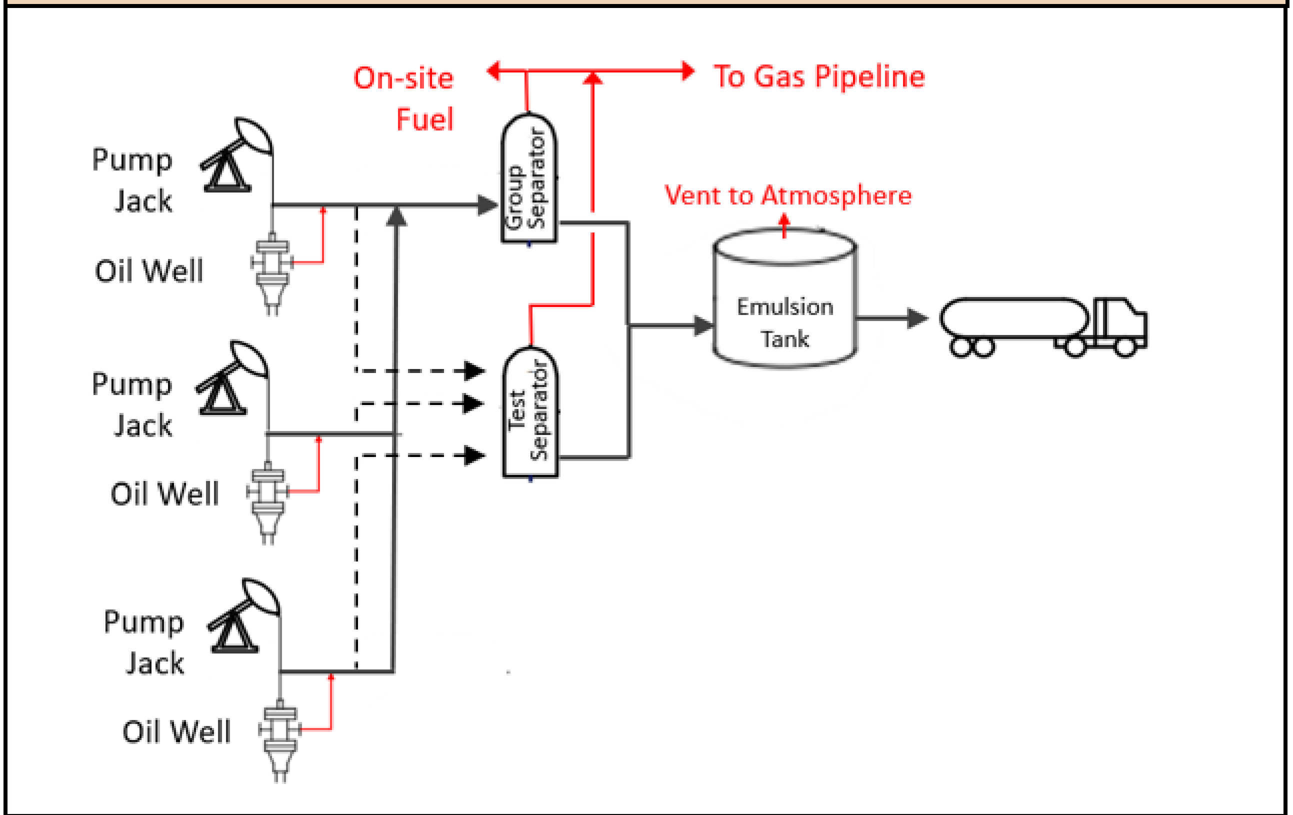
Figure B-6: Oil Multiwell Group Battery



Crude oil multiwell proration battery (subtype 322)

A production facility for two or more flow-lined crude oil wells having common group separation, measurement, and storage equipment. Total battery oil, gas, and water production is prorated to each well based on individual well proration tests and proration. See Figure B-7 below:

Figure B-7: Oil Multiwell Proration Group Battery



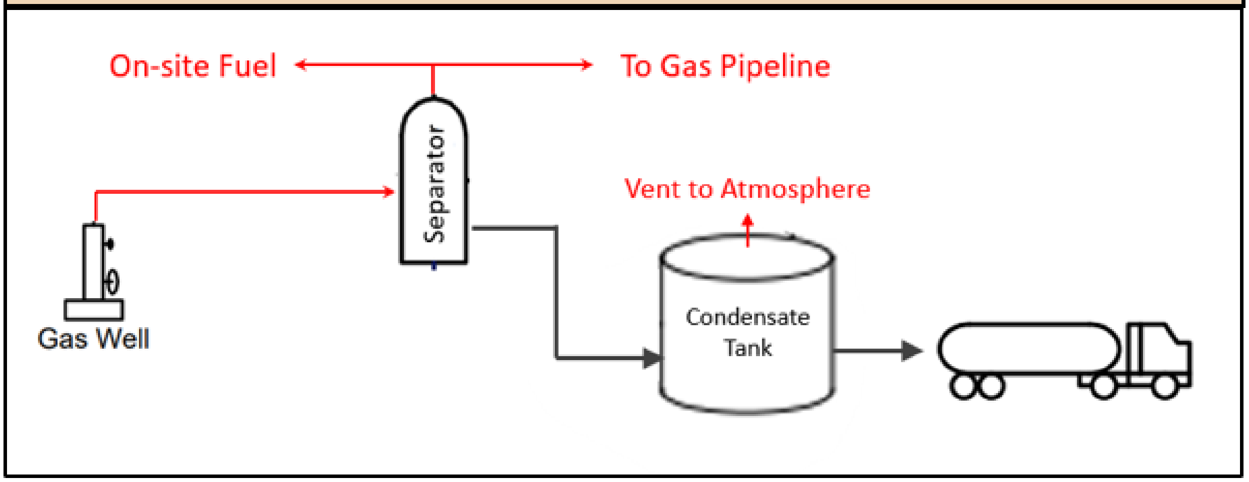
Gas Single–well Battery (subtype 351)

A production facility for a single flow–lined gas well where:

- gas and liquid production (including water) is continuously measured in a single phase;
- measurement may or may not occur at the wellhead; and
- production is not commingled with production from other wells before measurement or disposition. Production is delivered directly to a gas gathering system or other facility.

See Figure B–8 below:

Figure B-8: Gas Single-well Battery

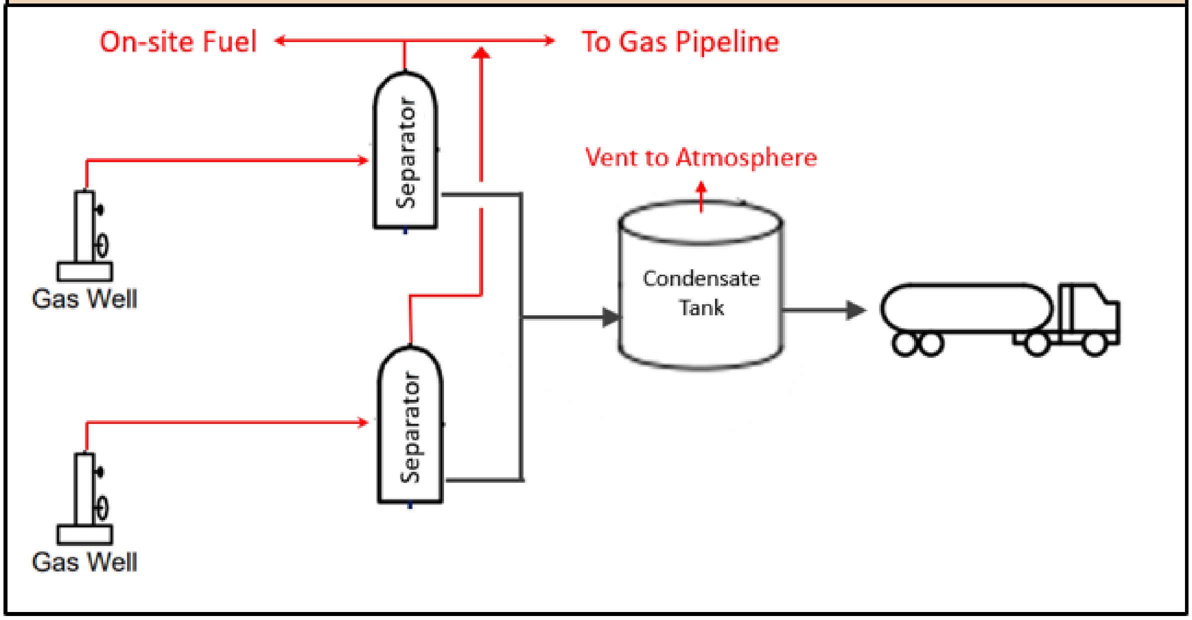


Gas Multiwell Group Battery (subtype 361)

A production reporting entity for two or more single-well gas batteries grouped and reported together under a single reporting code where:

- each gas well must meet the definition for subtype code 351.
- all wells must deliver to a common facility; and
- multiple gas groups could be delivering to a common facility.

Figure B-9: Gas Multiwell Group Battery



Description of Hydrocarbon Storage Tanks

Hydrocarbon storage tanks commonly used at conventional oil and gas batteries in Alberta have the following characteristics:

- Above ground
- Steel construction
- Vertical cylinder, typically 12 ft in diameter, 20 ft in height, 400 bbl capacity. Most tanks studied in this project are 400 bbl.
- Conical or flat roof fixed to the top of the cylinder.
- Insulated or uninsulated
- Vent stack typically 4" or 6" diameter, located at the center of the tank roof.
- Vent stack typically has a 180° bend to prevent water ingress, often referred to as a 'goose neck' or 'candy cane'.
- In the absence of a goose neck, the vent stack may just be a vertical pipe, with or without a 90o elbow to limit water ingress.
- Vertical transport skid, used for transporting the tank on its side.
- Access ladder for thief hatch inspection and level gauge maintenance.
- All tanks have a Thief Hatch, a closable aperture typically 8" in diameter on the tank top located close to the ladder top. The thief hatch has a spring-loaded gasket to protect the tank from over pressure or excessive vacuum.
- Berm or Dyke surrounds the tank or tanks to contain the contents of the tanks in the unlikely event of overfilling, leak, or rupture.

Table B1, below, summarizes the capacity and dimensions of tanks commonly used in upstream oil and gas operations.

Table B-3: Summary of Tank Capacity and Dimensions

Nominal Capacity (Bbl's)	Diameter (ft)	Height (ft)
100	8.0	12.0
200	12.0	10.0
400	12.0	20.0
500	16.0	14.0
750	15.0	24.0
1000	20.0	18.0
1500	24.0	19.0
2000	24.0	25.0

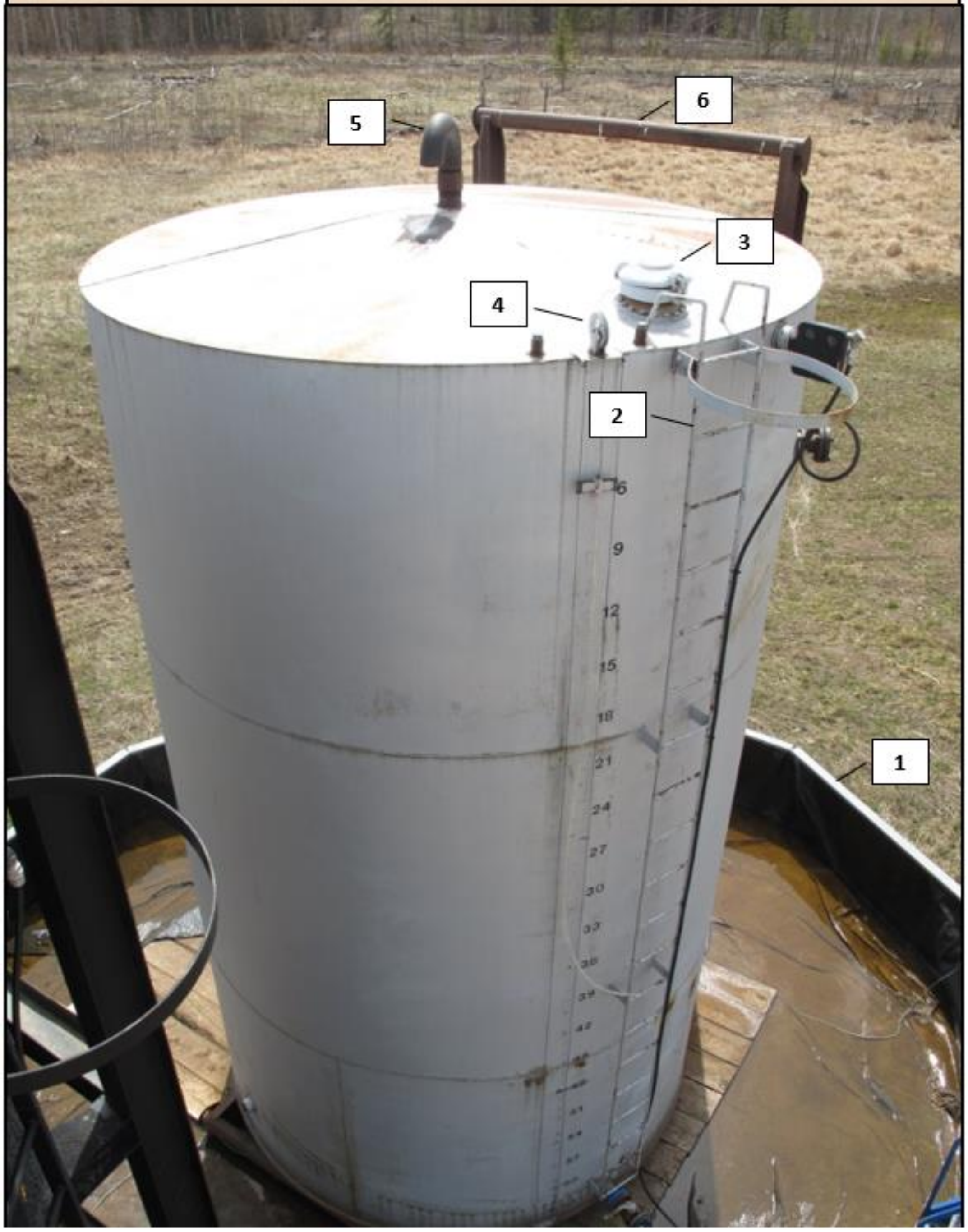
Additional comments with respect to hydrocarbon tanks that are pertinent to this study include:

- It is unsafe to stand directly on top of the tank. A 50ft boom lift with a personnel basket is required to gain access to the vent in the middle of the top of the tank. See Figure B–10.
- Since hydrocarbon vapours will be emitted from the tank vent, the lift operator requires personal LEL alarms and fresh air supply in the form of a Self-Contained Breathing Apparatus or SCBA.
- Tanks with diameters > 12 ft or height > 24 ft may restrict access to the vent with a 50 ft boom lift. Larger lifts will be required.
- It is common for 2 or 3 tanks to operate in parallel. One tank is filling while the others are empty or are full and awaiting truck loading.
- A single tank, or group of tanks, may have vapour recovery units (VRU's) installed to capture vent gas for conservation.

Figure B–11, following, identifies key components of a hydrocarbon storage tank.

Figure B-10: 50 ft Boom Lift with Personnel Basket

Figure B-11: 400 bbl Production Tank and Key Components



1. Dyke	2. Access Ladder
3. Thief Hatch	4. Level Gauge
5. 'Goose Neck' Vent	6. Transport Frame

Alberta Tank Inventory

At time of writing, a comprehensive inventory of active uncontrolled tanks in Alberta does not exist publicly.

In June 2008, Clearstone Engineering published a technical report titled ***Update of Equipment, Component and Fugitive Emission Factors for Alberta Upstream Oil and Gas.*** The report was based on a field study of 333 locations in Alberta, including 241 production accounting reporting entities and 440 wells. The field work included equipment count by facility type. The equipment count includes production storage tanks.

The Clearstone Study determined the average number of tanks for each facility type. The Study also identified the total population of facilities in 2017, by facility type. Combined, this provides an approximation of the number of tanks in service in oil and gas batteries in Alberta. See Table B-4 below:

Table B-4: Summary of Clearstone Engineering Tank Inventory Estimates

Subtype	Description	Total Facility Population[1]	Ave Count- Production Tank[2]	Estimated # of Tanks[3]
311	Crude Oil Single Well Battery	4,263	1.302	5,550
321	Crude Oil Multiwell Battery	368	1.302	479
322	Crude Oil Multiwell Proation Battery	1,720	2.508	4,314
351	Gas Single Well Battery	4,226	0.213	900
361	Gas Multiwell Battery	2,548	0.276	703
362	Gas Multiwell Effluent Battery	355	0.415	147
	Total			12,094

[1] **Clearstone Report Table 1: AB Active Facility Population (April 2017)**
[2] **Clearstone Report Table 3: Average process equipment counts per facility subtype**
[3] **# Tanks = Facility Population x Average count of tanks per facility**

Observations from Table B-4 include:

- In 2017, the estimated number of tanks in conventional oil and gas batteries exceeds 12,000.
- 85% of tanks are at oil batteries, the majority of which are Crude Oil Single Well Batteries

For the current study, the project team updated Clearstone's methodology. 2022 Petrinex data was used to identify active facilities, counting only facilities with 3 or more months of production accounting volumes.

The updated 2022 tank inventory for conventional oil and gas batteries is shown in Table B–5 below. The 2022 tank inventory aligns very closely with the 2107 inventory. Tanks at oil batteries now make up 88% of the total tank population.

Table B-5: Summary of 2022 Tank Inventory Estimates in Conventional Oi and Gas Batteries

Subtype	Description	Total Facility Population[1]	Ave Count- Production Tank[2]	Estimated # of Tanks[3]
311	Crude Oil Single Well Battery	4,164	1.302	5,422
321	Crude Oil Multiwell Battery	390	1.302	508
322	Crude Oil Multiwell Proation Battery	1,873	2.508	4,697
351	Gas Single Well Battery	3,586	0.213	764
361	Gas Multiwell Battery	2,054	0.276	567
362	Gas Multiwell Effluent Battery	363	0.415	151
	Total			12,108

1 **Based on 2022 Petrinex reporting, batteries with 3 or more months of production accounting volumes.**
2 **Clearstone Report Table 3: Average process equipment counts per facility subtype**
3 **# Tanks = Facility Population x Average count of tanks per facility**

Recommendation for Future Work

- Perform a desk top exercise to estimate the number of hydrocarbon storage tanks in Alberta. Validate the methodology using publicly available satellite or aerial images. Estimate the number of controlled tanks by facility type based on aerial images, and plot plans and process flow diagrams available thru AER's OneStop.

Volumetric Reporting Requirements

This section describes the volumetric reporting requirements in Alberta, including the reporting of tank vents.

Manual 15 – Estimating Methane Emissions provides valuable guidance to oil and gas operators for the quantification of methane emissions, as required by Directive 60. The AER first published Manual 15 in December 2018, and provided an update in December 2020. Section 4.2.2 of Manual 15 provides methodologies for Flashing, Working, and Breathing losses. This section of Manual 15 appears in Appendix 1 of this report.

Petrinex is the public records system used by all oil and gas operators in Western Canada. Petrinex facilitates efficient and standardized management of data used for the province's crown royalty assessments as well as supporting regulatory mandates and legislation. On a monthly basis, operators report production accounting volumetrics to Petrinex. The information is available publicly the 4th week of the following month. Presently, records back to 2017 are available on the Petrinex web site. Petrinex volumes of interest for this project include monthly oil, gas, and water receipts, disposition, and production, fuel, flare, vent, and tank opening and closing oil inventories.

OneStop is a single platform used by oil and gas operators for resource development applications. The Integrated Decision Approach shortens the application review process in an efficient and transparent manner. In 2019, the Measurement, Monitoring and Reporting (MMR) module was added to OneStop. Operators report annually the methane emissions data required by Directive 60.

With the addition of D60's methane requirements effective January 1st 2020 there are some notable changes to the definition of vent gas. Examples include:

- Emissions from thief hatches on uncontrolled tanks are now considered vents. Prior to this definition, releases from thief hatches were deemed to be 'unintentional' and therefore classified as fugitives.
- Gas vented from a pneumatic device is now considered a vent. Prior to 2020, this was reported as fuel.

Petrinex and OneStop have some overlap with respect to emissions reporting, but notable differences are seen with respect to Dehydrators, Fugitives, and reporting frequency. See Table B-5 below for a comparison of the 2 reporting systems.

Table B-5: Comparison between AER OneStop and Petrinex Reporting Requirements

Reporting Category		OneStop Reporting	Petrinex Reporting
Routine Venting	Pneumatics	Annual Total	included in monthly 'Vent' volume
	Glycol Dehydrators	Annual Total	included in monthly 'Vent' volume
	Compressor Seals	Annual Total	included in monthly 'Vent' volume
	Other, including Tank Venting	Annual Total	included in monthly 'Vent' volume
Nonroutine Venting	Planned	not reported	included in monthly 'Vent' volume
	Unplaned Upsets	not reported	included in monthly 'Vent' volume
	Unplanned Emergency	not reported	included in monthly 'Vent' volume
Fugitives		Annual Total	not reported

Petrinex and OneStop differ on Units of Measure. Gas volumes in Petrinex are in thousands of cubic meters (10^3m^3) and rounded to one decimal. Any volume below 49 m^3 in a month is rounded down to zero. Typically, zero is not entered in Petrinex. OneStop requires annual emissions in cubic metres (m^3).

A Word on the Units of Measure Used in This Report

Petrinex uses 10^3m^3 for monthly gas volumes. Directive 60's Vent Gas Limits (OVG and DVG) also are expressed as 10^3m^3. These are practical units of measure for production accounting and regulatory needs. However, it is impractical to express measured release rates in the field, measured over a period of minutes or hours, in terms of 10^3m^3 per month.

The methane detection and quantification devices used in this project have their own default unit of measure, be it litres per minute (lpm), standard cubic feat per hour (scfh), kilograms per hour (kg/hr), or grams per second (g/s). None of these are particularly useful for comparison against the OVG or DVG limits.

For this project, we express gas release rates as m^3/day. We also think of the OVG in terms of a daily limit, meaning 15 10^3m^3 can be thought of as ~ 500m^3/day. 500 m^3/day is not an accurate reflection of the monthly OVG. Rather it is used for relative comparison of releases measured in the field. A tank vent of 300 m^3/day measured over 4 hours is likely not a compliance issue. Similarly, an intermittent release spiking to 1,000 m^3/day is likely not a compliance issue when the average over 4 hours is 50 m^3/day. But a steady and continuous release of 650 m^3/day measured over 4 hours *may* be a compliance issue with respect to the monthly OVG limit.

Methane Detection and Quantification Technologies

This section describes the technologies used to detect and quantify methane releases from tanks.

Direct Measurement with Calscan's Hawk 9000 Data Logger and Turbine Meter

The Hawk 9000 is a reliable, low power data logger integrated with pressure, temperature, and flow sensors. Certified for Class 1 Div 1 Hazardous locations. It is battery operated and can be left unattended in field applications for up to a year.

For tank vent measurements, the Hawk 9000 is integrated with a 1" or 2" gas turbine meter, and temperature and pressure sensors. Two-inch (2") diameter, Schedule 40, light weight aluminum threaded pipe completes the portable meter run.

Calscan service technicians have an assortment of industrial-grade flexible pipes and fittings, allowing the technician to install the meter safely on the variety of tank vents seen in upstream oil and gas operations.

Figure B-12, below, shows 3 different field installations for Direct Measurement of tank vents.

Figure B-12: Calscan's Hawk 9000 Data Logger with 2" Gas Turbine and T&P Sensors

Vertex – Vent Gas Detection and Quantification with OGI/QOGI

Vertex Professional Services Ltd. (Vertex) provided technical field support during the entire project. Vertex and Calscan jointly deployed at all sites. Tank Vents were continuously measured with Calscan's turbine meters, and Vertex quantified and verified tank vent emissions with Optical Gas Imaging (OGI) cameras paired with Quantitative OGI technology, or QOGI.

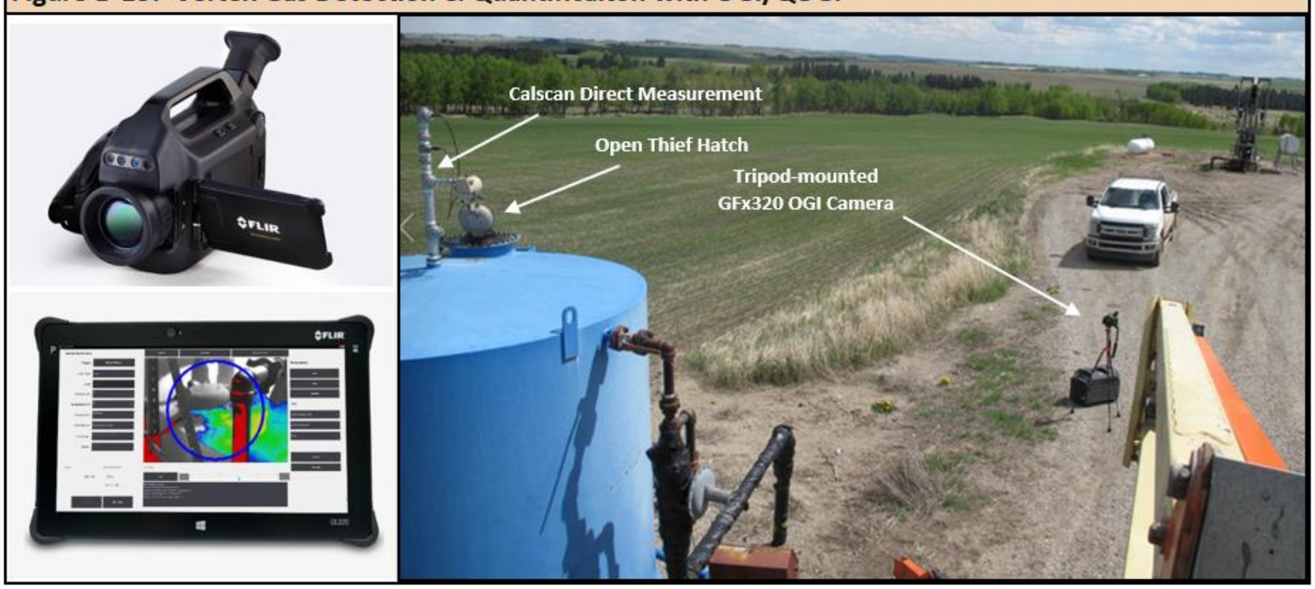
Vertex utilizes the FLIR GFx320 OGI camera to identify the emissions source, and a FLIR-Providence Photonics QL320 QOGI technology to quantify the emissions source.

The FLIR GFx320 OGI camera detects and visualizes infrared energy emitted or absorbed by hydrocarbons including methane.

The FLIR-Providence QL320 quantifies the hydrocarbon plumes made visible by the GFx320 OGI camera. The QL320 requires data inputs including videos of the methane plume from the GFx320 camera, distance to the source, wind speed and atmospheric temperature. Distance, wind speed, and temperature are measured locally by the Vertex technician.

The GFx320 camera, QL320 Quantification tablet, and field deployment on a tripod are shown in Figure B-13 below. Note the direct 'line-of-site' from the GFx320 camera and the vent source. The line of sight improves both the detection and quantification of the methane release.

Figure B-13: Vertex Gas Detection & Quantificaiton with OGI/QOGI



Bridger Photonics Gas Mapping LiDAR (GML)

Bridger Photonics Gas Mapping LiDAR (GML) technology uses laser light absorption of methane specifically to detect, localize, and quantify methane gas.

GML scans an eye–safe laser beam across the ground from an aircraft to produce path–integrated gas concentration imagery. Bridger uses proprietary processing techniques that incorporate lateral and vertical gas concentration profiles with vertically varying wind speed profiles, and other parameters, for emission rate quantification. Bridger's quantification accuracy and detection sensitivity are validated by internal and third–party studies.

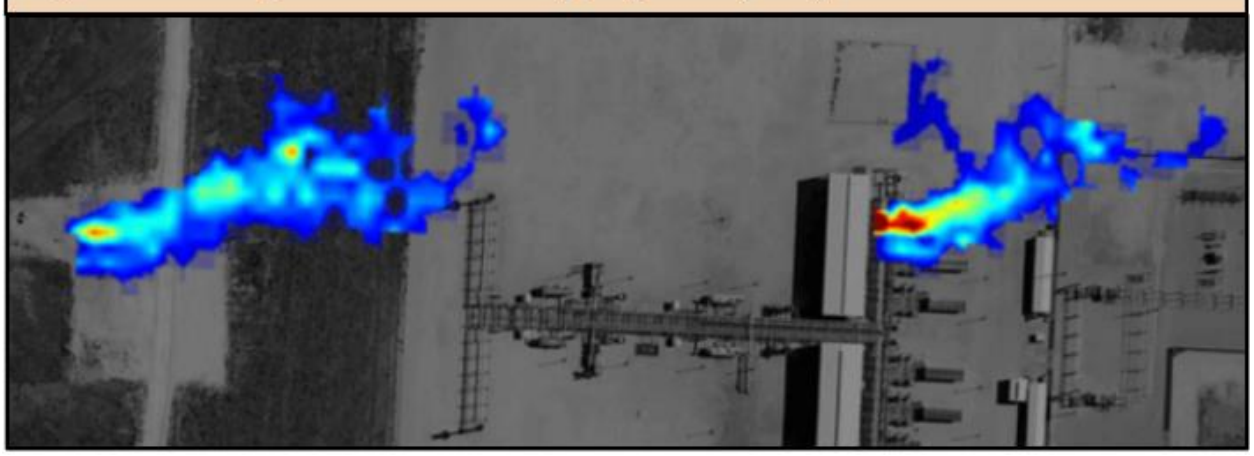
GML gas concentration maps locate methane emissions to the equipment and sub–equipment–level spatial resolution. Bridger also acquires digital aerial photography and topographical LiDAR, which can be used to attribute the emissions to specific equipment. Emissions are typically localized to within 2 meters of the actual emission source. Acquired data is geo–registered to a common global coordinate system.

An example of Bridger's gas mapping and localization is shown in Figure B–14, below.

Bridger's GML technology is incorporated in the AER–approved altFEMP program in the Sundre area. Screening results from 500 sites in June 2021 were used to identify uncontrolled hydrocarbon storage tanks with hydrocarbon releases. These sites were subsequently visited by Calscan and Vertex in September 2021

For Campaign 3 Bridger surveyed 206 sites west of Sylvan Lake Alberta. These sites have hydrocarbons storage tanks.

Figure B-14: Bridger Photonics Gas Mapping LiDAR (GML)



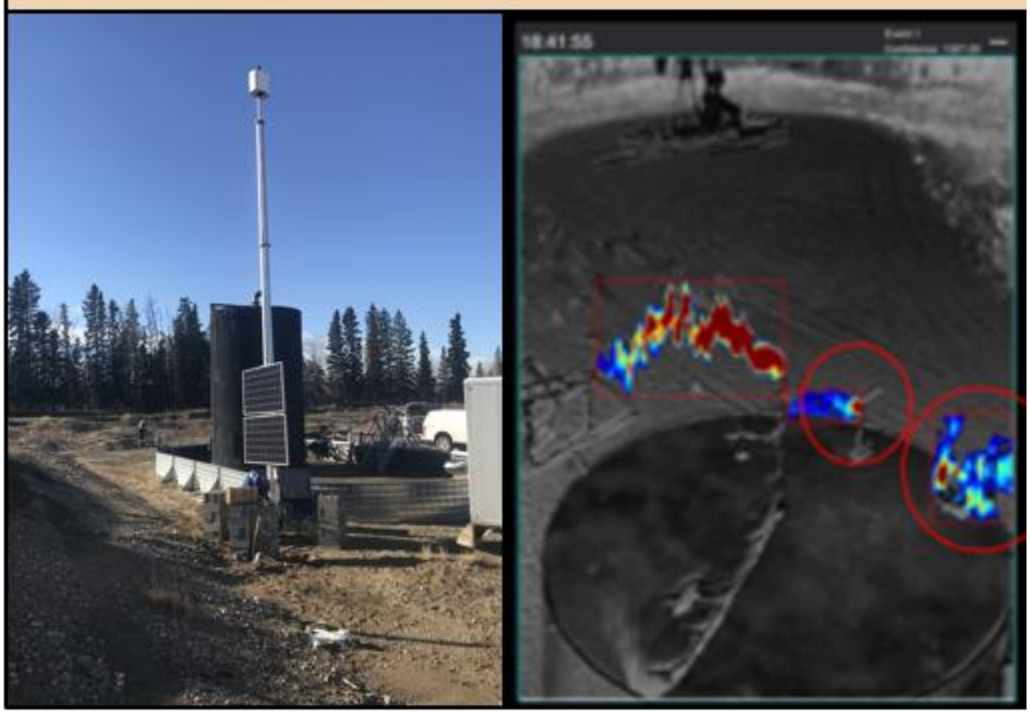
Kuva Systems – Gas Cloud Imaging

Kuva Canada provides visual continuous methane monitoring with its proprietary shortwave infrared camera and cloud solution for upstream and midstream oil and gas industry. Kuva Canada Inc. is based in Calgary and was founded in 2018 as a subsidiary of Kuva Systems (based in Cambridge, MA).

The Kuva GCI360 camera is a continuous Optical Gas Imaging (OGI) camera that uses a passive Shortwave Infrared (SWIR) sensor to detect hydrocarbon gas emissions. The system can be permanently installed or can be deployed temporarily. The entire system can be set up in less than two hours and is fully self-contained, cloud connected and autonomous, so it can be left in place to operate indefinitely and remotely. The camera operates by scanning each region-of-interest repeatedly to detect and measure emissions from a distance, while pinpointing emissions to their source.

As part of this Tanks project, Kuva cameras were installed at 16 upstream production sites for a period of at least 2 weeks per site from September 2021 to September 2022. The Kuva cameras were mounted on relocatable 30 ft tall towers. See Figure B-15 below for an example of one deployment and the resultant gas cloud image from the tank vent and leaking thief hatch.

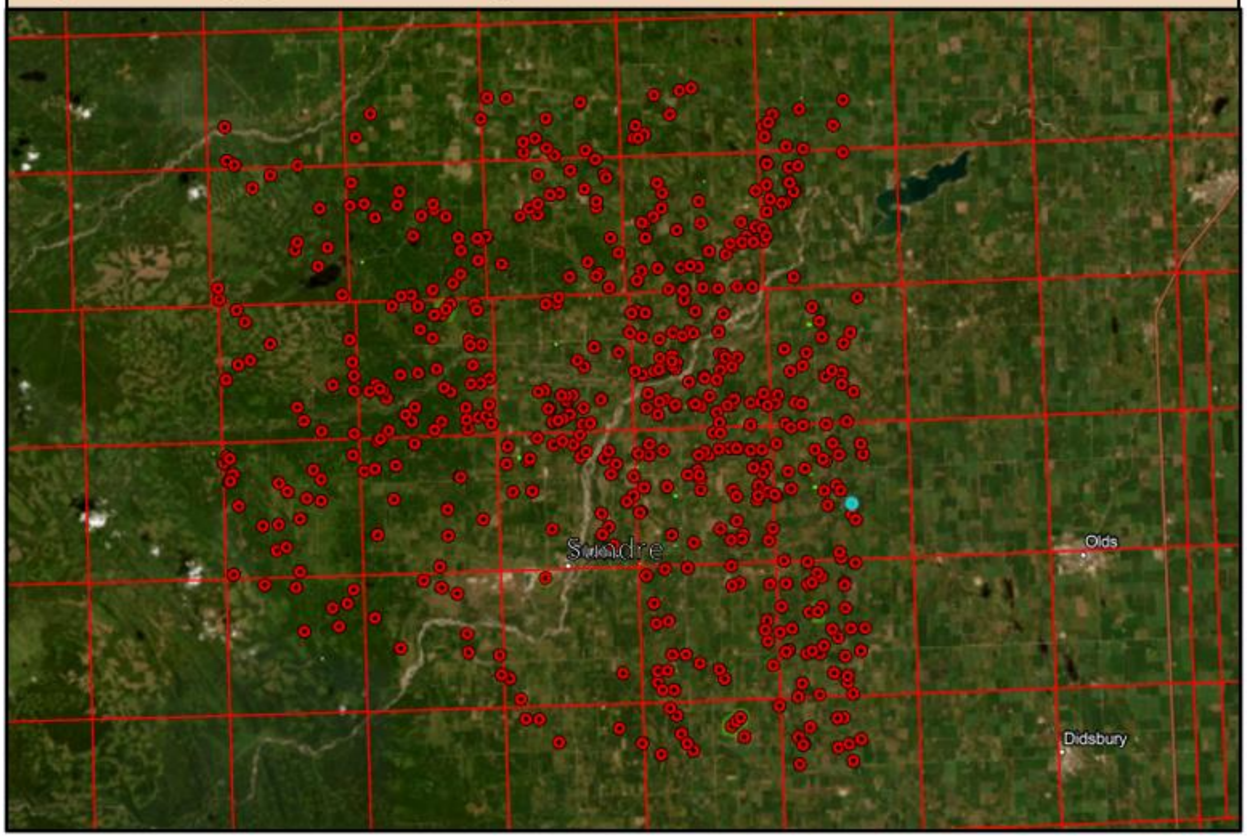
Figure B-15: Kuva Systems - Gas Cloud Imaging



Campaign 1 Part 1 Sundre Area

The Sundre Petroleum Operators Group (SPOG) is a multi-stakeholder organization with representation from the oil and gas sector, landowners, municipalities, and the provincial regulator. SPOG's boundary centers on Sundre, between Townships 31 and 36, Ranges 3 and 7, west of the 5th Meridian. The area contains approximately 500 operating oil and gas facilities, with 35 different operators, 15 of which are members of SPOG. Figure1.1 shows the Sundre area and the facilities within the SPOG boundary.

Figure 1.1: Campaign 1 - Sundre Study Area



In 2021, the AER approved an alternative Fugitive Emissions Management Program (altFEMP) for the SPOG area, as per Directive 60. The altFEMP program includes an annual screening for methane emissions using Bridger Photonics. The first screening was performed in June 2021, and repeated in May 2022.

Review of Bridger Aerial Survey June 2021

Bridger screening results from the June 2021 campaign was helpful to identify tanks with methane releases. Important attributes of the June 2021 campaign include:

- Over 500 sites surveyed.
- Over 400 batteries surveyed, both oil and gas, both single and multiwell.
  - Over 200 production tanks were identified at 400 batteries.
  - Thirty–four (34) different operators

The June 2021 Bridger campaign identified only 18 sites with tank releases. Releases at six (6) of the sites were from controlled tanks. Table 1.1 below summarizes the releases by Facility Type.

Table 1.1: Campaign 1 - Summary of Bridger Tank Releases by Facility Type

Facility Type	# Sites with Bridger Releases from Controlled Tanks	# Sites with Bridger Releases from Uncontrolled Tanks	# Sites in Study Area	# Sites with Tanks in Study Area	% of Sites with Tanks that have releases from Tanks
OSWBwoS		7	9	9	78%
OSWB		1	54	54	2%
OMWB	4	3	48	48	15%
GSWB	1	1	136	14	14%
GMWB	1		177	24	4%
Totals	6	12	424	149	

OSWBwoS = Oil Single-Well Battery without Separator
OSWB = Oil Single-Well Battery (with Separator)
OMWB = Oil Multiwell Battery
GSWB = Gas Single-Well Battery
GMWB = Gas Multiwell Battery

Observations from Table 1.1 include:

- Oil Single Well Batteries without Separators (OSWBwoS) are only 6% of the battery population with tanks (9 of 149) but are 60% of the sites with Bridger detections (7 of 12, uncontrolled tanks only).
- Two (2) of the 9 Oil Single–well Batteries without Separators (OSWBwoS) did not have Bridger detections. Both these sites had < 5m^3/month oil production.

- Seven (7) of the 9 Oil Single-well Batteries without Separators (OSWBwoS) that have Bridger detections had oil production > 5m^3/month and < 50 m^3/month.
- Only one (1) of 54 Oil Single Well Batteries (OSWB) had a Bridger detection. OSWB's implicitly have separators.
- Gas Single-well and Multiwell Batteries (GSWB and GMWB) dominate the Sundre area by count, but relatively few have hydrocarbon storage tanks (38 of 313, or 12%) compared to oil batteries.

Conclusions and Recommendations from Table 1.1 above:

- Oil Single Well Batteries without Separators (OSWBwoS) should be investigated further. These can be identified by reviewing Petrinex volumetric data. They can be easily screened using aerial surveillance such as Bridger Photonics. Large releases can be confirmed with direct measurement or portable test separator. Conservation projects can then be evaluated.
- An area-based aerial survey for methane releases is an effective way to estimate the population of tanks by each facility type, and the distribution of tanks with methane releases.

Table 1.2 below provides further details of the individual releases from uncontrolled tanks.

Table 1.2: Campaign 1 - Summary of Bridger Releases from Uncontrolled Tanks

Site ID	Facility Type	Bridger Tank Emissions m3/day	Bridger Tank Emissions Persistancy	Calscan/Vertex Deployment?	Kuva Deployment?	Comments
1	OSWBwoS	761	Persistent			Site Shut In July 2021, no follow-up possible
2	OMWB	367	Persistent	Yes	Yes	
3	OSWB	354	Persistent			Site Shut In July 2021, no follow-up possible
4	OSWBwoS	299	Persistent	Yes	Yes	
5	OSWBwoS	259	Persistent			
6	OSWBwoS + OSWB	211	Persistent	Yes	Yes	
7	OMWB	179	Persistent			
8	OSWBwoS	153	Persistent	Yes	Yes	
9	OSWBwoS	101	Persistent			
10	OSWBwoS	92	Intermittent			
11	GSWB + CS	64	Intermittent			
12	GSWB	62	Intermittent			

OSWBwoS	= Oil Single-Well Battery without Separator
OSWB	= Oil Single-Well Battery (with Separator)
OMWB	= Oil Multiwell Battery
GSWB	= Gas Single-Well Battery
GMWB	= Gas Multiwell Battery
CS	= Compressor Station

Observations from Table 1.2 include:

- Sites are sorted from largest release to smallest.
- The largest tank releases are persistent.
- Sites 1 and 3 were shut-in in July 2021, and have not produced since.
- Site 6 has 2 wells, but one separator for one of the wells. Oil and casing gas from one well, plus oil from the separator combine and flow to the uncontrolled tank.
- The team of Calscan, Vertex, and Kuva was deployed to Sites # 2, 4, 6, and 8 in September 2021. Each of these sites is reviewed in detail in the following sections.
- Site 7 was transitioning to wet metering and flow lines to eliminate the need for tankage.

Table 1.3 below provides further details of the individual releases from controlled tanks.

Table 1.3: Campaign 1 - Summary of Bridger Releases from Controlled Tanks

Site ID	Facility Type	Bridger Tank Emissions m3/day	Bridger Tank Emissions Persistancy	Calscan/Vertex Deployment?	Kuva Deployment?	Comments
1	GMWB + GGS	846	Persistent			Controlled Condensate Tank.
2	OMWB	658	Persistent			Controlled Tank, VRU repaired July 2021
3	OMWB	189	Intermittent			Controlled Tank
4	OMWB + GGS	165	Intermittent			Controlled Tank, VRU repaired July 2021
5	OMWB + GMWB + GGS + CS	133	Intermittent			Controlled Tank
6	OMWB + CS	103	Intermittent			Controlled Tank

OSWBwoS = Oil Single-Well Battery without Separator
OSWB = Oil Single-Well Battery (with Separator)
OMWB = Oil Multiwell Battery
GSWB = Gas Single-Well Battery
GMWB = Gas Multiwell Battery
GGS = Gas Gathering System
CS = Compressor Station

Observations from Table 1.3 above include:

- It is not uncommon for multiple facility types to co-locate on the same site. Site # 5 is an Oil Multiwell Battery (OMWB), two (2) Gas Multiwell Batteries (GMWB), a Gas Gathering System (GGS), and a Compressor Station (CS). Each of these facility types have production accounting volumes in Petrinex.
- Directionally, the more complex the facility, the greater the likelihood of a Vapour Recovery Unit (VRU) on the hydrocarbon storage tanks. To confirm this, an inventory of controlled tanks is necessary, not just an inventory of the controlled tanks with detected releases.
- Releases from controlled tanks are considered Fugitive Emissions as per the AER's Manual 11. At least 2 of the sites with releases from controlled tanks confirmed repair of the fugitive emissions. However, a comprehensive follow-up was not in scope.

Conclusions and Recommendations from Table 1.2 and 1.3 include:

- An aera-based aerial survey, combined with public plot plans and process flow diagrams, can be an effective tool to inventory controlled tanks, and to assess the frequency and percentage of controlled tanks that have significant fugitive emissions.

Example of a Tank Release detected by Bridger Photonics.

Figure 1.2 below is an example of Bridger's GML detection overlaid on an aerial image of an Oil Single–well Battery. The 2 tanks, pumpjack, and separator building are clearly visible in the image on the left. The plumes on the right are a composite of persistent detections seen on 2 different days. The red dot is the estimated release point determined by Bridger.

Bridger detections are discussed in more detail in Campaign 3.

Figure 1.2 Campaign 1: Example of a Bridger GML Tank Release at a Oil Single Well Battery

Vent Measurement with Calscan, Vertex, and Kuva

Table 1.2 above identifies 4 sites that the team of Calscan, Vertex, and Kuva deployed at.

The deployment methodology is described in detail in the Background, but summarized below:

- The 2 man-team of Calscan and Vertex safely access the top of the tank using a manlift.
- A 2" turbine meter is installed on the tank vent. The meter has an internal power supply and is intrinsically safe.
- The thief hatch gasket material is replaced, and the seal is confirmed with an Optical Gas Imaging (OGI) camera inspection.
- The meter run has a sample point allowing the vent gas to be sampled for analysis by an accredited laboratory.
- Kuva installs their camera solution, and monitors the tank venting during daylight hours, for up to 2 weeks.
- The metered vent rates can be shared with Kuva for comparison.

Figure 1.3 below shows the lift access to the tank top as well as a Kuva camera installation.

Figure 1.4 shows an installed turbine meter on the tank vent, thank thief hatch, tank wire level gauge with temporary gasket, and a Kuva camera in the background.

Figure 1.3 Campaign 1 - Direct Measurement & Kuva Installation

Figure 1.4: Campaign 1 - Turbine Meter, Thief Hatch, Wire Guage and Kuva Camera

Site Reviews

Table 1.4 below summarizes the Bridger GML releases in June 2021 with the Direct Measurements in September 2021 using Calscan's meter. September 2021 Petrinex reported volumes, expressed as m^3/day, are also provided.

Site–specific reviews follow Table 1.4

Table 1.4: Campaign 1 - Summary of Bridger and Direct Measurement

Site ID	Bridger Tank Emissions m3/day	Direct Measurement m3/day	Tank Vent Methane Concentration Vol %	Direct Measurement Corrected for [CH4] m3/day	September 2021 Petrinex Vent Volume m3/day
2	367	582	86%	501	33
4	299	404	82%	331	0
6	211	395	81%	320	7
8	153	56	83%	46	3

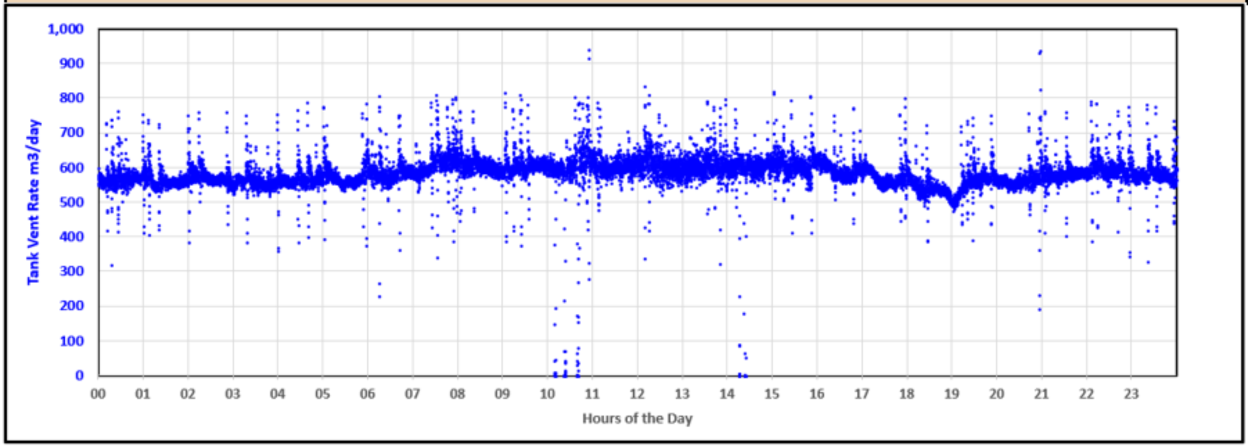
Observations from Table 1.4 above include:

- The Bridger detections and Direct Measurement with Calscan's meter are reasonably similar considering the measurements are 4 months apart.
- The reported vent volumes in Petrinex are well below the Direct Measurement and Bridger volumes.

Site 2 Review – Oil Multiwell Battery

Site 2 is an Oil Multiwell Battery, with 4 producing wells, a group separator and a test separator. Results from the Direct Measurement are shown below in Figure 1.5

Figure 1.5: Campaign 1 - Site 4 - Direct Measurement of Oil Multiwell Battery



Site 2 Observations from Table 1.4 and Figure 1.5 include:

- Direct Measurement is relatively constant, averaging 582 m3/day for the single day shown in Figure 1.5. Subsequent days of Direct Measurement looked similar.
- Tank vent methane concentration was 86% by Volume.
- Direct measurement flow rate, corrected for methane concentration, is reasonably close to the Bridger detection, considering the Bridger measurement was 4 months earlier.
- The constant high vent rate was somewhat of a surprise. A site review determined that liquid level was not visible in the group separator. The likely cause of the tank venting was low oil residence time in the separator, plus gas passing through the level control valve.
- Improvements in separator operations was confirmed in a subsequent Bridger survey in 2022, which did not detect tank venting.

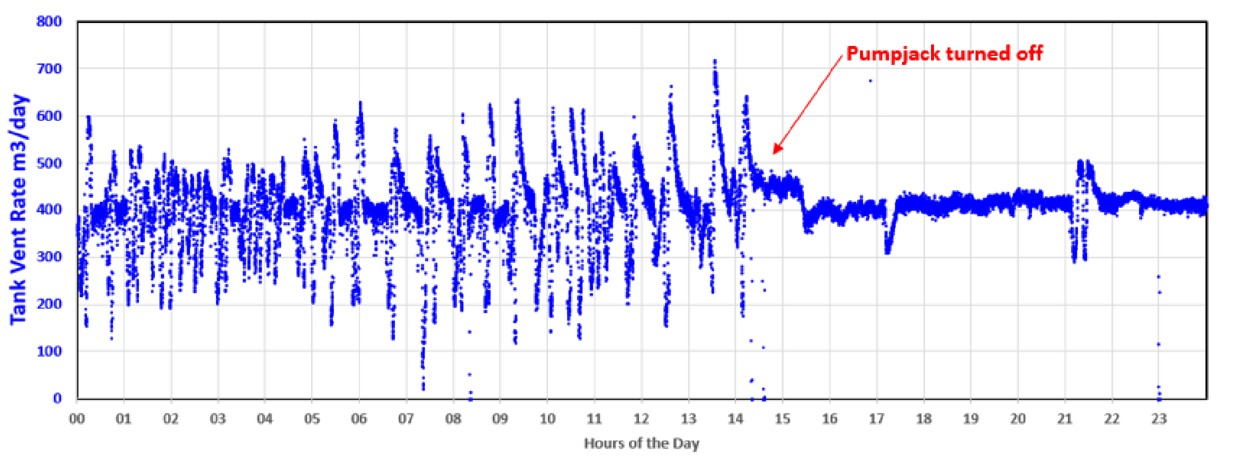
Conclusions and Recommendations from Site 2 Review

- Tanks at Oil Multiwell Batteries can vent persistently, in this case due to issues with the group separator.
- Reasonable alignment between Bridger GML and Direct Measurement with Calscan metering.

Site 4 Review

Site 4 is an Oil Single Well Battery without a Separator. Oil and Casing gas are recombined at the well head and flow together to the tank. Results from the Direct Measurement are shown in Figure 1.6 below:

Figure 1.6: Campaign 1 - Site 4 - Direct Measurement of Oil Single Well Battery without Separator



Site 4 Observations from Table 1.4 and Figure 1.6 include:

- The measured vent rate is variable until shortly after 2pm, or 1400 hrs, when the pumpjack was turned off. The vent rate stabilized at around 400 m3/day with the pumpjack not operating.
- The Direct Measurement, corrected for the methane concentration in the vent gas, aligns very well with the Bridger detections 3 months earlier.

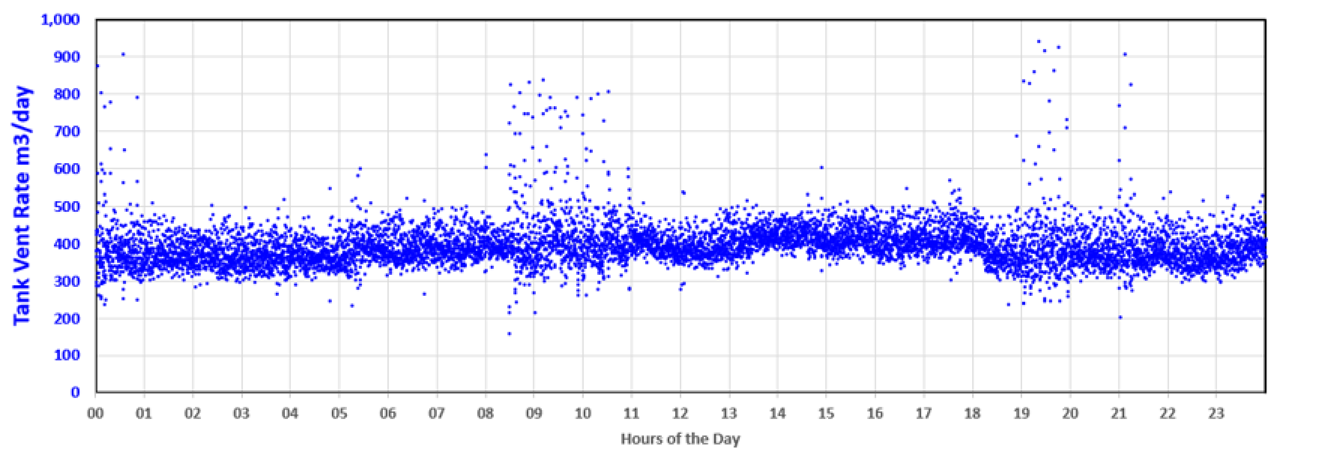
Conclusions and Recommendations from Site 4 Review

- Casing Gas can be a large contributor to tank vents at Oil Single-well Batteries without Separators.
- Confirming Casing Gas contribution is done by simply turning off the pumpjack for a short period of time. If the vent gas rate does not change significantly, then the casing gas is the significant source of tank venting. Otherwise, gas-in-solution can be the significant source.
- The relative contribution of casing gas and gas-in-solution will determine the vent control strategy.
- Obtaining volumetrically proportional samples of oil and casing gas is a challenge at Oil-Single-well Batteries without a separator. A 24-hour test with a portable separator is a viable option to generate a GOR for production accounting.

Site 6 Review

- Site 6 has an Oil Single Well Battery (with a separator) and an Oil Single Well Battery without Separator. Both wells have pumpjacks. The oil from the separator plus the oil and casing gas from the single well are comingled in the tank. Results from the Direct Measurement are shown in Figure 1.7 below:

Figure 1.7: Campaign 1 - Site 6 - Direct Measurement of Oil Single Well Batteries



Site 6 Observations from Table 1.4 and Figure 1.7 include:

- Site 6 is unusual, with two single well oil batteries, one with a separator and one without. One tank is used by both batteries.
- The measured tank vent rate is relatively constant at 395 m^3/day.
- Methane concentration of the tank vent is 81% by volume.
- Attempts were made to sample oil from the separator and well. For the separator, specialized liquid-displacement sample bombs are required. For the well, a representative sample of the comingled oil and casing gas was not possible.
- When corrected for methane concentration, the tank vent rate aligns reasonably well with the Bridger detections from 4 months earlier.

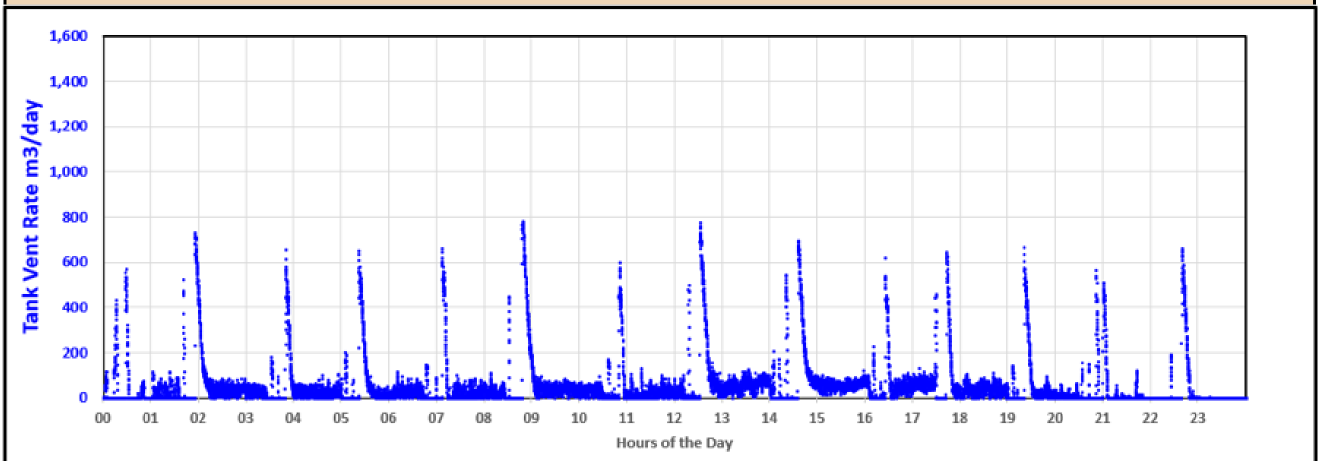
Conclusions and Recommendations from Site 6 Review

- Once again, sampling a Single-well Battery without a Separator proved challenging. A 24-hour portable test separator would be a viable option to GOR or GIS.

Site 8 Review

Site 8 is an Oil Single-well Battery without a Separator. Oil and Casing gas are recombined at the well head and flow together to the tank. Results from the Direct Measurement are shown in Figure 1.8 below:

Figure 1.8: Campaign 1 - Site 8 - Direct Measurement of Oil Single Well Battery without Separator



Site 8 Observations from Table 1.4 and Figure 1.8 include:

- Site 8 vent rate is cyclic; spiking to 600 to 800 m^3/day, rapidly dropping to approximately 50 m^3/day, even to zero m^3/day, before spiking again. This cycle repeated roughly every 90 minutes.
- The pumpjack was on continuously.
- Nothing about the surface operation would indicate a cyclic nature to the vent rate.
- Measured tank vent rate aligns reasonably with the Bridger detection from 4 months earlier.

Conclusions and Recommendations from Site 8 review include:

- Cyclic-vent profiles are not uncommon for oil single well batteries without separators (see Campaigns 2 and 3 for more examples). There may be value in understanding the downhole mechanisms that are the root cause.
- Consider including down-hole well testing in future studies where tank vent rate is persistent but cyclic.

Campaign 1 Part 2 – North of Sundre

Campaign 1 continued north of the Sundre area, deploying to 4 more sites in November 2021. Unlike Part 1, Bridger detections were not available. Table 1.5 below provides a summary of the 4 sites:

Table 1.5: Campaign 1 Part 2 - Summary of Direct Measurement

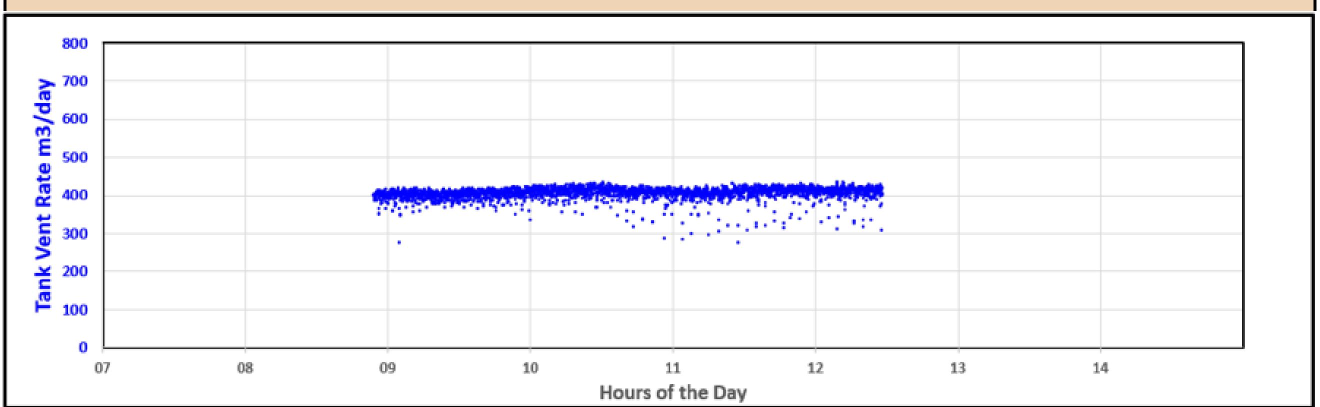
Site ID	Facility Type	Direct Measurement m3/day	Tank Vent Methane Concentration Vol %	Direct Measurement Corrected for [CH4] m3/day	Petrinex Reported Vent Volume m3/day
13	OSWBwoS	405	76%	308	37
14	OSWB	34	22%	7	47
15	OMWB	23	84%	19	57
16	OSWBwoS	109	76%	83	40

OSWBwoS = Oil Single-Well Battery without Separator
OSWB = Oil Single-Well Battery (with Separator)
OMWB = Oil Multiwell Battery

Site 13 Review

Site 13 is an Oil Single-well Battery without Separator (OSWBwoS). The tank vent was measured over a 4 hour period. See Figure 1.9 below.

Figure 1.9: Campaign 1 - Site 13 - Direct Measurement of Oil Single Well Battery without Separator



Observations from Site 13 Review, Table 1.5 and Figure 1.9

- Measured vent rate is very constant at 405 m^3/day.
- Methane concentration of the vent gas is 76%
- Petrinex underreports the vent volume by a factor of 10

Site 14 Review

This site is licensed as an Oil Single Well Battery, but it may technically be a gas battery. The Gas-to-Oil Ratio (GOR) is 4300 (m^3 gas/m^3 oil), and the well has a plunger lift typically used in gas wells.

Technical difficulties prevented Calscan from installing their Hawk 9000 data logger and turbine meter. Fortunately, Carleton University were jointly deployed at this location, and were able to install an experimental optical meter. The vent rate and methane analysis for Site 14 was provided by Carleton. A chart showing metered vents rates is not available.

The plunger lift was on a 4-hour cycle. When the plunger arrives at the well head, tank venting spikes in excess of 1,000 m^3/day, but only for a few minutes. The methane concentration in the vent gas is unusually low at 22%, likely due to air ingress during almost 4 hours of no oil flow to the tank. Average vent rate is less than 10 m^3/day.

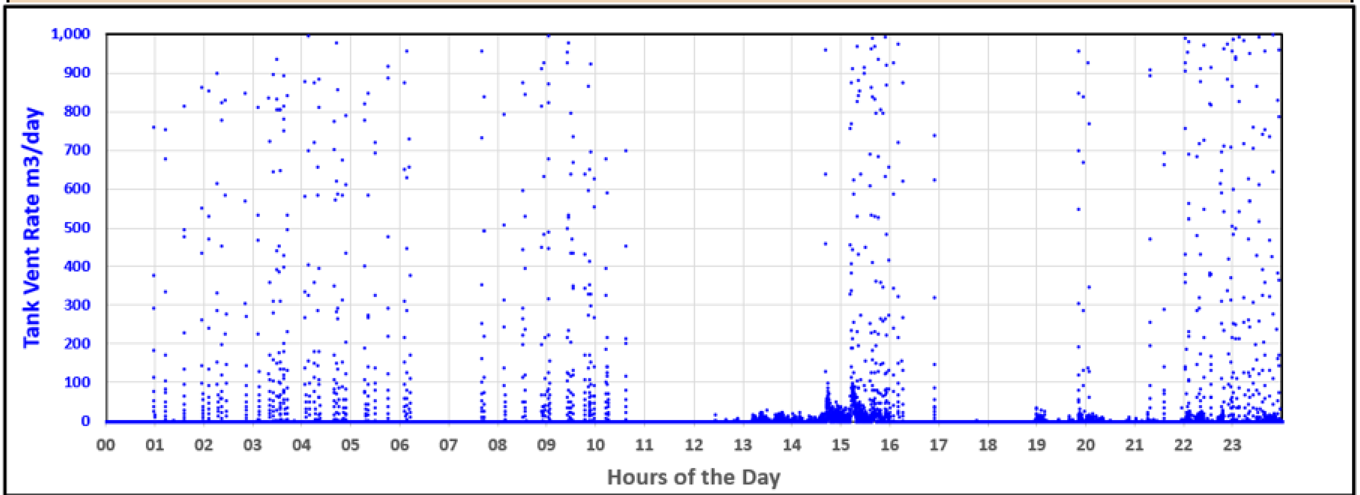
Observations from Site 14 Review and Table 1.5

- Sites with plunger lifts have unique challenges for direct measurement, including intermittent venting with large spikes.
- Regardless, Carleton University estimate of tank vent rate aligns with Petrinex reported vent volumes.

Site 15 Review

Site 15 is an Oil Multiwell Battery. Direct Measurement of the tank vent with Calscan's Hawk 900 and turbine meter is shown in Figure 1.11 below:

Figure 1.11: Campaign 1 - Site 15 - Direct Measurement of Oil Multiwell Battery



Site 15 Observations from Table 1.5 and Figure 1.11

- Site 15 displays a vent profile expected of an oil battery with a separator. When liquid is dumped from the separator to the tank, gas in solution can flash and vent.
- Short duration spikes up to 1,000 m^3/day were observed.
- However, the average vent rate over the 24-hour period is 23 m^3/day
- The 2" turbine used for direct measurement is accurate between 20 m^3/day to 2,000 m^3/day. The flow rate below 20 m^3/day may not be reported accurately.
- Methane concentration in the vent gas is 84%

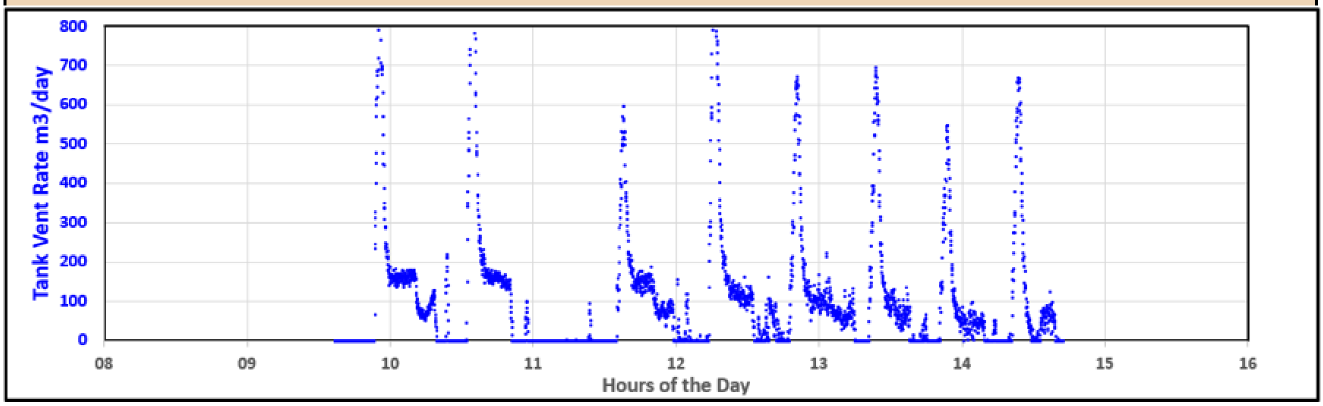
Conclusions and recommendations from Site 15 review

- Batteries with separators can see short-duration spikes in tank vent rates, but the average vent rate is low.
- Investigate adding a second meter in series with the 2" turbine meter. The second meter should be accurate between 0 m^3/day and 50 m^3/day, and have all the conveniences of the Hawk 9000 turbine meter, including battery operated, intrinsically safe, and light weight.

Site 16 Review

Site 16 is an Oil Single-well Battery without a Separator (OSWBwoS). Direct Measurement of the tank vent over 5 hours is shown in Figure 1.13:

Figure 1.13: Campaign 1 - Site 16 - Direct Measurement of Oil Single-well Battery wo Separator



Site 16 Observations from Table 1.5 and Figure 1.13 include:

- This vent profile is very similar to Site 8 shown in Figure 1.8 above.
- Short duration spikes up to 800 m^3/day can be seen, dropping quickly to 100 m^3/day, then approaching zero before the next spike. The cycle repeats roughly every 45 minutes.
- Despite the spikes, the averaged vent rate is 109 m^3/day
- Methane concentration in the tank vent gas is 76%

Conclusions and recommendations

- Oil Single Well Batteries without Separators are likely to have continuous tank vents.
- Investigate down-hole well testing to understand the nature of cyclic venting.

Kuva Camera Solutions

See Appendix 1 for a full report from Kuva. The following are excerpts from the Appendix.

Kuva Canada provides visual continuous methane monitoring with its proprietary shortwave infrared camera and cloud solution for upstream and midstream oil and gas operations. As part of this project, Kuva deployed at 16 locations from September 2021 thru September 2022. The cameras are mounted on relocatable 30 ft towers.

The tanks project provided valuable Direct Measurement of tank vent rates, and gas composition analysis. The data gathered during the field deployment has been and will continue to be helpful in developing and comparing the Kuva detection and quantification methodologies under a range of circumstances that cannot be easily replicated in a controlled environment.

The project also served as a valuable demonstration of the benefits of Kuva's continuous image-based monitoring compared to the other technologies deployed in the project.

Results

The results from a single site where the Calscan turbine meter was deployed concurrently is summarized below. Figure 1.13 below is captured from the visible camera inside the Kuva camera and shows the turbine meter installed on the top of the tank, with the pumpjack in the distance.

Figure 1.14 is a composite of Kuva detections and a chart of the Direct Measurement results. Kuva's short-wave infrared (SWIR)camera produced the grayscale images of the tank top. The detected gas is overlaid in colour, with red pixels indicating higher column density (ppm-m) and blue pixels indicating lower column density. The 4 SWIR images and 3 plumes align with the Direct Measurement chart.

The magnitude of the detections in the images clearly corresponds to the relative flow rate as measured by the turbine meter; the images with larger plumes that contain red pixels correspond to higher metered gas flow. The images as shown have their timestamp recorded (in UTC time zone) and were compared with the timestamped data from the turbine meter (in MDT time zone).

The Kuva Quantification method uses the column density measurements in the images, along with the environmental (wind speed and direction) and site information (distance to leak source) to estimate the emissions rate of each image. Figure 1.15 below compares the Kuva Quantification method to the Direct Measurement.

Direct Measurement in Figure 1.15 averaged 148 m^3/d, while Kuva's Quantification method averaged 106 m^3/d, or 28% lower. The maximum release measured by Kuva was 982m^3/d. The Kuva Quantification method is expected to improve as the algorithms to detect and quantify methane improves with the collection of more controlled testing data.

Benefits of Kuva Camera Solutions

- Non–contact emissions measurement. This form of passive instrumentation operates at a distance from emission sources.
- Can detect emissions from multiple sources (thief hatch, gauge board outlet, etc). The images produced allow for an easy identification of release points when the origin might not otherwise be known.
- Relatively low cost in comparison to alternative technologies
- Quick deployment with no ground penetration and no working from heights (<2 hour to install).
- Self contained, cloud connected, autonomous and solar powered.
- Monitor multiple tanks at once.
- No maximum metered rate.
- Capable of monitoring for long periods of time with little–to–no field maintenance required.
- Can be used as a leak detection and quantification device, such as for controlled tanks.
- Non–thermal based infrared detections, not affected by ambient temperature or temperature gradient of emissions.

Limitations

- Daylight only operation currently – in latitudes similar to Northern Alberta, the longer days of summer when solar irradiance is stronger will provide better detection probability.
- Minimum detection limit is variable and dependent on a number of factors (distance, weather and wind speed)
- Camera must be installed at heights greater than the emissions source. Kuva's maximum tower height is 40'.

Figure 1.13: Kuva Deployment

Figure 1.14: Kuva Detections verses Direct Measurement

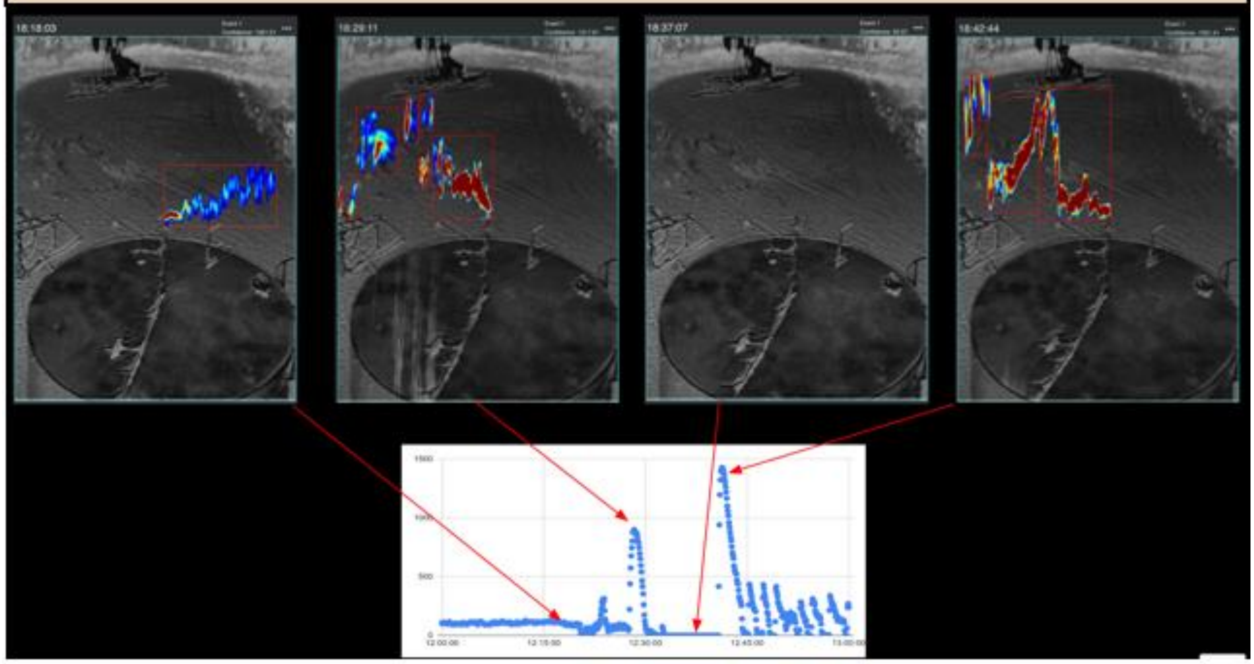
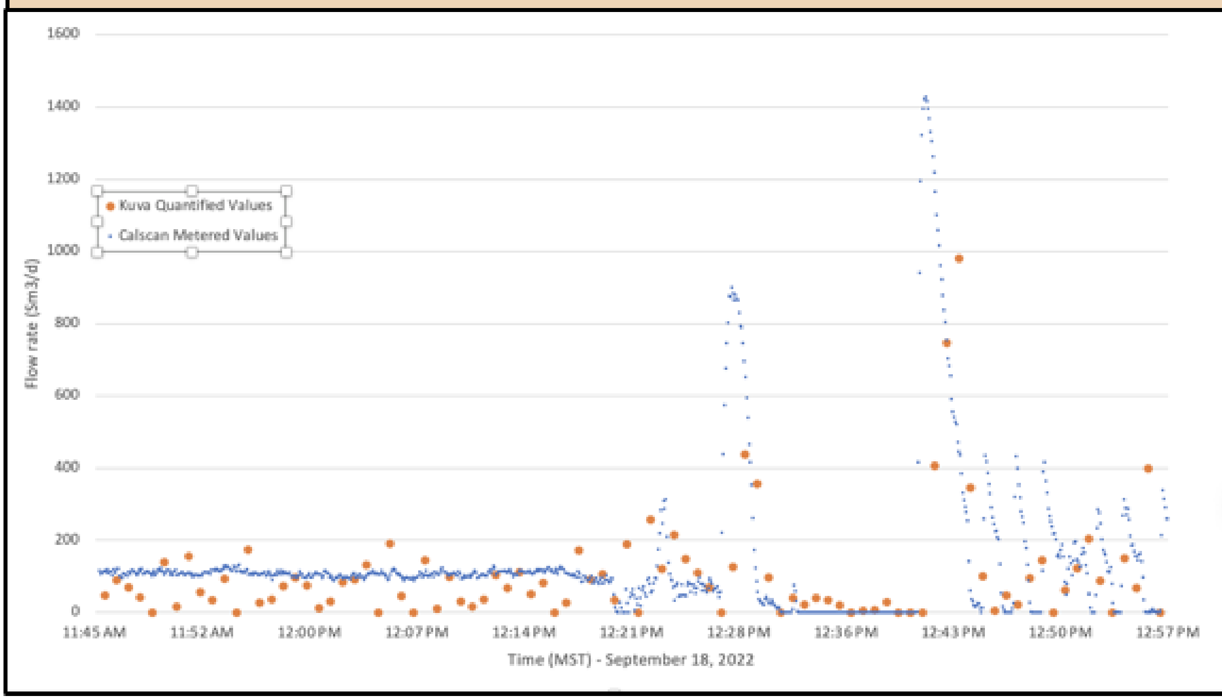


Figure 1.15 Kuva Quantification Method verses Direct Measurement



Campaign 2 Spring 2021 Oil Single–Well Batteries without Separators

Campaign 1 observed that Oil Single–well Batteries without Separators were a likely source of continuous tank vents. However, the sample size in Campaign 1 was small. Recognizing this, Campaign 2 was focused almost exclusively on Oil Single–well Batteries without Separators.

Study Area and Site Selection

The target study area for Campaign 2 was outside the Campaign 1 study area and ranged from Drayton Valley in the north to Calgary in the south.

Campaign 2 did not benefit from historical Bridger Photonics aerial surveys, so the sites were identified using Petrinex Volumetric Reports for 2021.

Petrinex monthly Volumetric Reports can contain upwards of 600,000 rows of data. A year's compilation of Volumetric reports contains over 7,000,000 rows. Microsoft Excel's Power Query and Power Pivot are necessary tools to analyze a data set this large.

Candidate sites were identified using January thru December 2021 Volumetric Data. The data set was expanded to include 2015 thru 2019 volumes to identify historical trends in reported vent emissions for selected sites. The data set was also extended to include January thru December 2022 to include the month that direct measurement occurred, and to assess if there was any change in reported vent volumes as a result of the spring campaign.

Table 2.1 below summarized the filters applied to the 2021 Petrinex Volumetric reports to identify Oil Single Well Batteries without separators (OSWBwoS).

Table 2.1: Campaign 2 - Petrinex Screening Criteria for OSWBwoS

Criteria	Reason
Reporting Facility Sub Type = 311	Crude Oil Single Well Battery
Oil Production > 5m3/month	This is an arbitrary threshold. Campaign 1 identified 2 OSWBwoS that did not have Bridger GML detections. Both were below 5m3/month oil production.
Gas Production, but *no* Gas Dispositions and *no* Gas Flaring	This implies that all produced gas is consumed on site as fuel, or vented, and no separator is needed. Casing gas is typically of sufficient volume to supply fuel to the pumpjack. Fuel volumes should also be reviewed for reasonablness
Relatively Constant Historical Oil Production	Provides some assurance the site will be operational during the Campaign.

Additional resources available to determine if a site has a separator include:

- Public Pipeline records. Gas Production and Dispositions require a natural gas pipeline at the lease. The absence of an active pipeline is an indicator that a separator is not at the site.
- Satellite imagery. See Google Earth, ArcGIS Pro, and AER OneStop Mapviewer.

The Petrinex Volumetric Screening identified 1,330 Oil Single Well Batteries with Oil Production > 5 m^3/month, and with Gas Production but no Flaring. This list was further confined to eliminate sites outside the study area. For sites within the study area, site operators were contacted and provided with a company–specific list. Resource constraints, maintenance schedules and budget further reduced the list to a manageable size.

Twelve (12) sites were selected for evaluation over a 3–week period in the spring of 2021.

All the data collected during the Campaign was reported back to the specific Operators for review and discussion.

The Calscan and Vertex team developed an effective and efficient deployment strategy, that included the following steps:

- Obtaining safe work permits covering several sites over several days.
- Upon arrival, set up the boom lift and inspect the tank top for the size and condition of the vent stack, and determine the meter placement.
- Inspect the thief hatch, custom fit a new gasket, and test for a proper seal with the OGI camera.
- Estimate tank vent rate with QOGI, to properly size the meter.
- Install the meter, attach a data cable to the meter computer. Connect the data cable to a laptop computer inside the service vehicle parked safely away from the tank.
- Obtain a representative gas sample during stable conditions.
- Monitor the vent rate routinely, in real time.
- If the site operator is present, consider turning off the pumpjack or blocking in the casing gas, to determine the impact on the tank vent rate.
- Typically, 3 to 4 hours of direct measurement provides sufficient data to identify trends, whether the vent is relatively constant, fluctuating, or cyclic with intermittent releases.
- After sufficient data has been obtained, remove the meter.
- Time on site is typically 6 to 7 hours, with up to 2 hours to set up, 4 hours of metering, and one hour to disassemble.

Evaluation of QOGI as a Vent Gas Quantification Tool

During Campaign 1 there was some evidence to suggest that the quantification of tank vent releases with the QOGI improved with a direct line-of-site to the vent release point. Direct line-of-site to the vent could be obtained several ways:

- Operate the OGI and QOGI from the boom lift, to allow the OGI operator to be level with or slightly above the top of the tank.
- Vertical installation of the meter essentially increases the vent height by ~ 4 feet and makes the release point visible from the ground.
- Horizontal installation of the meter moves the release point closer to the edge of the tank.

To confirm the benefits of line-of-sight, the project team established a routine of regular quantification using the QOGI, before and after the meter was installed. This routine evolved and improved during the campaign. Additional studies will be required to confirm the accuracy of OGI and QOGI for tank vent measurements. These studies can apply more scientific rigour, including blinding the metered release rates, clear rules for excluding data, and use of an independent 3rd party to compare the different quantification methods.

Vertex documented the OGI and QOGI methodology deployed in Campaign 2. See Appendix 3. The basic steps are as follows:

- Establish a suitable position for the OGI, QOGI, and tripod on the ground.
- Prior to the meter installation, measure vent rate over a 15-to-30-minute period
- Install meter on top of the tank.
- Measure vent rates in 15-minute intervals for the duration of the meter installation

Campaign 2 – Results

The results from Campaign 2 are summarized in Table 2.2 below. Direct Measurement refers to Calscan's Hawk 9000 and turbine meter.

Table 2.2: Campaign 2 - Summary of Results

			Petrinex Volumetrics			Direct Measurement		
ID	Facility Description	Tankage	Oil Production	Gas Vent		Vent Rate	Measurement Duration	Vent Gas [CH4]
		bbl's	m3/month	e3m3/month	m3/day	m3/day	Hours	Vol %
1	OSWBwoS	1x400	15	2.9	94	95	2.75	85.4
2	OSWBwoS	2x400	20	8.1	261	500	4	87.9
3	OSWBwoS	1x400	7	0.7	23	77	3	81.8
4	OSWBwoS	1x400	14	1.8	58	106	4.1	n/a
5	OSWBwoS	1x400	26	8.7	281	25	2	81.8
6	OSWBwoS	1x400	41	0.1	3	155	20.7	74.5
7	OSWBwoS	1x400	37	5.5	177	255	3	78.1
8	OSWB	2x400	30.9	0.6	19	4.7	3.5	n/a
9	OSWBwoS	1x200	41	5.3	171	112	4	58.8
10	OSWBwoS	1x400	28.7	5.1	165	136	3.3	73.3
11	OSWBwoS	1x400	26.2	0.3	10	67	4.2	n/a
12	OSWBwoS	1x400	11.5	0.5	16	337	1.3	n/a

OSWBwoS = Oil Single Well Battery with out Separator

OSWB = Oil Single Well Battery (with a Separator)

n/a = analysis not available due to sample contamination with air

Observations from Table 2.2 include:

Site #8 has an Operating Separator

- Site #8 does not have Gas Dispositions reported in Petrinex. Rather, the separator off-gas is routed to an incinerator and reported as Flare. Ninety eight percent (98%) of the total gas production was incinerated. Less than 2% of the produced gas, or 4.7 m^3/day was vented from the tank. Screening procedures described in Table 2.1 were updated to include flare volumes. Sites without gas disposition but with flare volumes will likely have separators.
- The vent rate was intermittent, spiking to highs of 100 m^3/day or more. See Figure 2.10 pg 77, following. This is typical of sites with separators seen in Campaign 1.

Methane Concentration in Vented Gas

- Methane concentration in the vented gas ranges from 73% to 88%. Four (4) samples identified as 'n/a' had a high N2 and O2 concentration and are believed to be contaminated with air. Site 9 analysis showed unusually low methane concentration and high C3+. The sample was taken during a time when the gas vent rate was spiking from < 5m^3/day to > 1,000 m^3/day and may not be representative.

Observations and Recommendations from Table 2.2

- Consider investigating reservoir properties and correlate with the vent gas methane composition.
- Investigate availability of portable methane analyzers to confirm concentrations in the field.

Average Measured Vent Rate

- Average Vent rate over the Measurement Period is automatically calculated by the Hawk 9000 computer. However, the average cannot describe the fluctuations in vent rate measured over time. This is discussed in the Detailed Site Review and shown in Figures 2.4 thru 2.13.

Petrinex Vent Gas Volumes vs Direct Measurement

- Site #2 had the highest direct measurement of the Campaign, but also has a high Vent volume reported to Petrinex. The metered vent rate fluctuated between 200 m^3/day and 800 m^3/day, averaging 500 m^3/day. See figure 2.4. The Operator is investigating control technologies at this site, including the installation of an enclosed combustor.
- Three sites, # 6, 11, and 12 have low Petrinex volumes but high metered volumes, possibly indicating an under reporting of vent volumes to Petrinex.

- The ratio of measured vent rate to Petrinex Vent rate was calculated. Sites with a Vent Ratio < 1 have measured vent rates below the reported Petrinex vent volumes. Sites with a Vent Ratio > 1 have measured vent rates greater than the reported Petrinex Vent volumes. Table 2.3 below list the 12 sites in Campaign 2, sorted from low Vent Ratio to high.

Table 2.3: Campaign 2 - Ratio of Direct Measurement to Petrinex Vent Volumes

Site ID	Direct Measurement m3/day	Petrinex Vent Rate m3/day	Ratio
5	25	281	0.1
8	4.7	19	0.2
9	112	171	0.7
10	136	165	0.8
1	95	94	1.0
7	255	177	1.4
4	106	58	1.8
2	500	261	1.9
3	77	23	3.4
11	67	10	6.9
12	337	16	20.9
6	155	3	46.5

Observations from Table 2.3 above:

- Five (5) of 12 sites have ratios ≤ 1, meaning measured volumes are less than that reported to Petrinex.
- Three (3) of 12 sites have ratios > 1 but < 2, meaning direct measurement is greater than that reported to Petrinex, but not alarmingly so.
- For the 8 sites with a ratio <2, the average of the Direct measurement and the Petrinex volumes are identical at 154 m^3/day.
- Two (2) of 12 sites have measured vent rates 20 and 45 times higher than reported to Petrinex.

This small sample size suggests that the industry is doing a reasonable job reporting tank vent emission, but some improvement is still required. To provide credibility to this statement, the reporting history of each site was investigated.

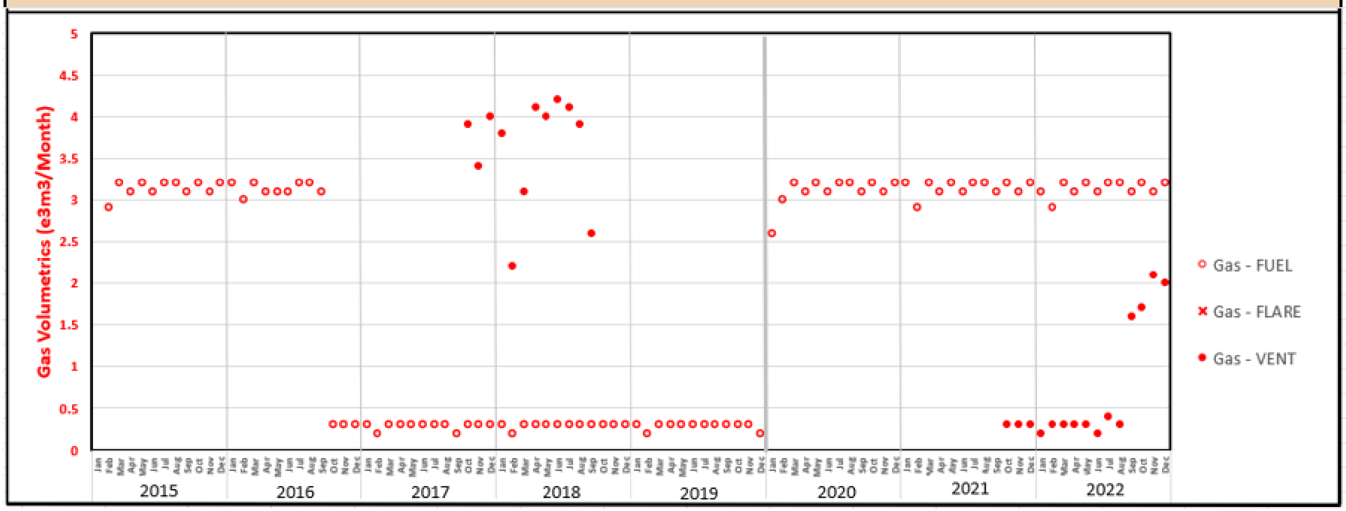
Review Historical Fuel Flare and Vent Volumes By Site

As discussed in Background, Directive 60 was updated with the December 2018 release to include new definitions of fuel, flare and vent sources, and to report vent sources to OneStop and Petrinex. The changes came into effect January 1st 2020.

Table 2.3 above directionally indicates that Petrinex vent volumes align with what is measured in the field. To evaluate the impact of Directive 60 on the reported vent volumes, Petrinex volumes from 2015 thru 2022 were reviewed for each site. This review is best done graphically.

Figure 2.1 below charts the Petrinex fuel, flare, and vent volumes for Site 11.

Figure2.1: Campaign 2 - Petrinex Fuel Flare and Vent Volumes since 2015 - Site 11



Observations of Figure 2.1 above include:

- Reported fuel use is relatively constant for extended periods of time, suggesting equipment specific fuel consumption factors have been used to estimate fuel rates.
- The decrease in fuel rate in Q3 2016, and the increase in Q1 2020 has not been investigated.
- The Vent volumes in Q4 2017 thru Q3 2018 has not been investigated.
- Vent volumes have been reported monthly since Q4 2021.
- Vent rates increased 6–fold in September 2022.

Petrinex volumes were reviewed for each site in Campaign 2, using charts like Figure 2.1 above. The review is summarized in Table 2.4 below.

Table 2.4: Campaign 2 - Review of Historical Petrinex Fuel, Flare, and Vent

Site ID	Vent Ratio DM/Petrinex	Pre -2020			2020/2021				Q4 2022 Stepchange Increase in Reported Venting
		Flare	Fuel	Vent	Flare	Fuel	Vent	Timing	
5	**0.1**	✓	✗	✗	✗	✓	✓	2020 Q2	
8	**0.2**	✓	✓	✗	✓	✓	✓	2021 Q1	
9	**0.7**	✗	✓	✗	✗	✓	✓	2021 Q4	
10	**0.8**	✗	✓	✗	✗	✓	✓	2021 Q4	
1	**1.0**	✓	✗	✗	✗	✗	✓	2018 Q4	
7	**1.4**				✗	✓	✓	2020 Q3	
4	**1.8**	✓	✗	✗	✗	✓	✓	2020 Q4	
2	**1.9**	✓	✗	✓	✗	✓	✓	2020 Q1	
3	**3.4**	✓	✗	✗	✗	✗	✓	2021 Q1	
11	**6.9**	✗	✓	✗	✗	✓	✓	2021 Q4	**6x increase**
12	**20.9**	✗	✓	✗	✗	✓	✓	2021 Q4	**10x increase**
6	**46.5**	✗	✓	✓	✗	✓	✓	no change	**45x increase**

Table 2.4 is a qualitative assessment of the fuel, flare and vent volumes reported to Petrinex since 2015. The following list describes key attributes of the table:

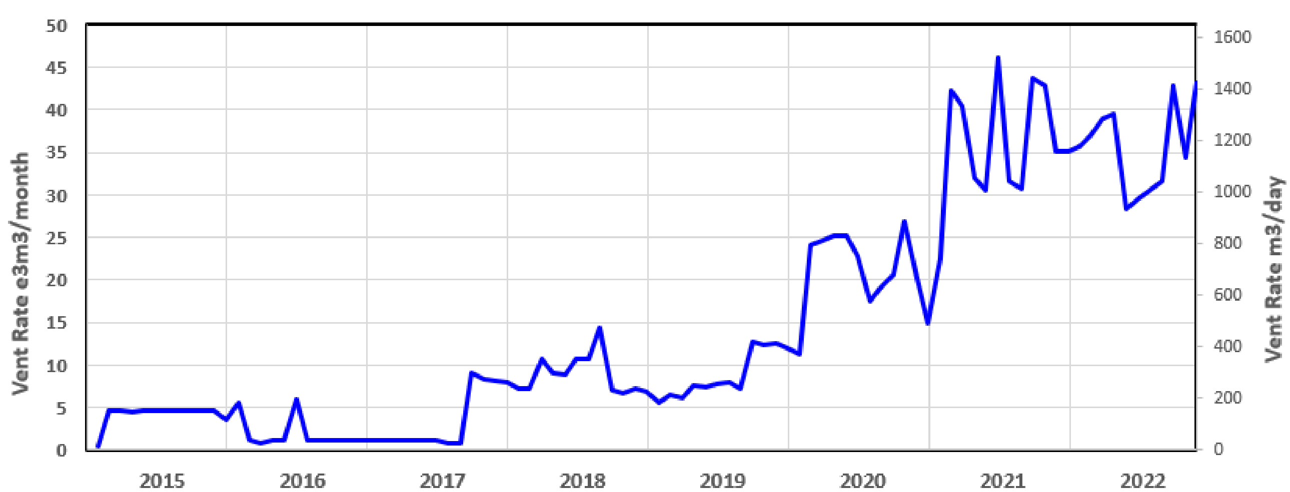
- Each Site in Campaign 2 is listed and ordered by the Vent Ratio (Direct Measurement ÷ Petrinex Vent Volume).
- Columns under 'Pre–2020' represents Petrinex 2015 thru 2019.
- Columns under '2020/2021' represents Petrinex 2020 and 2021
- Column 'Timing' identifies the calendar quarter when Petrinex volumes changed, for example, from flare to vent.
- Column 'Q4 2022 Step Change Increase in Reporting Vent' describes any obvious step change increase in reported vent volumes.
- ✓ indicates that flare, fuel or vent is routinely reported.
- ✗ indicates that flare, fuel, or vent is not reported or routinely reported.
- Site 8 has an incinerator and flare volumes are expected.
- Site 7's first production was 2020, so the is no pre–2020 history.

Observations from Table 2.4 include:

- Five (5) of 10 sites reported flare volumes before 2020, noting that Site 8 has a known incinerator, and Site 7 was not in operation before 2020.
- All 5 sites with pre-2020 flare volumes have stopped reporting flare volumes after 2020, and when flare reporting stopped, vent reporting began.
- Only 2 of 11 sites reported vent volumes before 2020 (0.1 and 0.8 e3m^3/day).
- Twelve (12) of 12 sites are now reporting vent volumes.
- All changes to vent reporting occurred throughout 2020 and 2021 (Site 1 is the exception, changing in 2018)
- The 3 sites with high Vent Ratio each increased the volume of Vent reported to Petrinex in the 4th quarter of 2022, ranging from 6 to 45-time increase.

Table 2.4 above is a qualitative assessment of changes to Petrinex reporting. A quantitative assessment appears in Figure 2.2 below:

Figure 2.2: Campaign 2 - Sum of Monthly Petrinex Vent Volumes for Campaign 2 Sites



Observations from Figure 2.2 include:

- Eleven (11) of the 12 sites in Campaign 2 have been in operation since 2015.
- There is a 10-fold increase in reported venting from 2015 thru 2022.
- Step changing increases are noticed in 2020 and 2021.

Conclusions and Recommendations from the Petrinex Review:

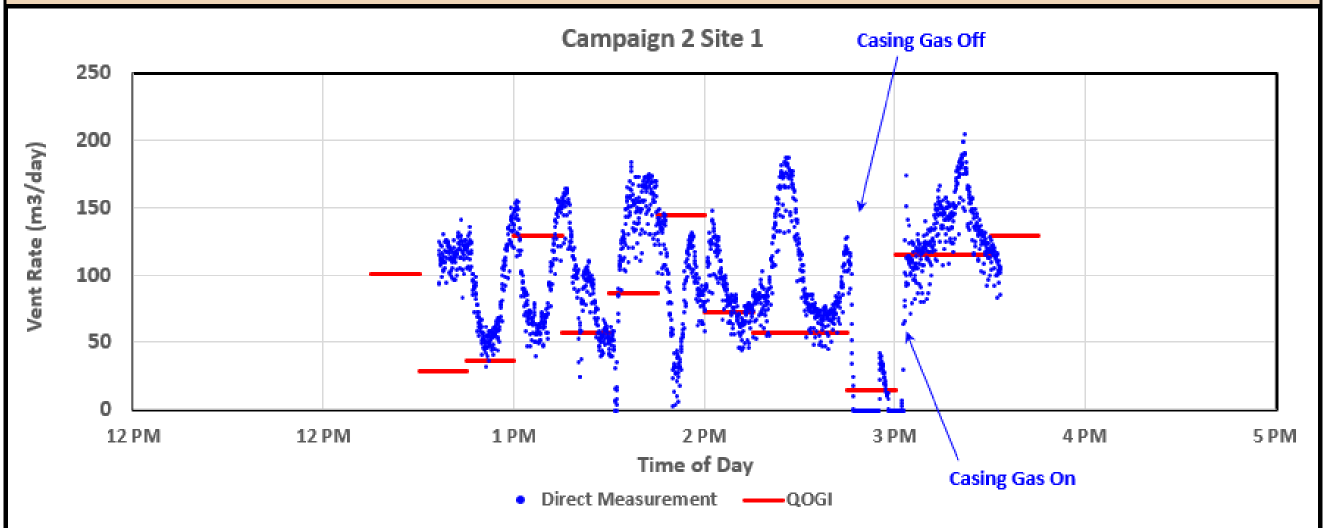
- Admittedly, the sample size is small, and admittedly the site selection process was not random. However, the increase in vent gas reporting to Petrinex post–2020 is obvious.
- Directive 60 coming into force in January 2020 is an implicit explanation for the increase in post–2020 vent gas reporting.
- The Q4 2022 Petrinex Vent Volumes closely aligns with Direct Measurement.
- Consider a more comprehensive review of Petrinex Vent Volumes by facility type and operator pre and post – 2020.

Detailed Site Review

The following section provides a review of each of the 12 sites visited during Campaign 2. Results of the Direct Measurement and QOGI are plotted, and short commentary provided.

Campaign 2 Site 1 Oil Single-well Battery without Separator

Figure 2.3: Campaign 2 Site 1 - Direct Mesaurement and QOGI Estimation

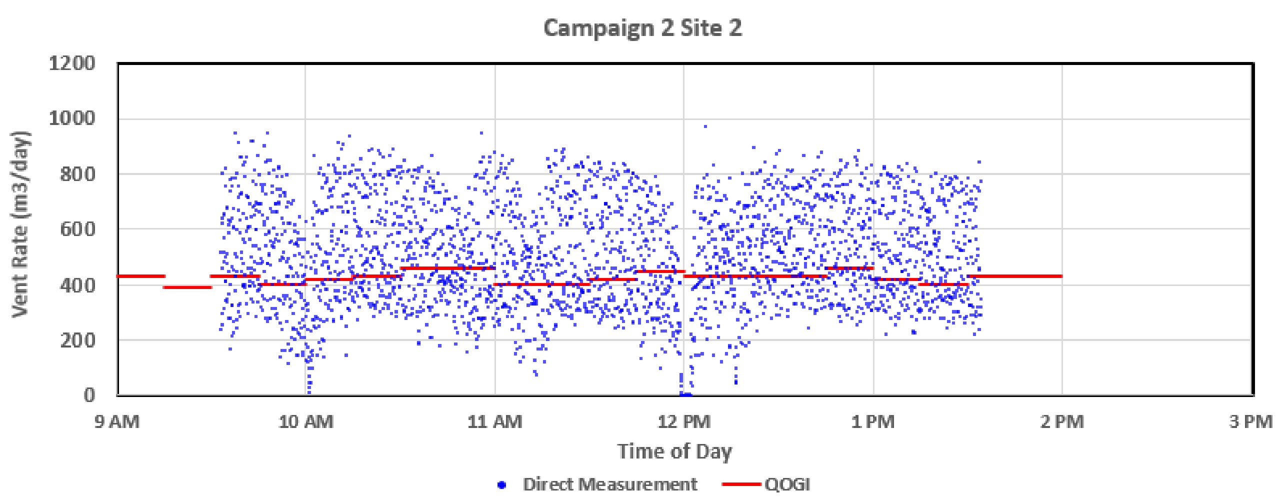


Observations from Figure 2.3 Include:

- Persistent but fluctuating vent rate with some cyclic tendencies.
- Despite the fluctuating rate, the QOGI aligned reasonably well with Direct Measurement.
- Release rate dropped to near zero when the casing gas was isolated.

Campaign 2 Site 2 Oil Single-well Battery without Separator

Figure 2.4: Campaign 2 Site 2 - Direct Measurement and QOGI Estimation

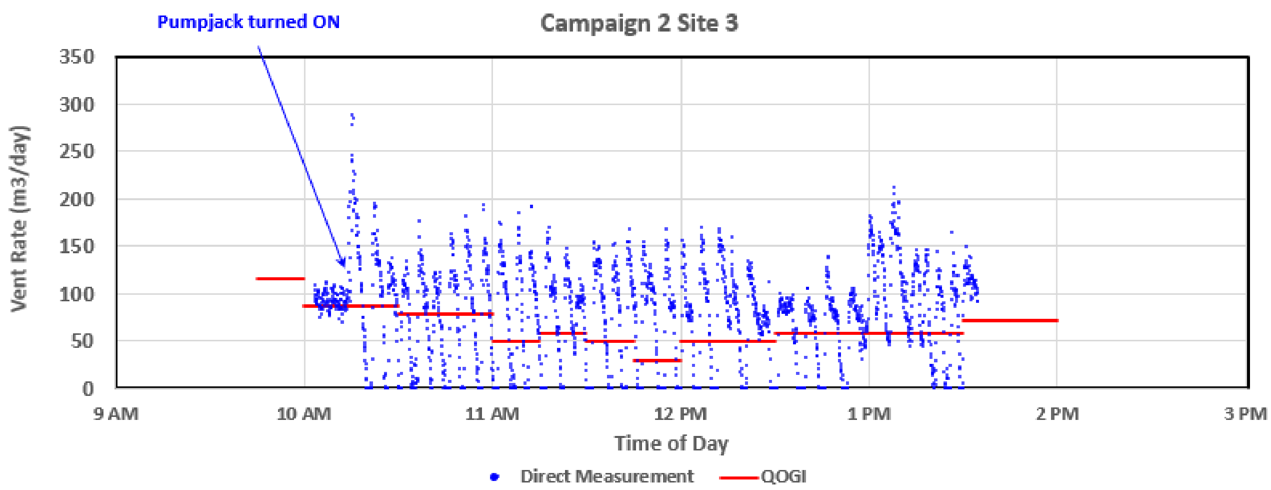


Observations from Figure 2.4 include:

- Persistent but fluctuating vent rate between 300 m^3/day and 800 m^3/day, averaging 500 m^3/day
- QOGI estimations relatively constant, averaging ~ 400 m^3/day.

Campaign 2 Site 3 Oil Single-well Battery without Separator

Figure 2.5: Campaign 2 Site 3 - Direct Measurement and QOGI Estimation

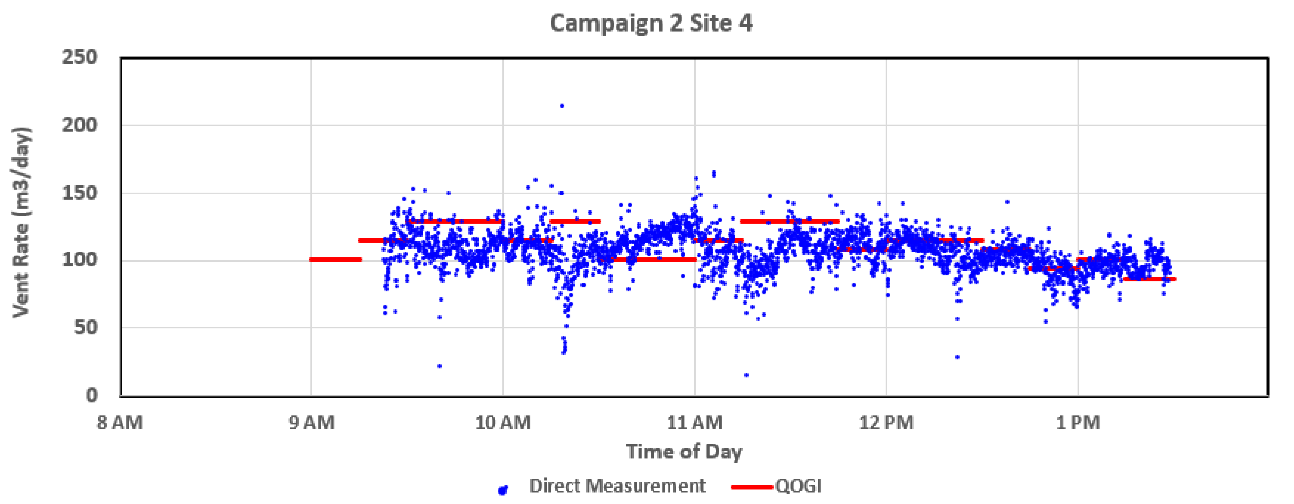


Observations from Figure 2.5 include:

- Persistent vent rate, but fluctuating with some cyclic tendencies, averaging 77m^3/day.
- While short in duration, the vent rate was persistent and relatively constant with the pump jack was not operating. Consistent with previous sites findings, casing gas seems to be the dominant contributor to tank venting at Oil Single-well Batteries without Separators,
- QOGI vent rate estimates align favourably with Direct Measurement

Campaign 2 Site 4 Oil Single-well Battery without Separator

Figure 2.6: Campaign2 Site 4 - Direct Measurement and QOGI Estimation

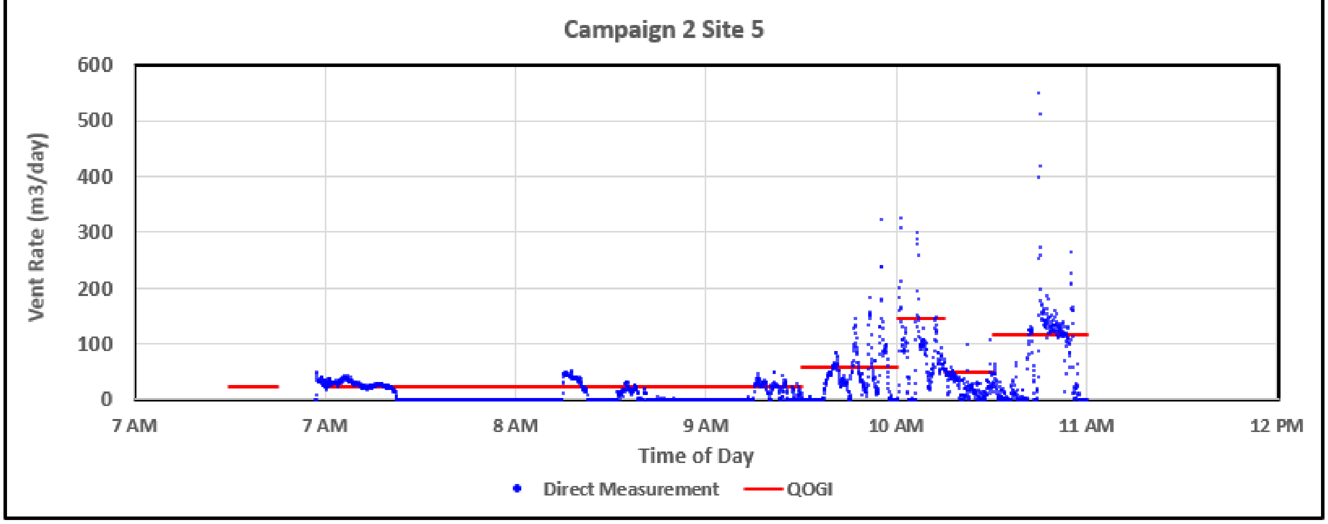


Observations from Figure 2.6 include:

- Persistent and relatively constant vent rate, averaging 105 m^3/day
- QOGI vent rate tracks reasonably well with Direct Measurement.

Campaign 2 Site 5 Oil Single-well Battery without Separator

Figure 2.7: Campaign 2 Site 5 - Direct Measurement and QOGI Estiamtion

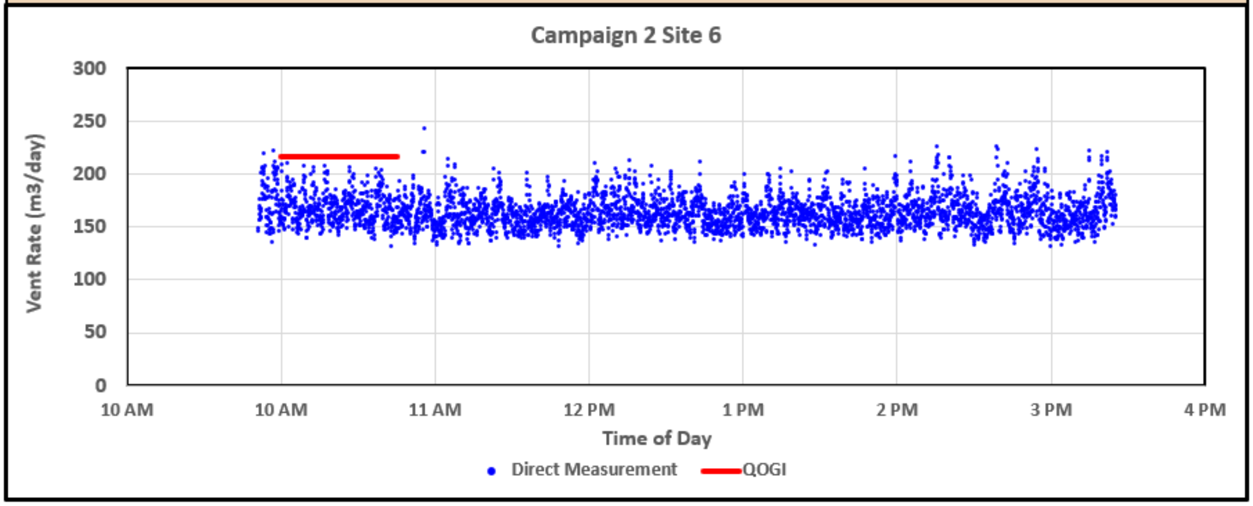


Observations from Figure 2.7 include:

- Intermittent release rate, averaging 25 m^3/day
- QOGI vent rate tracks reasonably well with Direct Measurement.

Campaign 2 Site 6 Oil Single-well Battery without Separator

Figure 2.8 Campaign 2 Site 6 - Direct Measurement and QOGI Estimation

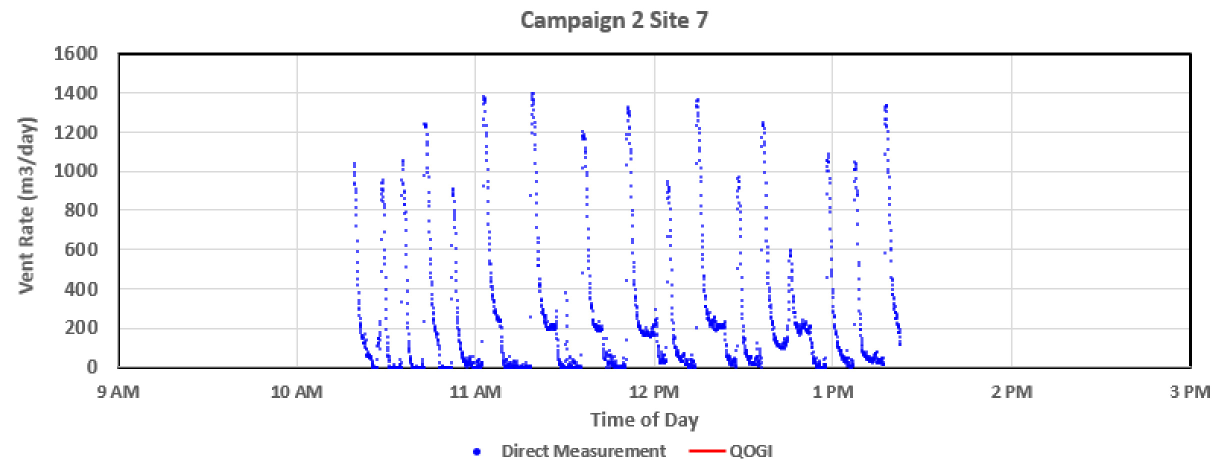


Observations from Figure 2.8 Include:

- Persistent and constant vent gas rate, averaging 155 m^3/day
- Meter was installed at ground level, not typical of a tank vent.
- QOGI estimate included for completeness.

Campaign 2 Site 7 Oil Single-well Battery without Separator

Figure 2.9: Campaign 2 Site 7 - Direct Measurement and QOGI Estimation

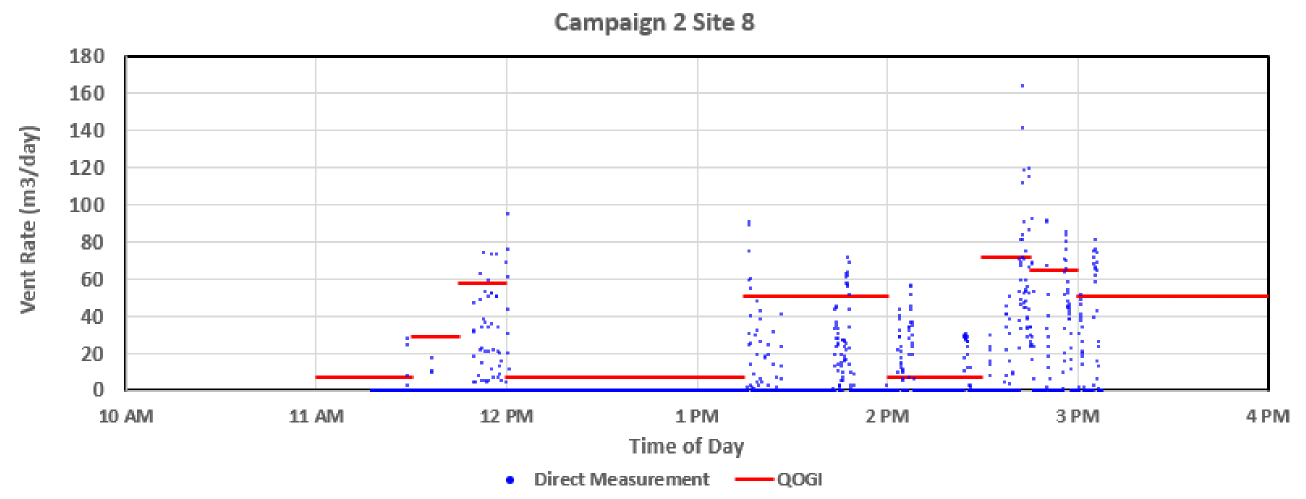


Observations from Figure 2.0 include:

- Persistent fluctuating and cyclic tank vent, averaging 255 m^3/day
- Spikes of 1,400 m^3/day were measured.
- QOGI quantification was challenged by the intermittent and cyclic nature of the tank vent. Both low and high rates were seen by the OGI camera, but could not be quantified by QOGI due to rapid changes in plume size.

Campaign 2 Site 8 Oil Single-well Battery ***with*** a Separator

Figure 2.10: Campaign 2 Site 8 - Direct Measurement and QOGI Estimation

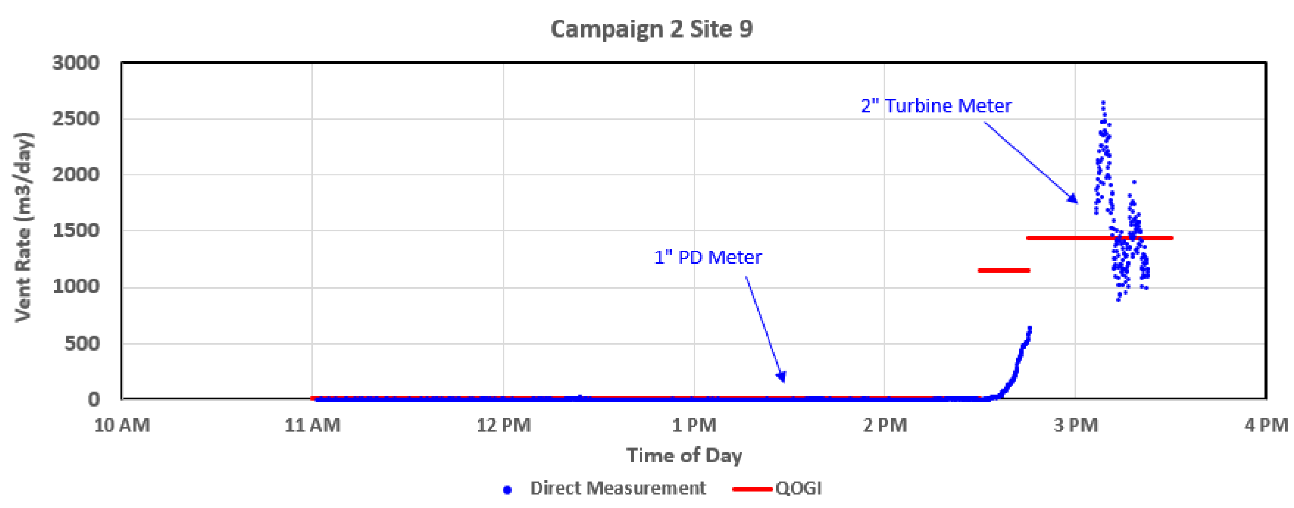


Observations from Figure 2.10 include:

- Site 8 has an operating separator!
- Greater than 98% of the produced gas is incinerated. Less than 2% of the produced gas is vented at the tank.
- Intermittent spikes in tank vent rate up to 100 m^3/day or higher, with spikes most likely tied to separator operation.
- Average vent rate is < 5m^3/day.
- Site 8 vent profile is similar to sites with separators surveyed in Campaign 1.

Campaign 2 Site 9 Oil Single-well Battery without Separator

Figure 2.11: Campaign 2 Site 9 - Direct Measurement and QOGI Estimation



Observations from Figure 2.11 include:

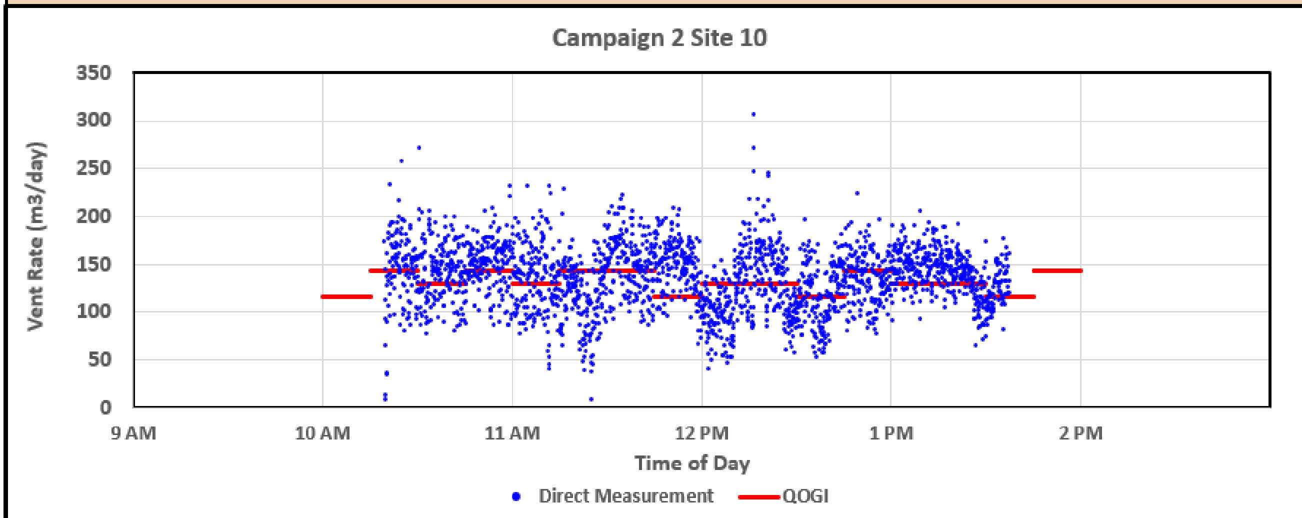
- For more than 3 hours, the measured vent rate was ~ 5 m^3/day, measured with a 1" positive displacement (PD) meter.
- QOGI estimated vent rate is 15 m^3/day during this time.
- Without notice, vent rate began to increase steadily. The 1" PD meter was replaced with a 2" turbine.
- Average vent rate over the duration of the test was 112 m^3/day.
- QOGI estimated vent rate aligns reasonably with the Direct Measurement
- The duration of the high vent rate was < 90 minutes.
- It is unknown how often episodes of high vent rate occur.
- It is unknown why episodes of high vent rates occur.

Recommendations

- Vent profiles of this nature will be a challenge to quantify. But tanks with intermittent profiles are ideal sites to evaluate the capabilities of 24/7 monitors such as fixed sensors installed at the site perimeter.

Campaign 2 Site 10 Oil Single-well Battery without Separator

Figure 2.12: Campaign 2 Site 10 - Direct Measurement and QOGI Estimation

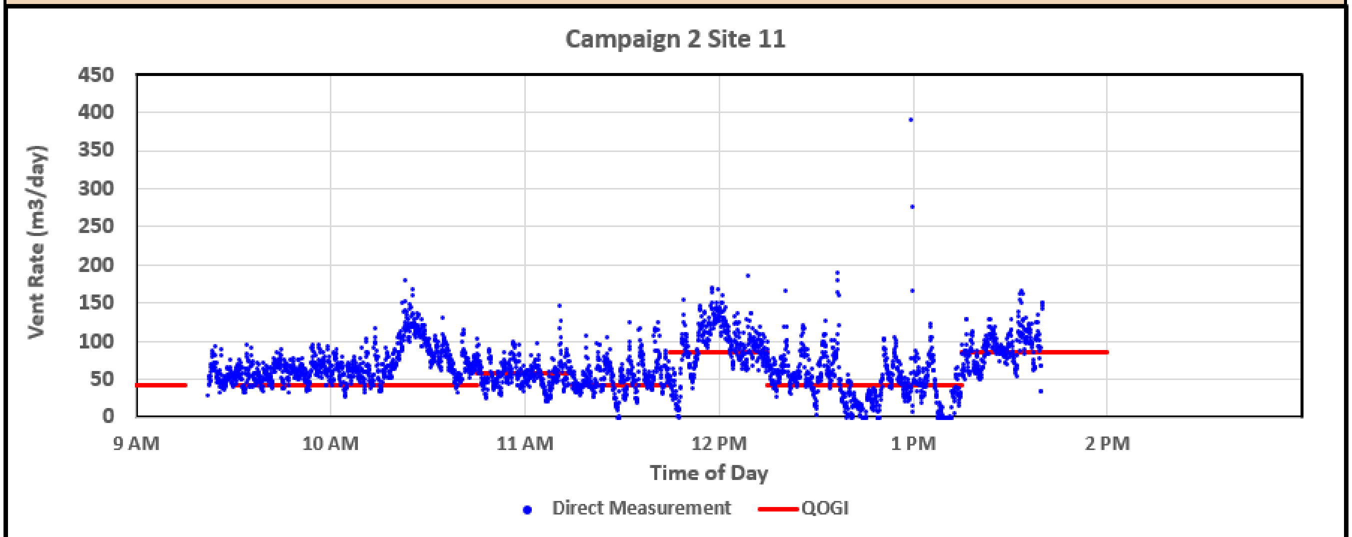


Observations from Figure 2.12 include:

- Persistent and fluctuating tank vent, averaging 136 m^3/day.
- QOGI estimated vent rate aligns reasonably with Direct Measurement

Campaign 2 Site 11 Oil Single-well Battery without Separator

Figure 2.13: Campaign 2 Site 11 - Direct Measurement and QOGI Estimation

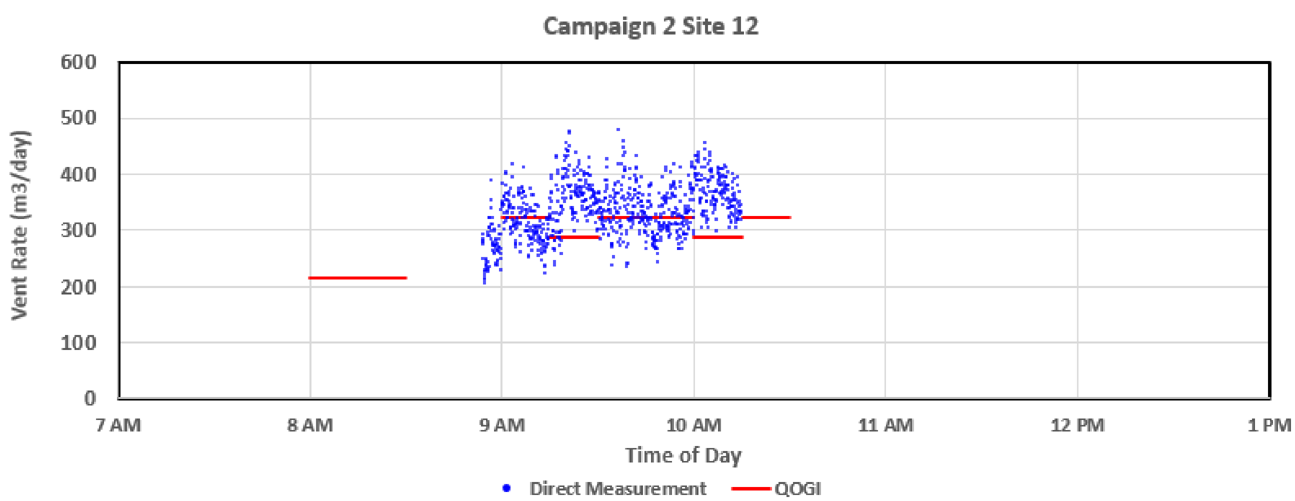


Observations from Figure 2.13 include:

- Persistent and fluctuating tank vent rate, with some cyclic tendencies
- Average vent rate is 67 m^3/day.
- QOGI estimated vent rate aligns reasonably well with Direct Measurement

Campaign 2 Site 12 Oil Single-well Battery without Separator

Figure 2.14: Campaign 2 Site 12 - Direct Measurement and QOGI Estimation



Observations from Figure 2.14 include:

- Persistent release averaging 337 m^3/day, fluctuating between 250 m^3/day and 400 m^3/day.
- QOGI estimated vent rate aligns reasonably well with Direct Measurement

Campaign 3

Campaign 1 in the fall of 2021, followed by Campaign 2 in the spring of 2022 confirmed that Oil Single Well Batteries without Separators are likely to have continuous vents. However, there are outstanding questions about the frequency and nature of tank venting at other facility types. Also, there are outstanding questions about the intermittent nature of tank vents and the challenges of detecting and quantifying them.

Campaign 3 was designed to address these questions. Key components of Campaign 3 include:

- The use of Bridger Photonics Gas Mapping LiDAR (GML) to survey 209 sites representing the regions mix of Operators and oil and gas single and multiwell batteries.
- Two (2) of the 209 locations were selected for long term meter installation, providing a unique opportunity to compare direct measurement with Bridger GLM results.
- One (1) location was selected for Kuva deployment, to further evaluate Kuva's camera for detecting and quantifying intermittent tank vents.

Campaign 3 Study Area

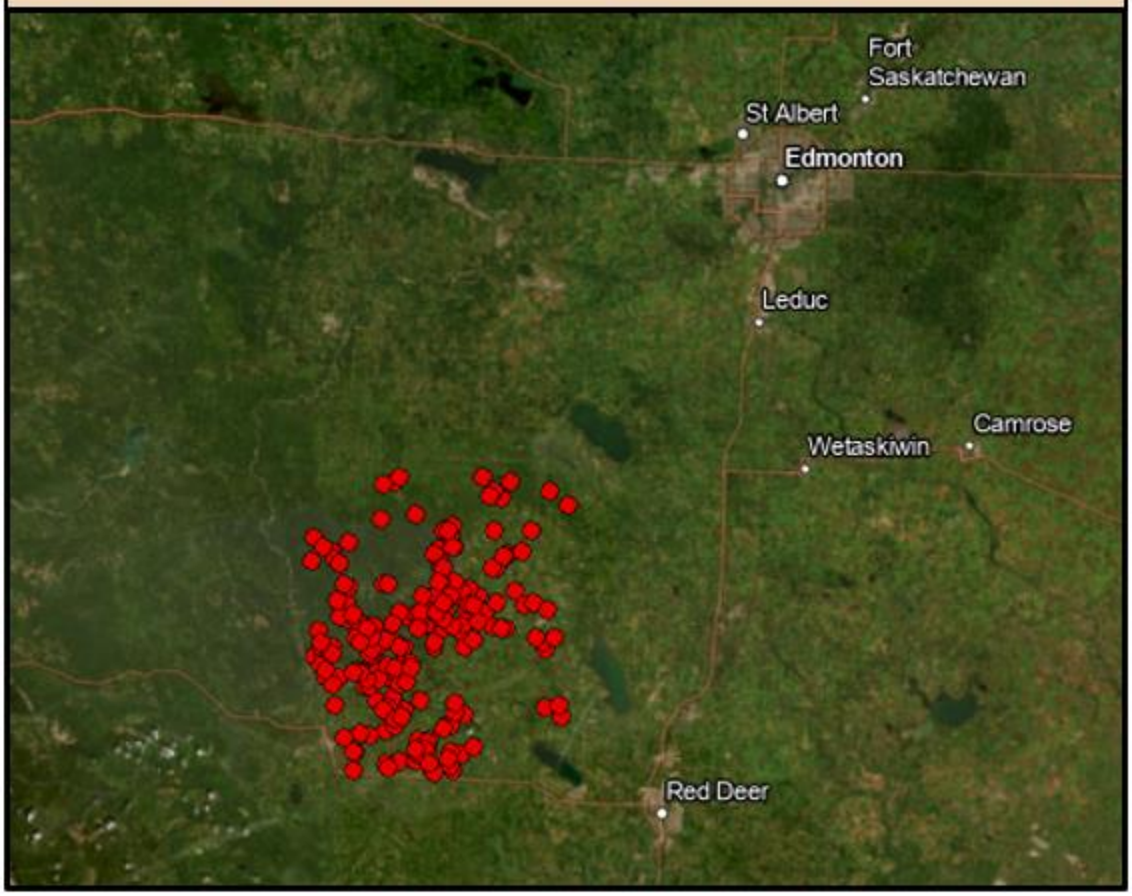
The study area is roughly defined by Township 39 to 45, Range 2 to 7, West of the 5th Meridian. There are 1226 Legal Subdivisions containing 1 or more active Oil and Gas facilities within this area. Sites were culled to a manageable number using the following selection criteria:

- Exclude Gas Plants
- Exclude sites without oil or condensate production, oil receipts or oil dispositions.
- Exclude sites with multiple Petrinex Facility ID's with reported Petrinex volumes
- Include sites with monthly Opening and Closing inventories of Oil.
- Maintain a proportionate mix of operators.
- Maintain a proportionate mix of oil and gas, single and multiwell batteries.
- Oil Single Well Batteries without Separators were identified using the procedures listed in Table 2.1. Oil Single-well Batteries are included in Campaign 3 to the proportion found in the study area defined by Township 39 – 45, Range 2 to 7, west of 5 Meridian.

Thirty-six (36) operators are represented. The final count and facility type is summarized in Table 3.1, below. The study area is shown in Figure 3.1, also below.

Table 3.1: Campaign 3 - Facility Count and Type		
Description	**Count**	**% of Total**
Crude Oil Single Well Batteries *with* Separators	83	40%
Crude Oil Single Well Batteries *without* Separators	23	11%
Crude Oil Multiwell Batteries	47	22%
Gas Single Well Batteries	44	21%
Gas Multiwell Batteries	12	6%
Total	209	

Figure 3.1: Campaign 3 Study Area



Campaign 3: Comparison of Direct Measurement of Tank Vents with Bridger Surveys

Two (2) tanks were fitted with Calscan's Hawk 9000 data logger and turbine meters. The meters were installed for 12 days. This provided Bridger Photonics with flexibility to fly repeatedly during the survey as their schedule allowed. Both sites were identified in Campaign 2 and were selected because of the vent characteristics.

The first site, identified as Site 3-1, has a very stable vent rate. This is shown in Figure 3.2 below. Bridger Photonics surveyed this site multiple times a day on 2 days spaced 3 days apart. The Bridger measurements for one day are also shown in Figures 3.2.

The second site, identified as Site 3-2, displayed various fluctuating vent release profiles. Figure 3.3, below, displays 3 profiles as well as the Bridger results.

Figure 3.2: Campaign 3 - Site 3-1 Direct Measurement and Bridger GLM

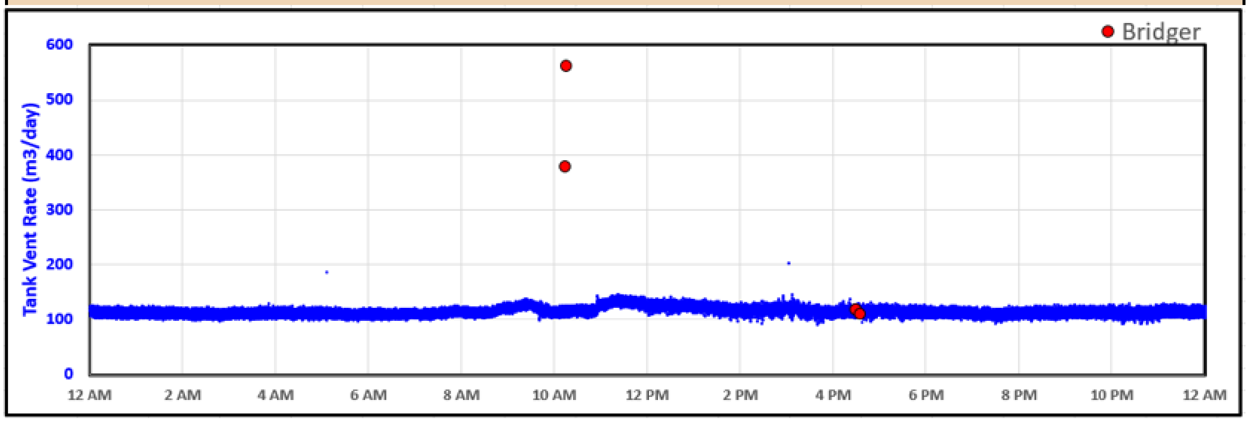
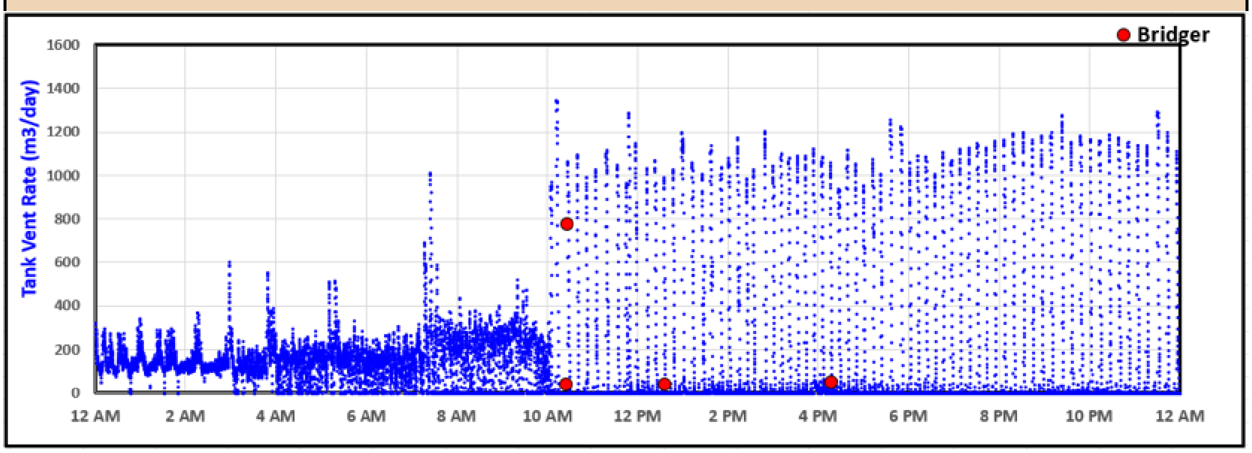


Figure 3.3: Campaign 3 - Site 3-2 Direct Measurement and Bridger



The Direct Measurement results were shared with Bridger Photonics. The following are observations from Figure 3.2 and Figure 3.3 above, jointly developed by MWA and Bridger:

- Site 3–1 Bridger Results aligned favourably with the Direct Measurement in the afternoon, but not in the morning. The difference is likely attributed to wind speed estimations.
- Site 3–2 vent profile changed at 3am, and then again at 10 am, just before the Bridger survey. The reason or reasons for the changes in profile was not investigated.
- Bridger's results align favourably with Site 3–2's fluctuating profile.
- Site 3–2 Direct Measurement averaged 150 m^3/day. The average of Bridger's 4 detections of 35, 775, 38 and 46 m^3/day is 225 m^3/day.
- Bridger would typically scan a site twice in a day. The average of any 2 of the 4 detections at Site 3–2 would be either 400 m^3/day, or 40 m^3/day. The average of all 4 detections is closer to the Direct Measurement average, directionally indicating that for sites with fluctuating vent rates, quantification accuracy improves with increased flyovers.

Local wind measurement can improve the accuracy of indirect methods of methane release quantification, including Bridger's GML. In Canada, Bridger utilizes meteoblue, a meteorological service which provides localized wind data. Bridger applies this wind data to characterize the emission rate of methane plumes. In general, this approach is accurate when averaging and/or aggregating emissions measurements acquired over many days, however, it can have bias error on any given day, which will cause the associated emission rate estimates to be inaccurate.

Very low wind speeds of 1m/s can cause a systematic positive bias in Bridger's emission rate measurements.[3]

Future studies to determine the performance of Bridger's GML should include on–site wind measurements using a calibrated anemometer positioned away from structures and foliage and at least 3 meters off the ground.

Bridger's GML sensor version 1.0 has a detection sensitivity of 3kg/hr (105m^3/day) with a 90% probability of detection. Wind speed impacts probability of detection (PoD).

[3] Bell, C. et al. Single–blind determination of methane detection limits and quantification accuracy using aircraft–based LiDAR. Elementa: Science of the Anthropocene 10, (2022).

Independent controlled release studies for GML 1.0 indicates a PoD of 0.41 (kg/h)/(m/s) wind speed at 675' above ground level[3].

Detection sensitivity also depends on received light levels, which can vary site by site due to changes in terrain reflectivity, meteorological conditions during the scan, and other factors. Bridger has developed methods to use GML sensor data to measure these effects and is able to determine detection sensitivity on a site-by-site basis.

Bridger is currently developing GML 2.0, which is anticipated to have improved detection sensitivity and improved probability of detection.

Bridger's GML is a useful technology for quantifying vented emissions because it provides complete spatial coverage of emission sources within line of sight from the air. However, intermittent venting can introduce sampling error. A short duration vent may not be captured in a single aerial scan. Appropriate statistical representation of emissions can be achieved for a set of vented sources with a single scan if it is a large set of similar sources, or if a smaller set of sources is measured with a suitable number of replicate scans.

A single measurement is subject to uncertainty that diminishes with replicate measurements. If only one measurement is collected of a reoccurring large emission event, then there is less certainty about the magnitude of that event. Replicate measurements help to cancel out errors in quantification and provide more certainty in the measurement.

Conclusions from this data set include:

- Due to a limited sample size, few conclusions can be confidently drawn. An expanded sample size and additional high frequency flyovers and/or several campaigns throughout the year may help gain insight into the delta between Direct Measurement and Bridger GML emission rates.
- Quantified intermittent releases have a higher uncertainty than persistent releases.
- Site selection was very good. Uniform sites provided a good data set to compare and contrast and begin building statistics for tank venting.
- Localized wind data may prove to be important on these site types.
- Additional quantification methods could be helpful to increase confidence in emissions measurements.

Recommendations

- Design a study with a statistically- significant sample size that includes:
  - Tanks with intermittent and continuous vent profiles
  - Direct measurement with calibrated meters

- Comprehensive facility and well data collection
- High frequency aerial flyovers

Analysis of Bridger Results from Aerial Surveys of 209 sites

Data Collection and Analysis

Components of Bridger's data products that are relevant to this study include:

- Images of methane plumes, with emissions localized to within 2 metres of the actual emission source. The plumes are typically composite images from multiple scans.
- Geo–referenced digital aerial photography with higher definition than satellite images commonly used by GIS applications like Google Earth or ArcGIS.
- Emission release rate in m^3/day
- An indication of 'Detection Persistence'. A release can be either 'Persistent', meaning it was detected every flyover, or 'Intermittent', meaning it was detected at least once, but not detected in all flyovers.
- Number of flyovers or 'scans' of the site, typically 2 to 4 over 2 days. Larger sites may require more scans for complete coverage.

Analysis of the Bridger data included the following:

- Review of the geo–referenced digital aerial images for all 209 sites to count the visible hydrocarbon storage tanks.
- Review of every scan and release point and identify the 'Process Block' the plume is from. Process Block is a grouping of equipment by purpose or function. For example, Separation is a process block that includes all equipment in and around the Separator Building, including the Separator itself, the attached Pop Tank, and pneumatic controllers and pneumatic pumps inside the building. An aerial detection of methane from a Separation Process Block could be fugitive emissions or vents from the Pop Tank or pneumatic devices. Aerial surveillance cannot differentiate between a fugitive or a vent, or attribute releases to specific pieces of equipment. Regardless, there is value in distinguishing releases by Process Block.
- Major Process Blocks identified in this study include:
    - Tanks (Hydrocarbon Storage)
    - Controlled Tanks (tanks with a Vapour Recovery Unit)
    - Separation Equipment (includes Separator buildings and POP tanks)
    - Well Head
    - Pumpjack Prime Mover
    - Compression

- Dehydration (if stand alone, otherwise included in Separation).
- Flare

- Other Process Blocks with a small number of plumes include GenSets, Truck Loading, Treater, Water Tank, and Inlet Buildings. "tbd" or 'to be determined' was used when the Process Block could not be identified. Only 5 of 175 distinct plumes are labelled 'tbd'

Additional resources that are incorporated into the analysis includes:

- Publicly available plot plans and process flow diagrams, which can help identify Process Blocks and controlled tanks.
- AER's ST37: List of Wells in Alberta to precisely identify well locations.
- Petrinex Volumetric Reporting, used to obtain the reported Vent Volumes during the month of Campaign 3.

Understanding Persistent and Intermittent Releases

Bridger's reports products include an assessment of whether a release is 'Persistent' or 'Intermittent.'

It is likely incorrect to sum persistent and intermittent release rates to obtain a total site release rate. As discussed above, intermittent releases are a challenge to quantify accurately. A single detection does not represent the average rate of an intermittent release. Previous studies by Dr. Matt Johnson averaged the intermittent release with zero. Persistent releases are believed to be more representative of the actual release rate.

Summary of Results

The following sections review the results of the Bridger aerial surveys by individual facility type, followed by a comparison of the facility types.

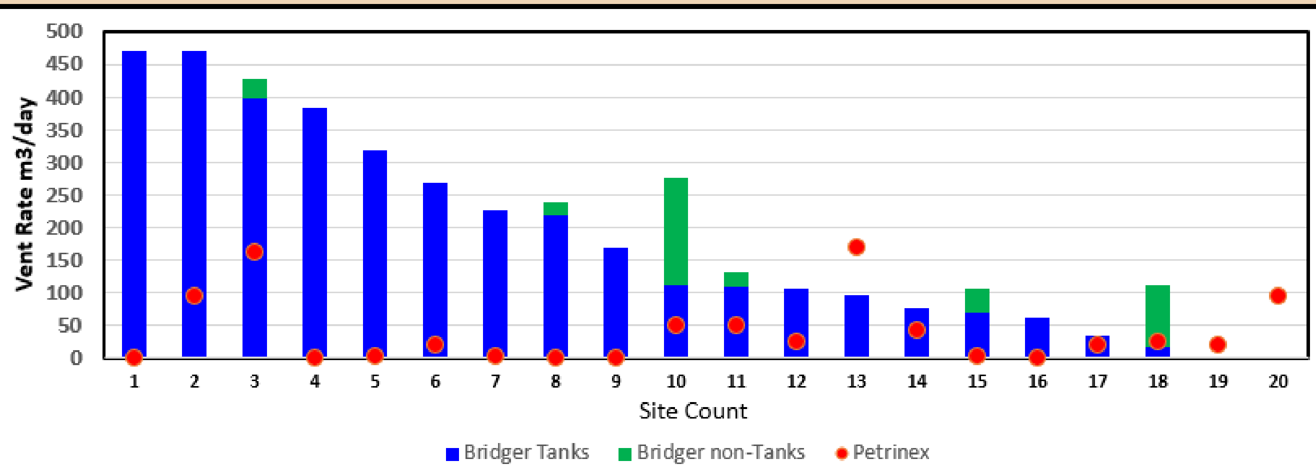
Campaign 3: Oil Single-well Batteries without Separators

Table 3.2 summarizes the Bridger Tank Emissions, Tank Emission Persistency, and non-Tank Emissions. Total Bridger emissions is the sum of tank and non-tank emissions, regardless of the persistency. Petrinex Volumes, expressed as m^3/day, are also provided. Petrinex volumes are for the month that Campaign 3 was performed, The data in Table 3.2 is also shown in chart form. See Figure 3.4.

Table 3.2: Campaign 3 - Summary of Oil Single Well Batteries without Separators

Count	Object ID	# Tanks on Site	Bridger Tank Emissions m3/day	Bridger Tank Emissions Persistency	Bridger Non-Tank Emissions m3/day	Total Bridger Emissions m3/day	Petrinex Vent Rate m3/day	Comments
1	101	1	471	Persistent	0	471	0	0.1 e3m3/month or 3.3 m3/day reported as Fuel
2	178	1	471	Persistent	0	471	97	
3	193	2	399	Persistent	29	428	163	
4	114	1	383	Persistent	0	383	0	1.4 e3m3/month or 47 e3m3/day reported as fuel
5	113	1	318	Persistent	0	318	3	
6	61	1	269	Persistent	0	269	20	
7	96	1	226	Persistent	0	226	3	
8	112	1	219	Persistent	20	239	0	1.4 e3m3/month or 47 e3m3/day reported as fuel
9	179	1	168	Persistent	0	168	0	1.4 e3m3/month or 47 e3m3/day reported as fuel
10	131	2	112	Persistent	164	276	50	
11	214	1	109	Persistent	23	132	50	
12	132	1	106	Persistent	0	106	27	
13	75	1	96	Persistent	0	96	170	
14	46	1	77	Persistent	0	77	43	
15	220	1	69	Persistent	37	106	3	
16	211	1	62	Persistent	0	62	0	0.1 e3m3/month or 3.3 m3/day reported as Fuel
17	180	1	34	Persistent	0	34	20	
18	105	1	16	Persistent	96	112	27	
19	64	2	0		0	0	20	
20	208	1	0		0	0	97	
21	102	0	0		0	0	50	No Tank, Oil P/L at lease. Well site, not a battery
22	97	1	0				0	No Oil production in Q3 Q4 2022
23	111	1	0				0	No Oil production in Q3 Q4 2022

Figure 3.4: Campaign 3 - Oil Single Well Batteries without Separators - Bridger Measurement vs Petrinex



Persistent and intermittent releases are delineated in Figure 3.5 below. Figure 3.5 also delineates releases by Process Block. The Process Blocks listed on the horizontal axis are all the Process Blocks identified from the 209 facilities surveyed.

Figure 3.5: Campaign 3 - Bridger Releases by Process Block and Persistency - Oil Single-well Batteries wo Separators

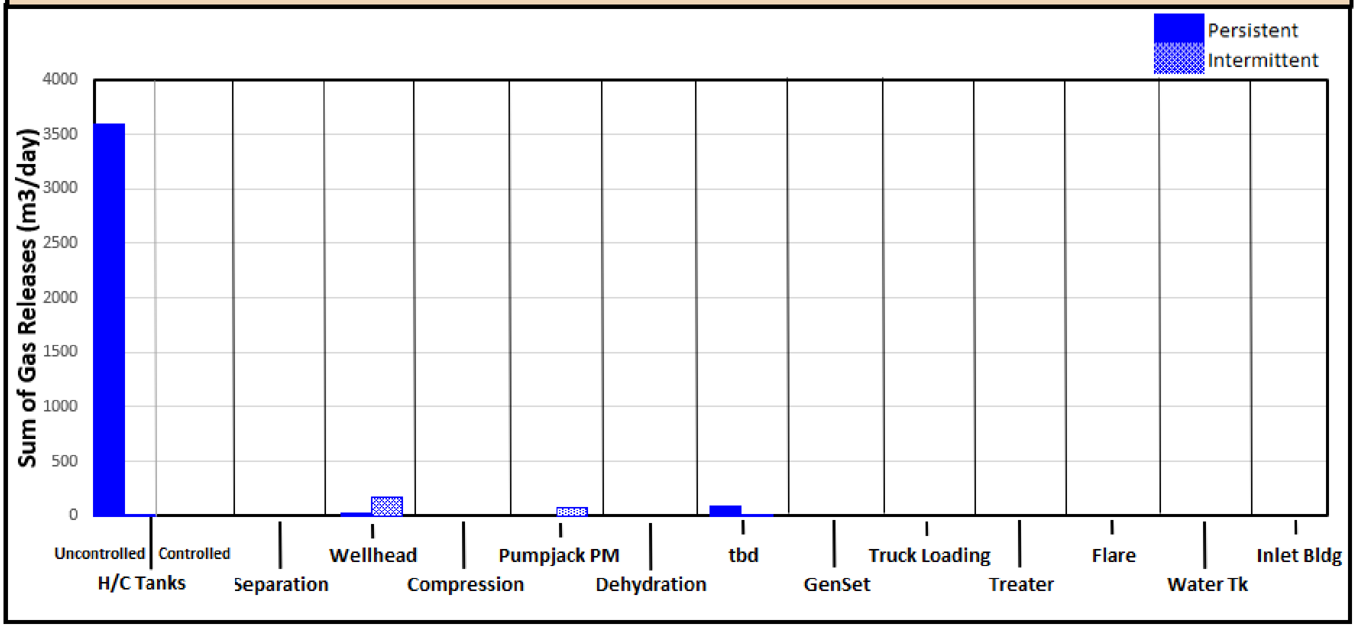


Figure 3.6 following is an example of the data collection and analysis performed. The top figure is a satellite image of the site, from ArcGIS Pro. The second image is an aerial photograph taken during the Bridger flyovers, clearly showing the well head and well shack, as well as the tanks. The 3rd image is a composite of the methane plumes detected by Bridger's GML, with the release point identified by a red circle.

Figure 3.6: Campaign 3 - Oil Single-well Battery w/o Separator

Observations from Table 3.2, and Figures 3.4, 3.5, and 3.6 include:

- Two (2) of the 23 Oil Single-well batteries without Separators were not producing during the month of Campaign 3.
- One (1) of the 23 Oil Single-well batteries without Separators has no surface equipment other than an electrified pumpjack. This site also has an oil pipeline on lease. This site is an oil well and not an oil battery as identified in Petrinex.
- Twenty-three (23) tanks are on the remaining 20 sites.
- Eighteen (18) of 20 Oil Single-well Batteries without Separators have persistent tank releases. None had intermittent tank releases.
- None (0) of the sites exceeded Directive 60's vent gas limit.
- With one exception, the Direct Measurement of all sites exceeded the reported vent volumes in Petrinex for the month of the Campaign.
- Five (5) sites did not report venting to Petrinex.
    - All 5 sites had persistent tank vents.
    - All 5 sites reported Fuel to Petrinex.
        - Three (3) sites reported 1.4e3m^3/month or 47 m^3/day fuel use, which suggests there is additional equipment other than a pumpjack prime mover that consumes fuel. There may be tank heaters for example.
- Persistent Tank venting contributes > 90% of emissions from Oil Single Well Batteries without Separators.
- Intermittent releases were seen at pumpjack prime movers (3 sites) and at the well head (1 site)
- The process block for one (1) persistent release could not be identified and is shown as 'to be determined' or tbd. This happens on occasion, when the estimated release location does not align well with any visible process equipment.

Conclusions from this Data Set

- Oil Single-well batteries without Separators are a likely source of continuous tank vents.
- Unlike the 12 Oil Single-well Batteries without Separators studied in Campaign 2, the estimate of tank vents using Bridger's GML is higher than the vent rate reported to Petrinex. Twelve different (12) operators with Oil single-well Batteries without Separators, with possible different approaches to estimating vent gas.

Recommendations from this Data Set

- Continue to work with Operators to identify methodologies used to estimate tank vent rates for Petrinex Volumetric reporting.
- Investigate opportunities for gas conservation or combustion and offset generation at Oil Single-well Batteries without Separators.

Campaign 3: Oil Single-well Batteries

Consistent with the presentation of results above, results from the 83 Oil Single Well Batteries are provided below.

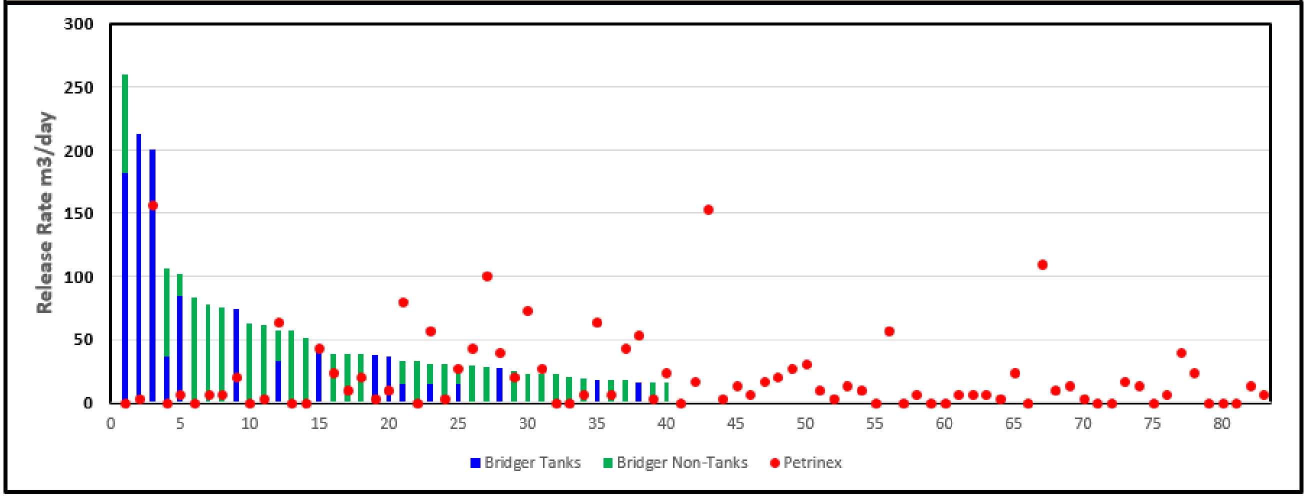
Table 3.3 summarizes the Bridger Tank Emissions, Tank Emission Persistency, and non-Tank Emissions. Total Bridger emissions is the sum of tank and non-tank emissions, regardless of the persistency. Petrinex Volumes, expressed as m^3/day, are also provided,

The data in Table 3.3 is also shown in chart form. See Figure 3.7.

Table 3.3: Campaign 3 - Summary of Oil Single Well Batteries with Bridger Tank Detections

Count	Object ID	# Tanks on Site	Bridger Tank Emissions m3/day	Bridger Tank Emissions Persistency	Bridger Non-Tank Emissions m3/day	Total Bridger Emissions m3/day	Petrinex Vent Rate m3/day	Comments
1	161	1	213	Persistent	0	213	3	
2	123	3	200	Persistent	0	200	157	
3	8	4	182	Persistent	78	260	0	Controlled Tank
4	51	5	85	Intermittent	17	102	7	Controlled Tank
5	199	1	74	Intermittent	0	74	20	
6	17	1	43	Persistent	0	43	43	
7	83	1	37	Intermittent	0	37	3	
8	185	2	36	Intermittent	70	106	0	
9	117	1	36	Intermittent	0	36	10	
10	42	1	33	Persistent	24	57	63	
11	143	4	27	Persistent	0	27	40	
12	124	1	18	Intermittent	0	18	63	
13	206	1	16	Intermittent	0	16	53	
14	115	1	15	Intermittent	16	31	57	
15	207	2	15	Intermittent	14	29	27	
16	137	1	14	Intermittent	19	33	80	

Figure 3.7: Campaign 3 Oil Single Well Batteries Bridger Tank and Non-Tank releases verses Petrinex Vent



Persistent and intermittent releases are delineated in Figure 3.8 below. Figure 3.8 also delineates Bridger detections by Process Block.

Figure 3.8: Campaign 3 - Bridger Releases by Process Block and Persistency - Oil Single-well Batteries

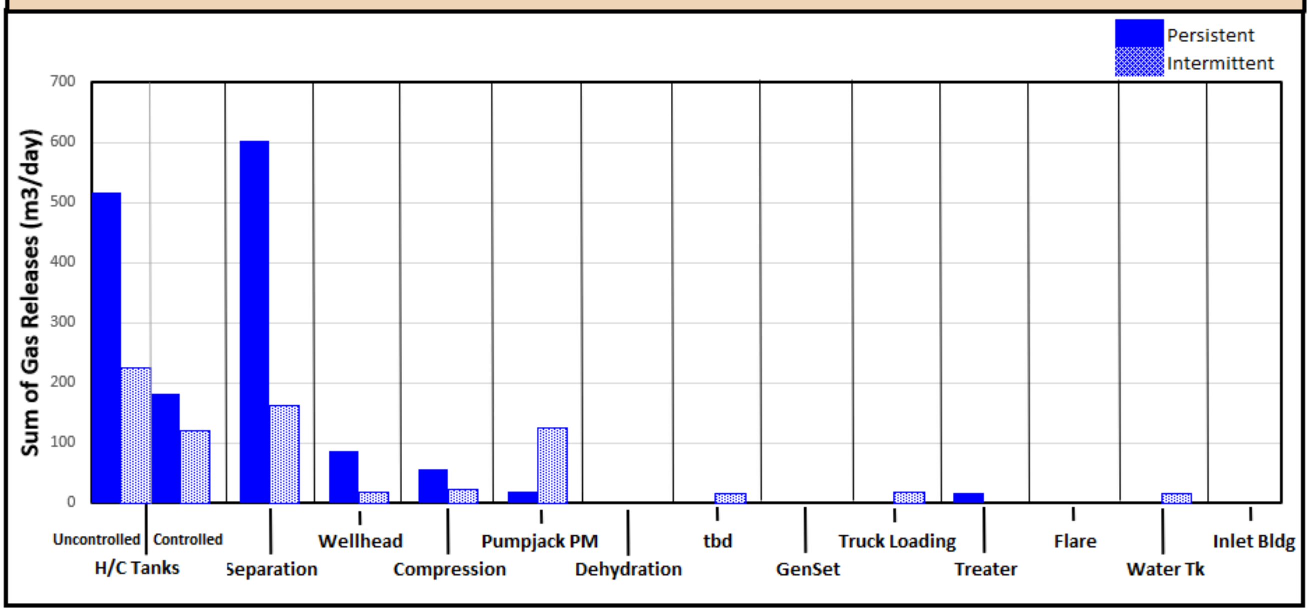


Figure 3.9 is another example of the data collection and analysis performed. The top figure is a satellite image of an Oil Single–well Battery from ArcGIS Pro. The second image is an aerial photograph taken during the Bridger flyovers, clearly showing the well head and well shack on the right, separator building and POP tank, and a single tank within an oval dyke. The 3rd image is a composite of the methane plumes detected by Bridgers GML, with the release point identified by a red circle.

Table 3.9: Campaign 3 - Oil Single Well Batteries Bridger Review

Observations from Table 3.3, and Figures 3.7, 3.8, and 3.9 include:

- One Hundred and Thirty–Seven (137) tanks on 83 Oil Single–Well Batteries
- Six (6) of 83 Oil Single–well Batteries have persistent tank releases, or 7%
  - One (1) of the 6 cites was a controlled tank.
- Ten (10) of 83 Oil Single–well Batteries have intermittent tank releases, or 12%.
  - One (1) of the 10 sites was a controlled tank.
- Thirty–one (31) of 83 sites had non–tank releases
- Forty–three (43) sites had no Bridger detections, or 52%.
  - Of these 43, 31 reported Vent volumes to Petrinex
  - Of the 31, 26 report volumes below 30 m^3/day
- Persistent vents from Separation are the largest category of releases, followed by persistent vents from uncontrolled tanks.
- Intermittent releases are 30% of the total (assuming that the intermittent release rate is representative of the average release rate)
- Sites with persistent tank releases > 100m^3/day tend to be underreported in Petrinex.
- Sites with total releases (both persistent and intermittent) < 35m^3/day tend to be over reported in Petrinex. This likely makes sense, given that 35m^3/day is well below Bridgers stated detection threshold, and Petrinex volumes are likely the sum of several small releases that would be difficult for Bridger to detect.

Conclusions from this Data Set

- Only a small number of Oil Single–well Batteries (with Separators) have emissions > 100 m^3/day, with the largest source of emission being persistent releases from hydrocarbon storage tanks.
- Releases from Separators are, in aggregate, a large contributor to the releases. Separator emissions could include fugitives or vents from pneumatic devices, pneumatic pumps and the pop tanks.
- Intermittent releases may be a significant contributor to emissions, but this is difficult to confirm due to the challenges of quantifying intermittent releases.

Recommendations from this Data Set

- Oil single–well batteries are simple in design and therefore relatively simple to study. Identify a statistically significant sample size, perform Bridger screening, and follow–up with ground crews to:
  - Investigate sites with Bridger detections < 35 m^3/day and Petrinex monthly volumes > 35 m^3/day,
  - Investigate all sites with persistent tank vents > 100 m^3/day

- Investigate all sites with persistent releases from Separators > 50 m^3/day
- Identify sites for future Direct Measurement/Bridger study

Campaign 3: Oil Multiwell Batteries

Consistent with the above analysis for Oil Single-well Batteries with or without Separators, Bridger results and analysis for the 47 Oil Multiwell Batteries are provided below.

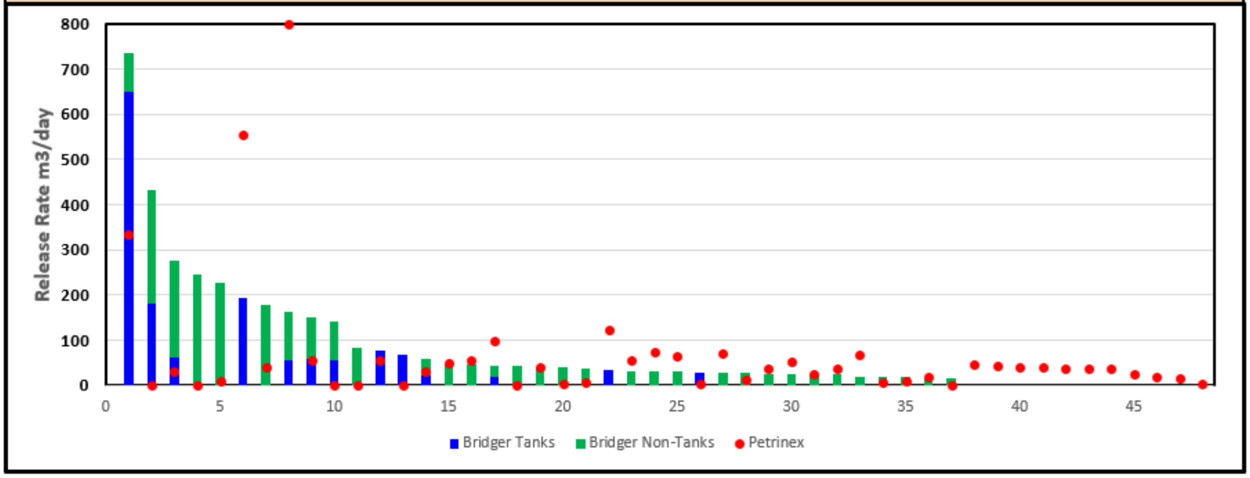
Table 3.4 summarizes the Bridger Tank Emissions, Tank Emission Persistency, and non-Tank Emissions. Total Bridger emissions is the sum of tank and non-tank emissions, regardless of the persistency. Petrinex Volumes, expressed as m^3/day, are also provided,

The data in Table 3.4 is also shown in chart form. See Figure 3.10.

Table 3.4: Campaign 3 - Summary of Oil Multiwell Batteries with Bridger Tank Detections

Count	Object ID	# Tanks on Site	Bridger Tank Releases m3/day	Bridger Tank Releases Persistency	Bridger Non-Tank Releases m3/day	Total Bridger Releases m3/day	Petrinex Vent Rate m3/day	Comments
1	50	2	648	Persistent	87	735	333	
2	118	6	194	Persistent	0	194	553	
3	104	4	180	Persistent	252	432	0	Controlled Tank
4	10	4	78	Persistent	0	78	57	
5	135	2	69	Persistent	0	69	0	
6	41	1	62	Intermittent	213	275	30	
7	31	2	57	Intermittent	94	151	57	
8	11	2	56	Persistent	85	141	0	
9	106	4	54	Intermittent	109	163	1353	40 e3m3/month reported for 9 of previous 12 months
10	194	2	35	Intermittent	0	35	123	
11	129	1	28	Persistent	0	28	3	
12	151	1	21	Intermittent	36	57	30	
13	153	2	18	Persistent	26	44	97	Controlled Tank

Figure 3.10: Campaign 3 - Oil Multiwell Batteries - Bridger Tank and Non-Tank Releases verses Petrinex Vent



Persistent and intermittent releases are delineated in Figure 3.11 below. Figure 3.11 also delineates Bridger detections by Process Block.

Figure 3.11: Campaign 3 - Bridger Releases by Process Block and Persistency - Oil Multiwell Batteries

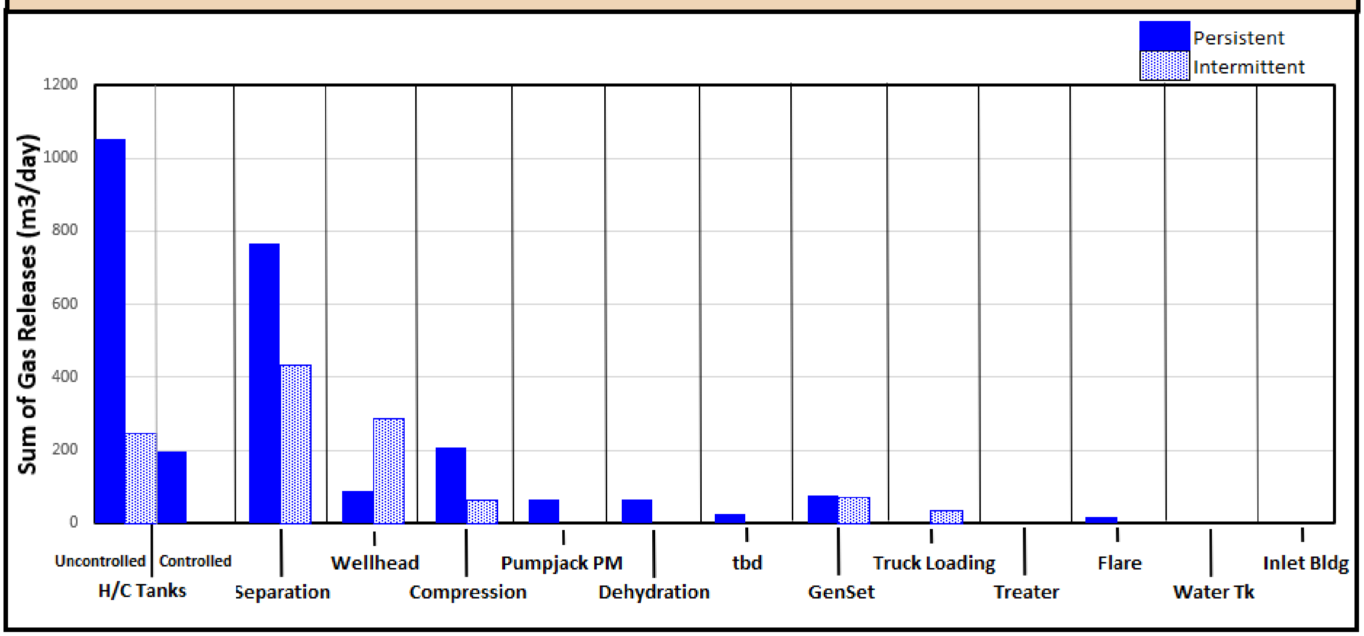


Figure 3.12 is an example of Bridger's images and plumes for an Oil Multiwell Battery. The top figure is a satellite image from ArcGIS Pro. The second image is an aerial photograph taken during the Bridger flyovers, clearly showing one pumpjack in the NE

corner, another pumpjack with two Separator Buildings in the middle, and 2 tanks inside an oval steel dyke to the south. The third image is a composite of the methane plumes detected by Bridgers GML, with the release points identified by a red circle.

Figure 3.12: Campaign 3 - Oil Multiwell Batteries - Bridger Review

Observations from Table 3.4, and Figures 3.10, 3.11, and 3.12 include:

- Ninety-nine (99) tanks on 43 Oil Multiwell Batteries.
- Seven (7) of 43 Oil Multiwell Batteries have persistent tank releases, or 16%
    - Two (2) of the 7 persistent releases are controlled tanks
- Six (6) of 43 Oil Multiwell Batteries have intermittent tank releases, or 14%
- Thirty (30) of 43 Batteries do *not* have tank releases as per Bridger, or 70%
- Six (6) of 43 sites have no Petrinex Vent volumes. All 6 have Bridger releases.
- One site had exceptionally high Vent volumes reported to Petrinex. 40e3m^3/month or 1350 m^3/day! Bridger identified 109 m^3/day of persistent release from the Dehydrator and Separation process blocks. Tanks had an intermittent vent rate of 54m^3/day.

Campaign 3: Gas Single-well and Multiwell Batteries

Following the data presentation above, results for Gas Single-well and Multiwell Batteries is presented in the tables and figures following.

Observations from Tables 3.5 and 3.6. and Figures 3.13, 3.14, 3.16 and 3.17 include:

- Four (4) of 44 Gas Single Well Batteries had tank vents, or 9%
- Three (3) of 12 Gas Multiwell Batteries had tank vents, or 25%
- Tanks Vents can be both persistent and intermittent.
- With the exception of one large intermittent vent at a Gas Single-well Battery, the average Bridger releases are well below the average Petrinex reported vent volumes.
- Total releases from Separation process block is almost equal to the total releases from uncontrolled tanks.

Table 3.5: Campaign 3 - Summary of Gas Single-well Batteries with Bridger Tank Detections								
Count	Object ID	# Tanks on Site	Bridger Tank Releases m3/day	Bridger Tank Releases Persistency	Bridger Non-Tank Releases m3/day	Total Bridger Releases m3/day	Petrinex Vent Rate m3/day	Comments
1	80	1	448	Intermittent	24	472	3	
2	67	1	58	Persistent	0	58	0	
3	200	2	32	Persistent	36	68	30	
4	108	1	15	Intermittent	34	49	0	

Figure 3.13: Campaign 3 - Gas Single-well Battereis - Bridger Tank and Non-Tank Releases verses Petrinex Vent

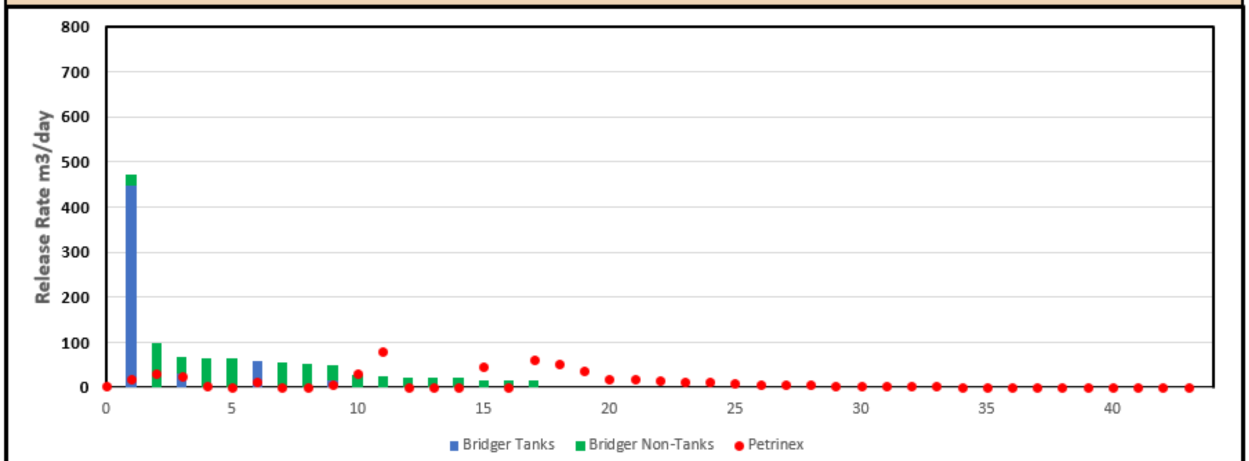


Figure 3.14: Campaign 3 - Bridger Releases by Process Block and Persistency - Gas Single-well Batteries

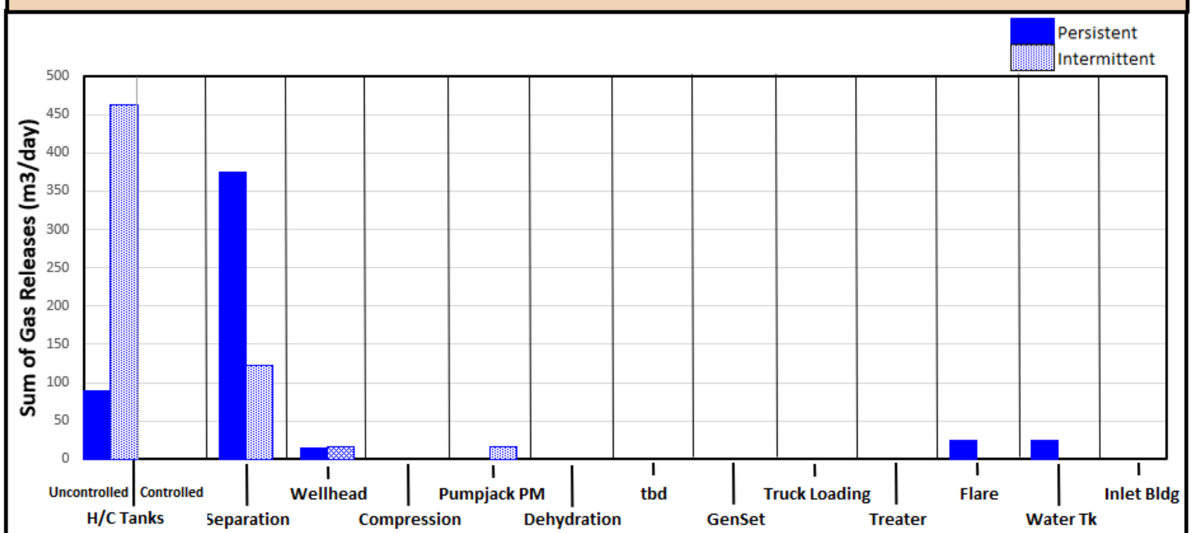


Figure 3.15: Campaign 3 - Gas Single-well Batteries - Bridger Review

Table 3.6: Campaign 3 - Summary of Gas Multiwell Batteries with Bridger Tank Detections

Count	Object ID	# Tanks on Site	Bridger Tank Releases m3/day	Bridger Tank Releases Persistency	Bridger Non-Tank Releases m3/day	Total Bridger Releases m3/day	Petrinex Vent Rate m3/day	Comments
1	80	2	173	Persistent	0	173	3	
2	67	3	79	Persistent	176	255	220	Controlled Tanks
3	200	2	43	Intermittent	200	243	0	Controlled Tanks

Figure 3.17: Campaign 3 - Gas Multiwell Batteries - Bridger Tank and Non-Tank Releases verses Petrinex Vent

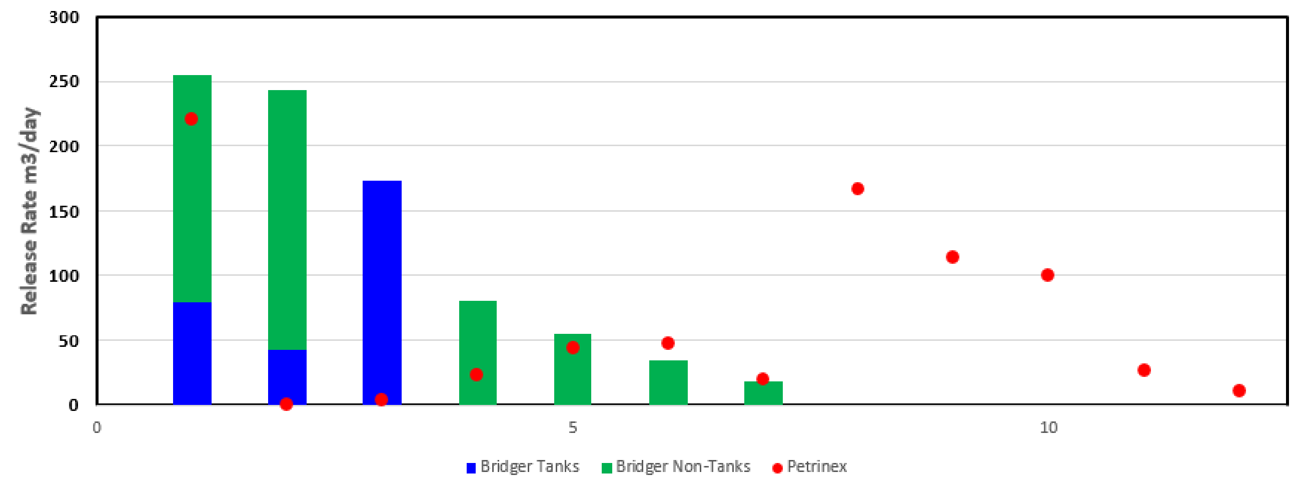
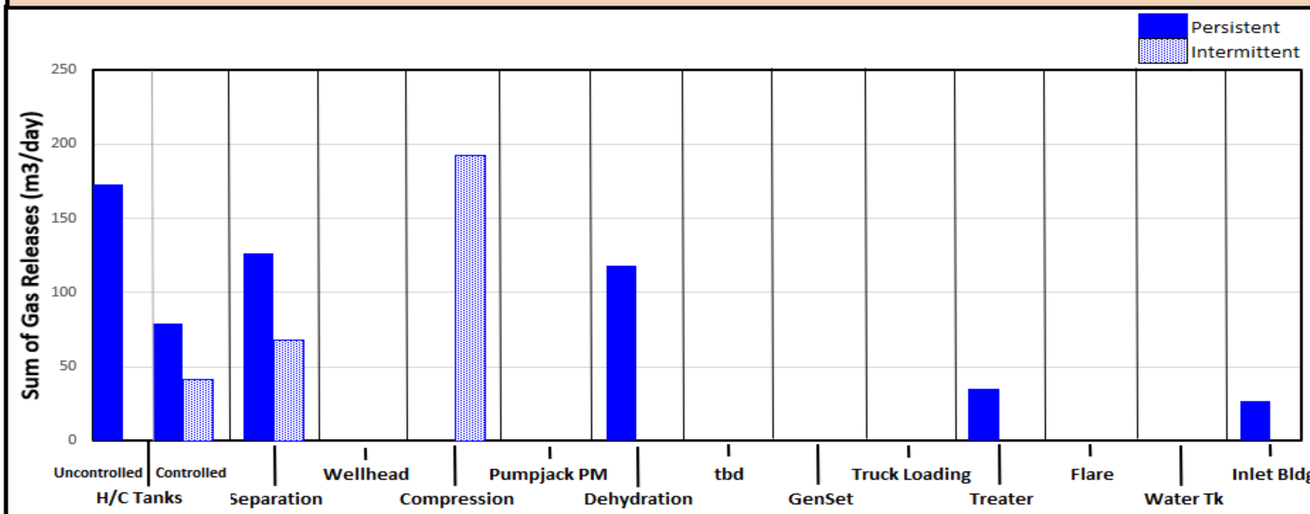


Figure 3.18: Campaign 3 - Bridger Releases by Process Block and Persistency - Gas Multiwell Batteries



Comparison of Persistent and Intermittent Releases by Facility Type and Process Block

Figure 3.19a and 3.19b, below, attempts to show a large data with a simple 3-axis bar chart.

Persistent releases are shown in sold blue. Intermittent releases are shown in a textured blue. The various process blocks are along the x axis, and the 5 facility types are on the z access.

Figure 3.19a is the entire data set from Campaign 3. Figure 3.19b is the identical data set, but the process blocks with relatively small emissions are not show, and the y-axis scale has been adjusted to crop the highest release to provide more detail of the smallest releases.

Persistent releases from tanks at OSWBwoS, OSWB, and OMWB dominate the inventory, followed by persistent releases from Separator blocks at OSWB, OMWB, and GSWB.

Figure 3.19: Campaign 3 - Persistent and Intermittent Releases by Process Block and Facility Type

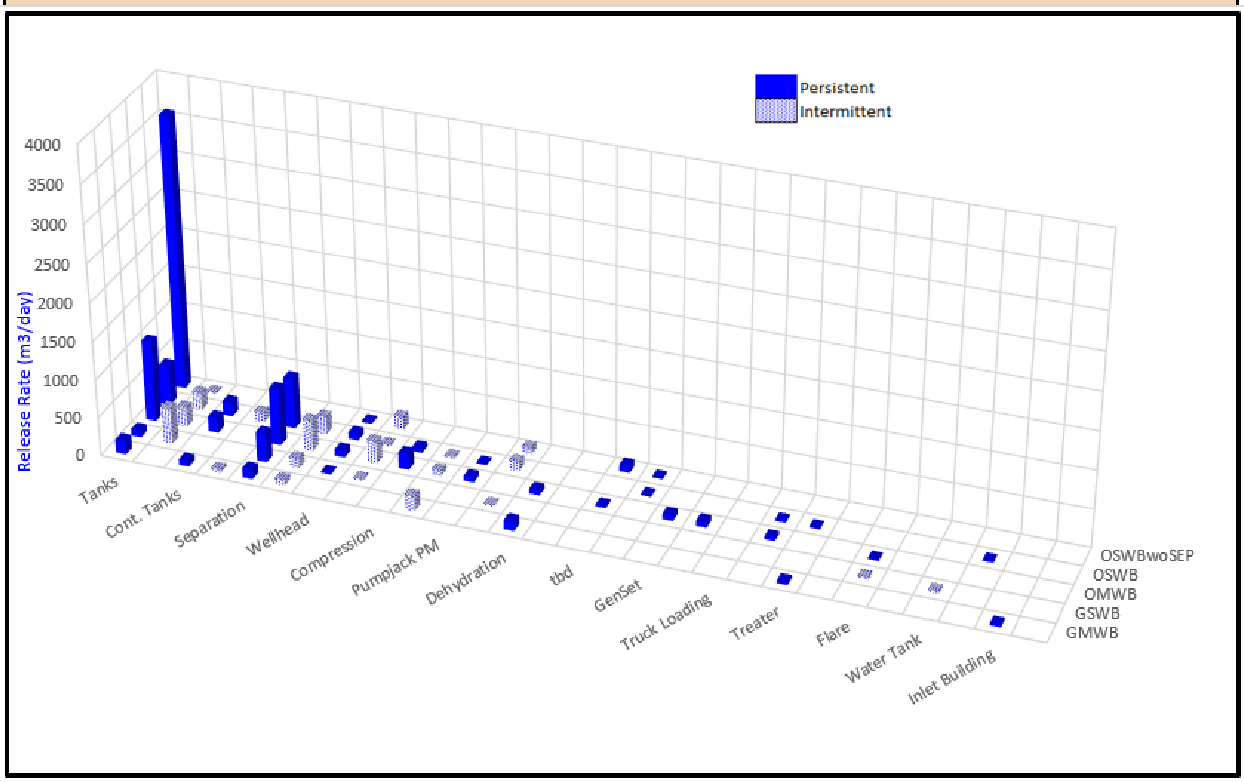
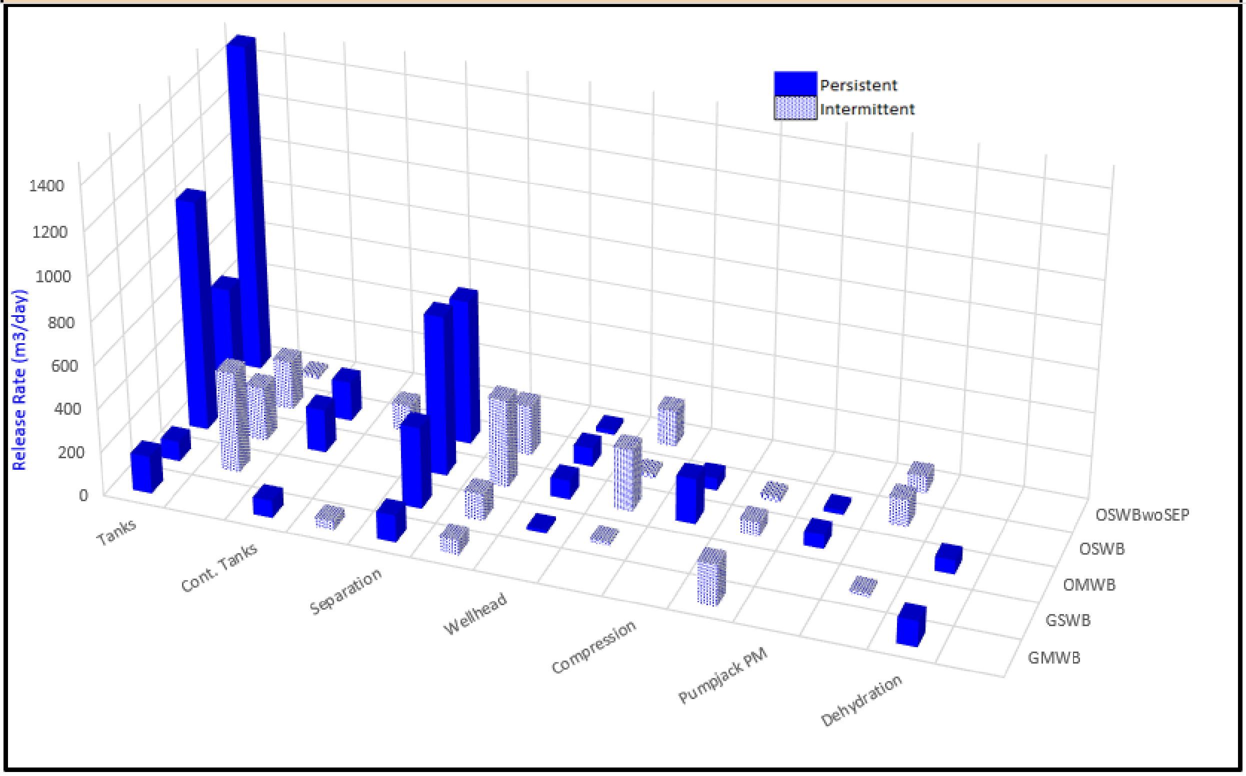


Figure 3.19: Campaign 3 - Persistent and Intermittent Releases by Process Block and Facility Type



Summary of Observations, Conclusions, and Recommendations

The following is a list of key Observations, Conclusions, and Recommendations made throughout the report, with page numbers provided in parentheses.

- The estimated inventory of production tanks at conventional oil and gas batteries in Alberta is approximately 12,000. 88% o the tanks at are oil batteries, split almost equally between single-well and multiwell facilities (pg. 3, 7, 31)

- We estimate that 1,200 to 1,500 of the 5,400 Crude Oil Single-well Batteries do not have separators (pg.3, 60)

- Recommend a desktop study to estimate the number and location of controlled and uncontrolled hydrocarbon storage tanks in Alberta (pg. 32)

- Temporal characteristics of tank vents can be described as persistent and constant, persistent and fluctuating, persistent and fluctuating and cyclic, and intermittent. (pg. 8, 9, 48, 49, 50, 51, 52)

- Calscan's Hawk 9000 Data Logger and Turbine Meter has proven to be a reliable and accurate vent gas meter. It is battery operated and intrinsically safe, making it ideal for studies of this kind (pg. 15, 35, 45, 61)

- Vertex Ltd developed confidence in quantifying persistent and intermittent tank vents using FLIR's GFx320 OGI camera and FLIR/Providence QL320 quantification tablet. Quantification improves with visible line of site to the vent, and extended survey times (pg. 15, 45, 61, 62, 70-81, Appendix 3)

- Recommend further field work to refine and document Vertex's methodology using FLIR's OGI/QOGI for tank vents. (pg. 15, 62)

- Kuva's Continuous OGI Camera's unique benefits include continuous non-contact emission detection and quantification from multiple sources. Limitations include daylight operation only. Winter operation may be limited due to low or insufficient solar illumination (pg. 16, 38, 45, 56-59, Appendix 2)

- Bridger's Gas Mapping LiDAR (GML) is an effective aerial technology for quickly screening for intermittent and persistent releases from tanks. (pg 16, 37, 84-88)

- Area-based Aerial Detection and Quantification Surveys are a valuable and effective way of establishing a methane inventory of persistent and intermittent releases by facility type and process block, including tanks (pg. 4, 11, 12, 41, 43, 90, 94, 98, 101, 103, 104, 105)

- Area-based Aerial Detection and Quantification Surveys can also support valuable research studies while establishing a methane inventory for the area. Include local wind measurements to determine impact on quantification accuracy. Integrate with other detection technologies. Semi-annual or annual surveys will identify any trends in methane emissions. (pg. 4, 11, 12, 16)

- Recommend additional Area-based Aerial Detection and Quantification surveys across Alberta ((pg. 4, 11, 12, 16)

- Campaign 1's area-based aerial survey demonstrated that uncontrolled hydrocarbon tanks contributed only 13% to the area's total emissions (pg. 5, 10)

- Oil Single-well Batteries without Separators will vent persistently at 50 to 500 m3/day (pg. 3, 13, 49, 51, 52, 55, 70-76, 87-81, 89)

- Oil Single-well Batteries without Separators are a major source of tank vent emissions. (pg. 5, 11, 40)

- In total, tanks contribute 25% of an area's total methane emissions. This aligns closely with other studies. However, half of the 25% are leaks from VRU's on controlled tanks, and a third of the 25% are vents from oil single-well batteries *without* separators. Only one sixth of the 25% (or 4% of the total) are vents from oil or gas batteries with separators. (pg. 5, 10, 11)

- Recommend Oil Single-well Batteries without Separators be investigated further to confirm persistent releases and to identify vent reduction opportunities (pg. 5, 13, 41)

- Batteries with Separators, either Oil or Gas, Single or Multiwell, will vent intermittently with an average vent rate typically between 5 m3/day and 50 m3/day (pg. 4, 54, 77, 93, 97, 101, 103)

- Batteries with Separators, either Oil or Gas, Single or Multiwell, can indeed vent persistently at rates up to or exceeding 500 m3/day, but this is indicative of mechanical issues at the separator, design issues with the separator, or upstream well issues (pg. 4, 48)

- Recommend PTAC AUPRF host a workshop with subject matter experts to identify root causes of persistent tank venting due to mechanical issues at the separator, design issues with the separator, or upstream well issues, and to identify monitoring, mitigation, and reporting best practices (pg. 4

- While it has been widely assumed that tank venting has been under reported in Petrinex, the study suggests otherwise. Campaign 2 showed that sites were indeed underreporting tank vents prior to 2020, but reporting has improved since 2020. Campaign 3 showed the sum of Bridger releases was within 25% of Petrinex volumes for oil batteries with separators. (pg. 14, 64–69, 89, 94, 98, 101, 103).

- Methane concentration of tank vents variable between 73% and 88% (pg. 47, 63)

Manual **015**

Estimating Methane Emissions

December 2020

4.2.2 Storage Tank Venting

Liquids stored in uncontrolled tanks (without vapour recovery units or vapour destruction) can be a source of vent gas through flashing, breathing losses, and working losses.

Vent gas from uncontrolled, open atmospheric tanks that arise due to the processes described in the following subsections should be estimated based on best available information and methods described below and reported as DVG.

Vent gas emissions from controlled tanks that arise due to maintenance or periodic, planned, or unplanned shutdowns of vapour recovery or vapour destruction systems should be determined by engineering estimates and reported as nonroutine vent gas.

Gas emissions from controlled tanks that arise due to stuck or malfunctioning thief hatches or failures of equivalent pressure-management devices should be determined by engineering estimates and reported as fugitive emissions.

Gas may be emitted from tank vents when pneumatic level controllers upstream of the tank malfunction. This may entrain undesired gas volumes in liquid flow lines to tanks, which may then be vented through tank vents (i.e., gas carry-through). If detected, these abnormal process emissions should be determined by engineering estimates and reported as fugitive emissions.

Fixed-roof tanks are the primary equipment for storing hydrocarbon liquids (oil and condensate) in the upstream oil and gas industry. If a tank is equipped with a vapour collection system, there is still a potential for some emissions due to potential inefficiencies of the vapour collection system—for example, due to overloading of the system due to inadequate sizing for peak emission rates, down time of the end control device, fouling of the vapour collection piping, etc. These emissions would be considered nonroutine vent gas. Additionally, tanks connected to vapour collection systems can be a source of fugitive equipment leaks (mostly due to leakage around the thief hatch or level gauge seal), see section 1.1.2.

Venting from fixed-roof tanks includes contributions from the following:

- flashing losses
- breathing losses
- working losses
- blanket gas losses

For quantification of produced gas, if a gas-in-solution (GIS) factor is determined that represents the vented gas volumes, it may be used. For sites configured with multiple pressure drops, commingled streams, or other liquids processing, reportable vent volumes may not equate well to GIS factors determined for production measurement requirements. In these cases, other methods for estimating vent volumes are provided below for each of the types of losses, flashing, breathing, and working.

4.2.2.1 Flashing Losses

Flashing may occur when liquids with dissolved gases that have a vapour pressure greater than local barometric pressure are produced into vented storage tanks. When the liquid first enters a tank, a rapid boiling or flashing process occurs as the liquid tends towards a more stable state and the volatile components vapourize. The dissolved gas that flashes out of the liquid is called gas in solution (GIS). A GIS factor is given in equation 3.

$$V_{GIS} = V_{liq} \times GIS \tag{3}$$

V_{GIS}	GIS venting in a month [m^3]
GIS	GIS factor for the stored hydrocarbon product [m^3 of gas/m^3 of oil] where gas volumes are presented on a dry basis at reference conditions 101.325 kPa and 15° C
V_{liq}	Monthly volume of liquid hydrocarbon entering the subject tank [m^3]

All methods of quantifying vent gas emissions that are listed in section 4.1 are acceptable for determining the GIS factor. For estimation methods based on publicly available studies, if the oil can be assumed to be saturated with gas, and conditions are relevant to the dataset used to develop the correlation, a bubble-point pressure correlation may be used. Otherwise use estimation methods based on engineering specifications or where appropriate, use the GIS factor "rule of thumb" from *Directive 017*.

Bubble-Point Pressure Correlation – Vazquez and Beggs

Repeated analyses of various production oils have been compiled into useful references for estimating the GIS that will evolve from saturated oils as they undergo pressure drop. The Vazquez and Beggs correlation is widely cited as the most accurate and comprehensive. Other correlations include Lasater or Standing correlations but are not referenced here further. Duty holders may use the Vazquez and Beggs correlation to estimate vent gas from flashing saturated oils to atmospheric pressure and directed towards tanks (Vazquez and Beggs 1980).

The Vasquez and Beggs correlation is based on a regression of experimentally determined bubble-point pressures for a variety of crude oil systems. The range of parameters for which the correlation is derived is presented in table 16. It is accurate to within 10% more than 85% of the time when input data in the range of values listed in table 16 are used.

If a suitable correlation is not available, the duty holder may apply other methods to determine emission rates described in section 4.1 or the GIS factor "rule of thumb" from *Directive 017*.

Table 16. Range of data used to develop the Vasquez & Beggs correlation (from Vazquez and Beggs 1980)

Parameter	Range
Size of dataset	5008
Bubble pressure, kPa	345 to 36 190
Reservoir temperature, °C	21 to 146
Solution gas-to-oil ratio at bubble-point pressure, m^3/m^3	3.5 to 369
Oil API gravity, °API	16 to 58
Oil Specific gravity, (-)	0.56 to 1.18

4.2.2.2 Breathing and Working Losses

Evaporative losses promoted by daily temperature or barometric pressure changes during the storage of hydrocarbons are known as breathing losses. Evaporative losses during filling and emptying operations are known as working losses and are caused by the displacement of tank vapours during changes in liquid level. Breathing and working losses occur for both stable and unstable products. However, if the product is unstable, the latter type of loss is obscured by the flashing losses. Accordingly, storage losses at oil wells or batteries are taken to be the sum of breathing and flashing losses. Storage losses at gas processing plants and pipeline terminals (i.e., facilities storing stable products) are taken to be the sum of breathing and working losses.

Mass emissions of product vapours from tanks (i.e., breathing and working) containing weathered or stabilized hydrocarbon liquids are estimated using the “Evaporative Loss from Fixed-Roof Tanks” algorithms (US EPA 2006).

Blanket gas may be added to a tank’s dead space to maintain a safe atmosphere above the liquids. For tanks equipped with a blanket gas system, the volume of blanket gas supplied to a tank is a reasonable analogue for estimating working and breathing losses.

4.2.3 Hydrocarbon Liquid Loading Losses

Tank trucks transport low-vapour-pressure (LVP) products such as crude oil, condensate, and pentanes plus. Emissions due to the displacement of tank vapours (i.e., evaporated product) can occur during the loading of these carriers. The volume of emissions depends on the vapour pressure of the liquid product, the recent loading history, and the method of loading. When not measured or when the estimation approaches discussed in section 4.1 are not employed, LVP carrier emissions may be quantified using equation 4.

$$V_{LL} = \frac{SF \times P_v \times T_{std}}{P_{std} \times T_t} \times V_{oil} \tag{4}$$

V_{LL} volume of gas vented from evaporation losses during LVP product loading in a month [m^3]

SF saturation factor in table 17 to account for the method of loading [dimensionless]

V_{oil} monthly volume of the LVP product loaded [m^3]

About Kuva

Kuva Canada provides visual continuous methane monitoring with its proprietary shortwave infrared camera and cloud solution for upstream and midstream oil and gas industry. Kuva Canada Inc. is based in Calgary and was founded in 2018 as a subsidiary of Kuva Systems (based in Cambridge, MA). Kuva has become the leading solution for camera-based continuous monitoring for methane and VOC emissions at oil and gas sites. The Kuva solution is a breakthrough because it provides a continuous, visual methane detection solution that has by far the lowest price point of all infrared (IR) cameras available globally. Moreover, it is ruggedized, built on modern cloud technologies, and can be deployed at large scale (eventually tens of thousands of cameras per year) to enable the oil and gas industry to find and fix methane emission fast and to gain deeper operational insights into what causes emissions events in the first place. Kuva's detection results have recently been confirmed by blind testing at the Methane Emissions Technology Evaluation Center (METEC) of Colorado State University as a leading continuous monitoring solution and as the only one with no false positive alarms and 100% leak pinpointing capabilities.

Project Scope and Objectives

As part of this project, Kuva cameras were installed at 16 upstream production sites in the SPOG area for a period of at least 2 weeks per site from September 2021 to September 2022. The Kuva cameras were mounted on relocatable 30 ft tall towers. See the image below for an example of one deployment.

A portion of these sites had alternative emission monitoring methods employed for a portion of the Kuva Camera deployment. The variety of measurement methods that were deployed helped inform what was going on at the wellhead. Each technology provided a slightly different approach to the overall evaluation of the site emissions.

The gas and liquid sampling and analysis that was performed on a handful of the sites was useful in developing a better understanding of the chemical and physical properties of emissions from upstream sites and how these differences were observed with the Kuva camera. The data gathered during these deployments from other technologies has been and will continue to be helpful in developing and comparing the Kuva detection and quantification methodologies under a range of circumstances that cannot be easily replicated in a controlled environment.

The project also served as a valuable demonstration of the benefits of Kuva’s continuous image based monitoring compared to the other technologies deployed in the project.

Description of the Technology

The Kuva GCI360 camera is a continuous Optical Gas Imaging (OGI) camera that uses a passive Shortwave Infrared (SWIR) sensor to detect hydrocarbon gas emissions. The system can be permanently installed or can be deployed temporarily. The entire system can be set up in less than two hours and is fully self-contained, cloud connected and autonomous, so it can be left in place to operate indefinitely and remotely. The camera operates by scanning each region-of-interest repeatedly to detect and measure emissions from a distance, while pinpointing emissions to their source. Emissions images are processed on the camera in real-time and uploaded over an ethernet connection or via LTE modem.

What makes the GCI360 affordable is the nature of operation of the camera. Rather than using a large format, expensive sensor, it uses a single pixel and scans it across the scene in a 2D raster pattern to generate imagery that gets processed right on the camera. A variety of algorithms then shape and evaluate this scan data to generate images that clearly show the absence or presence of emissions across the facility.

The Kuva camera captures a visible image along with a short wave infrared (SWIR) image approximately once per minute and stores that data on the camera until it is confirmed to be received by the cloud. The images are preprocessed on the device and further filtering is done at regular intervals (hourly or daily, depending on the purpose) by a human reviewer in order to provide a zero-false-positive service to the customers. Once an emissions event is confirmed, it is then accessible to the customer immediately via the Kuva dashboard. Quantification is an additional service that will be commercially available in early 2023 and allows for every event to be quantified.

Example Results

The results from a single site where the Calscan turbine meter was deployed concurrently is presented in this section. The image to the right is captured from the visible camera inside the Kuva camera and shows the turbine meter installed on the top of the tank.

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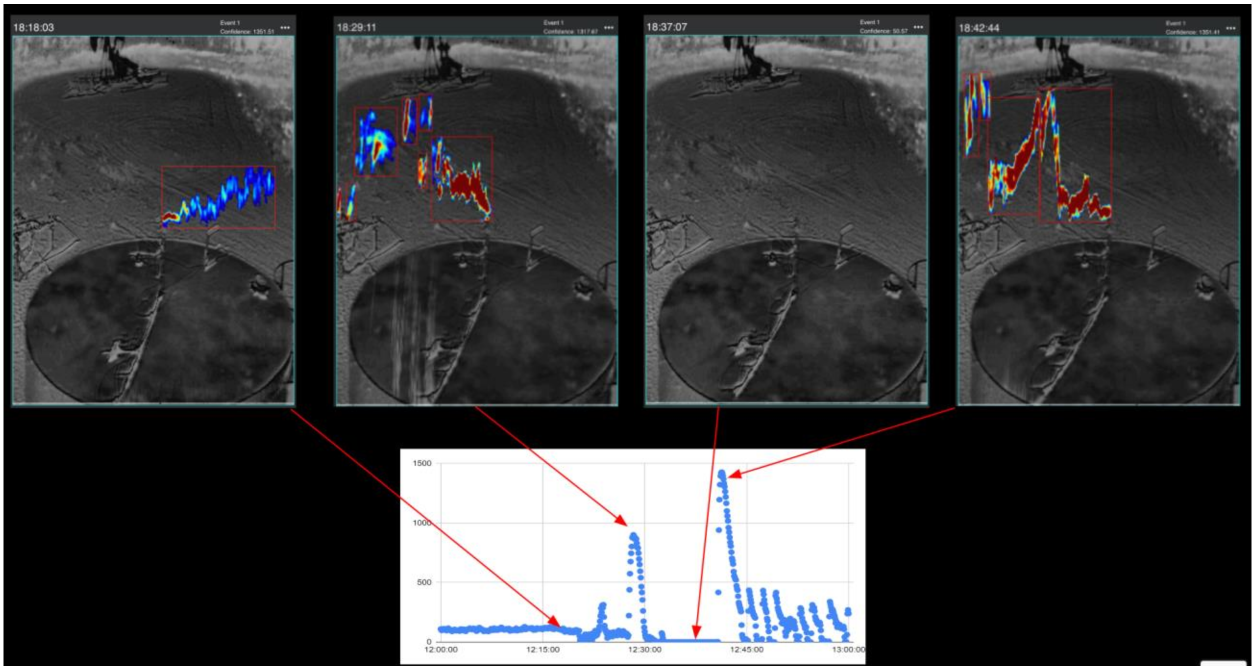
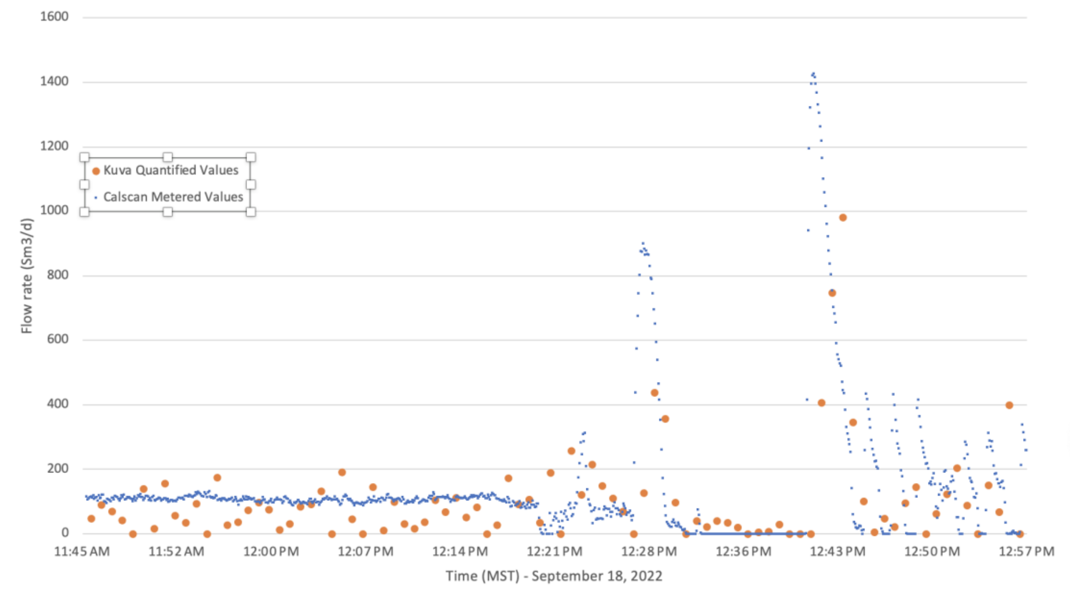
Presented below is an image with an inset graph that shows an excerpt from the turbine flow meter data with the corresponding gas detection images as provided by Kuva. The SWIR images are grayscale and the detected gas is overlaid in colour, with red pixels indicating higher column density (ppm-m) and blue pixels indicating lower column density. The magnitude of the detections in the images clearly corresponds to the relative flow rate as measured by the turbine meter; the images with larger plumes that contain red pixels correspond to the moments that have higher metered gas flow. The images as shown have their timestamp recorded (in UTC timezone) and were compared with the timestamped data from the turbine meter (in MDT timezone).



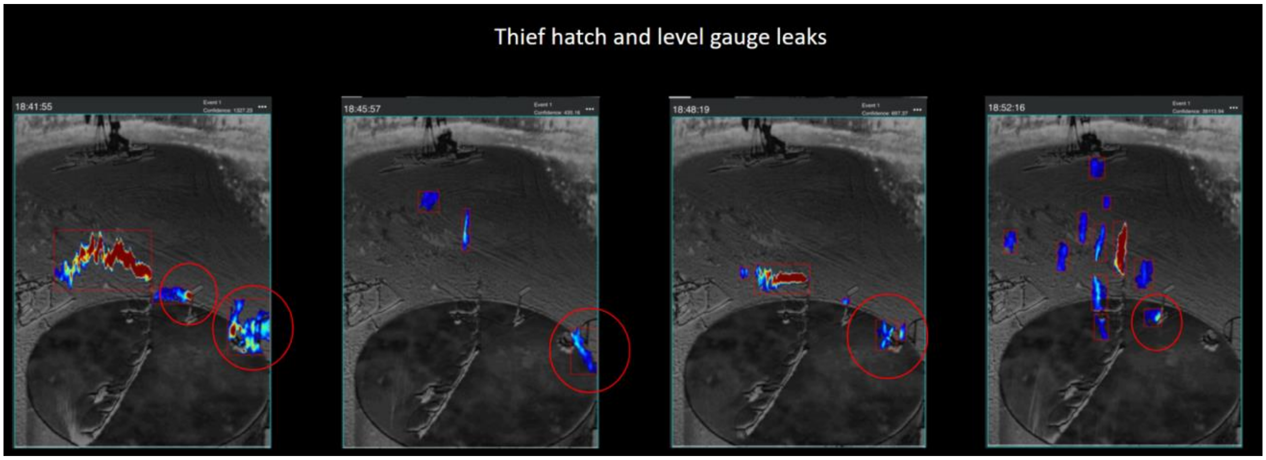
The Kuva Quantification method uses the column density measurements in the images, along with the environmental (wind speed and direction) and site information (distance to leak source) in order to estimate the emissions rate of each image. The results of the example as shown above are presented in the graph below and overlaid with the vent meter results.



The average of the measured leak rates over that time frame is 148 m^3/d, while the average of Kuva estimates is 106 m^3/d, these estimates are 28% low. The maximum measured leak by Kuva was 982m^3/d. These results were not blinded to Kuva however they were not used to train or adjust the results. It should also be noted that these estimates will become more accurate as the algorithms to detect and quantify improve as more controlled testing data is collected.

While the main objective of this exercise was detecting and measuring the primary vent from tanks, there were two other benefits provided by the Kuva camera, as noted below:

- The Kuva camera was able to detect gas escaping through the thief hatch and gauge board ports, resulting in underreporting of metered data from the turbine meter. The fact that the Kuva camera can detect these secondary emissions sources means that they can also be quantified. They were omitted from the Kuva estimates in the previous graph.
- Visible confirmation that the pump jack in the background of the image was also in operation during this time, which is valuable information that can help determine the root cause of the emissions. RGB image data is collected along with all SWIR images and can often have valuable information related to physical changes that occur on site, like when tank loading occurs or for security and safety purposes.



Discussion of Kuva Technology

All emissions detection and measurement technologies have their benefits and limitations; the Kuva camera is no different. It is important to understand these as a user of the technology so that the equipment is used in the correct application and that the results are interpreted with the correct accuracy and context. As a technology developer, these are also important so that the benefits can be emphasized and the limitations can be improved upon.

METEC (the Methane Emissions Technology Evaluation Center affiliated with Colorado State University), released their results of performance of continuous emission monitoring solutions under the Advancing Development of Emissions Detection protocol, a single-blind controlled testing protocol in December 2022[1]. Over the period of several months, METEC compared blind controlled test results of eleven continuous monitoring vendors, including Kuva. Kuva showed strong detection performance as well as being the only solution that had zero false alarms.

Kuva has conducted controlled release testing at a variety of test facilities. At the Oilfield Test Center atTexas Tech University in Lubbock, TX, Kuva collected over 600 single blinded images of releases ranging from <1 to 10 kg/h and at distances ranging from 15 to 180 m. The mean percent error over all of the images was 24%. To learn more about these tests and for a discussion on the results, please contact your Kuva representative.

The following is a non-exhaustive list of the benefits and limitations of the Kuva camera in the context of temporary tank vent measurement:

Benefits

- Non-contact emissions measurement. This form of passive instrumentation operates at a distance from emission sources. Unlike flow meter technologies, the Kuva camera does not affect tank pressure and can be used on any tank vent style or size.
- Can detect emissions from multiple sources (thief hatch, gauge board outlet, etc). The images produced allow for an easy identification of release points when the origin might not otherwise be known.
- Relatively low cost in comparison to alternative technologies, particularly other ‘optical gas imaging’ (OGI) based systems.
- Quick deployment with no ground penetration and no working from heights (<2 hour to install).
- Self contained, cloud connected, autonomous and solar powered: set it, forget it and get results from the cloud for weeks, months or years.
- Monitor multiple tanks at once. Monitoring objectives can also be adjusted easily without revisiting the site through Kuva’s cloud based remote control system.
- No maximum metered rate.
- Capable of monitoring for long periods of time with little-to-no field maintenance required.
- Can be used as a leak detection and quantification device, such as for controlled tanks where no emissions are expected in normal operations but frequently do occur
- Non-thermal based infrared detections, not affected by ambient temperature or temperature gradient of emissions

Limitations

[1] Performance of continuous emission monitoring solutions under single-blind controlled testing protocol. | Energy | ChemRxiv | Cambridge Open Engage

- Daylight only operation currently - in latitudes similar to Northern Alberta, the longer days of summer when solar irradiance is stronger and more hours to detect provide better detection probability.
- Minimum detection limit is variable and dependent on a number of factors (distance, weather and wind speed)
- Quantification of the vented emission originating from a single source such as a tank vent pipe is not as accurate as direct measurement, however when considering unaccounted emissions that come from thief hatches and gauge boards, the overall accuracy of total tank emissions is unknown: the Kuva camera can quantify emissions from both thief hatch and vent pipes. This may in fact make the quantification provided by Kuva more accurate, depending on the circumstances. More research is needed to determine the extent of missed emissions.
- Camera must be installed at heights greater than the emissions source; some tanks are taller than the current 40’ Kuva tower.

Conclusion

The current technologies that are available to measure tank vent emissions are limited. The Kuva camera offers a multitude of benefits that have yet to be available in a single, cost-effective package. In regards to tank emissions specifically, the following are some practical applications where it can be utilized:

- The Kuva solution has promise to be a relocatable quantification solution for a service provider in Alberta for roughly 8-9 months when there is sufficient solar illumination.
- To determine whether one or more tanks on a site are emitting more or less than the permitted regulatory maximum, in lieu of using the current engineering estimate as a standard, which is known to poorly reflect actual emissions in many cases.
- As a temporary installation to follow up on high emitting tanks as reported by survey technologies such as fly-overs, in order to confirm the total volume of emissions over a given time period.
- For controlled tanks, to monitor for fugitive emissions and to determine whether the control measures are functioning as intended. This can also be used to diagnose problems when they occur by providing time stamped images that identify leak source and can be correlated with process data..

February 7, 2023 Vertex Project #: 22A-03182

Modern West Advisory Inc.
600, 505 – 2nd Street SW
Calgary, Alberta T2P 1N8

Attention: Wayne Hillier

Re: Methods for Estimating Emissions from Tanks – Summary Report

Mr. Hillier,

Modern West Advisory Inc. (MWA) retained Vertex Professional Services Ltd. (Vertex) to participate in the Methods for Estimating Emissions from Tanks project sponsored by the Alberta Upstream Petroleum Research Foundation, Petroleum Technology Alliance Canada's Canadian Emissions Reduction Innovation Consortium, and Clean Resource Innovation Network. Vertex's role was to support the project by quantifying and verifying tank vent emissions with optical gas imaging cameras (OGI), paired quantitative optical gas imaging (QOGI) technology. The tank vents were continuously measured by turbine meters that were provided and installed by Calscan Solutions Inc. (Calscan), while Vertex used the OGI and QOGI technologies periodically throughout the testing interval for each location and emissions source.

Vertex personnel completed the scope of work between September 20th, 2021, and June 3rd, 2022. This letter provides an overall summary of the Vertex portion of the program and results thereof.

Executive Summary

There were three main objectives of this project: to deploy relevant measurement and monitoring techniques for methane vents from uncontrolled fixed-roof liquid storage tanks in Alberta, to understand the magnitude of tank emissions and the reasons for variability in emissions rates, and to recommend alternate methods, techniques, and technologies to estimate tank emissions. Vertex used OGI and QOGI technology to gather tank vent rates from 12 hydrocarbon liquid tanks throughout Alberta to compare to mounted turbine meters installed and provided by Calscan.

Vertex used a 15-minute monitoring window throughout the determined testing interval and found that OGI rates, when outliers were ignored, was comparable to rates determined by Calscan when reviewing data provided by MWA. The data gathered from each location are included in Attachment 1.

Vertex was able to measure emissions from all 12 tanks with the OGI camera and QL320 device, and results appear to be similar to the rates metered by Calscan. The dataset is limited to the intervals specified by the on-site contract owner's representative; however, comparing the Vertex results with graphs provided for review by MWA for the

Calscan turbine meter indicate a strong correlation and potential for a high level of accuracy between the turbine meters and the QOGI technology.

Recommendations and limitations have been identified, such as atmospheric conditions, vent plumes caused by a rapid increase in tank vent rates that cause high variability, optimal QOGI/OGI viewing angle and the capability/training of each OGI/QOGI technician.

Setup and Methodology

Equipment and Set-Up

Vertex personnel attended all sites with Calscan. Calscan used their own proprietary turbine meters, while Vertex personnel utilized a FLIR GFx320 OGI camera to identify the emission source and a FLIR-Providence Photonics QL320 QOGI system to quantify emissions sources.

The OGI camera works by detecting and visually presenting infrared energy being emitted or absorbed by hydrocarbons exiting the tank as the temperature of the venting hydrocarbons equalizes with the surrounding ambient temperature. The QL320 device works by placing an artificial plane (line or full/partial circle) around or beside an emission source, and measures infrared energy emitted or absorbed by the emission plume as it crosses the artificial plane. The QL320 does this to calculate the gas concentration, which can be used to generate a flux based on the entered distance to the source, wind speed and atmospheric temperature.

Methodology

When arriving on-site, Vertex personnel would warm up and verify the OGI camera was operating correctly, and use the camera to verify that the tank was a source of venting emissions. To complete this, the Vertex technician would find the optimal angle and distance to view the vent source(s) from the tank tops, preferably with a clear sky background, the emission source visible, and as close as possible without obscuring the point source. The Vertex technician would look at all potential sources such as thief hatches, the gauge board port and other fittings to determine if any leakage was occurring. If it was, the leak would have to be corrected before the tank was metered.

The Vertex technician set up the OGI camera with a tablet running the QL320 software on a tripod to start collecting quantified volumes from the tanks vent source. The important factors for QL320 accuracy are consistent wind, a strong delta temperature between the gas plume and atmospheric conditions, distance to the plume, the image background, viewing time and image stability.

The Vertex technician managed these variables by placing the tripod mounted OGI camera the optimal distance from the tank for a viewing angle to see the source points, with a clear sky background, which was found to be approximately 9 to 12 m from the base of the tanks, unless berms or other ground level elevation changes allow for being closer. The Vertex technician would adjust the temperature band on their infrared camera to the most suitable range for identification and quantification of the emission sources based on atmospheric and vented gas temperatures. As the only uncontrollable variable were the wind and a consistent velocity or vector, the Vertex technician would minimize this variable by placing the camera perpendicular to the point source and predominant wind direction to catch the plume moving across the field of vision.

After the OGI camera was set up at the optimal distance, angle and viewing background, a range finder, thermometer and wind meter were used by the Vertex technician to accurately enter the correct atmospheric variables into the QL320 software for adjusting the measured flow rates. The Vertex technician would take a series of 1-minute tests to determine the average flow rate over 15 minutes. Any readings that would be impacted significantly by extreme changes in wind speed, such as sudden gusts or stoppages in wind speed or change of wind direction and the gas plume no longer crossing the artificial plane, would be discarded. An initial reading from the tank prior to the installation of the Calscan turbine meter would be taken from the QL320 and a decision would be made regarding detectability of the QL320 measure flow rates above the turbine meter minimum detection limit. Vertex would then halt vent rate quantification while the turbine meter was installed, and qualitatively monitor the top of the tank for other emission sources (fugitive emissions) that might occur from installation of the meter, due to any changes on top of the tank or backpressure caused by metering.

After the meter was installed and there were no fugitive emissions generated by installation or increased backpressure on the tank, the Vertex technician resumed quantification for the duration of the testing, recording 15-minute averages of 1-minute tests when conditions were optimal and no significant impacts to the reading were noted. The Vertex technician would note any abnormal observations during the 15-minute intervals such as sudden spikes or stoppages in vent flow, audible cues to flow rate change or atmospheric conditions, and process changes such as equipment outages.

Findings and Limitations

Vertex was able to measure emissions from all tanks with the OGI camera and QL320 device, and results appear to be similar to the rates metered by Calscan. The dataset is limited due the measurement intervals specified by the on-site contract owner's representative; however, comparing the Vertex results with graphs provided for review by MWA for the Calscan turbine meter, indicates a strong correlation and comparable level of accuracy between the turbine meters and the QOGI technology.

The QOGI measurements were used to calculate a mean daily vent rate in m^3/day, and a standard deviation calculated for the group of 15-minute average results. This determined how much any one 15-minute average varied from the daily vent rate average from all measured results and to determine how much variance could be expected in m^3/day for any one 15-minute test, and if it was within 1 standard deviation of the mean. The 1 standard deviation calculation was also expressed as a percentage of the daily vent rate calculated from the mean flow rate measured. This was done to assess how accurate any one 15-minute test could be expected to be, as compared to monitoring with the OGI and QOGI combination for extended periods as a percent of the averaged daily vent rate.

The standard deviation ranged from 14 m^3/day to 58 m^3/day, for any given 15-minute set of one-minute tests, as compared to the mean result from all tests, excepting two tanks, presented in Table 8 and Figure 9, and Table 6 and Figure 6, one of which saw no variance over 45 minutes and one tank that saw a significant vent spike at the end of the test resulting in a variance of 566 m^3/day. The standard deviation expressed as a percentage of the daily vent rate calculated from the mean vent rate was ± 5% to 85% for any one 15-minute average, excepting the tested tank that had no variance and the tank that had a standard deviation of 566 m^3/day, which is a difference of ± 180% between any 15-minute average with the daily mean calculated. Excluding these two tanks, the average percent difference for any 15-minute average was ± 32% from the daily flow rate calculated from monitoring the tank for 2.5 to 5 hours. Extrapolating a daily flow rate for tanks that have high vent rate variability (significant peaks/valleys to vent rates) may be less accurate, without extended monitoring timelines.

These results are limited to a dataset of 12 tanks, which were monitored for periods of 0.75 to 5 hours and may not be representative of what is occurring before or after monitoring, and does not account for differences in site setup, different distances, weather conditions, and variance between camera operators for example. There has been no comparison by Vertex with rates metered by Calscan other than reviewing graphs created by MWA, or any measurements by other parties, and the provided variance calculations are representative of the QOGI results compared to itself, when comparing short term measurements to longer term measurements to determine the accuracy of a 15-minute test.

Observations and Recommendations

Qualitative Observations

- When the Calscan turbine meter was installed vertically with a 1.5m stack assembly, the QOGI quantification accuracy improved
- Emission sources that are not clearly visible are difficult to quantify, with increased distance required to make the source visible and have a clear sky background
- High variability in wind speed, wind direction, lack of wind, a poor delta temperature, or a poor thermal background (precipitation, moving objects, clouds, etc.) reduce quantification accuracy
- Atmospheric and process conditions can affect the emission rates, which can change over the course of a day, and testing during one part of the day may not be representative of the whole day

Recommendations

- Using a stack assembly allowed the OGI/QOGI cameras to easily identify and quantify rates as the emission source was moved farther from the tank. This gave a better background and unobscured viewing angle for the OGI/QOGI to identify rates and the emission source
- Each tank needs to be assessed individually based on its emission rate variance. Each tank may require a different monitoring timeline to determine vent rate consistency and determination of a representative flow rate
    - For example, depending on site setup, potentially having to watch through an operational cycle of the separator or cycling of a plunger lift well, including the “dump” cycle
- The OGI/QOGI manufacturer recommendations for determining optimal atmospheric and weather conditions should be reviewed to ensure the best quality of OGI/QOGI data being gathered and ensure that tank vent rates are captured during those conditions

Vertex recommends further investigation through another study to help aide in understanding the accuracy of extrapolating a vent rate compared to a fix rate turbine meter. A further study would also help in determining the accuracy of the OGI and QOGI technology on more sites, with multiple scenarios, such as determination of the number of tests required to attain acceptable accuracy, accuracy when the vent is fully visible versus obscured, repeatability between technicians, how much variance is introduced including all QL320 readings regardless of atmospheric condition effects on the QL320 reading and lowering accuracy (wind speed/direction changes affecting reading).

Closure

Should you have any questions or concerns, please do not hesitate to contact the undersigned at 780.203.3811 or bwiedemannkomarnicki@vertex.ca.

Sincerely,

B. Wiedemann-Komarnicki

Bailey Wiedemann-Komarnicki, B.Sc.
PROJECT MANAGER – EMISSIONS MANAGEMENT

Attachments

Attachment 1. Field Data

Limitations

This letter has been prepared for the sole benefit Modern West Advisory Inc. (MWA), Alberta Upstream Petroleum Research Foundation (AUPRF), Petroleum Technology Alliance Canada's (PTAC) Canadian Emissions Reduction Innovation Consortium (CanERIC), and Clean Resource Innovation Network (CIRN). This document may not be used by any other person or entity, without the express written consent of Vertex Professional Services Ltd. (Vertex) and MWA, AUPRF, PTAC CanERIC, and CIRN. Any use of this letter by a third party, or any reliance on decisions made based on it, or damages suffered as a result of the use of this letter are the sole responsibility of the user.

The information and conclusions contained in this letter are based upon work undertaken by trained professional and technical staff in accordance with generally accepted scientific practices current at the time the work was performed. The conclusions and recommendations presented represent the best judgement of Vertex based on the data collected during the surveys. Due to the nature of the surveys and the data available, Vertex cannot warrant against undiscovered environmental liabilities. Conclusions and recommendations presented in this letter should not be considered legal advice.

ATTACHMENT 1

Attachment 1

Table 1. Site 1.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m3/day (%)	Weather Notes	Comments
1.0	Oil	2022-05-12	1:00 PM	1:15 PM	High Angle - Ground Level	12	Yes	70	100.8	39	46	Clear Sky	
			1:15 PM	1:30 PM				70	100.8				
			1:30 PM	1:45 PM				20	28.8				
			1:45 PM	2:00 PM				25	36				
			2:00 PM	2:15 PM				90	129.6				
			2:15 PM	2:30 PM				40	57.6				
			2:30 PM	2:45 PM				60	86.4				
			2:45 PM	3:00 PM				100	144				
			3:00 PM	3:15 PM				50	72				
			3:15 PM	3:30 PM				40	57.6				
			3:30 PM	3:45 PM				40	57.6				
			3:45 PM	4:00 PM				10	14.4				
			4:00 PM	4:15 PM				80	115.2				
			4:15 PM	4:30 PM				80	115.2				
			4:30 PM	4:45 PM				90	129.6				
			4:45 PM	5:00 PM				90	129.6				
			Mean Flow rate measurement					**60**	**86.0**	-	-		

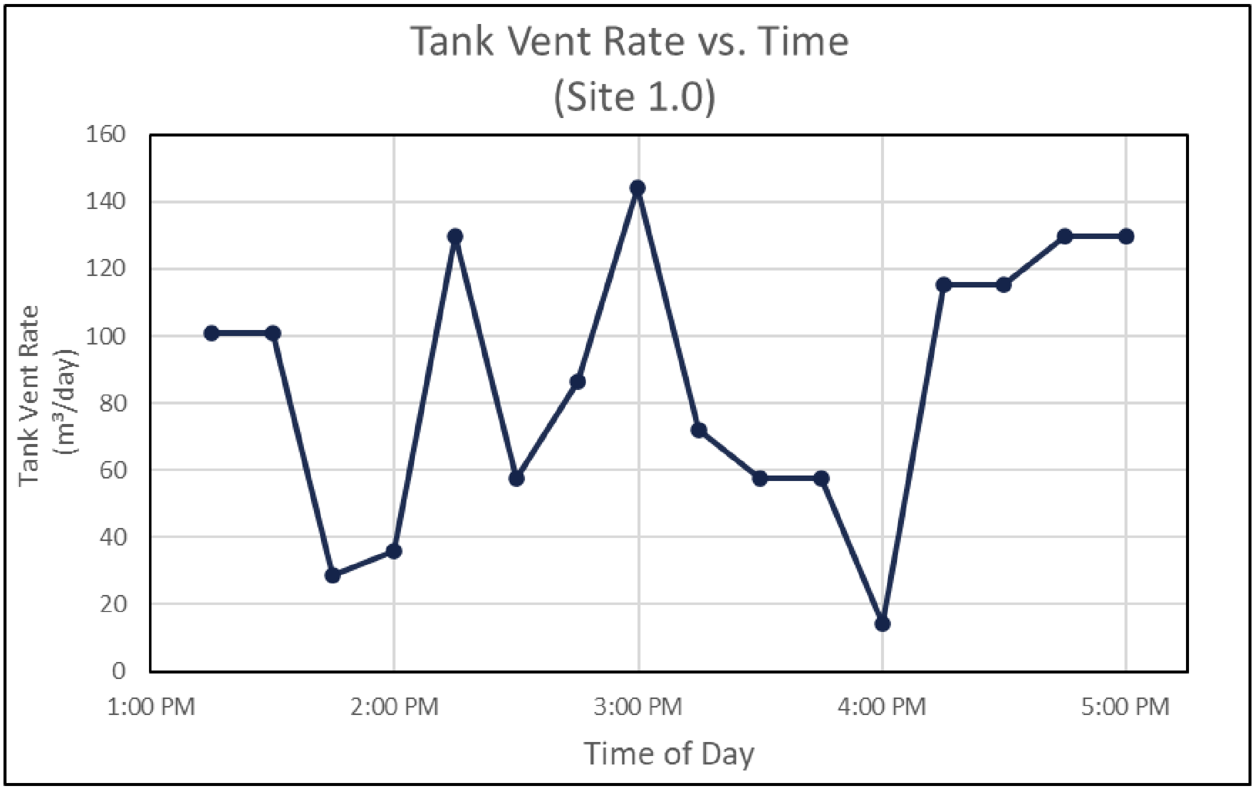


Figure 1. Site 1.0 Extrapolated Tank Vent Rate vs. Time

Attachment 1

Table 2. Site 2.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m3/day (%)	Weather Notes	Comments
2.0	Emulsion	13-05-22	9:00 AM	9:15 AM	High Angle - Ground Level	12	Yes	300	432	20	5	Clear Sky	
			9:15 AM	9:30 AM				270	388.8				
			9:30 AM	9:45 AM				300	432				
			9:45 AM	10:00 AM				280	403.2				
			10:00 AM	10:15 AM				290	417.6				
			10:15 AM	10:30 AM				300	432				
			10:30 AM	10:45 AM				320	460.8				
			10:45 AM	11:00 AM				320	460.8				
			11:00 AM	11:15 AM				280	403.2				
			11:15 AM	11:30 AM				280	403.2				
			11:30 AM	11:45 AM				290	417.6				
			11:45 AM	12:00 PM				310	446.4				
			12:00 PM	12:15 PM				300	432				
			12:15 PM	12:30 PM				300	432				
			12:30 PM	12:45 PM				300	432				
			12:45 PM	1:00 PM				320	460.8				
			1:00 PM	1:15 PM				290	417.6				
			1:15 PM	1:30 PM				280	403.2				
			1:30 PM	1:45 PM				300	432.0				
			1:45 PM	2:00 PM				300	432.0				
			Mean Flow rate measurement					**297**	**427.0**	-	-		

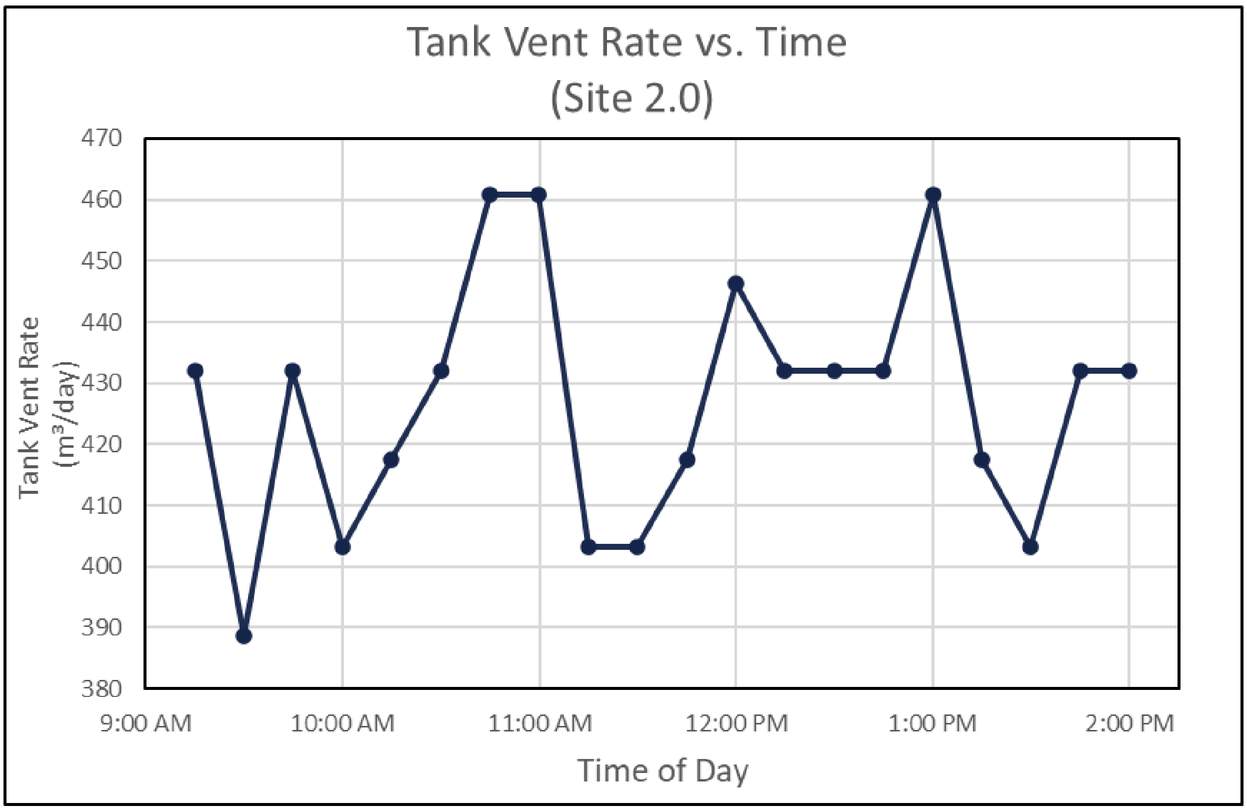


Figure 2. Site 2.0 Extrapolated Tank Vent Rate vs. Time

Attachment 1

Table 3. Site 3.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m3/day (%)	Weather Notes	Comments
3.0	Oil	16-05-22	9:30 AM	9:45 AM	High Angle - Ground Level	6	No	80	115.2	22	32	Clear Sky	Intermittent Release of Gas. Spikes from 10 Lpm to 90 Lpm
			9:45 AM	10:00 AM				80	115.2				
			10:00 AM	10:15 AM				60	86.4				
			10:15 AM	10:30 AM				60	86.4				
			10:30 AM	10:45 AM				55	79.2				
			10:45 AM	11:00 AM				55	79.2				
			11:00 AM	11:15 AM				35	50.4				
			11:15 AM	11:30 AM				40	57.6				
			11:30 AM	11:45 AM				35	50.4				
			11:45 AM	12:00 PM				20	28.8				
			12:00 PM	12:15 PM				35	50.4				
			12:15 PM	12:30 PM				35	50.4				
			12:30 PM	12:45 PM				40	57.6				
			12:45 PM	1:00 PM				40	57.6				
			1:00 PM	1:15 PM				40	57.6				
			1:15 PM	1:30 PM				40	57.6				
			1:30 PM	1:45 PM				50	72				
			1:45 PM	2:00 PM				50	72				
			Mean Flow rate measurement					**47**	**68.0**	-	-		

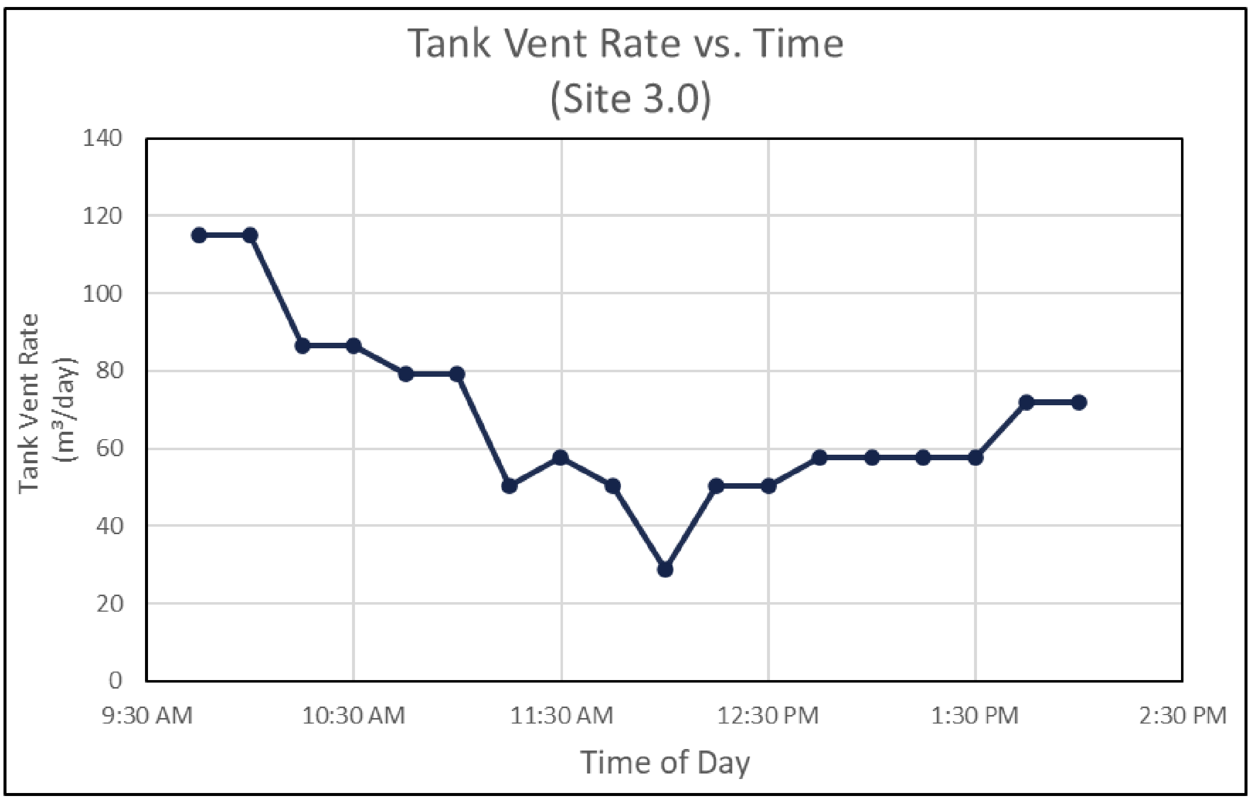


Figure 3. Site 3.0 Extrapolated Tank Vent Rate vs. Time

Attachment 1

Table Site 4.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m3/day (%)	Weather Notes	Comments
4.0	Emulsion	17-05-22	9:00 AM	9:15 AM	High Angle - Ground Level	12	Yes	70	100.8	14	13	Clear Sky	
			9:15 AM	9:30 AM				80	115.2				
			9:30 AM	9:45 AM				90	129.6				
			9:45 AM	10:00 AM				90	129.6				
			10:00 AM	10:15 AM				80	115.2				
			10:15 AM	10:30 AM				90	129.6				
			10:30 AM	10:45 AM				70	100.8				
			10:45 AM	11:00 AM				70	100.8				
			11:00 AM	11:15 AM				80	115.2				
			11:15 AM	11:30 AM				90	129.6				
			11:30 AM	11:45 AM				90	129.6				
			11:45 AM	12:00 PM				75	108				
			12:00 PM	12:15 PM				80	115.2				
			12:15 PM	12:30 PM				80	115.2				
			12:30 PM	12:45 PM				75	108				
			12:45 PM	1:00 PM				65	93.6				
			1:00 PM	1:15 PM				70	100.8				
			1:15 PM	1:30 PM				60	86.4				
			1:30 PM	1:45 PM				60	86.4				
			1:45 PM	2:00 PM				65	93.6				
			Mean Flow rate measurement					**77**	**110.2**	-	-		

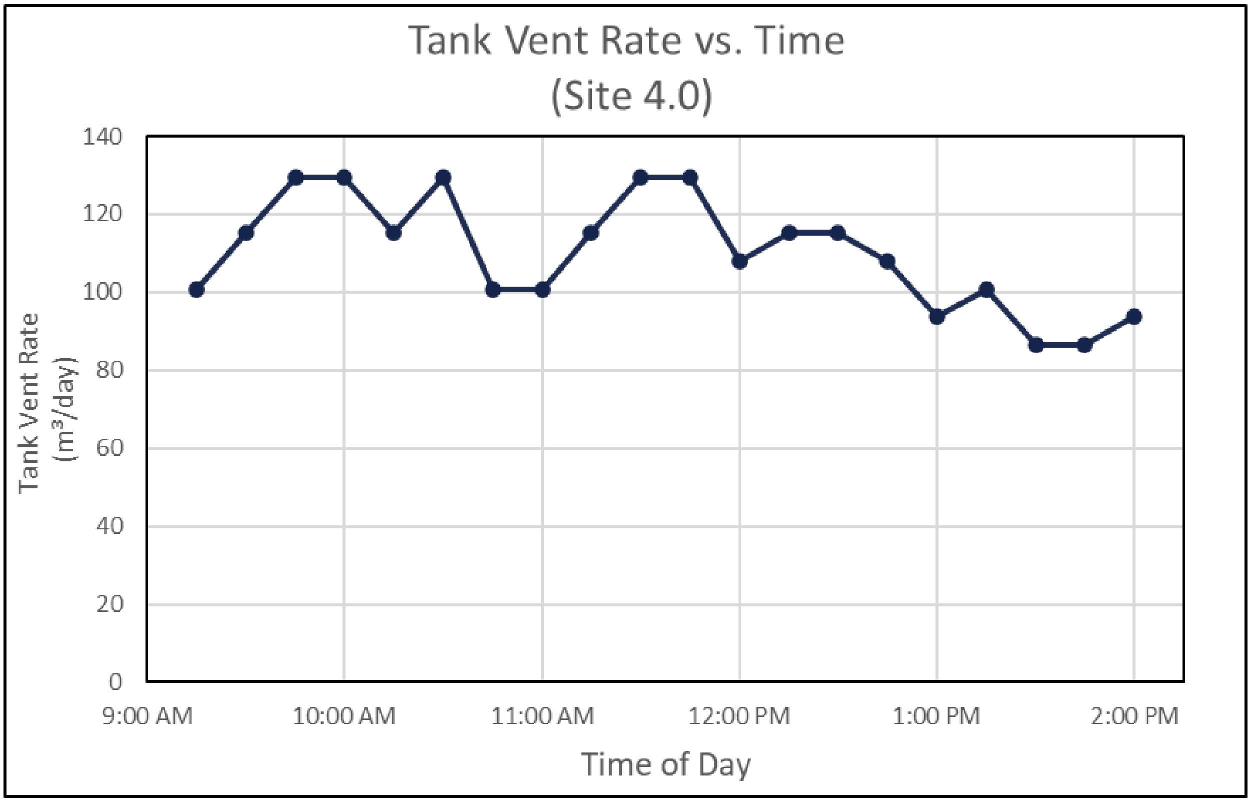


Figure 4. Site 4.0 Extrapolated Tank Vent Rate vs. Time

Attachment 1

Table 5. Site 5.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m3/day (%)	Weather Notes	Comments
5.0	Emulsion	2022-05-18	7:30 AM	7:45 AM	High Angle - Ground Level	12	Yes	15	21.6	39	85	Clear Sky	
			7:45 AM	8:00 AM				15	21.6				
			8:00 AM	8:15 AM				15	21.6				
			8:15 AM	8:30 AM				15	21.6				
			8:30 AM	8:45 AM				15	21.6				
			8:45 AM	9:00 AM				15	21.6				
			9:00 AM	9:15 AM				15	21.6				
			9:15 AM	9:30 AM				15	21.6				
			9:30 AM	9:45 AM				15	21.6				
			9:45 AM	10:00 AM				15	21.6				
			10:00 AM	10:15 AM				15	21.6				
			10:15 AM	10:30 AM				15	21.6				
			10:30 AM	10:45 AM				40	57.6				
			10:45 AM	11:00 AM				40	57.6				
			11:00 AM	11:15 AM				100	144				
			11:15 AM	11:30 AM				50	72				
			11:30 AM	11:45 AM				80	115.2				
			11:45 AM	12:00 PM				80	115.2				
			Mean Flow rate measurement					**32**	**45.6**				

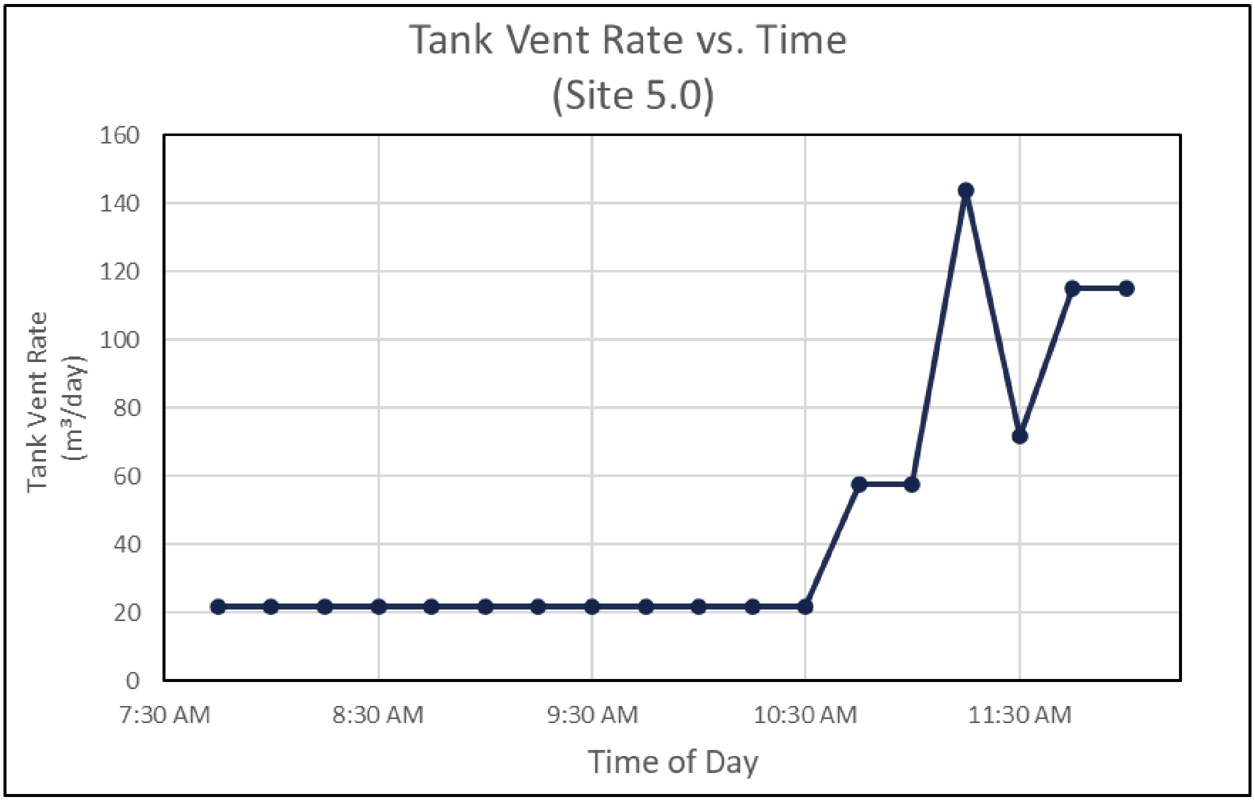


Figure 5. Site 5.0 Extrapolated Tank Vent Rate vs. Time

Attachment 1

Table 6. Site 6.0 and Site 7.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m3/day (%)	Weather Notes	Comments
6.0	Oil	19-05-22	11:00 AM	11:15 AM	Low Angle - Elevated, below	3	No	150	216	0	0	Clear Sky	Vent Line is at Ground Level. HAWK meter was on for 24 hours. Left Site after setting up the Hawk Meter.
			11:15 AM	11:30 AM				150	216				
			11:30 AM	11:45 AM				150	216				
			Mean Flow rate measurement					**150**	**216**	-	-		
7.0	Oil	2022-05-20	10:00 AM	10:15 AM	High Angle - Ground Level	12	Yes	50 to 1000	Undefined	Undefined	Undefined	Clear Sky	Intermittent Release of Gas. Spikes from 50 Lpm to 1000+ lpm
			10:15 AM	10:30 AM				50 to 1000					
			10:30 AM	10:45 AM				50 to 1000					
			10:45 AM	11:00 AM				50 to 1000					
			11:00 AM	11:15 AM				50 to 1000					
			11:15 AM	11:30 AM				50 to 1000					
			11:30 AM	11:45 AM				50 to 1000					
			11:45 AM	12:00 PM				50 to 1000					
			12:00 PM	12:15 PM				50 to 1000					
			12:15 PM	12:30 PM				50 to 1000					
			12:30 PM	12:45 PM				50 to 1000					
			12:45 PM	1:00 PM				50 to 1000					
			1:00 PM	1:15 PM				50 to 1000					
			1:15 PM	1:30 PM				50 to 1000					
			Mean Flow rate measurement					**Undefined**	**Undefined**	-	-		

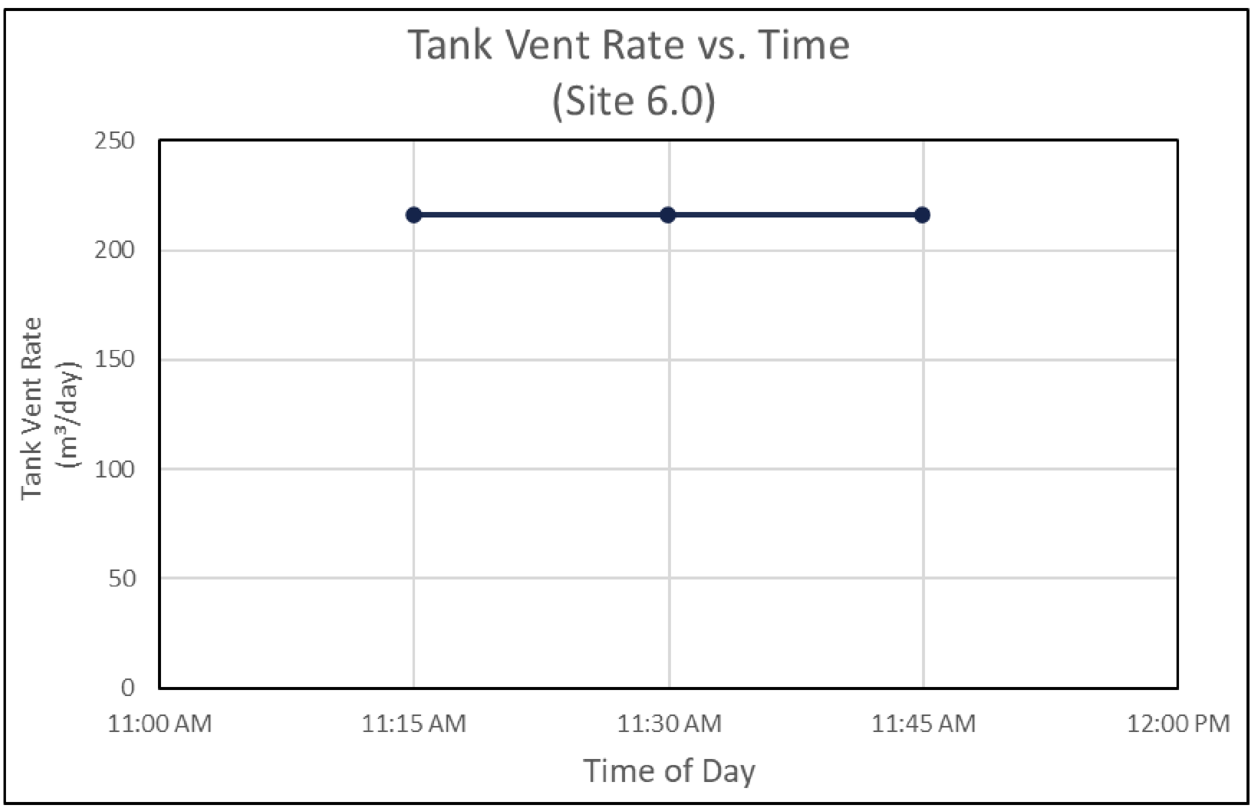


Figure 6. Site 6.0 Extrapolated Tank Vent Rate vs. Time

Attachment 1

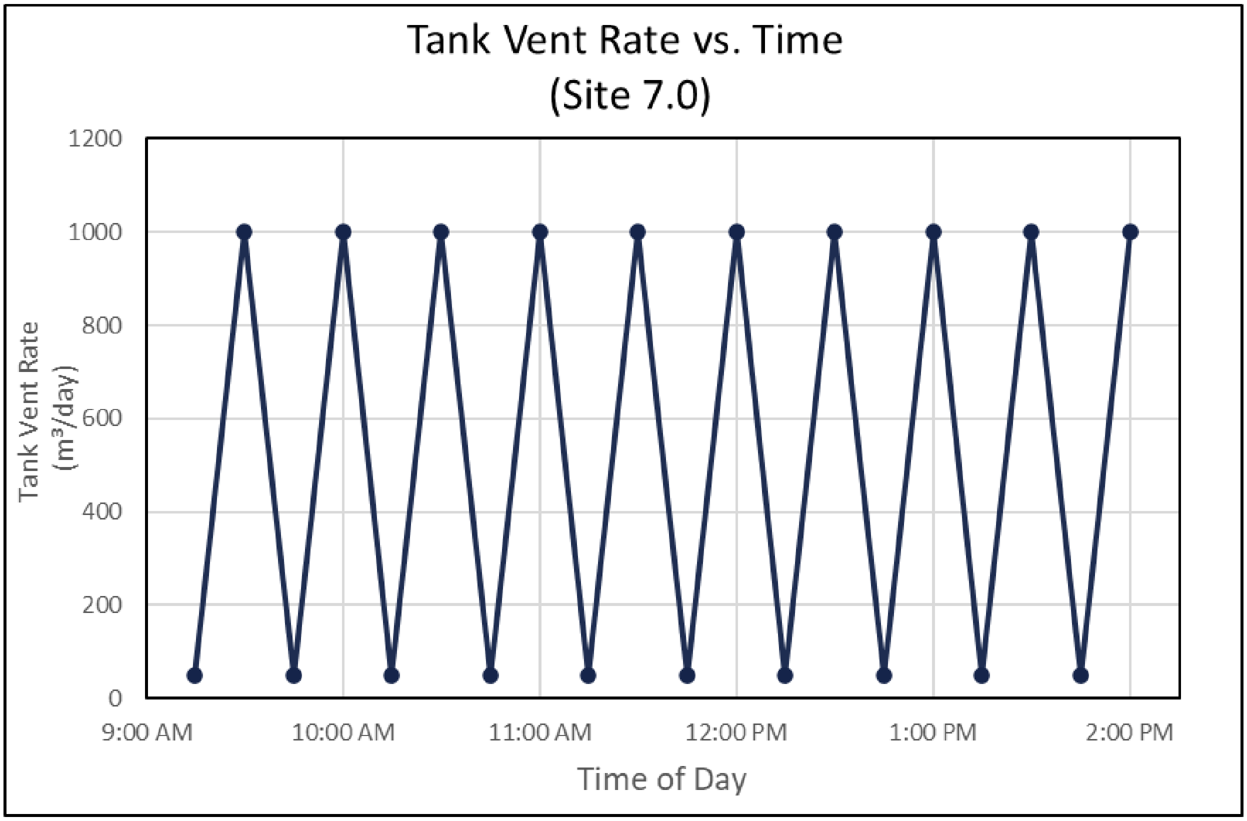


Figure 7. Site 7.0 Extrapolated Tank Vent Rate vs. Time

Table 7. Site 8.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m^3/day (%)	Weather Notes	Comments
8.0	Oil	24-5-22	11:00 AM	11:15 AM	High Angle - Ground Level	12	Yes	5	7.2	24	74	Clear Sky	
			11:15 AM	11:30 AM			Yes	5	7.2				
			11:30 AM	11:45 AM			Yes	20	28.8				
			11:45 AM	12:00 PM			Yes	40	57.6				
			12:00 PM	12:15 PM			Yes	5	7.2				
			12:15 PM	12:30 PM			Yes	5	7.2				
			12:30 PM	12:45 PM			Yes	5	7.2				
			12:45 PM	1:00 PM			Yes	5	7.2				
			1:00 PM	1:15 PM			Yes	5	7.2				
			1:15 PM	1:30 PM			Yes	35	50.4				
			1:30 PM	1:45 PM			Yes	35	50.4				
			1:45 PM	2:00 PM			Yes	35	50.4				
			2:00 PM	2:15 PM			Yes	5	7.2				
			2:15 PM	2:30 PM			Yes	5	7.2				
			2:30 PM	2:45 PM			Yes	50	72				
			2:45 PM	3:00 PM			Yes	45	64.8				
			3:00 PM	3:15 PM			Yes	35	50.4				
			3:15 PM	3:30 PM			Yes	35	50.4				
			3:30 PM	3:45 PM			Yes	35	50.4				
			3:45 PM	4:00 PM			Yes	35	50.4				
			Mean Flow rate measurement					**22**	**32.0**				

Attachment 1

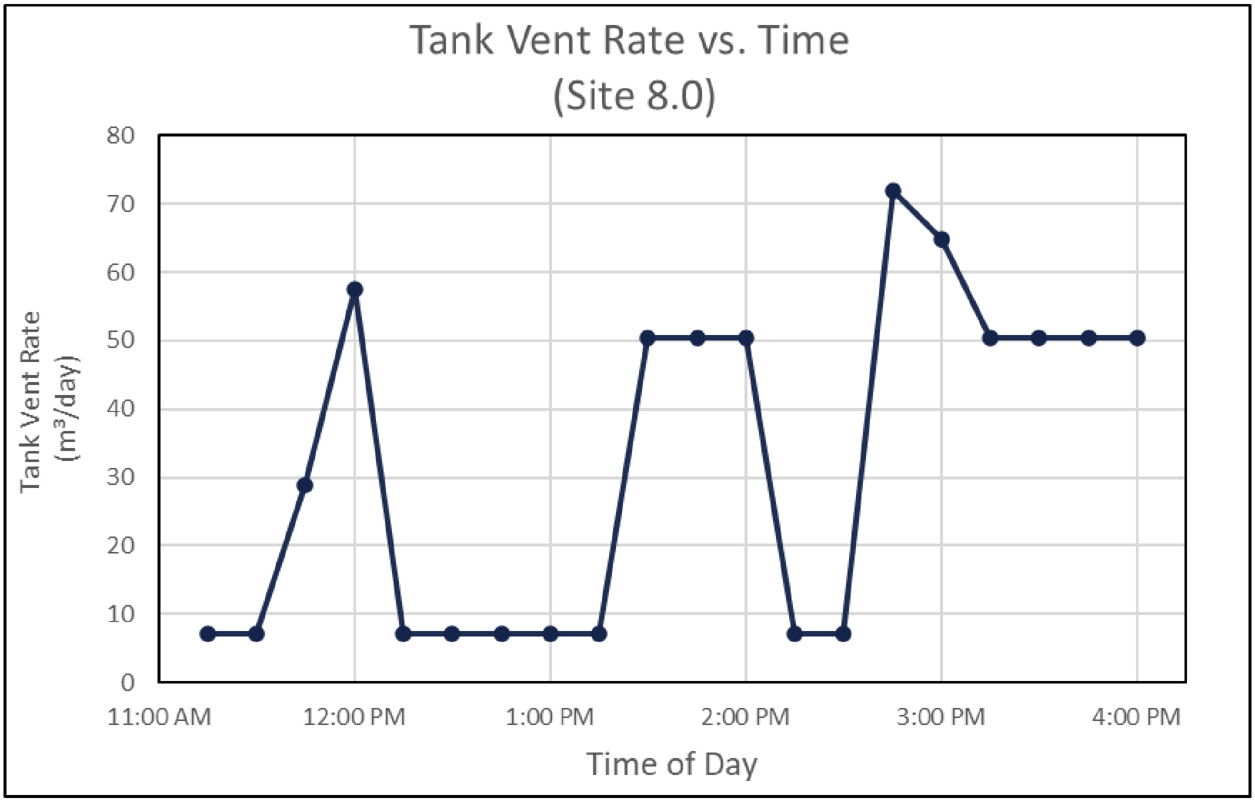


Figure 8. Site 8.0 Extrapolated Tank Vent Rate vs. Time

Table 8. Site 9.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m3/day (%)	Weather Notes	Comments
9.0	Oil	2022-05-31	11:00 AM	11:15 AM	High Angle - Ground Level	7	No	10	14.4	566	180	Clear Sky	The tank vent rate changed significantly during the last hour of the test, spiking to 1600 liters per minute, from 10 liters per minute. This caused a large variance when calculating the mean average.
			11:15 AM	11:30 AM				10	14.4				
			11:30 AM	11:45 AM				10	14.4				
			11:45 AM	12:00 PM				10	14.4				
			12:00 PM	12:15 PM				10	14.4				
			12:15 PM	12:30 PM				10	14.4				
			12:30 PM	12:45 PM				10	14.4				
			12:45 PM	1:00 PM				10	14.4				
			1:00 PM	1:15 PM				10	14.4				
			1:15 PM	1:30 PM				10	14.4				
			1:30 PM	1:45 PM				10	14.4				
			1:45 PM	2:00 PM				10	14.4				
			2:00 PM	2:15 PM				10	14.4				
			2:15 PM	2:30 PM				10	14.4				
			2:30 PM	2:45 PM				800	1152				
			2:45 PM	3:00 PM				1000	1440				
			3:00 PM	3:15 PM				1000	1440				
			3:15 PM	3:30 PM				1000	1440				
			Mean Flow rate measurement					**219**	**315.2**	-	-		

Attachment 1

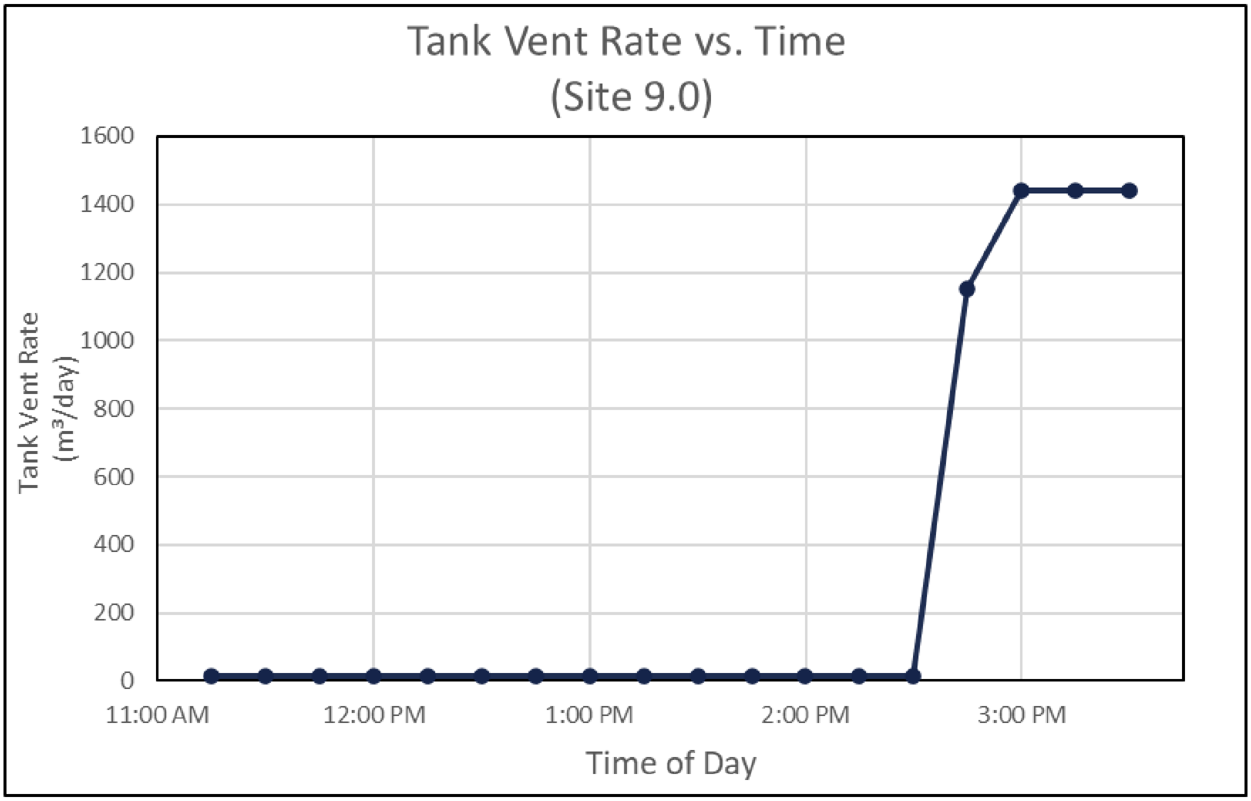


Figure 9. Site 9.0 Extrapolated Tank Vent Rate vs. Time

Table 9. Site 10.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m3/day (%)	Weather Notes	Comments
10.0	Oil	01-06-22	10:00 AM	10:15 AM	Low Angle - Elevated, below source	3	No	80	115.2	11	9	Clear Sky	Vent Line is at Ground level.
			10:15 AM	10:30 AM				100	144				
			10:30 AM	10:45 AM				90	129.6				
			10:45 AM	11:00 AM				100	144				
			11:00 AM	11:15 AM				90	129.6				
			11:15 AM	11:30 AM				100	144				
			11:30 AM	11:45 AM				100	144				
			11:45 AM	12:00 PM				80	115.2				
			12:00 PM	12:15 PM				90	129.6				
			12:15 PM	12:30 PM				90	129.6				
			12:30 PM	12:45 PM				80	115.2				
			12:45 PM	1:00 PM				100	144				
			1:00 PM	1:15 PM				90	129.6				
			1:15 PM	1:30 PM				90	129.6				
			1:30 PM	1:45 PM				80	115.2				
			1:45 PM	2:00 PM				100	144				
			Mean Flow rate measurement					**91**	**131.4**	-	-		

Attachment 1

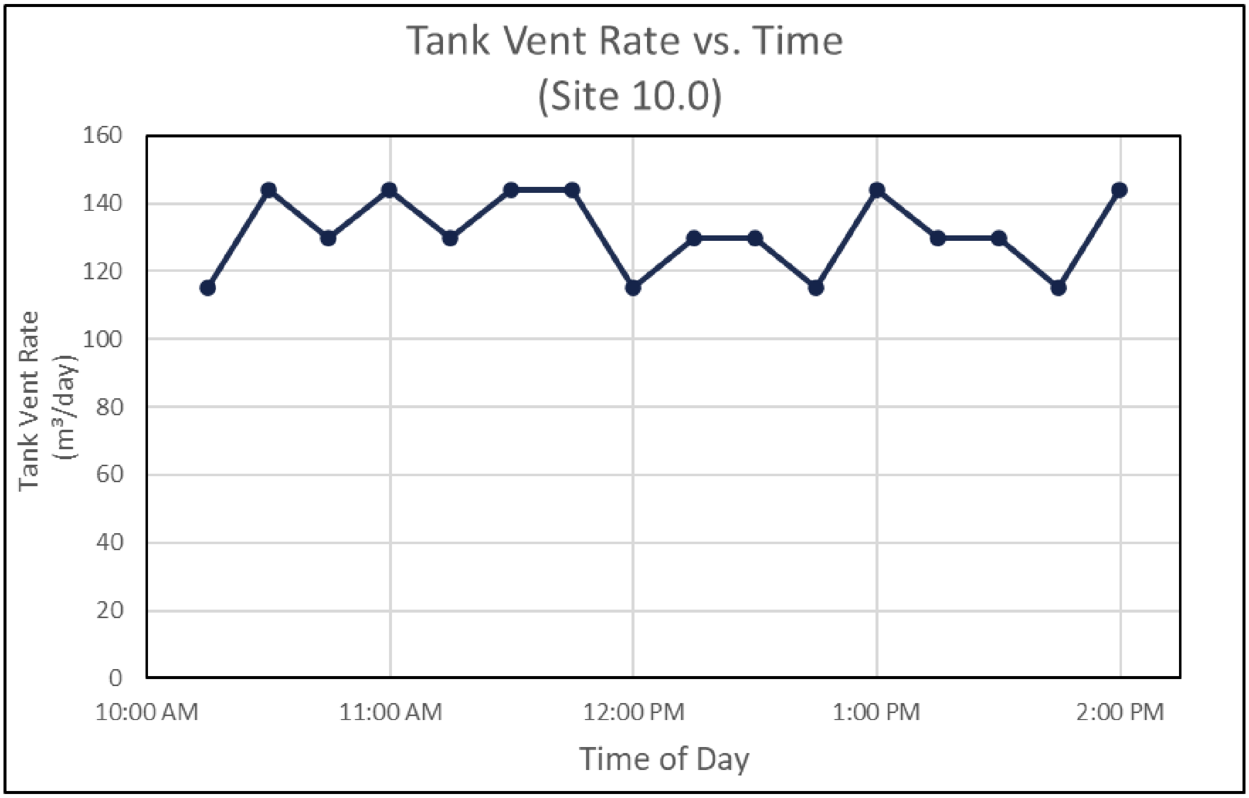


Figure 10. Site 10.0 Extrapolated Tank Vent Rate vs. Time

Attachment 1

Table 10. Site 11.0 and Site 12.0 Field Data

Site	Fluid Type	Date (d-m-y)	Start Time	End Time	Viewing Angle	Distance (m)	Clear line of sight (yes/no)	QOGI rate (lpm)	QOGI Extrapolated (m^3/day)	1 Standard Deviation (m^3/day)	% of the mean Extrapolated m^3/day (%)	Weather Notes	Comments
11.0	Oil	02-06-22	9:00 AM	9:15 AM	High Angle - Ground Level	12	Yes	30	43.2	14	26	Clear Sky	
			9:15 AM	9:30 AM				30	43.2				
			9:30 AM	9:45 AM				30	43.2				
			9:45 AM	10:00 AM				30	43.2				
			10:00 AM	10:15 AM				30	43.2				
			10:15 AM	10:30 AM				30	43.2				
			10:30 AM	10:45 AM				30	43.2				
			10:45 AM	11:00 AM				40	57.6				
			11:00 AM	11:15 AM				40	57.6				
			11:15 AM	11:30 AM				30	43.2				
			11:30 AM	11:45 AM				30	43.2				
			11:45 AM	12:00 PM				60	86.4				
			12:00 PM	12:15 PM				60	86.4				
			12:15 PM	12:30 PM				30	43.2				
			12:30 PM	12:45 PM				30	43.2				
			12:45 PM	1:00 PM				30	43.2				
			1:00 PM	1:15 PM				30	43.2				
			1:15 PM	1:30 PM				60	86.4				
			1:30 PM	1:45 PM				60	86.4				
			1:45 PM	2:00 PM				60	86.4				
			Mean Flow rate measurement					**39**	**55.4**	-	-		
12.0	Oil	03-06-22	8:00 AM	8:15 AM	High Angle - Ground Level	10	Yes	150	216	49	18	Clear Sky	
			8:15 AM	8:30 AM				150	216				
			8:30 AM	8:45 AM				150	216				
			8:45 AM	9:00 AM				150	216				
			9:00 AM	9:15 AM				225	324				
			9:15 AM	9:30 AM				200	288				
			9:30 AM	9:45 AM				225	324				
			9:45 AM	10:00 AM				225	324				
			10:00 AM	10:15 AM				200	288				
			10:15 AM	10:30 AM				225	324				
			Mean Flow rate measurement					**190**	**273.6**	-	-		

Attachment 1

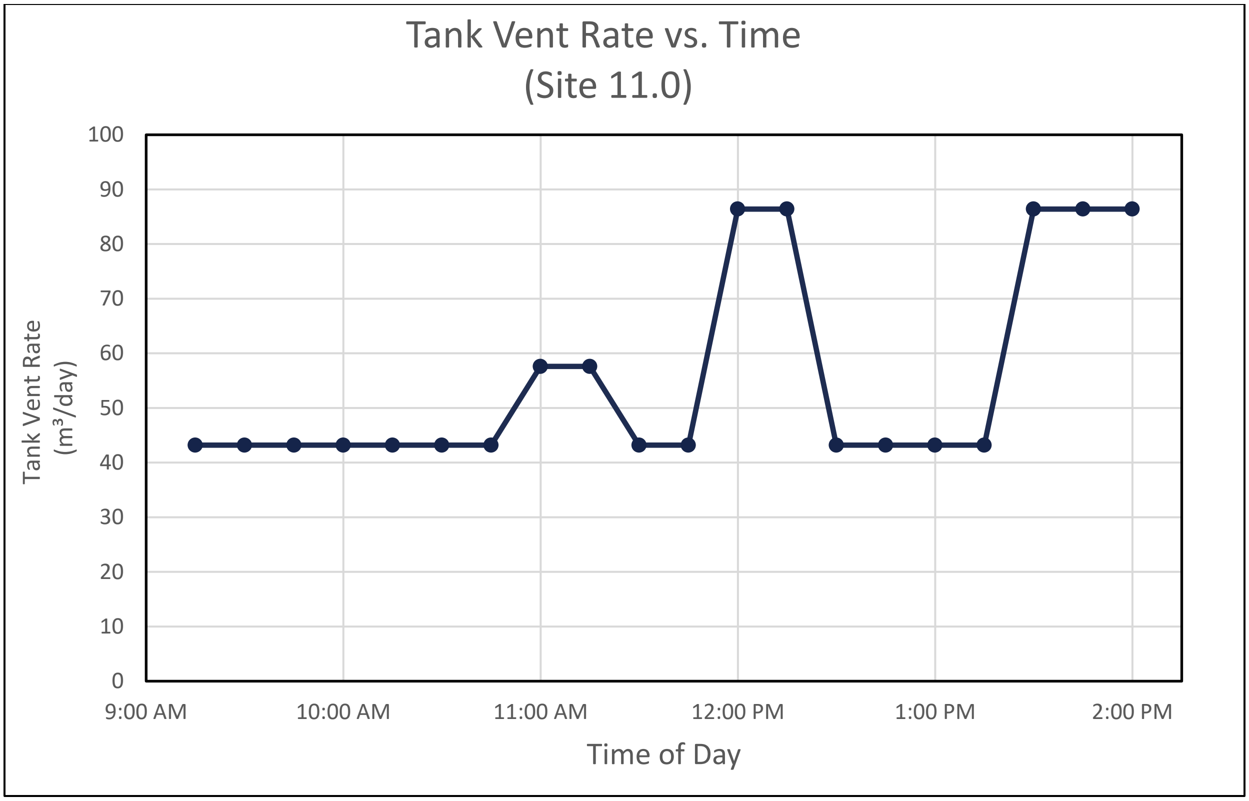


Figure 11. Site 11.0 Extrapolated Tank Vent Rate vs. Time

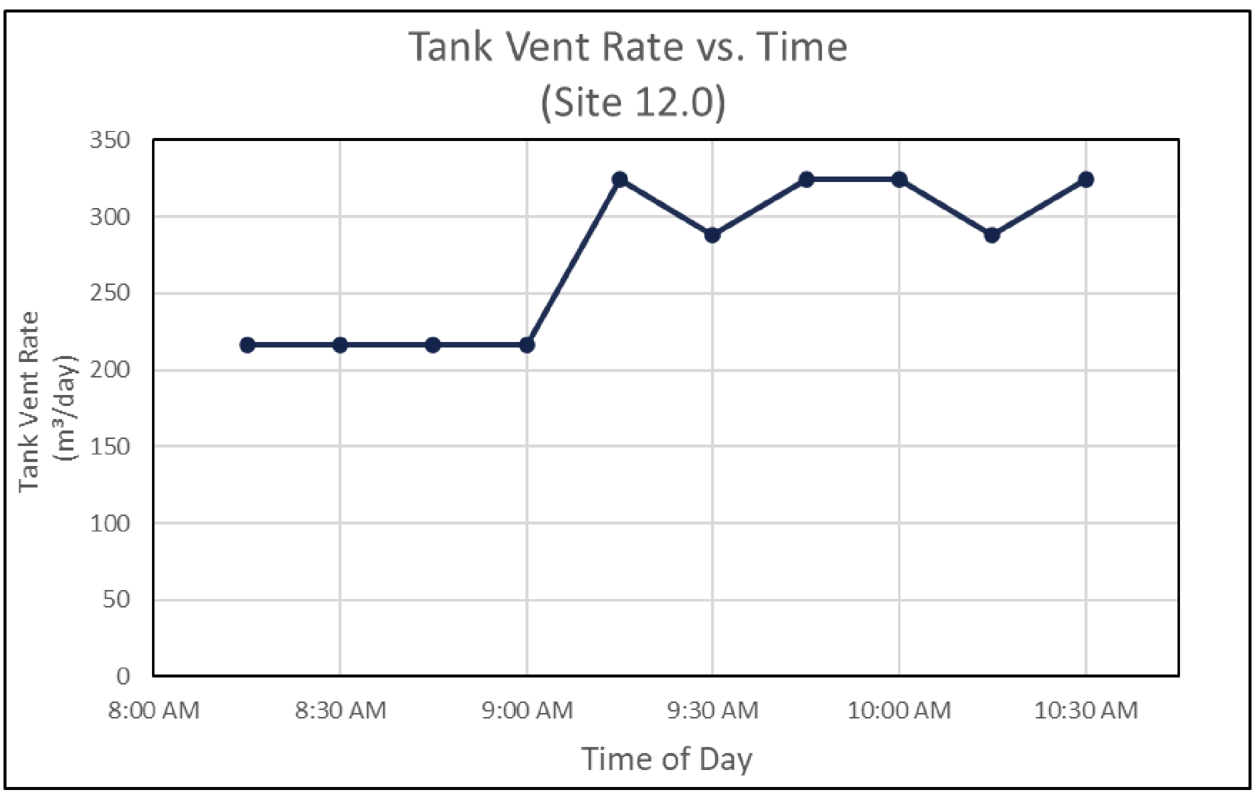


Figure 12. Site 12.0 Extrapolated Tank Vent Rate vs. Time