COLORADO
Air Pollution Control Division
Department of Public Health & Environment

Application Timeline and Summary

Alternative Approved Instrument Monitoring Method (AIMM)

Clean Connect AI, Inc.

Alternative AIMM Application:	Clean Connect AI, Inc.
Detection Approval Requested:	Qualitative, capable of Continuous Monitoring
Date submitted:	02/28/22
Record of Application Review:	SEE BELOW

Date	Subject
02/28/22	Application Submitted
03/31/22	AIMM initial comments to Clean Connect
04/26/22	Working meeting between AIMM team and Clean Connect on application questions
05/11/22	Completed AIMM review and sent comments on 1st application revision
05/24/22	Clean Connect completed revisions to transmit 2nd application revision
06/23/22	Completed AIMM review and sent comments on 2nd application revision
July-Oct	AIMM team and Clean Connect update Supplemental Documentation regarding comments on 2nd application revision
10/19/22	AIMM team discussion on Leak Rate Distribution data sets for equivalency demonstration
12/06/22	Date considered a complete application for Alternative AIMM approval

<u>Introduction</u>

The Colorado Air Pollution Control Division (division) received an application for an Alternative Approved Instrument Monitoring Method (Alternative AIMM) from Clean Connect AI, Inc. (Clean Connect or Applicant), for the Clean Connect monitoring system and associated work practices. Consistent with the requirements under Air Quality Control Commission Regulation No. 7, Part D, Section I.L.8, the Division's AIMM team has reviewed the application and recommends it be submitted to the U.S. Environmental Protection Agency for approval as an Alternative AIMM that may be used by operators to comply with the Leak Detection and Repair (LDAR), Storage Tank Emissions Management, and Pneumatic Controller requirements of Regulation No. 7, Part D. This document summarizes the Clean Connect Alternative AIMM Application and Additional Information supplement as they relate to the minimum criteria required in Regulation No. 7, Part D, Section I.L.8. Elements of the Application and

Additional Information supplement are referenced in this summary; the full documents are available to view on the division's Alternative AIMM public notices page.

Review of Regulation No. 7, Part D, Section I.L.8 criteria (regulatory language bolded):

I.L.8.a.(i) The proposed alternative approved instrument monitoring method manufacturer information;

- *Clean Connect was founded in March 2020 and is headquartered in Berthoud, Colorado. (Additional Information, Sec 5.a.iv)*

I.L.8.a.(ii) A description of the proposed alternative approved instrument monitoring method including, but not limited to:

I.L.8.a.(ii)(A) Whether the proposed alternative approved instrument monitoring method is a quantitative detection method, and how emissions are quantified, or qualitative leak detection method;

- *The Clean Connect system analyzes qualitative infrared (IR) optical gas imaging (OGI) camera videos. (AIMM Application form, Sec 2)*

I.L.8.a.(ii)(B) Whether the proposed alternative approved instrument monitoring method is commercially available;

- *The Clean connect monitoring system is commercially available worldwide. (AIMM Application form, Sec 1)*

I.L.8.a.(ii)(C) Whether the proposed alternative approved instrument monitoring method is approved by other regulatory authorities and for what application (e.g., pipeline monitoring, emissions detected);

- *No. (AIMM Application form, Sec 2)*

I.L.8.a.(ii)(D) The leak detection capabilities, reliability, and limitations of the proposed alternative approved instrument monitoring method, including, but not limited to, the ability to identify specific leaks or locations, detection limits, and any restrictions on use, as well as supporting data;

- *The Clean Connect monitoring system reliably demonstrated capability of detecting 1.8 kg/hr methane emissions at 18.6 m through testing of archival IR camera footage. On-site testing showed reliable detection at 27.4 m of emissions as low as 10 scf/hr. Additional blind field testing in October 2022 of releases of 2 kg/hr demonstrated consistent successful identification of releases and non-releases at distances of 120 m (Additional Information, Sec 6.b-d)*
- *The Clean Connect monitoring system is operational 24 hours per day as no sunlight is required for the OGI camera system to effectively monitor for methane*

emissions. Solar powered deployments are feasible and are currently in circulation, however, a battery bank which can support 7 days of autonomy is necessary. (Additional Information, Sec 7.a)

- *Field deployments have shown that wind speed is not a significant factor in the efficacy of the system's ability to detect methane emissions. Due to the large coverage capable from the camera system, even in high winds which would lead to accelerated plume dispersion, the camera and detection algorithm are often able to pinpoint the source of the emission. (Additional Information, Sec 7.a)*
- *The Clean Connect camera(s) is/are installed at a location and height to best observe as many equipment groups as possible. Field deployment experience has shown that most facilities are effectively monitored with 1 camera. The larger the site and the more equipment requiring monitoring, the more likely additional cameras will be required. Clean Connect Cameras will be mounted 20-30 feet above ground level to ensure that the system is able to "look-down" on equipment. Looking down on equipment benefits the detection algorithm as contrasting an emission plume against the sky is more difficult than contrasting an emission plume against ground level background. If an emissions event is flagged by the Clean Connect monitoring system and the operator is unable to identify or localize the leaking component using the Clean Connect video alone, a handheld OGI or Method 21 approved device survey is required. (Additional Information, Sec 7.a)*
- *In addition to the continuous, year-round operation of the Clean Connect system, an annual handheld OGI survey is also completed at the facility as part of the AAIMM program. (Additional Information, Sec 4.a)*
- *IR camera installations are swapped out every 8,000 hours of service to perform routine calibration. Cameras are housed in IP-67 weatherproof enclosure. Continuous monitoring of incoming IR camera data will be used to determine whether the camera housing needs cleaning or replacement. (Additional Information, Sec 5.a.ii)*

I.L.8.a.(ii)(E) The frequency of measurements and data logging capabilities of the proposed alternative approved instrument monitoring method;

- *The Clean Connect camera continuously monitors a facility in a panoramic observational path known as a tour. The tour is composed of "tour stops," points where the camera is stationary and continuously observing a predefined field of view. The number of tour stops during a given facility's tour is dependent on the size of the facility and the number of equipment groups requiring monitoring: the larger the facility, the more tour stops are required. Each tour stop has a duration of 2 minutes. (Additional Information, Sec 5.a.vii)*
- *The OGI camera(s) directly communicate (through data cables) with the on-site intelligent edge data center, while the data center uploads OGI video and detection event data to the cloud platform using a wired internet connection. Typically, uploads are done through wired connection while some deployments*

have relied on p2p radio. Ultimately it is the responsibility of the Operator to ensure the Clean Connect data can be uploaded. In the event of a loss of internet connection, the intelligent edge data center can be used as temporary storage for OGI video and detection event data. Data stored at the intelligent edge data center will be synced up with the cloud-based platform when internet connection is restored. Data will be stored in "hot storage" (immediately accessible) for 90 days while all data will be accessible for 7 years. (Additional Information, Sec 7.a)

I.L.8.a.(ii)(F) Data quality indicators for precision and bias of the proposed alternative approved instrument monitoring method;

- *The OGI camera will be swapped out every 8,000 hours. When the camera is swapped out, Clean Connect will perform a maintenance check of all components. The IP67 rated weather-proof enclosure provides effective protection against potential accelerated lens degradation (faster than the 8,000 hour swap-out window). (Additional Information, Sec 5.a.ii)*
- *All camera components are monitored autonomously by the intelligent edge data center. The data center, via the detection algorithm, monitors:*
    - *A. Camera deployment time*
    - *B. Quality of incoming OGI video*
    - *C. Pan and tilt unit operation (is the camera pointing in the correct direction at the correct zoom level) (Additional Information, Sec 5.b)*
- *Clean Connect is alerted if the intelligent edge data center detects any anomalous behavior. Anomalous behavior could include the camera not moving through all tour stops, a marked decrease in the quality of incoming video (potentially due to weather, such as raindrop build-up on the lens), or a complete stop to incoming camera footage. If anomalous behavior occurs, Clean Connect will attempt to remedy the situation remotely but will make site visits to carry out calibration/maintenance if required. (Additional Information, Sec 5.b)*

I.L.8.a.(ii)(G) Quality control and quality assurance procedures necessary to ensure proper operation of the proposed alternative approved instrument monitoring method;

- *The OGI camera will be swapped out every 8,000 hours. When the camera is swapped out, Clean Connect will perform a maintenance check of all other components listed in Section 5.a.ii. The IP67 rated weather-proof enclosure provides effective protection against potential accelerated lens degradation (faster than the 8,000 hour swap-out window). In addition, extensive research and development went into the on-board cooling system of the camera. All camera components are monitored autonomously by the intelligent edge data center. The data center, via the detection algorithm, monitors (a) camera deployment time; (b) quality of incoming OGI video; and (c) pan and tilt unit operation. Clean*

Connect is alerted if the intelligent edge data center detects any anomalous behavior. Anomalous behavior could include the camera not moving through all tour stops, a marked decrease in the quality of incoming video (potentially due to weather, such as raindrop build-up on the lens), or a complete stop to incoming camera footage. If anomalous behavior occurs, Clean Connect will attempt to remedy the situation remotely but will make site visits to carry out calibration/maintenance if required. (Additional Information, Sec 5.b)

I.L.8.a.(ii)(H) A description of where, when, and how the proposed alternative approved instrument monitoring method will be used; and

- *Where: The Clean Connect monitoring system is installed at sites subject to Regulation No. 7, Part D, Sections I.L, II.E, and III.F leak detection and repair (LDAR) requirements, which consists of well production facilities and natural gas compressor stations in the state of Colorado. (Additional Information, Sec 3.c)*
- *When: The Clean Connect system continuously monitors the facility for methane emissions, passing along a predefined path of tour stops consisting of 2-minute observation periods of individual equipment groups. At the completion of all tour stops at the facility, the camera begins the same path again starting at the first tour stop. Any emissions identification surpassing the defined level of persistence (20 seconds) results in an alert, which is immediately sent to the Operator. (Additional Information, Sec 5.a & c)*
- *How: The Clean Connect system continuously analyzes OGI camera footage from one or more fixed mount cameras located at a facility. Upon the Clean Connect system identifying a possible leak, the Operator will observe the OGI video to determine whether the flagged emission is a leak needing to be addressed, or if it is a planned or otherwise allowable event. Should the Operator deem the flagged emission event a leak, the leaking component must be pinpointed. Typically, Clean Connect video in conjunction with Operator expertise is enough to pinpoint a leaking component. However, should the Operator not be able to localize the leaking component using the Clean Connect video alone, a handheld OGI or Method 21 approved device survey is required. Once the leaking component is identified via the Clean Connect OGI footage or handheld investigation, the leak is tagged, and repair is required. The tagged leak will be repaired in accordance with timelines established in Regulation 7. (Additional Information, Sec 4.a)*

I.L.8.a.(ii)(I) Documentation (e.g., field or test data, modeling) adequate to demonstrate the proposed alternative approved instrument monitoring method or program is capable of achieving emission reductions that are at least as effective as the emission reductions achieved by the leak detection and repair provisions in Section I.L.

- *The Clean Connect monitoring system reliably demonstrated capability of detecting 1.8 kg/hr methane emissions at 18.6 m through testing of archival IR* *camera footage. On-site testing showed reliable detection at 27.4 m of emissions as low as 0.2 kg/hr. (Additional Information, Sec 6.a)*

- *The company conducted controlled release testing at an operational well production facility in October 2022. The company tested the Clean Connect system in blind trials, testing the efficacy of the system to correctly identify releases and non-releases at varying distances with a consistent methane release of 2 kg/hr. In accordance with the testing protocol approved by the division, the system accurately identified greater than 99% of releases and non-releases at distances up to 100 m. (Additional Information, Sec 6.d)*
- *The company also used LDAR-Sim to model emissions mitigation performance of Clean Connect monitoring program versus adherence to Regulation No. 7 AIMM inspection frequency requirements for well production facilities and natural gas compressor stations. The company used an assumed minimum detection level of 5 kg/hr for the Clean Connect system, leak rate distributions requested by the Air Pollution Control Division, and leak production rates based on Colorado-specific regulatory inspection frequencies. In all regulatory frequency categories for both well production facilities and natural gas compressor stations, the Clean Connect system surpassed emissions reduction equivalency compared with the Regulation No. 7 OGI program. Simulation modeling showed that, on average, when compared to a baseline case in which no LDAR was present, the Clean Connect monitoring system achieved a 52.83% reduction in emissions. When compared to a regulatory LDAR program consisting of regular handheld OGI surveying as described in Regulation 7, the Clean Connect monitoring system, on average, results in a 10.9% improvement in emissions reduction over the regulatory program. (Additional Information, Sec 8)*

Issued on: DATE via email

David Conley
Clean Connect AI, Inc.
7352 Greenridge Road, Unit A9
Windsor, CO 80550

RE: Approval of Request for Clean Connect Monitoring System and Work Practices to be an Alternative Approved Instrument Monitoring Method for Colorado Air Quality Control Commission (AQCC) Regulation No. 7 STEM and LDAR Requirements

Dear David Conley:

The Air Pollution Control Division (Division) reviewed Clean Connect AI, Inc.'s application dated February 28, 2022, applying for approval of the Clean Connect Monitoring System as a proposed Alternative Approved Instrument Monitoring Method (Alternative AIMM) for purposes of AQCC Regulation No. 7 Storage Tank Emission Management (STEM) monitoring and Leak Detection and Repair (LDAR) requirements. That application, along with information provided to the Division as described in the supplemental information and Division summary, is sufficient for the Division to issue an approval letter for the Clean Connect Monitoring System.

The Division determined the application and supplemental information submitted meets the minimum requirements for approval of the Clean Connect Monitoring System as an Alternative AIMM under the Non-Quantitative Classification. Please review AQCC Regulation No. 7, Part D, Sections I.L. & II.E. for the requirements for terms of use under the Non-Quantitative Classification.

The Division hereby approves the use of the Clean Connect Monitoring System as an Alternative AIMM by operators of facilities subject to AQCC Regulation No. 7 STEM monitoring and LDAR requirements provided the following additional conditions are met:

1. The facility operator ***must*** follow the Work Practices for the Clean Connect Monitoring System established in Sections 5 (Operator Leak Classification Standard Operating Procedure) and 7 (Proposed Work Practices) of the application supplement. Figure 14 in Section 7.b.ii of the application supplement provides the work practice that must be followed when a detection event is reported by the system.
2. The optical gas imaging (OGI) camera(s) of the Clean Connect Monitoring System must be located no more than 100 meters from any components to be monitored. Additionally, the OGI camera(s) must be located, positioned, and operated such that at least 90% of the components at a facility subject to monitoring are adequately monitored meaning any potential emissions from those components can be detectable

by the system. Components inside enclosed spaces such as a compressor building that are included as part of the 90% requirement will require an OGI camera inside the enclosed space to ensure adequate monitoring or will require a periodic manual AIMM inspection according to the applicable monitoring schedule in AQCC Regulation No. 7, Part D., Sections I.L or II.E.

3. The operator of a facility monitored by the Clean Connect Monitoring System must retain and make available for inspection upon request a copy of this approval letter.

For the facilities subject to Title V Operating Permit requirements: Division-approved alternative AIMM (other than infrared camera or EPA Method 21) must be documented within each Title V Operating Permit. A complete Title V modification application or revision to a previously submitted application must be submitted by any operator seeking to use the Clean Connect monitoring system and Work Practices at a facility prior to implementation.

Please note that the Division is making this determination based on a reliance on the validity and accuracy of the information provided by Clean Connect AI, Inc. in its submittal and through working meetings identified in the Divisions' Summary of the Alternative AIMM. Please do not hesitate to contact me at 303-921-8134 or jennifer.mattox@state.co.us if you have any questions regarding this letter or would like to further discuss this approval. Thank you.

Sincerely,

Jennifer Mattox
Compliance Oversight & Inspections Supervisor
Oil & Gas Program
Colorado Air Pollution Control Division

cc:

Additional Information

Alternative Approved Instrument Monitoring Method (AAIMM) Application

Clean Connect, Inc.

1. Executive summary

The purpose of this document is to present a proposed alternative approved instrument monitoring method centered around the Clean Connect monitoring system technology. The Colorado Department of Public Health & Environment detail leak detection and repair (LDAR) regulations in Regulation 7. These requirements rely exclusively on periodic close-range inspections using handheld instruments known as approved instrument monitoring methods (AIMM's). The proposed alternative AIMM detailed in this application rapidly identifies emissions and through OGI video, provides the ideal medium for an Operator to deliberate on the nature of these emissions, avoid unnecessary follow-up investigations and minimize leak duration. Work practices of the proposed alternative AIMM as well as investigation into reduction equivalency when compared to currently approved methods is included in detail.

2. Table of Contents

3. Proposal description

3.a. Overview

Clean Connect, Inc. ("Clean Connect"), with support from Highwood Emissions Management Inc. (Highwood) and PDC Energy (PDC), is proposing to the Colorado Department of Public Health and Environment (CDPHE) an Alternative Approved Instrument Monitoring Method (AAIMM) Application.

3.b. Applicant team

3.b.i. List all applicants and contact information

Applicant	Company	Role	Applicant
Mark Smith	Clean Connect, Inc.	Continuous measurements	mark@cleanconnect.ai
David Conley	Clean Connect, Inc.	Continuous measurements	david@cleanconnect.ai
Thomas Fox	Highwood Emissions Management Inc.	Consultant	thomas@highwoodemissions.com
Brendan Moorhouse	Highwood Emissions Management Inc.	Consultant	brendan@highwoodemissions.com
Susan Gomez	PDC Energy	Industry proponent	susan.gomez@pdce.com
Beau Hastings	PDC Energy	Industry proponent	beau.hastings@pdce.com

Table 1 Program participants, their organizations, roles, and contact information

3.c. Program scope

3.c.i. Facilities, companies, production types, and value chain segments

The scope of this proposed AAIMM is all regulated facilities that require a leak detection and repair (LDAR) program under the Department of Public Health and Environment, Air Quality Control Commission, Regulation 7. Regulation 7 has separate rules for facilities that reside inside and outside of the 8-hour Ozone Control Area, however, regardless of facility jurisdiction, the facility types that require mandatory LDAR are well production facilities and natural gas compressor stations. All natural gas compressor stations require an LDAR program, regardless of jurisdiction. Whether a well production facility requires an LDAR program is based on a facility's yearly total volatile organic compound (VOC) emissions on a 12-month rolling total. Well production facilities require an LDAR program if: they are within the 8-hour Ozone Control Area and their total VOC emissions are greater than 1 ton per year, or if they are outside the 8-hour Ozone Control Area and their VOC emissions are greater than 2 tons per year. The specifics of required LDAR programs for well production facilities which require one are based on the facility's VOC emissions, proximity to occupied areas, and, beginning January 1, 2023, if the facility resides in a disproportionately impacted (DI) community.

The scope of this application encompasses the monitoring requirements of all facility types which require LDAR and all components which require monitoring with an approved instrument monitoring method (AIMM) under the Colorado Department of Health and Environment, Regulation 7.

The Colorado Oil and Gas Conservation Commission indicates that there are currently 322 active natural gas processing facilities in the state. The U.S. Energy Information System indicates that in 2019 there were 49,237 producing wells in Colorado. Figure 1 shows the locations of active wells in Colorado. If approved, Operators will have the option to choose to build an LDAR program based around the technology described in this AAIMM, or construct an LDAR program based on an existing AIMM.

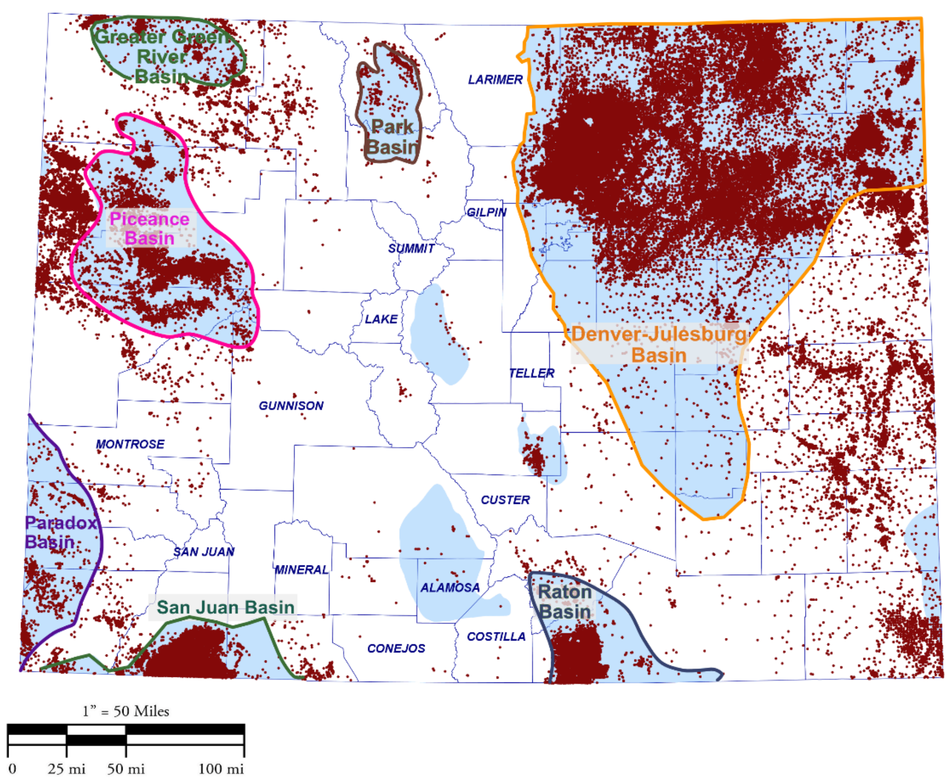


Figure 1: Colorado facilities requiring LDAR

3.c.ii. Geographical coverage

Colorado accounts for just over 4% of total U.S. petroleum production and has the 7th largest gas reserves of any state. Most hydrocarbon production stems from the Denver-Julesburg (DJ) Basin in northeastern Colorado and the Piceance Basin in western Colorado (Figure 1). Within the DJ basin, the largest producing field is the Wattenburg Field which accounts for 9 out of every 10 barrels of crude oil produced in Colorado.

Natural gas production has recently migrated away from dry natural gas production in the Piceance basin to the liquid natural gas exploration and production of the DJ basin.

With the advent and widespread adoption of horizontal drilling and hydraulic fracturing, hydrocarbon bearing shale reservoirs have become exploitable. As a result, the Niobrara Shale Formation is Colorado's most productive formation

4. Description of the alternative LDAR *program* (see glossary for definitions)

4.a. Summary of alternative LDAR program

The proposed alternative LDAR program sees the implementation of the Clean Connect monitoring system, annual handheld OGI surveys and follow-up handheld OGI surveys in the case that the source of a detection from the Clean Connect monitoring system cannot be localized down to a specific component.

The Clean Connect monitoring system is installed at sites requiring LDAR. The monitoring system is the combination of an autonomous, OOOOa certified OGI camera which observes the facility in a rotational "tour". OGI footage is analyzed with the proprietary Clean Connect detection algorithm, which employs deep learning computer vision to assess the footage for the presence of an emission. All OGI footage and associated data is uploaded to a secure cloud-based platform where it can be accessed by parties involved in the LDAR program.

As the Clean Connect OGI camera proceeds through its tour, all equipment groups which require monitoring are observed. Leak detection is based on persistence. Should the Clean Connect detection algorithm consistently detect the presence of an emission at a given equipment group, the Operator is notified (details of persistence are covered in Section 5.c.i). Once an emission has been detected and the Operator is alerted of the potential presence of a leak, the Operator, using the Clean Connect OGI footage in conjunction with SCADA systems and facility knowledge will investigate the nature of the detected emission. Scheduled or allowed emissions will be detected by the Clean Connect monitoring system, however, the operator will be able to quickly ignore these detection events. If the Operator does decide the detection event is a fugitive emission, the Clean Connect OGI footage is used to pinpoint the leaking component. In the cases that the Operator cannot pinpoint the leaking component using Clean Connect OGI footage, it is their responsibility to conduct a follow-up investigation to localize the leak source. This follow-up investigation requires the use of a handheld OGI camera or Method 21 device and is further described in Section 7.b.ii of this application.

Once the leaking component has been identified, it is digitally tagged for repair. Repairs will be conducted on tagged leaks along the timelines set forth in Regulation 7 Part D, sections I.L.5. and II.E.7 and for pneumatic controllers III.F.2. When the repairs have been completed, the previously leaking component will be re-monitored using the Clean Connect monitoring system installed on site, or, if necessary with a handheld OGI investigation.

All LDAR program data, including OGI footage, meteorological data and all details around repairs are stored on cloud-based servers. It is the responsibility of the Operator to grant access to these servers to the regulator should they require it.

4.b. Roles and responsibilities:

Parties with responsibilities in the proposed alternative AIMM are Clean Connect and the Operator (this may be an oil and gas operator for well production facilities or the company that owns / operates a natural gas compressor station). The roles and responsibilities of each party are as follows:

1. Clean Connect
    a. Work collaboratively with the Operator to identify the ideal number and location of Clean Connect camera systems as well as number and location of camera system tour stops (the Operator has the ability to name tour stops for easy tracking once they have been established) on a per-facility basis. Collaboration is necessary as the logistics of site monitoring (number of camera systems, camera location, number of tour stops, etc.) are highly variable across different facilities and Operator expertise on their facility is required. Although a collaborative process, the responsibility of ensuring all equipment and components which require monitoring are adequately monitored with the Clean Connect camera system ultimately falls to the operator.
    b. Ensure OGI camera to be used in a monitoring system is OOOOa certified and meets the specific requirements of the LDAR program plan (sufficient zoom length, etc.). See Section 5.a.ii for further details.
    c. Continuously, autonomously monitor incoming OGI camera feed and supplemental environmental data for anomalous recordings indicating a potential leak.
    d. Continuously monitor incoming data for quality assurance and quality control.
    e. Swap out the deployed OGI cameras every 8,000 hours (just under a year). This frequency of camera swaps will cover any routine calibration concerns.
    f. Perform an inspection of system components during camera swap-outs to guarantee functionality.
    g. Notify the Operator when a potential leak is detected (detection event) via cellular and/or SCADA networks.
    h. Ensure all deployed camera systems have access to the cloud for proper algorithm function and record keeping.
    i. Maintain a database of all installed camera systems, the facilities they are installed at and their specific install locations.
    j. Supply the Operator with all applicable data needed to compile annual reports.
2. Operator:
    a. Work collaboratively with Clean Connect to ensure the Clean Connect monitoring system installation contains a sufficient number of Clean Connect OGI cameras and tour stops.
    b. Facilitate Clean Connect site visits to install and maintain camera systems.
    c. Ensure Clean Connect data can be uploaded to the cloud-based platform
    d. Perform preventative maintenance to minimize fugitive emissions, see Section 5.b.i for a more detailed description of preventative maintenance.
    e. Follow the standard operating procedure detailed in Section 5.c.ii, or, provide a custom SOP to evaluate **all** Clean Connect system detection events (events in

which the camera system and AI algorithm has observed potential fugitive emission for a sustained threshold of time) to decide if the detection event is a routine emission (i.e., blowdowns or pneumatic venting) or is a fugitive emission (AKA leaks) and repair is required.

f. Facilitate handheld OGI or Method 21 approved instrument inspections (recurring annual inspections or follow-up of Clean Connect detection events in the rare case where the leak origin cannot be pinpointed using the Clean Connect footage).
g. Ensure all emissions detected by the Clean Connect monitoring system are addressed. Confirm routine emissions are accurately classified and the routine emissions self-remedy. Ensure all fugitive emissions/leaks are repaired following Regulation 7, Part D, sections I.L.5, II.E.7, or III.F.3 timelines.
h. Maintain a database of all emissions detected by the Clean Connect monitoring system, this includes both routine and fugitive emissions. Details include date of detection event, classification of detection event, justification for classification of "routine emission" if selected (justification could include reference to SOP of the equipment, such as a pneumatic with permitted emissions), source location of emission, and means of identification.
i. Keep a database of each leak requiring repair. Details include date of leak identification, monitoring method used to identify leak, and leaking equipment ID.
j. Maintain a database of each remedied emission. Details include full timeline of emission, method used for repair if repair required and proof of repair through re-monitoring of the leaking component with the Clean Connect camera system.
k. Submit an annual report of all LDAR details to the regulator as per Regulation 7, Part D, Sections I.L.7 and II.E.9, and, in regards to reporting of pneumatics, Part D, Section III.F.5 (CDPHE Instructions)

4.c. Description of each *method* used in the program

4.c.i. Clean Connect monitoring system

The Clean Connect monitoring system consists of a Clean Connect OGI camera(s) working in tandem with the Clean Connect detection algorithm, Clean Connect's proprietary AI driven software. The system is capable of rapidly and accurately identifying leaks and is the sole method in the proposed AAIMM. This section details the Clean Connect monitoring system in detail.

5. Clean Connect camera detailed overview

5.a. Description of *technology* used by the Clean Connect monitoring system

5.a.i. General technology description

The Clean Connect monitoring system is composed of 4 main components:

1. The Clean Connect camera: an OGI camera mounted at an elevated position that continuously surveys the facility in a panoramic "tour" through the use of a pan and tilt device.

2. The “Intelligent edge” data center: an on-site computing system which processes incoming OGI camera footage.
3. Meteorological station: Often the facility requiring monitoring will have a pre-existing meteorological station on site which can be used alongside the Clean Connect monitoring system. In the instances where no MET station is present, Clean Connect can facilitate an installation.
4. The Clean Connect detection algorithm: a “computer vision” algorithm which can effectively “see” fugitive emissions. Is applied to OGI video footage at the intelligent edge data center.
5. The Clean Connect cloud-based platform: where footage of detection events is uploaded.

5.a.ii. Clean Connect camera components

There are four primary components of the Clean Connect camera (component 1 in previous section), summarized in Figure 2.

Figure 2: The Clean Connect OGI camera

A.) OGI camera

There are a range of cameras that can be used in the Clean Connect camera system, the main stipulation is that the camera to be used has been deemed compliant with EPA's NSPS 40 CFR part 60, subpart OOOOa sensitivity standard for optical gas imaging equipment. In addition, the camera is required to have a 3.3 µm spectral range. Examples of cameras that have achieved compliance include those from FLIR (GF620, GFx320, GF320, GF300, and G300a) or the Ventus range of cameras from Sierra Olympic (25mm-SL-VG63-025-10, 50mm- SL-VG63-050-10).

OOOOa certified cameras are capable of detecting multiple gasses including Benzene, Ethanol, Ethylbenzene, Heptane, Hexane, Isoprene, Methanol, MEK, MIBK, Octane, Pentane, 1-Pentene, Toluene, Xylene, Butane, Ethane, Methane, Propane, Ethylene, and Propylene.

It is Clean Connect's responsibility to ensure that the OGI camera(s) used in the monitoring system are capable of effectively monitoring the facility at which they are deployed. This includes ensuring the cameras used in the program have sufficient zoom and spectral range. The Operator and Clean Connect will collaboratively ensure the camera(s) are appropriately placed for optimal monitoring of the facility(s) they are deployed on. Further specifics of the make and model of the cameras which have been used in field deployments, and which are capable of future deployment under this AAIMM are detailed in later sections. Regardless of the make and model of the camera used in the LDAR program, it is mounted inside an IP67-rated housing.

B.) Pan and tilt device

The pan and tilt device autonomously rotates the camera in a circular observation path known as a tour. The circular path encompasses 360° and the tilt is capable of 180° of vertical movement.

C.) Mounting device

The camera system requires an elevated view to "look down" on operational activities. The standard height is 20-30 feet. Efforts will be made to mount the camera system to existing infrastructure, however, in the absence of an adequate structure, additional equipment (i.e., mast) may be required.

D.) Communication wiring and antenna

Necessary for sending incoming camera system data (OGI video footage and meteorological data) to the "intelligent edge" data center.

5.a.iii. How the technology works

Clean Connect cameras will be installed around the facility such that they can effectively monitor all equipment prone to leaks regardless of wind direction. The number of required cameras is dependent on the amount of equipment and the size of the facility being monitored. To date, all upstream oil and gas facilities in Colorado have been sufficiently monitored with one camera.

As the Clean Connect camera continuously monitors the facility through a predefined tour (further defined in Section 5.c.i) incoming OGI video footage is sent to the on-site intelligent edge computing center. There, the OGI video footage is passed through the Clean Connect detection algorithm in real time.

The Clean Connect detection algorithm is a proprietary "computer vision" algorithm, meaning the algorithm has been trained to "see" certain characteristics of incoming video. At a high level, the algorithm works by assessing the characteristics of the pixels in each frame of the OGI video, such as the pixel's color and how quickly these colors are changing from one frame to the next. Clean Connect has trained the model with more than 100,000 hours of OGI video, ensuring that the algorithm has "learned" which patterns of pixel behaviour are indicative of targeted emissions. Development is underway which will allow the Clean Connect detection algorithm to classify emissions as "fugitive" vs. "scheduled" or allowed based on equipment group and timing of emission. However, in its current form, the detection algorithm will identify targeted emissions and the Operator, through their expertise of the facility and knowledge of scheduled or allowed emission, will decide on the nature of the detected emission.

The Clean Connect detection algorithm is the centerpiece of the technology. The cameras used, where they are installed, and the nature of their tours may vary between deployments, however, all OGI video will be interpreted by the Clean Connect detection algorithm.

From the edge computing center, all detection events (defined in Section 5.c.i) OGI video and metadata are uploaded to the Clean Connect cloud-based platform. It is through this platform that Clean Connect will store and distribute OGI video and metadata to the Operator. If a detectable emission is present, the Clean Connect monitoring system can detect it, log relevant data, and notify the Operator in less than 5 minutes. The Operator can then submit all necessary data to the regulator via the cloud-based platform. The timeline of a detection through to an Operator notification is detailed in Section 5.c.i. The flow of information is shown in Figure 3.

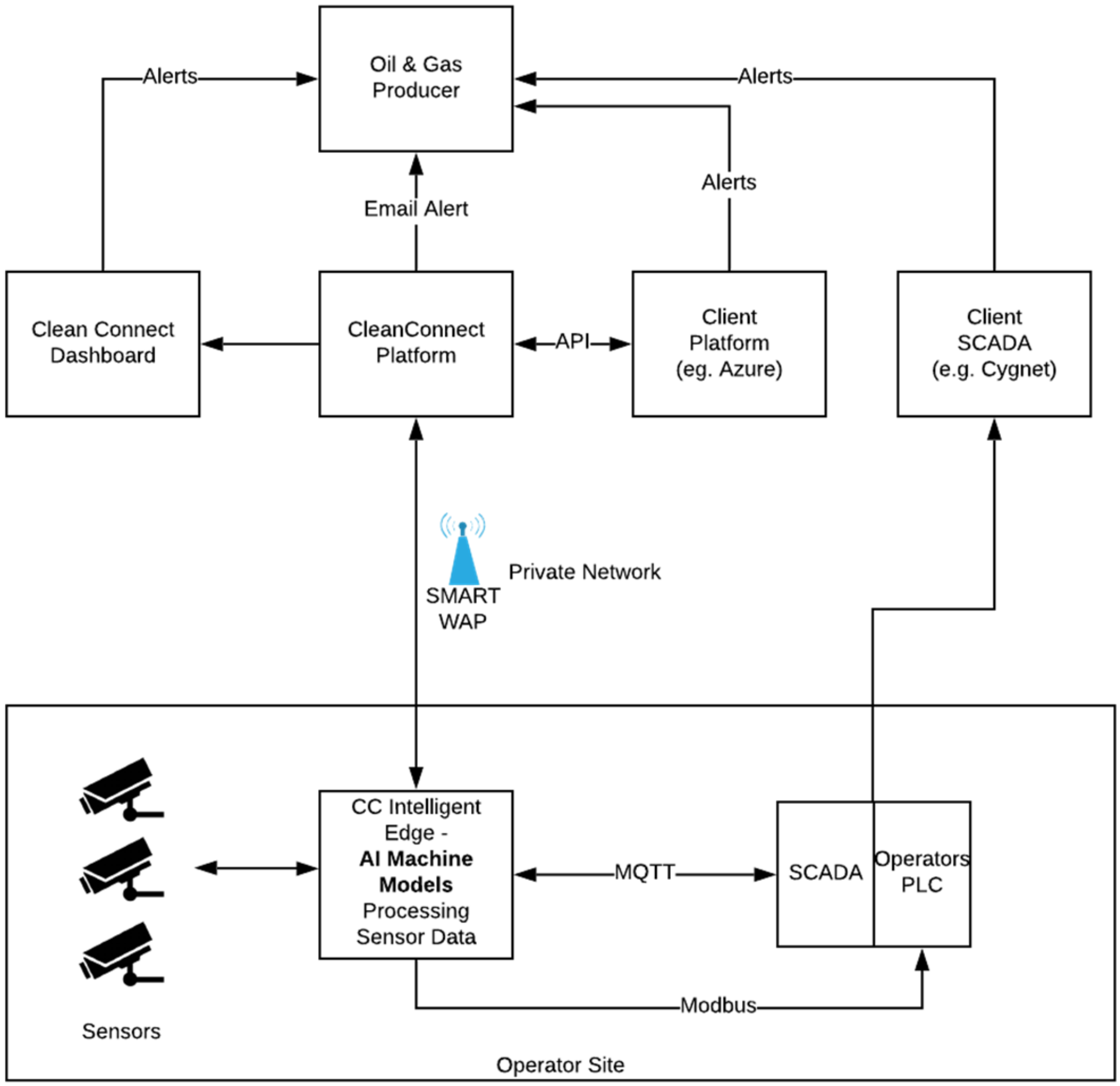


Figure 3: Clean Connect monitoring system data flow

5.a.iv. Manufacturer information

Clean Connect was founded in March 2020 and is headquartered in Berthoud, CO.

5.a.v. Technology maturity

The Clean Connect system is technology readiness level (TRL) 9 and has been used by operators on dozens of production facilities throughout Colorado for over one year.

5.a.vi. Commercial availability

The Clean Connect monitoring system is commercially available worldwide.

5.a.vii. Temporal and spatial scale

Temporal Scale:

The Clean Connect camera continuously monitors a facility in a panoramic observational path known as a tour. The tour is composed of “tour stops”, points where the camera is stationary and continuously observing a predefined field of view. The number of tour stops at a given facility’s tour is dependent on the size of the facility and the number of equipment groups requiring monitoring; the larger the facility, the more tour stops are required. A tour stop has a duration of 2 minutes. To date, the highest number of required tour stops was 42. Therefore, with a tour stop taking 2 minutes of time, on that facility a complete survey took 84 minutes. Conversely, some small facilities are effectively monitored with a single tour stop.

Spatial scale:

The Clean Connect camera can observe a depth of up to 300 feet in a 360° circular range. Spatial coverage capabilities are in part dictated by the lens used by the Clean Connect camera. Lenses capable of larger zoom distances and fields of view will decrease the number of required camera installations.

5.b. Quality control and assurance procedures and data quality indicators

5.b.i. Calibration and/or maintenance requirements

The OGI camera will be swapped out every 8,000 hours. When the camera is swapped out, Clean Connect will perform a maintenance check of all other components listed in Section 5.a.ii. The IP67 rated weather-proof enclosure provides effective protection against potential accelerated lens degradation (faster than the 8,000 hour swap-out window). In addition, extensive research and development went into the on-board cooling system of the camera.

All camera components are monitored autonomously by the intelligent edge data center. The data center, via the detection algorithm, monitors:

A. Camera deployment time
B. Quality of incoming OGI video
C. Pan and tilt unit operation (is the camera pointing in the correct direction at the correct zoom level)

Clean Connect is alerted if the intelligent edge data center detects any anomalous behaviour. Anomalous behaviour could include the camera not moving through all tour stops, a marked decrease in the quality of incoming video (potentially due to weather, such as raindrop build-up on the lens), or a complete stop to incoming camera footage. If anomalous behaviour occurs, Clean Connect will attempt to remedy the situation remotely but will make site visits to carry out calibration/maintenance if required.

5.b.ii. Training, certification, and user competence

Operators can start using the system to remotely diagnose detected leaks with a few hours of training. Clean Connect will provide Operators with a document describing the work practice (see 7.b.ii) so that an Operator is aware of what entails a detection event.

5.b.iii. Additional functionality and features

All visual logs are recorded and can be retrieved by date, time, location, tour stop, detected emission size and duration.

5.c. Description of alternative technology analytics

5.c.i. Detection method and definition of a detection event

As the Clean Connect leak monitoring system is continuously monitoring equipment at the site at which it is deployed, methane leak detection is based on persistence. The Clean Connect system must “see” a methane emission for 20 seconds to confirm it is indeed an emission event. Figure 4 details what constitutes a detection event:

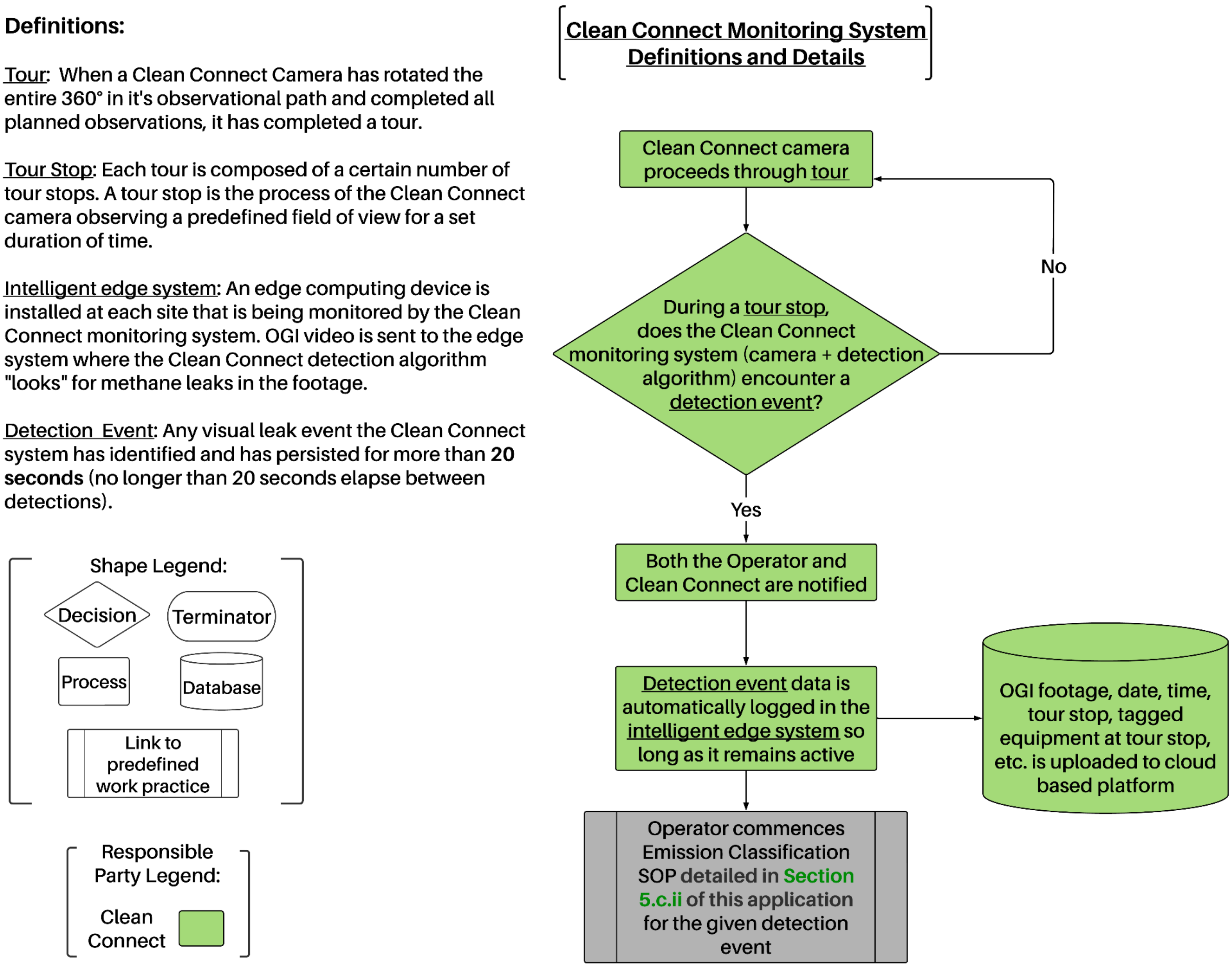


Figure 4: Clean Connect monitoring system definitions flowchart

5.c.ii. Operator emission event classification standard operating procedure

Upon receiving a detection event alert, the Operator must classify the detection event as either:

1. Routine emissions: “expected” emissions which occur during routine operations at compressor stations and well production facilities. Examples include pneumatic device venting or compressor blowdowns.
2. Fugitive emissions: “unexpected” emissions associated with some form of mechanical failure or malfunction.

A record of the classification of each detection event including the associated justification must be kept.

The Operator must follow a standard operating procedure (SOP) when classifying Clean Connect detection events.

The following SOP (Figure 5) provides an overview of the steps an Operator must undertake in classifying a Clean Connect monitoring system detection event. The Operator can elect to follow this SOP, or, should they require a more specific SOP more tailor made to their facilities, they can submit one to the CDPHE, which must be approved by CDPHE prior to use of the Clean Connect system by the Operator for AAIMM purposes.

Definitions:

Trained and qualified: The Operator(s) conducting the emission classification SOP must be trained in both interpreting Clean Connect OGI footage as well as qualified to understand all routine operations at the monitored facility. Clean Connect and the Operator will work collaboratively to ensure alerts are going to, at a minimum, the Operator in charge of the leak classification SOP.

Existing data: The Operator will begin by reviewing all existing data. This includes the Clean Connect OGI footage, SCADA data if available, knowledge of scheduled routine or allowable emissions (e.g., blowdowns), etc. Oftentimes, the Operator can classify an emission with only existing data. Furthermore, the Clean Connect OGI footage alone is often sufficient material for an Operator classifying an emission as fugitive or routine/allowable.

Additional data: Additional data could be an investigation into activities at the facility the Operator is not immediately aware of (e.g., vacuum/pumping truck operations), or a close range OGI or Method 21 inspection. A close range inspection is useful in the case where a Clean Connect detection event shows the emission plume but not the source.

Note on existing and additional data: Existing and additional data are intentionally broad terms as the Operator is encouraged to use multiple data sources concurrently when assessing a detection event, as opposed to a rigorous step-by-step approach. For example, Clean Connect OGI footage can be complemented by available SCADA data to understand the nature of a detected emission. In addition, existing and additional data will vary across facilities.

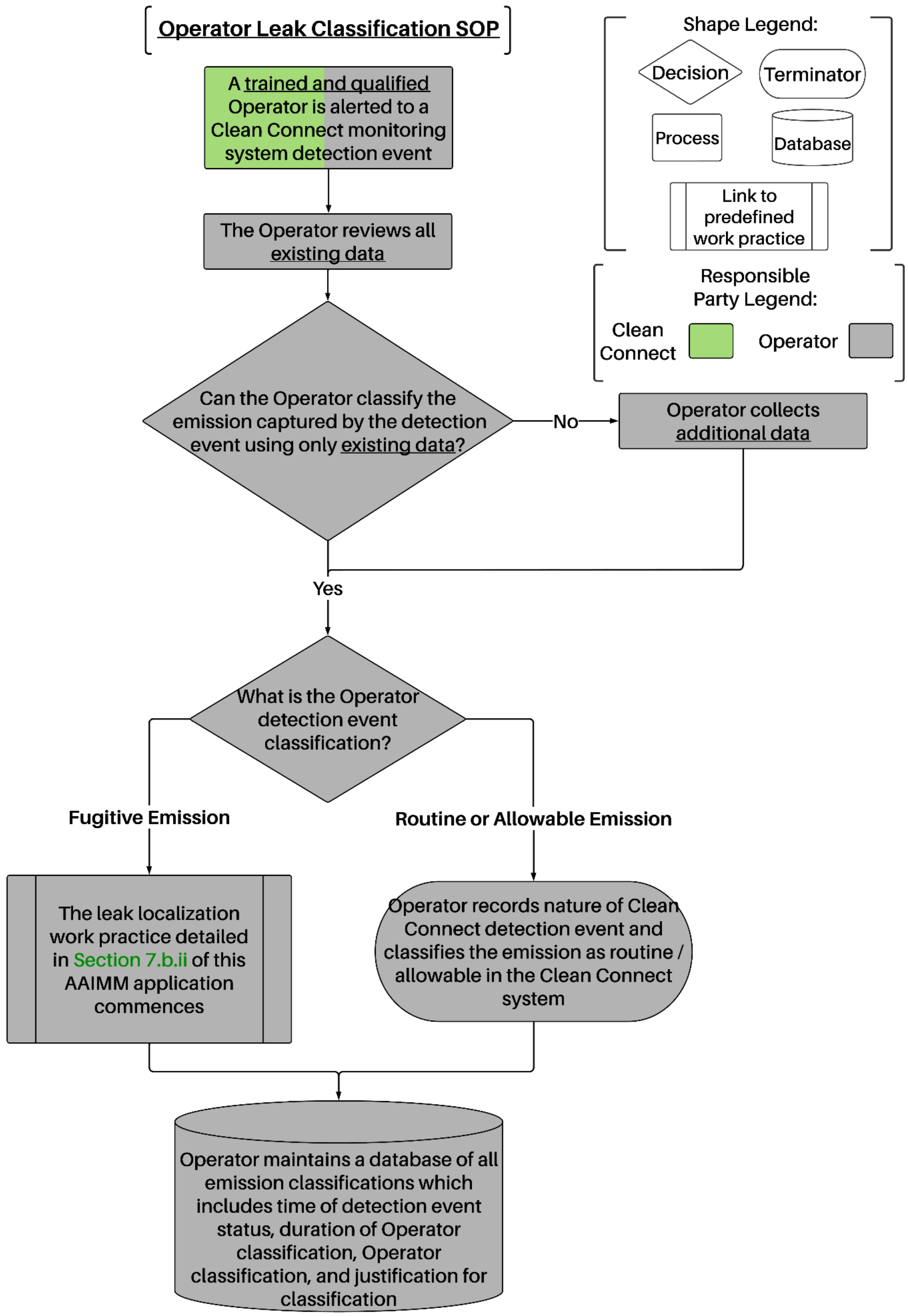


Figure 5: Operator emission classification SOP template

5.c.iii. Localization method

As the system relies on OGI video footage, localization is an intrinsic component of the technology. An operator can simply observe a recorded detection event and from the

OGI video, visually pinpoint the component that the leak has arisen from. In the event that an Operator cannot pinpoint the leaking component causing a Clean Connect detection event, or, the Operator can pinpoint the source of a detection event but cannot confirm it is not a fugitive emission, a handheld OGI / Method 21 follow-up investigation is conducted. The Operator must facilitate the follow-up investigation, any handheld Approved Instrument Monitoring Device (as per Regulation 7) may be used, and the investigation can be carried out by any personnel trained in the use of the given device.

6. Clean Connect field deployments and controlled release testing

6.a. Deployment case studies

Through field deployments, the Clean Connect monitoring system has proven to be effective at detecting emissions, localizing their sources, and enabling operators to quickly react and remedy the cause of the emissions.

The following case studies detail typical Clean Connect deployment scenarios, both case studies illustrate the effectiveness of the Clean Connect monitoring system. In both case studies, the Clean Connect system efficiently detected an emission, identified the source, and alerted the Operator who was able to resolve the issue without the need for handheld OGI or Method 21 follow-up investigation. Specific details such as facility type are unspecified due to non-disclosure agreements.

6.a.i. Case study 1

During a deployment the Clean Connect monitoring system detected an emission event at 2:30 AM. When viewing the Clean Connect video footage, it can be seen that the Clean Connect algorithm identifies the emission source nearly instantaneously upon its inception. Clean Connect was able to precisely identify the source within 50 minutes of initial detection and notify the operator of the situation by 5:50am, allowing them to resolve the problem. The leak in question in this example was an incomplete combustion event from a fire tube stack. The site in question was under additional forms of fugitive emissions monitoring but the Clean Connect monitoring system proved to be the fastest, and, due to the OGI video, the most accurate with regards to localizing the emission.

Around the time of detection of the emission from the fire tube, there was another visible emission event occurring in the background of the video, at a different site, around a half mile away. The Clean Connect system identified this source, but it had no impact on the Clean Connect system's ability to detect and localize the incomplete combustion emission in this example.

6.a.ii. Case study 2

During a deployment, the Clean Connect monitoring system detected a single, continuous event from 7:39pm on October 19, 2021, until 4:09pm on October 22, 2021. The system classified the event as an emission with 5 minutes of detection and quickly localized the source. The Clean Connect system was able to track this emission as a single event, despite all other factors, such as changing meteorological conditions, across the 3 days of detection. The Clean Connect monitoring system confirmed the exact source was a venting, unlit fire tube which the Operator was able to remedy. This example highlights the robustness of the stationary camera system and the Clean Connect detection algorithm against changing conditions.

6.b. Controlled release testing 1: Archival OGI video footage

At the time of submission of this AAIMM proposal, Clean Connect has yet to conduct blind controlled release field testing but is scheduled to perform testing at METEC in Q1 2022. In the interim, Highwood Emissions Management and Clean Connect devised a method of conducting blind testing of the Clean Connect detection algorithm using archival OGI video. The purpose of this testing was to acquire preliminary performance metric data which can be used to inform simulation modelling (Section 8 of this application).

6.b.i. Methodology

The Clean Connect detection algorithm does not require live, incoming OGI video to function. Archival OGI footage can be passed through the algorithm, which will then assess if emissions are present in the footage. By providing the algorithm with pre-recorded OGI video, the detection algorithm can be effectively tested.

To test the system using archival OGI footage, Clean Connect developed a website to host the Clean Connect detection algorithm. The user can upload OGI video to the website, which is then passed through the Clean Connect detection algorithm. After analyzing the OGI video, the user who uploaded it is automatically sent a reporting email which states if the uploaded video contained an emission. This reporting email also contains a link to download a video file. This video file consists of 4 panels:

- The upper left is the raw OGI video which was submitted to the website for testing while other panes show the visual output of the Clean Connect detection algorithm.
- This visual output will trace the suspected plume in blue pixels in the top right panel.
- A detection is represented by a green square which encompasses the predicted emitting component in the lower right pane and the plume in the upper right pane.
- The lower left pane represents quantification, which is the development stage.

Figure 6 is a still of the video which can be downloaded from a reporting email. The video from which Figure 6 is taken was correctly identified as containing footage of an emission.

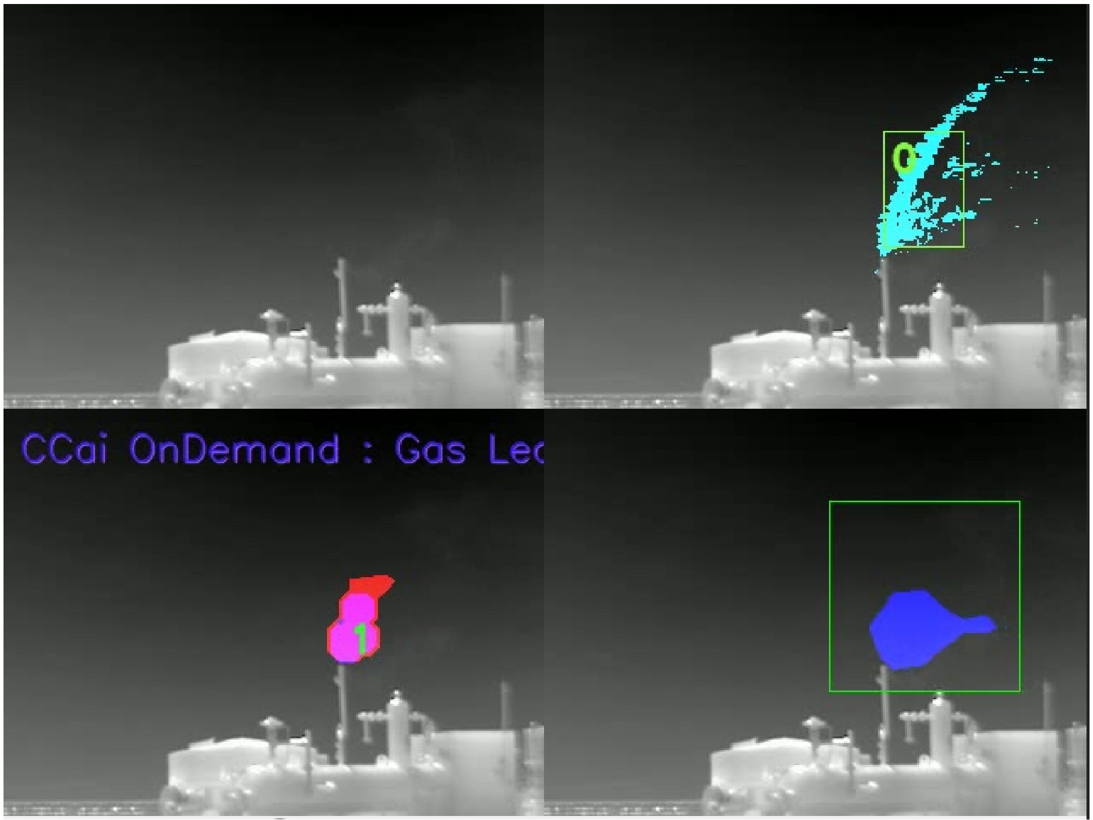


Figure 6: Processed footage of a correct detect. Distance: 18.6m, emission rate: 124.3 ± 2.9 scf/hr (2051.6 ± 48 kg/hr)

To ensure testing was single blind, Highwood sourced OGI video footage to be used for testing independently, not informing Clean Connect of its origin. Highwood performed some necessary modifications to this video (to be discussed in the following section) and then uploaded the most pertinent video files to the detection algorithm hosting website, not informing Clean Connect of when uploads took place. Highwood then assessed the results prior to alerting Clean Connect to the test's conclusion.

6.b.ii. Sourced OGI video

The OGI video used was recorded to serve as key data in the writing of the papers VideoGasNet: Deep learning for natural gas methane leak classification using an infrared camera (Wang *et al* 2022) and Machine vision for natural gas methane emissions detection using an infrared camera (Wang *et al* 2020). A link to the online repository of the OGI videos is included as a reference in Wang *et al* 2022.

The OGI video was recorded at METEC using a tripod mounted FLIR GF-320. All recorded emissions are controlled releases from a separator. OGI video was recorded from 5 imaging distances (distance from OGI camera to release point), 4.6m, 6.9m, 12.6m, 15.6, and 18.6m. For each of these distances, the OGI camera was placed in 5 unique locations. When recording at a given location and distance, the CH4 emission rate of the controlled release was increased in 8, 3 minute steps (9 total steps if the period of time before any emissions are released is considered). Testing was focused on the upper two emission rates/steps: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr) and 124.3 ± 2.9 scf/hr

(2051.6 ± 48 kg/hr) as well as the confirmed video footage of non-release periods (to test for false positives).

The original video files are single, continuous video files for a given distance and location. These videos are, on average, 24 minutes in length (3 minutes for each "step" of release rate with a period of "no release" at the start of the video). For the purposes of testing, Highwood cropped the original video files down to individual files, each one pertaining to a specific distance, location, and emission rate. Cropping the original OGI video resulted in 92 videos to be used in testing with emission rates of 0 scf/hr, 109.5 ± 2.5 scf/hr, and 124.3 ± 2.9 scf/hr from imaging distances of 4.6m, 6.9m, 12.6m, 15.6, and 18.6m. OGI video used was 320 X 240 pixels.

6.b.iii. Results

Highwood found the following key results from submitting OGI video to the Clean Connect detection algorithm via the testing website:

A. The Clean Connect detection algorithm correctly classified 82/92 (89%) of the submitted video files. A correct classification indicates that video containing an emission was classified as having an emission and video of a "non release" was correctly classified as not containing any instances of emission. Figures 7 - 9 are stills of correctly assigned detection events:

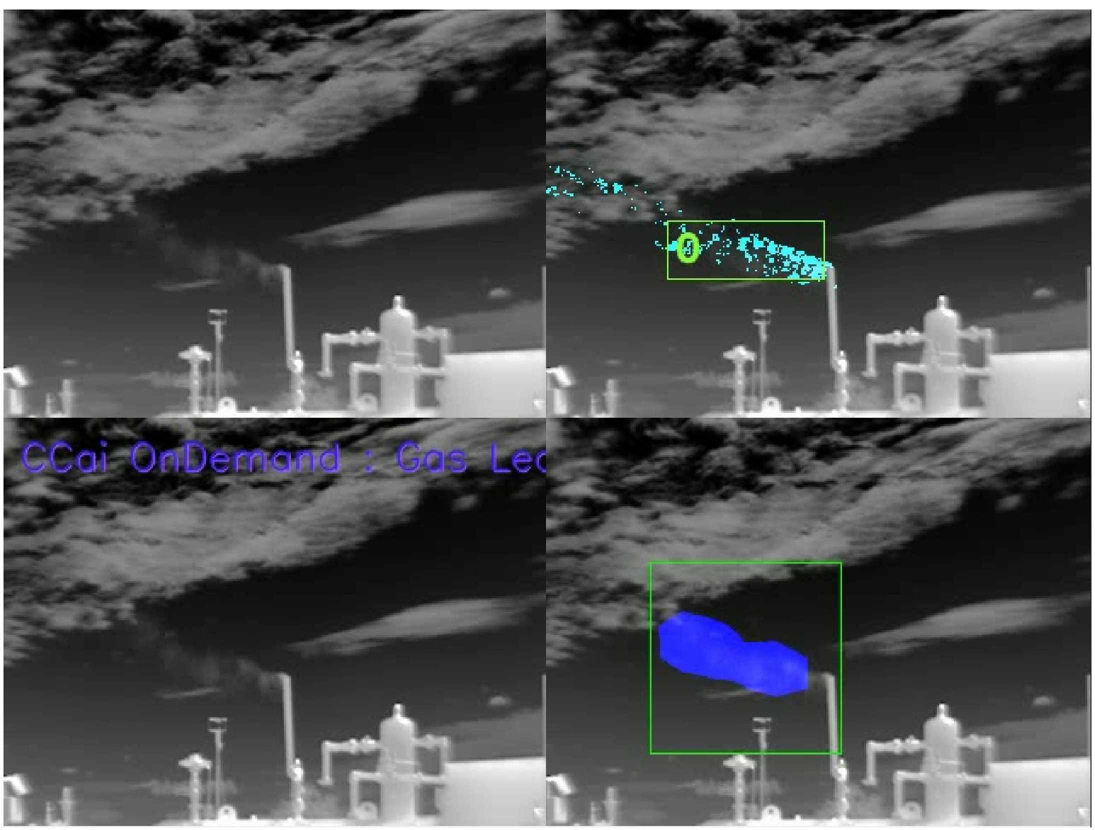


Figure 7: Processed footage of a correct detect. Distance: 15.6m, emission rate: 124.3 ± 2.9 scf/hr (2051.6 ± 48 kg/hr)

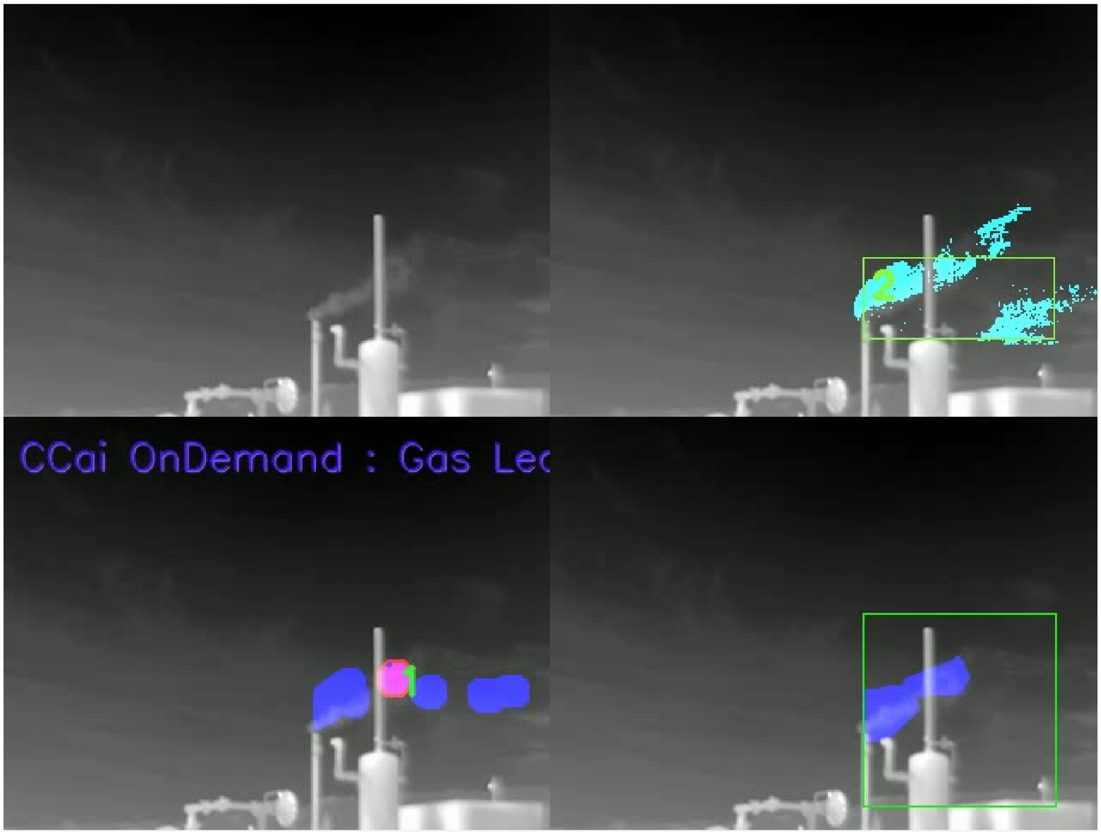


Figure 8: Processed footage of a correct detect. Distance: 15.6m, emission rate: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr)

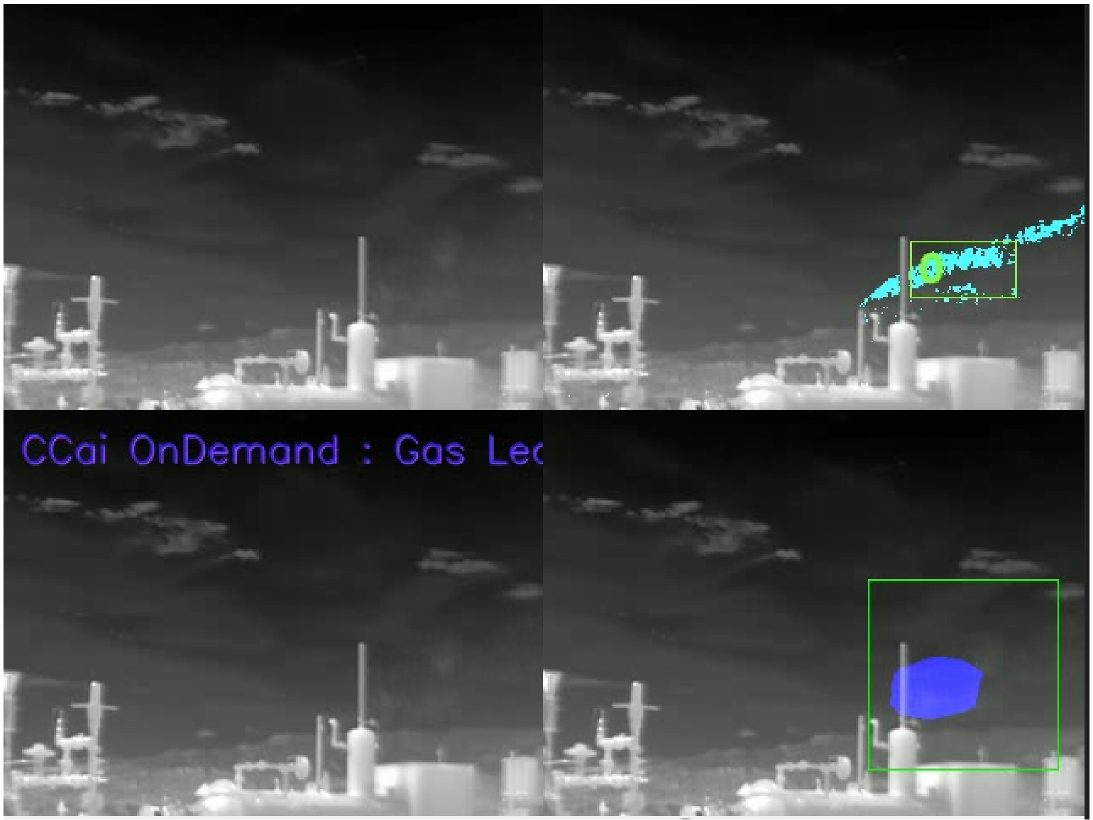


Figure 9: Processed footage of a correct detect. Distance: 18.6m, emission rate: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr)

B. No false positives were reported. All OGI videos of “non-release” were correctly identified as not containing an emission.

C. At the furthest imaging distance of 18.6m, 13/15 (87%) of the submitted videos were correctly classified.

6.b.iv. Misclassification investigation

The processed video provided through reporting emails indicate that all misclassifications can be associated with the reporting functionality of the testing website, not with the detection capabilities of the algorithm. Figures 10 and 11 are stills from misclassifications (a known emission was not correctly identified as such).

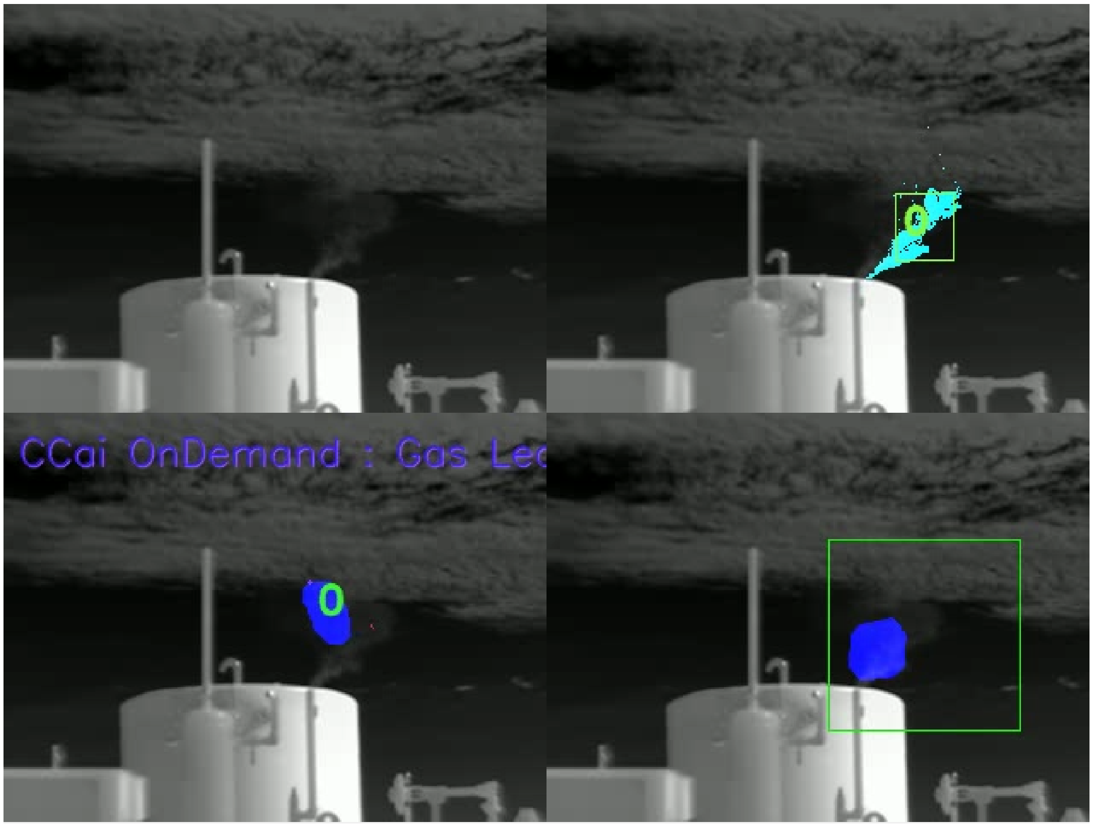


Figure 10: Processed footage of a missed detection. Distance: 9.8m, emission rate: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr)

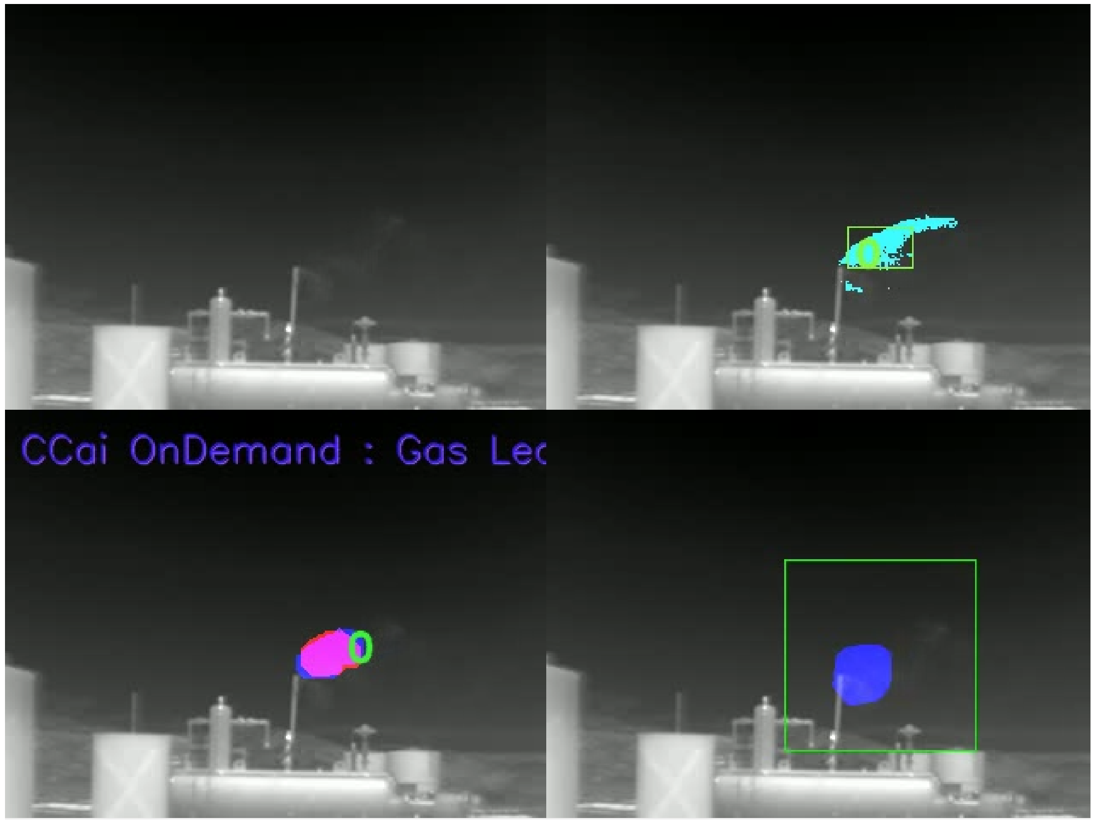


Figure 11: Processed footage of a missed detection. Distance: 18.6m, emission rate: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr)

The green square around the plume and suspected emitting equipment in Figures 10 and 11 indicate the algorithm has correctly identified emissions, however, the reporting emails failed to indicate a detection event was present. Using the results of this investigation Clean Connect has modified the reporting component of the system in preparation for METEC testing.

6.c. Controlled release testing 2: Blind, on-site testing, April 2022

On April 22, 2022, Clean Connect conducted blinded controlled release testing on two separate production facilities in Weld County. During testing, a fuel gas line was used as the emission source and flow rate was confirmed using a dual chamber flow meter.

6.c.i. Methodology

A combination of emission rates and distances of the Clean Connect camera to the emission source were tested. All distances, emission rates and wind speeds are recorded in Appendix B of this application. The average time of each emission (a given emission rate at a given distance) was 2 minutes.

6.c.ii. Results

The full table of results is presented in Appendix B of the application. The most noteworthy result is the successful detection of 150 scf/hr (2.86 kg/hr) at 100 yards

(91.44 m). This result represents the smallest detected release at the greatest distance from available blind, controlled release testing.

6.d. Controlled release testing 3: Blind testing to establish performance at greater distances, October 2022

Across October 20th and 21st 2022 the Clean Connect monitoring system underwent independent blind testing at an operational production facility within the Denver Julesburg basin. The goal of the testing was to evaluate performance of the Clean Connect system at distances greater than those available in the testing described in Sections 6.b and 6.c of this application.

6.d.i. Testing Methodology

The Clean Connect camera system was installed in a fixed position at the site. Multiple controlled natural gas release points were used throughout testing, the distance of these points from the Clean Connect camera system incrementally increasing (the Clean Connect Camera System remained stationary while different release points were set on and off). Controlled release points were chosen at distances of 40m, 60m, 80m, 100m and 120m from the Clean Connect camera system. The release rate was kept consistent at 2 kg/hr throughout testing so as to keep the distance component as the primary variable being explored.

At each distance, a target of 15 releases, each followed by a non-release period, were performed with both the release period and the non-release period lasting approximately 5 minutes. Testing at further distances only saw 8-10 release and non-release pairs due to time constraints, further detailed in the discussion of results. Each release and non-release "window" was represented as a row in a testing results template which was provided to the Operator conducting the testing and had been previously approved as a means of communicating results by CDPHE. The Clean Connect Monitoring System autonomously sent time stamped "alarm packages" to the Operator's alarm management system during the testing period. The alarm packages contained details of the detection including the initial time of detection, the wind speed, and a copy of the OGI video recorded of the detection event. If an alarm package coincided with a scheduled 2 kg/hr release, that release was deemed a true positive by the operator whereas if no alarm package was received during a non-release window, that non-release was deemed a true negative by the operator. The Operator conducting the testing and receiving alarm packages populated the aforementioned testing results form. The testing results form included the columns: Release/Non-Release, Distance (m), Period Start (YYYY-MMDD_00:00), Period End (YYYY-MMDD_00:00), Wind Speed (m/s), Clean Connect alarm package received (1 or 0), Correct result (1 or 0), Link to OGI video. All testing result forms were signed off by the Operator conducting testing and sent directly to CDPHE.

6.d.ii. Maintaining testing blindness

Clean Connect was not aware of when the testing would occur and at which site (the operator partner who conducted testing has multiple sites with an installed Clean Connect Monitoring System). The Operator facilitating the testing set off the controlled releases. The alarm packages were sent directly to the Operator who used them to populate a testing result template which had been approved by CDPHE. Upon completion of testing at a given distance, the results were signed off on by the operator conducting testing. Once testing was completed at all distances, all results were sent directly to CDPHE.

6.d.iii. Testing results

Testing saw a total of 63 releases and 63 non-releases. The Clean Connect Monitoring System sent an alarm package which identified 62/63 releases (98% true positive rate) and did not send an alarm package for 63/63 non-releases (100% true negative rate). A summary table of testing results, including a link to a representative OGI video included in an alarm package for each given distance, follows. Full testing results, represented as images of all PDF testing forms sent from the Operator to CDPHE are included in Appendix A.

Testing Distance (Clean Connect camera system to release point, meters)	True Positive Ratio	True Negative Ratio	Sample OGI video of a True Positive Alarm Package
40	14/15	15/15	Link
60	15/15	15/15	Link
80	15/15	15/15	Link
100	10/10	10/10	Link
120	8/8	8/8	Link

Results of blind controlled release testing at a Colorado based well production facility

Items of note when viewing the linked OGI video:

- There are 4 “panes” within each video. The lower left pane is most directly related to the decision making process of the classification of a detection event, and subsequent sending of an alarm package. Attention in particular should be drawn to the presence of red pixelation in this lower left hand pane. While specifics remain proprietary, at a high level, the average consistent duration of this red pixelation is what will decide if what the camera is “seeing” constitutes a detection event.
- Emission rate values visible in the provided video in standard cubic feet per hour (scfh) are part of an in-development quantification enhancement to the system which is not finalized and falls out of the scope of this application.
- The wind speeds reported on the testing result forms sent directly to the CDPHE (and included in full in Appendix A) vary slightly from the wind speed values annotated in the linked OGI video footage. The Clean Connect Monitoring

System is displaying local weather API data while the wind speed recorded in the testing result forms was measured directly at the testing site.

6.e. Description of performance metrics derived from testing

The goal of the blind testing is to define performance metrics such as probability of detection. Probability of detection is typically represented as a curve or surface that delineates true positives from false negatives. The detection capability of the system is dependent on many factors such as wind speed, proximity of camera system to emission source and emission rate. A probability curve is 1 dimensional and takes 1 condition into account whereas a probability surface is 2 dimensional and takes 2 conditions into account.

As the testing performed thus far contains relatively limited data, and the misclassification investigation associated with the archival OGI video testing led to enhancements in the system, construction of a probability curve/surface based on testing results will not yield a highly accurate result. In addition, the Clean Connect monitoring system algorithm is continually undergoing enhancements.

The testing did, however, provide enough evidence to inform a simplified minimum detection limit (MDL) to be used in simulation modelling based exclusively on CH4 emission rate. The following results will be taken into consideration:

- **From the archival OGI video testing**: The Clean Connect detection algorithm correctly classified 100% of emissions (with the misclassification investigation in mind) from the furthest distance (18.6m) and the lowest emission rate (1806.1 ± 41.4 g/hr) used in testing.
- **From the on-site testing**: At 27.4m (30 yards) the smallest emission successfully detected by the Clean Connect system was 0.19 kg/hr (10 scf/hr). At 36.6m, 73.1m, 91.4m (40, 80, and 100 yards) the smallest emission rate successfully detected by the Clean Connect camera system was 2.86 kg/hr (150 scf/hr).
- **From subsequent blind testing of various distances**: Greater than 90% detection of controlled releases of 2 kg/hr (98.8 cf/hr) at distances of 40m to 120m from the Clean Connect camera system to the controlled release point.

The results of the on-site testing illustrate that the Clean Connect monitoring system is capable of detecting emissions at greater distances than the available data used in the archival OGI video showed. The smallest confirmed detectable emissions at varying distances, taking all testing discussed in Sections 6.b-6.d into account, are summarized in Figure 12. The spacing of the concentric circles is to scale.

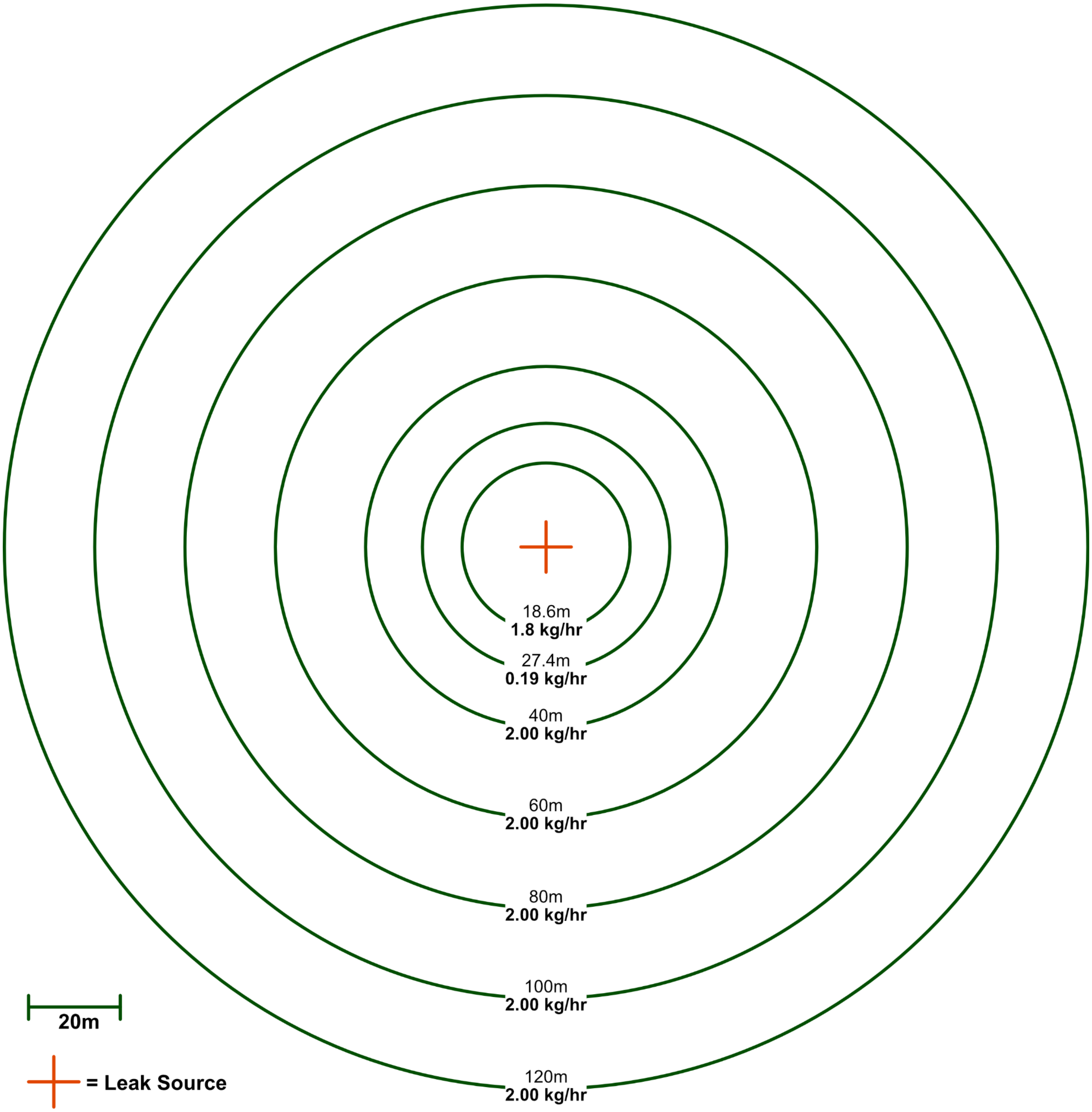


Figure 12: Minimum detected emission rate at varying distances from blind, controlled release testing

Based on the results of the blind testing investigations, a highly conservative minimum detection limit of **260 scf/hr (5 kg/hr)** will be used in simulation modelling.

7. Proposed work practices

7.a. Requirements of use

Facility type: The proposed Alternative AIMM can be used to continuously detect, and report methane emissions from any oil or natural gas production facility or compressor station in Colorado that has the potential to emit methane. The system can be used at both open and closed sites, however, at closed sites (such as one with sound barriers present), obstructed lines of sight could lead to necessary installation of additional Clean Connect cameras.

Number of devices and coverage: Field deployment experience has shown that most facilities are effectively monitored with 1 camera. The larger the site and the more equipment requiring monitoring, the more likely additional cameras will be required. The number of stops for a given camera's tour will also be influenced by the area requiring monitoring. Clean Connect Cameras will be mounted 20-30 feet above ground level to ensure that the system is able to "look-down" on equipment. Looking down on equipment benefits the detection algorithm as contrasting an emission plume against the sky is more difficult than contrasting an emission plume against ground level background.

Connectivity: The OGI camera(s) are directly communicating (through data cables) with the intelligent edge data center while the data center uploads OGI video and detection event data to the cloud platform using a wired internet connection. Typically, uploads are done through wired connection, however, ultimately it is the responsibility of the Operator to ensure the Clean Connect data can be uploaded (see Section 4.b), for example, some deployments have relied on p2p radio. In the event of a loss of internet connection, the intelligent edge data center can be used as temporary storage for OGI video and detection event data. Data stored at the intelligent edge data center will be synced up with the cloud-based platform when internet connection is restored. Data will be stored in "hot storage" (immediately accessible) for 90 days while all data will be accessible for 7 years.

Wind speed and direction: Field deployments have shown that wind speed is not a significant factor in the efficacy of the system's ability to detect methane emissions. Due to the large coverage capable from the camera system, even in high winds which would lead to accelerated plume dispersion, the camera and detection algorithm are often able to pinpoint the source of the emission. If extreme wind speeds prevent detection, Clean Connect will be able to detect the source when wind speeds eventually decline (or between gusts). Wind speed will be logged and used to further refine the Clean Connect detection algorithm.

Cloud coverage / sunlight: The Clean Connect monitoring system is operational 24 hours per day as no sunlight is required for the OGI camera system to effectively monitor for methane emissions. As OGI video is thermal video footage, no sunlight is required. Solar powered deployments are feasible and are currently in circulation, however, if the Operator deems to power the monitoring system via solar, they must ensure a battery bank is available which can support 7 days of autonomy.

7.b. Program deployment plan and scheduling

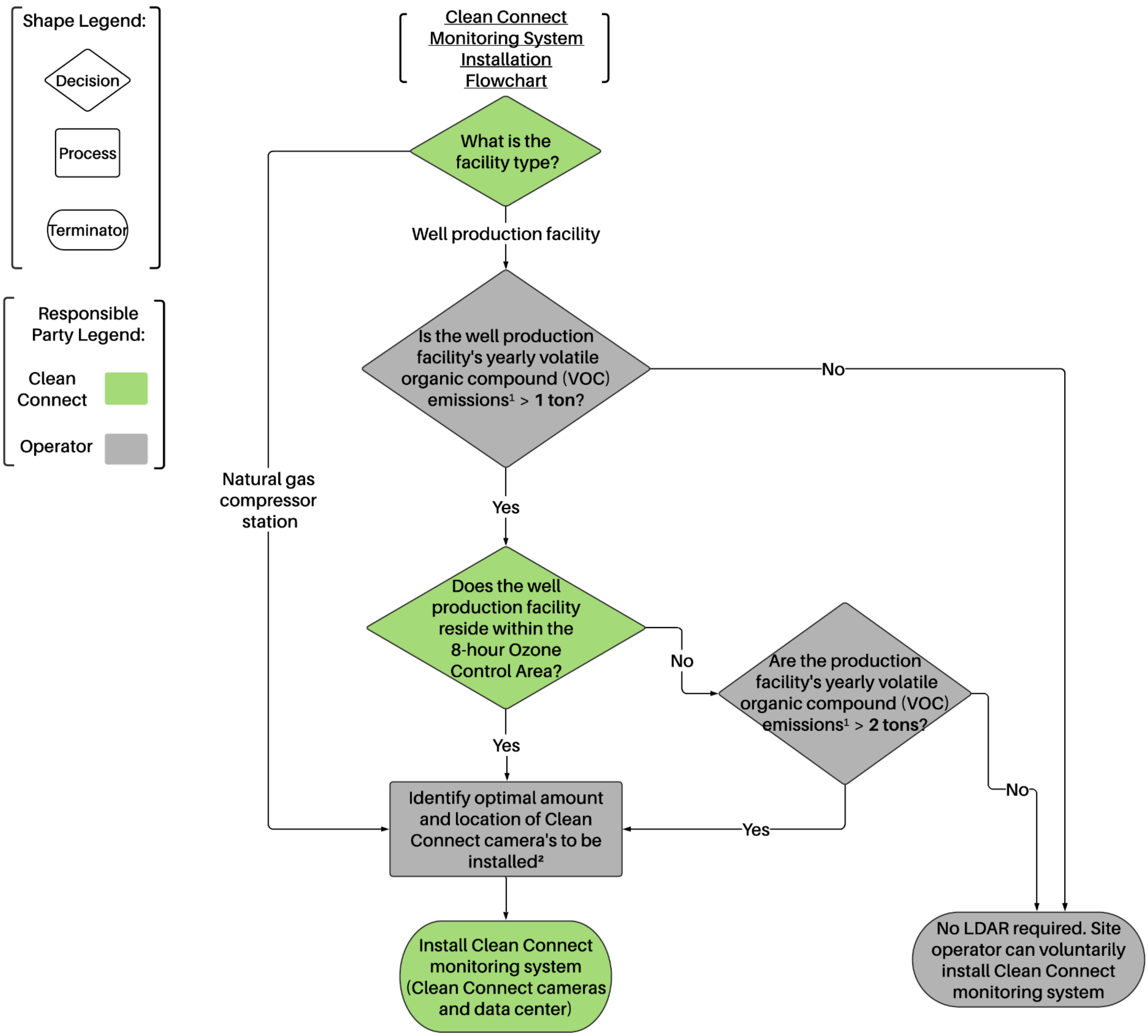
All oil and gas facilities in Colorado which require LDAR are within the scope of this proposed AAIMM and are eligible to have a Clean Connect monitoring system installed on site. The Clean Connect monitoring system will continuously monitor for methane emissions, raising a flag and alerting the Operator should an observed emission surpass a predefined level of persistence.

Following a site being flagged for a possible leak, the Operator will observe the OGI video from the Clean Connect system to decide if the flagged emission is a leak or is a routine/allowable emission event. Final say regarding the nature of the flagged emission is given to the Operator as they are most familiar with the site's operations. Should the Operator deem the flagged emission event a leak, the leaking component must be pinpointed. Typically, Clean Connect video in conjunction with Operator expertise is enough to pinpoint a leaking component. However, should the Operator not be able to localize the leaking component using the Clean Connect video alone, a handheld OGI or Method 21 approved device survey is required. Requiring the use of handheld OGI follow-up has yet to occur in any existing Clean Connect field deployment. Once the leaking component is identified via the Clean Connect OGI footage or handheld investigation, the leak is tagged, and repair is required. The tagged leak will be repaired in accordance with timelines established in Regulation 7.

Elements of the proposed alternative AIMM including installation/deployment, monitoring, and repair are laid out in the following sections through a series of flowcharts.

7.b.i. Clean Connect monitoring system installation flowchart

The factors which influence Clean Connect monitoring system installation are described in Figure 13:



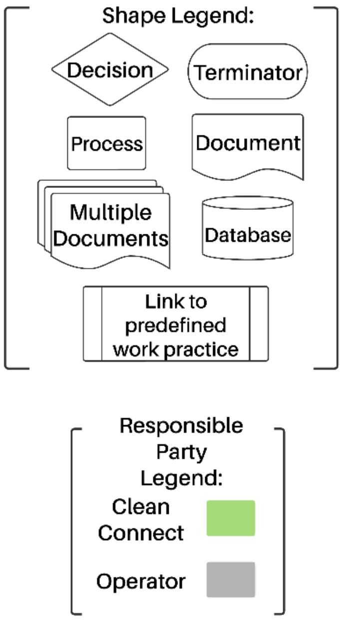
1: Regulation 7 establishes yearly VOC emissions as a rolling 12 month total based on : "*...the estimated uncontrolled actual volatile organic compound emissions from the* ***highest emitting storage tank*** *at the well production facility...If no storage tanks storing oil or condensate are located at the well production facility, owners or operators must rely on the* ***facility emissions*** *(controlled actual volatile organic compound emissions from all permanent equipment, including emissions from components determined by utilizing the emission factors defined as less than 10,000 ppmv of Table 2-8 of the 1995 EPA Protocol for Equipment Leak Emission Estimates).*"

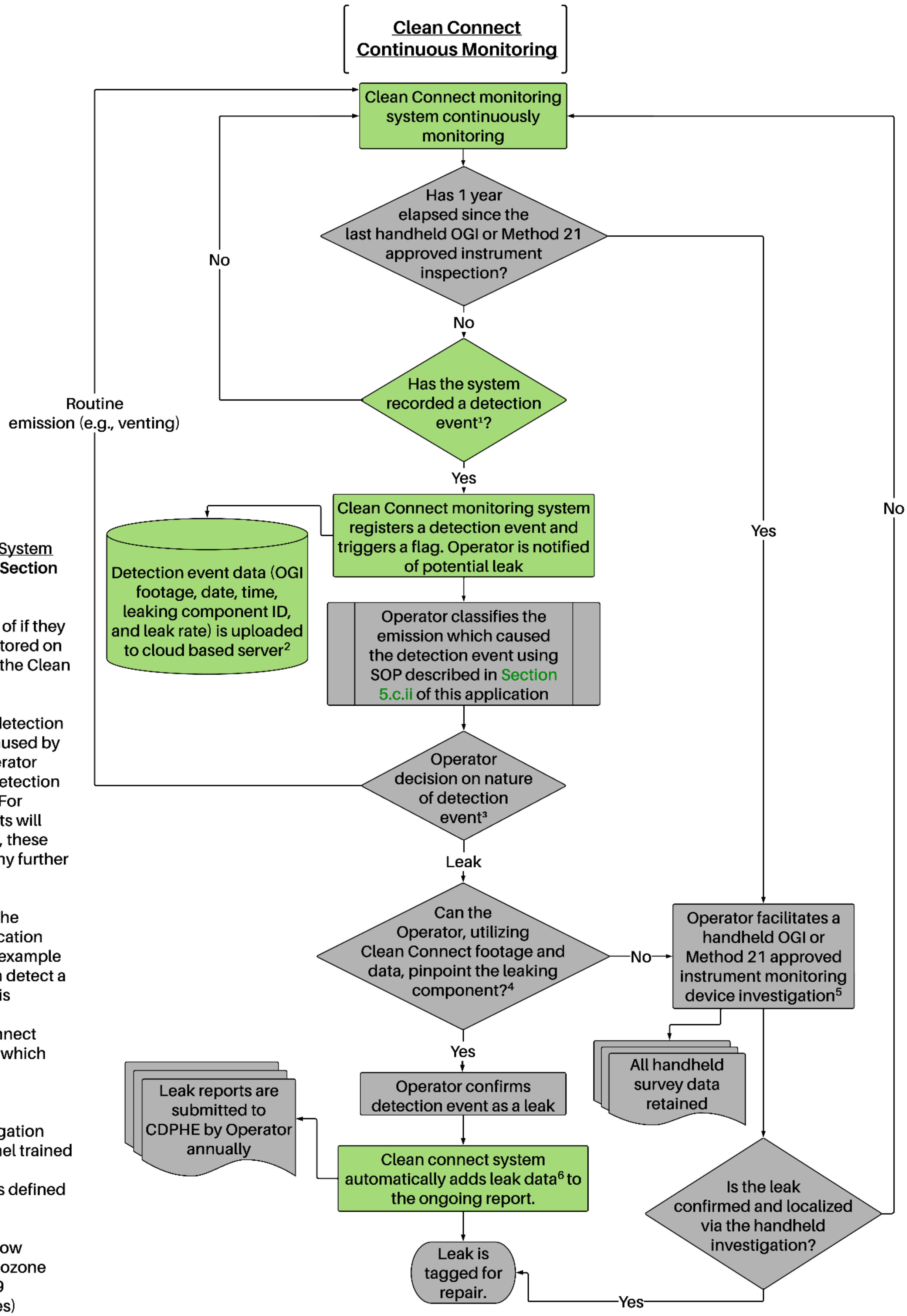
2: The Clean Connect camera has a detection range of 300 ft (depth) X 150 ft (width). Facility size and lines of sight will both have bearing on how many systems much be installed. Ensuring the installed monitoring system effectively monitors all equipment is ultimately the Operator's responsibility, however Clean Connect will work with them collaboratively if required.

Figure 13: Clean Connect monitoring system installation flowchart

7.b.ii. Clean Connect continuous monitoring flowchart

Once the Clean Connect monitoring system has been installed, the system will continuously monitor for emissions. The decision-making process associated with continuous monitoring which could lead to an emission being flagged as a leak are described in Figure 14





1: See Clean Connect Monitoring System Definitions and Details flowchart (**Section 5.c.i**) for more details.

2: All detection events, regardless of if they are ultimately deemed leaks, are stored on the cloud and used to strengthen the Clean Connect detection algorithm.

3: The Operator will decide if the detection event is a leak, or, if the event is caused by normal equipment operation. Operator judgment is necessary as not all detection events can be attributed to leaks. For example, scheduled venting events will result in a flagged event, however, these are not leaks and do not require any further action.

4: Certain situations will prohibit the Operator from pinpointing leak location using Clean Connect footage. An example is if the Clean Connect system can detect a plume but view of the equipment is obstructed. These situations are uncommon as typically Clean Connect cameras are installed in a manner which ensures all equipment groups are effectively monitored.

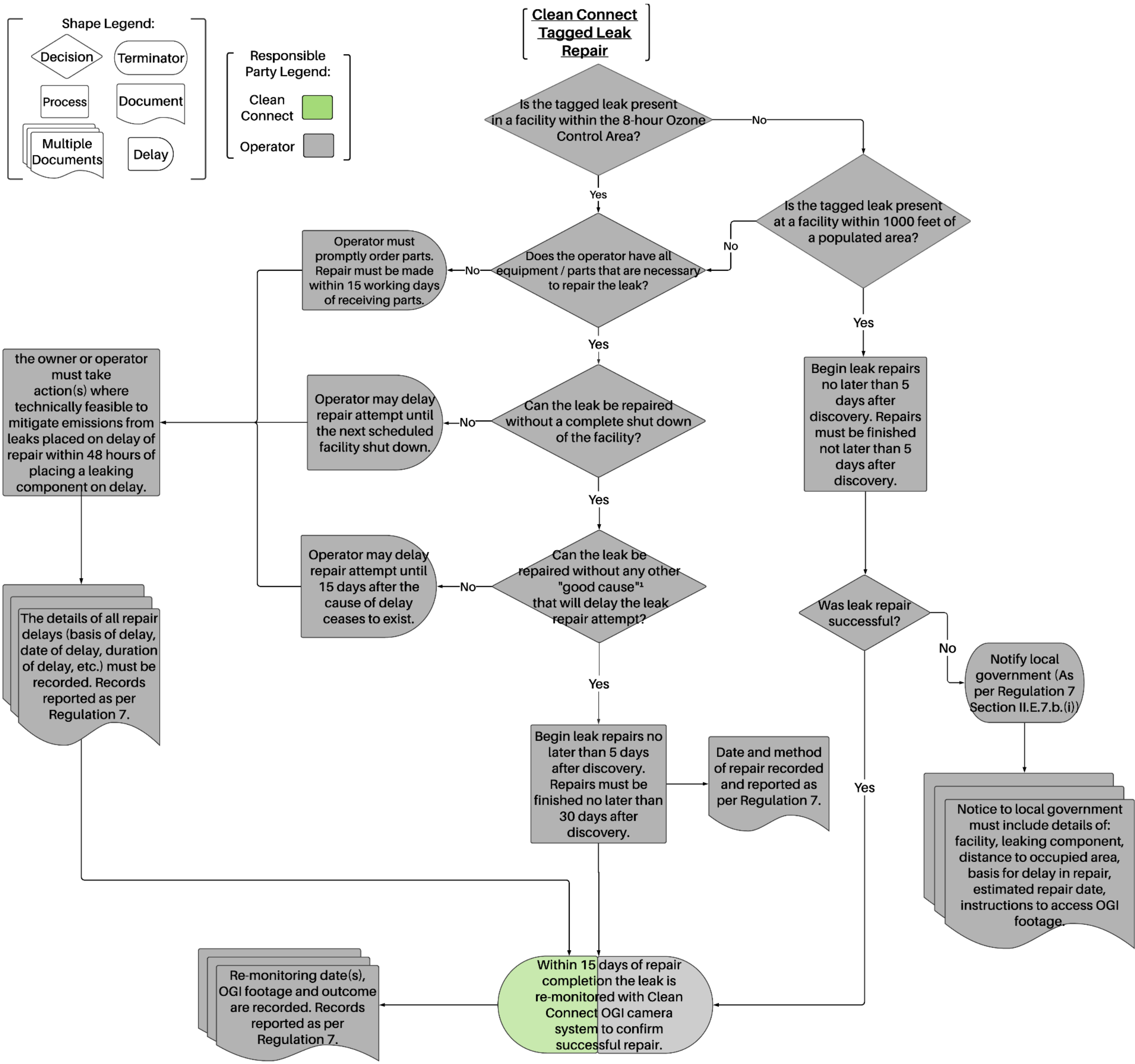
5: The handheld follow-up investigation can be conducted by any personnel trained in the use of handheld Approved Instrument Monitoring Devices (as defined in Regulation 7).

6: Reporting requirements will follow Regulation 7 Section I.L.7 (8-hour ozone control facilities) and Section II.E.9 (Non-8-hour ozone control facilities)

Figure 14: Clean Connect monitoring system installation flowchart

7.b.iii. Clean Connect repair flowchart

Once a leak has been tagged the repair process begins. Repair procedures and timelines of this proposed AAIMM will follow the procedures and timelines established in Regulation 7. As per Regulation 7, these leak repair timelines vary by jurisdiction and justifiable repair delays are acceptable. Figure 15 describes the leak repair work practice of this AAIMM application:



1: As per Regulation 7 Section I.L.5.a.(iii) (8-hour ozone control facilities) and Section II.E.7.a.(iii) (Non-8-hour ozone control facilities) the facility operator can delay a leak repair attempt if they can justify the cause of delay to the Regulator.
2: The operator will follow reporting regulations laid out in Regulation Section I.L.7 (8-hour ozone control facilities) and Section II.E.9 (Non-8-hour ozone control facilities)

Figure 15: Repair work practice and timelines

7.c. Source tracking for repair

Once a detection event has occurred (following the processes highlighted in Sections 5.c.i and 7.b.ii) and the detection event metadata has been sent to both the Clean Connects cloud platform and the Operator, the Operator assumes responsibility for confirming the nature of the detection event (leak, scheduled release, leak with unknown location). Should the emission be confirmed as a fugitive emission, it is tagged (potentially following a handheld OGI or Method 21 follow-up) and repaired with all timelines followed and documents retained as per Regulation 7, see Figure 13.

As per Regulation 7, Part D, Section I.L.4.b (8-hour Ozone Control Area) and Section II.E.6.c (statewide), repair will be carried out on any confirmed leaks not associated with normal equipment operation. The first attempt at leak repair will be made no later than five working days after leak discovery, and leak repair must be completed no later than thirty working days after leak discovery. Exclusions to this timeline are shown in Figure 15. Within 15 working days of leak repair, the leak will be re-monitored using the Clean Connect devices installed on site. To facilitate effective re-monitoring, if required, a new tour stop which optimally observes the repaired equipment (optimal zoom level and centering of equipment) can be added to the list of tour stops in the monitoring path if required. If the repair cannot be effectively re-monitored with the Clean Connect monitoring system, as per Regulation 7, Part D, Section I.L.5.b (8-hour Ozone Control Area) and Section II.E.7.c (statewide), it must be re-monitored within 15 working days with an approved instrument monitoring method. Regulation 7, Part D, Sections II.E.8 (statewide) and I.L.6 (8-Hour Ozone Control Area), regarding recordkeeping will be followed upon confirmation of a detection event requiring leak repair. Records will be kept of the date of first repair attempt, and if necessary, any additional repair attempts. Records of the date of leak repair, and the repair method applied will also be kept. Any records pertaining to delays in leak repair, including dates, duration, and cause of delay will be kept. Upon completion of the repair, dates and results of re-monitoring will be kept. All records will be maintained and available for a minimum of five years.

7.d. Program-level data collection, analysis, storage, and interpretation

For the proposed AAIMM, there will be two parties responsible for record keeping and communication of LDAR program-level data. All records will be stored on secure cloud-based servers for a minimum of five years, and the party responsible for the records will make them available to the Division upon request. Records to be kept follow the requirements laid out in Regulation 7, Sections II.E.8 (statewide) and I.L.6 (8-hour Ozone Control Area). As per Regulation 7 record keeping is similar across the two jurisdictions. The two parties and their required record keeping duties are:

1. Clean Connect:
    a. Keep a database of the locations of all installed Clean Connect devices.
    b. Maintain servers that house Clean Connect continuous monitoring data. The data uploaded to the cloud-based servers includes continuous monitoring data (in the form of OGI video footage), as well as characteristics of detection events, including the timing of the detection event, and the most likely leaking component identified by the OGI cameras.

2. Operators of facilities using the Clean Connect Monitoring system:
   a. Keep a database of the characteristics of all facilities (facility type, size, number of installed Clean Connect devices, etc.) which use Clean Connect devices.
   b. Keep a database of details of each leak requiring repair. These details include date of leak identification, leaking component and duration of the leak.
   c. Keep a database of each repaired leak. These details include timeline of repair (detailing delays which arise), method used for repair and proof of repair through re-monitoring Clean Connect data

7.e. Program reporting plan

7.e.i. Reporting amongst program participants

Flow of information between LDAR participants under the proposed AAIMM will be open and facilitated through the sharing of access privileges to cloud-based databases. The main channel of communication will be between Clean Connect and the Operator(s). As Clean Connect data is continuously uploaded to the cloud-based platform, both the Operator and Clean Connect will have constant access to measurements collected by the system. The Operator will interact with Clean Connect measurements through an interactive dashboard, access of which will be provided by Clean Connect.

Should Clean Connect require information collected by the Operator, such as follow up information on detection events (e.g., the determination of a confirmed leak vs. a routine emission event),Clean Connect can request access to the database of interest. The Operator shall provide an access key to facilitate the collection of this information. Information sharing will occur between the Operator and Clean Connect. It is the responsibility of Clean Connect to keep a database of OGI footage that is collected. The Operator can request access to this database for purposes such as internal reviews, or in preparation of annual reports to the regulator(s).

Information sharing will be limited to the parties participating in the unifying LDAR program detailed in this proposal. For example, an oil and gas company will not be granted access to a different company's Clean Connect monitoring data.

7.e.ii. Reporting to the regulator

As per Regulation 7, Part D, Sections II.E.9 (statewide) and I.L.7 (8-hour Control Area), and III.E.5 (statewide pneumatic controller program), an annual report will be submitted to the relevant regulatory body. All noted records which are the duty of the Operator to collect, as described in Section 7.d of this proposal, will be provided to the regulator. It is ultimately the responsibility of the Operator to submit yearly reports. As this program captures additional information to that of an approved instrument monitoring method, if the Air Pollution Control Division requires additional reporting standards, those can be established with Clean Connect.

An example of the tabular time series of monitoring system data which will be provided to the Operator, who in turn will provide it to the regulator following timelines established in Regulation 7 is found in Appendix A of this application. Additional video footage can be provided upon request.

7.f. Auditability of proposed program

Cloud-based databases will store all relevant program data, including OGI video footage that is collected by the OGI camera system, and atmospheric data from local weather API's. The cloud-based platform will also store Leak repair data, allowing regulators to ensure that any leaks requiring repair are being repaired properly and within the allowed timeframe. The regulator can request access permissions to the cloud-based server through established data request channels.

7.g. Best management practices

7.g.i. Continuous improvement

The Clean Connect monitoring system is centered around the Clean Connect detection algorithm, a computer vision model (described in more detail in Section 5.a.iii). Computer vision algorithms are trained, or "learn", by being shown labeled (confirmed "leak" or "no leak") OGI video. With computer vision models built using "deep learning", like the Clean Connect detection algorithm, the more labeled training data the model is shown, the more accurate it will be. Therefore, the Clean Connect detection system will be continuously improving during deployment as Operators confirm flagged emission events as "leaks" or "no leaks".

8. Emissions reduction equivalence demonstration analysis

8.a. Overview and synthesis of procedures and results

To ensure the efficacy of the proposed Alternative AIMM described by this application, it must be established that the Alternative AIMM is at least as effective at achieving emissions reductions as the currently approved instrument monitoring methods (AIMM(s)) and work practices (survey frequencies) in Colorado. Testing if the proposed alternative AIMM can achieve reduction equivalence with established AIMMs through controlled field experiments is extremely cost prohibitive and logistically challenging. As such, an ideal way to test for reduction equivalence is through simulation modeling. Simulation modeling showed that, on average, when compared to a baseline case in which no LDAR was present, the Clean Connect monitoring system achieved a **52.83%** reduction in emissions. When compared to a regulatory LDAR program consisting of regular handheld OGI surveying as described in Regulation 7, the Clean Connect monitoring system, on average, results in a **10.9%** improvement in emissions reduction over the regulatory program. This increase grows to **17.75%** in simulations designed to represent facilities which require quarterly or monthly OGI survey frequency. This improvement in emissions reduction shows the Clean Connect monitoring system meets and exceeds reduction equivalency with the regulatory handheld OGI based program primarily due to the Clean Connect system's ability to detect leaks rapidly after their initial appearance, greatly reducing leak duration over regulatory OGI.

The following sections describe the simulation modelling software and these results in further detail.

8.b. Modeling system background

The Leak Detection and Repair Simulator (LDAR-Sim) was used to compare anticipated performance of regulatory LDAR in Colorado against the Clean Connect monitoring system LDAR program as described in this application. LDAR-Sim is an open-source, agent-based numerical model developed at the University of Calgary used to predict emissions reduction effectiveness and costs of different LDAR programs and work practice configurations. LDAR-Sim works by building a "virtual world" of oil and gas infrastructure and emissions sources that is informed by empirical measurement data and historical environmental data. Different LDAR programs, which consist of unique methods, are then applied to the virtual world to predict emissions reductions and compare performance amongst the programs.

LDAR-Sim uses a geospatial approach to simulating LDAR, accounting for actual facility locations and local environmental conditions anywhere in the world. In this case, historical Colorado weather and oil and gas infrastructure locations were used. The model is widely accepted by regulators, industry, academics, and innovators in Canada and the U.S. as a credible tool for evaluating LDAR programs. All relevant LDAR-Sim information can be found on the GitHub page.

8.c. Simulated LDAR programs

For this investigation, LDAR-Sim compared emissions reductions across three programs by applying them to a virtual world representing Colorado oil and gas infrastructure which require LDAR. The three programs compared were:

1. A baseline "program", in which no LDAR is performed (**P_none**). The baseline scenario shows the emissions that would be expected in Colorado in the absence of any LDAR.
2. A regulatory OGI program, in which facilities receive handheld OGI surveys in accordance with Colorado Regulation 7 survey frequency requirements (**P_Regulatory_OGI**). Note that as per Regulation 7, OGI or Method 21 are both approved instrument monitoring methods and as such are considered equivalent. In addition, performance metrics of handheld OGI surveying are much better established than Method 21. Because of these factors, a regulatory program which employs handheld OGI cameras exclusively is modelled as the program with which to establish reduction equivalence.
3. An alternative LDAR program centered around the Clean Connect monitoring system which employs work practices described in this application (**P_CleanConnect_5kghr**). Note the use of "5kghr" in the naming convention of the Clean Connect program, this represents the minimum detection limit (MDL) of the Clean Connect method. While controlled release testing detailed in Section 6.d of this application establishes that the Clean Connect Monitoring System is capable of detecting 2 kg/hr emissions at a distance up to 120m, this testing was conducted after initial modelling runs had been completed. During initial modelling the Clean Connect method was parameterized with an MDL of 5 kg/hr as a conservative estimate of detection performance. As this simulated Clean Connect program achieved emissions reduction equivalency with the regulatory OGI based program, further simulation modelling assuming an MDL of 2 kg/hr was deemed unnecessary as Clean Connect performance would only improve. The 5 kg/hr was added to the naming scheme as a reminder of the conservative estimation of this important parameter.

8.d. Equivalency cases

Regulatory LDAR survey requirements in Colorado, as per Regulation 7, involve manually surveying a facility with an approved instrument monitoring method (AIMM) at a predetermined frequency. An important element in accurately modeling the regulatory program (P_Regulatory) is correctly assigning the frequency at which facilities in the virtual world undergo these handheld OGI surveys. Survey frequency requirements for a given facility in Colorado vary by its type (well production vs. compressor station), jurisdiction (whether the site is in a federal ozone nonattainment area), total yearly VOC emissions, proximity to occupied areas or disproportionately impacted communities, and if it has storage tanks on site. Table 2, populated with data from Regulation 7 sections I.L and II.E, shows the minimum required survey frequency of a facility based on all relevant factors. Table 2 is up-to-date as per the December 17th, 2021 amendments to Regulation 7:

Minimum Required Inspection Frequency	**Facilities within the 8-hour Ozone Control Area**		**Facilities outside the 8-hour Ozone Control Area**	
	Natural gas compressor stations VOC emissions (tpy)	**Well production facilities VOC emissions (tpy)**	**Natural gas compressor stations VOC emissions (tpy)**	**Well production facilities VOC emissions (tpy)**
Annually	-	· ≥ 1 and ≤ 6	-	· > 0 and < 2
Semi-annually	-	· > 6	-	· > 0 and < 2 **and** located within 1,000 feet of an occupied area
Quarterly	· **ALL** compressor stations	-	· > 0 and ≤ 12	· ≥ 2 and ≤ 50
Bi-Monthly	**-**	-	· > 0 and ≤ 50 **and** located within a disproportionately impacted community or within 1,000 feet of an occupied area	· ≥ 2 and ≤ 12 **and** located within a disproportionately impacted community or within 1,000 feet of an occupied area

Monthly	-	-	· >50	· > 12 **and** located within a disproportionately impacted community or within 1,000 feet of an occupied area · > 20, well production facilities **without** storage tanks · > 50, well production facilities **with** storage tanks

Table 2: Regulation 7 regulatory AIMM survey frequency requirements

The factors that dictate survey frequency make it difficult to create a single regulatory program to serve as the basis of comparison for the proposed alternative LDAR program (P_CleanConnect). In addition, it is assumed that the more frequent the survey requirements of a given facility, the more prone that facility is to more frequent and larger leaks.

To account for the variability in regulatory survey frequency and associated leak behaviour of Colorado facilities, six simulations were run, each representing the facilities in a given "tier" of regulatory frequency: annual well production facilities, semi-annual well production facilities, quarterly / bi-monthly well production facilities, quarterly/bi-monthly compressor stations, monthly well production facilities, and monthly compressor stations. For each simulation tier, a representative regulatory survey frequency, leak rate distribution (parameter dictating average leak size), and leak production rate (parameter describing leak frequency), were assigned.

The Clean Connect program (P_CleanConnect) was then compared against the regulatory OGI program for each tier of facilities. For a straightforward comparison, during each of the six simulations, it was assumed all facilities belonged to the given tier being simulated. For example, in the annual tier simulation, all facilities in the virtual world are assumed to be well production facilities which undergo one OGI survey per year and have leak characteristics indicative of real-world well production facilities which only require this single annual survey.

The leak rate distributions chosen for each tier of facility are based on empirical data from recent field campaigns and are broadly representative of a typical lognormal leak distribution found by many different studies across different North American basins.[1] As no known extensive leak distribution is available for Colorado facilities, these distributions are chosen to correspond with the emissions characteristics associated with the varying survey frequencies set forth by Regulation 7 for different facility types. While all distributions allow the presence of super-emitters in the simulation, it is exceedingly rare that a leak of super-emitter size will be generated from the distributions used for the Annual and Semi-annual simulation tiers. It is important to incorporate the potential for super-emitters in modelling as they can occur at Colorado facilities, as evidenced by Carbon Mapper.

In general, all distributions used in LDAR-Sim are representative of “heavy tailed” distributions repeatedly observed in the literature. Figure 16 is a visual representation of the differences in behaviour of the leak rate distributions used. Dashed lines represent the cumulative density function of total emissions contributions from leaks of a given size, while solid lines represent the cumulative density of individual leak sizes.

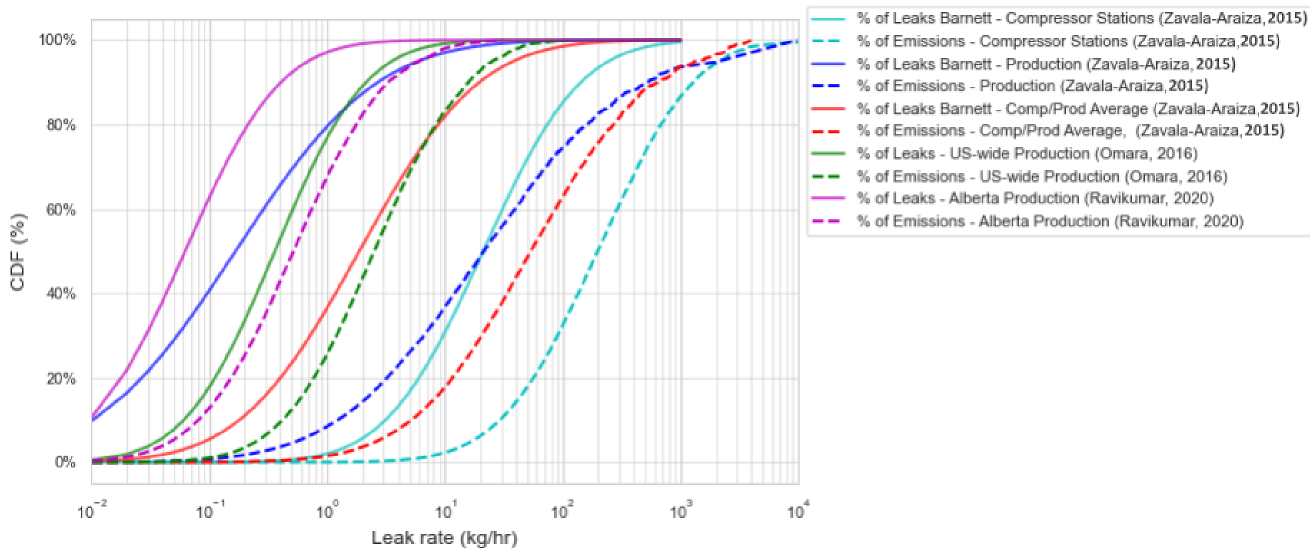


Figure 16: Visual representation of various leak rate distributions used in modelling

A unique Leak Production Rate (LPR) is also chosen for each survey frequency (it is assumed that compressor stations and well production facilities both requiring quarterly surveys or both requiring monthly surveys will have the same LPR). LPR is the probability that a leak will arise at a given facility in a given day. The LPR used for each tier of facility is based on data from the 2020 Colorado LDAR Annual Report Summary (Table 3). To calculate LPR using these data:

P(leak) = (leaks identified / inspections) / # of days in the frequency period

Frequency	Method	Inspections		Leaks identified	
		2019 *(18,808 WPFs Inspected)*	2020 *(15,245 WPFs Inspected)*	2019	2020
One-time	AIMM	679	656	267	113
Annual	AIMM	3,824	1,180	1,592	401
Semi-annual	AIMM	3,990	5,024	2,516	1,677
Quarterly	AIMM	4,277	5,886	3,726	2,786
Monthly	AIMM	11,520	13,608	10,547	10,640
Subtotal from AIMM inspections		24,290	26,354	18,648	15,617
Monthly	AVO	549,297	525,433	2,318	1,850
Total from all inspections		**573,587**	**551,787**	**20,966**	**17,467**

Table 3: 2020 Colorado LDAR report data

Table 4 summarizes the LRD and LPR used for each tier of facilities.

Facility tier (based on required survey frequency as per Regulation 7)	Leak Rate Distribution (LRD)	Leak Production Rate (LPR)	Average leaks per site per year based on LPR
Annual	Ravikumar et al 2020: [lognormal, -2.775, 1.462]	0.00093	0.33
Semi-annual	Omara 2016 Conventional: [lognormal, -1.020, 1.390]	0.0018	0.67
Bi-monthly / Quarterly* well production facilities	Zavala Araiza 2015 production facilities: [lognormal, -1.790, 2.170]	0.0051	1.89
Bi-monthly / Quarterly* compressor stations	Zavala Araiza 2015 compressor stations: [lognormal, 3.05, 1.49]	0.0051	1.89
Monthly well production facilities	Zavala Araiza 2015 production facilities: [lognormal, -1.790, 2.170]	0.026	9.38

Monthly compressor stations	Zavala Araiza 2015 compressor stations: [lognormal, 3.05, 1.49]	0.026	9.38

*Quarterly surveys (4 times per year) are used in modeling as LPR data of facilities undergoing bi-monthly surveys is not available (Table 3).

Table 4: Facility tiers used in modeling. Each tier received an independent simulation to effectively compare programs against facilities representative of that tier.

8.e. LDAR-Sim parameterization

LDAR-Sim contains many parameters which are used to accurately model both the virtual world and the programs which are applied to it. The hierarchy of LDAR-Sim parameters used in this investigation is shown in Figure 17.

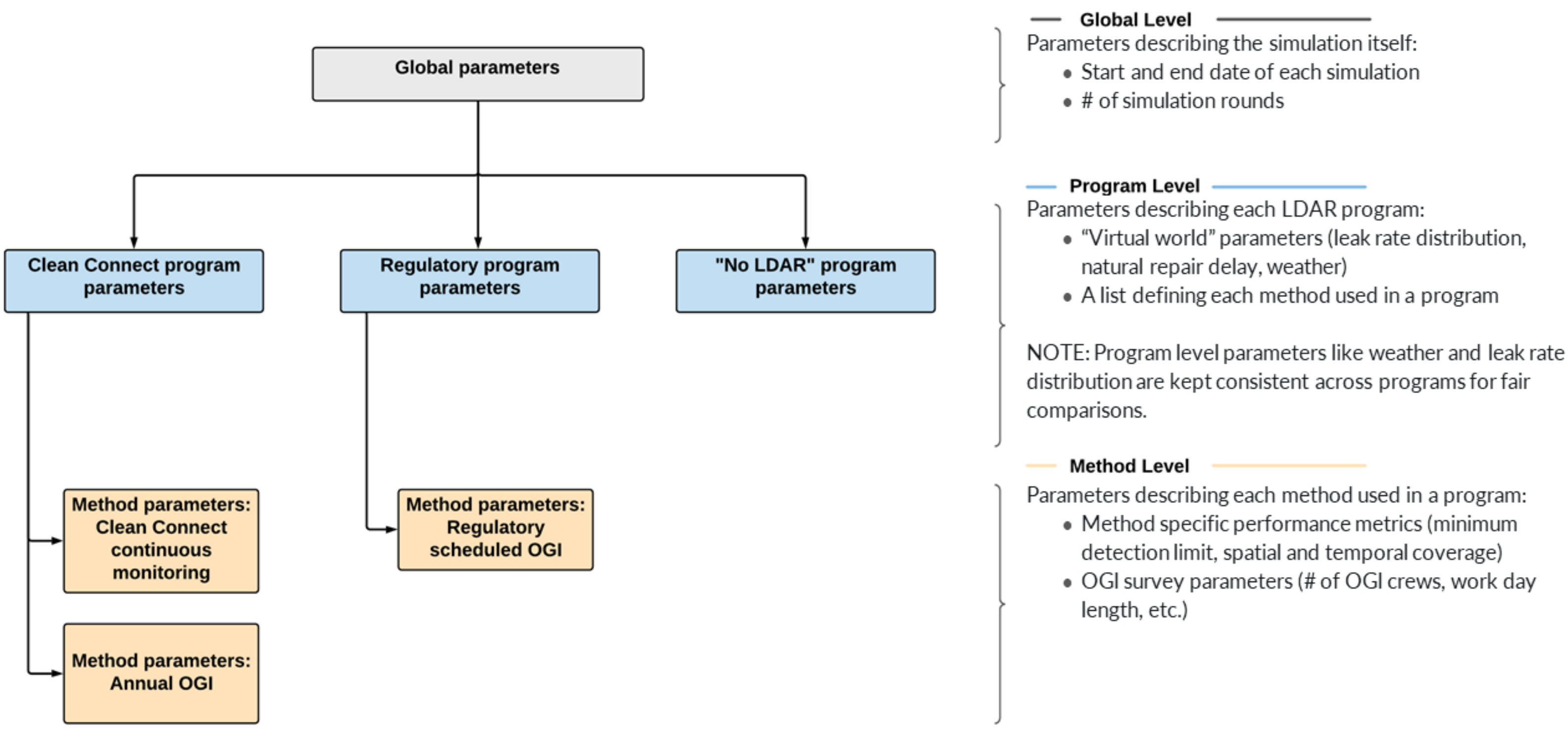


Figure 17: LDAR-Sim Hierarchy

The following sections provide more detailed descriptions of all parameters used, organized by parameter level. A detailed description of all parameters is available on the LDAR-Sim GitHub page. If not described in the following sections, a parameter assumes the default value. Note that nomenclature of some parameters described in the following sections is simplified to enhance readability.

8.e.i. Global level parameters

Global Parameters	
Region	Colorado
Programs	[P_CleanConnect_5kghr, P_Regulatory_OGI, P_none]
Simulations	5
Start date	[2022, 1, 1]
End date	[2026, 12, 31]
Reference program	P_Regulatory_OGI
Baseline program	P_none
Pregenerate leaks	TRUE

Table 5: Global parameters used in simulations

Region: For naming purposes.

Programs: A list of the programs applied to the virtual world in the simulation.

Simulation rounds: The number of times the simulation runs from the start date through to the end date. Final results are an averaging across all 5 simulation rounds.

Start date: The start date of each simulation round. The default value is used.

End date: The end date of each simulation round. A value that will result in 5 years per simulation round will be used.

Reference program: The program against which the Clean Connect program will be compared. In this case, we are investigating how the Clean Connect program compares to the regulatory scheduled OGI inspection-based program (P_regulatory).

Baseline program: A program that represents a scenario where there is no formal LDAR, or that has no LDAR methods. The only way a leak is repaired under this program is when a leak has existed for longer than the natural repair delay parameter. P_none will describe a program with no formal LDAR program.

Pregenerate leaks: If set to True, leaks will be generated prior to running the simulations, those pre-generated leaks are consistently applied to all programs (each program must handle the same leaks at the same sites). Setting to True allows for direct comparisons amongst the programs.

8.e.ii. Program level parameters

A unique set of program parameters is created for each simulation tier, as indicated by the orange "see Table 4" for leak rate distribution and leak production rate.

Clean Connect Program Parameters	
Methods	[M_CleanConnect, M_OGI_CleanConnect]
Program name	P_CleanConnect_5kghr
Weather file	ERA5_2019_2020_CO.nc
Weather is hourly	True
Site samples	500
Repair delay (days)	30
Leak rate distribution (LRD)	See Table 4
Leak distribution type	Lognormal
Leak production rate (LPR)	See Table 4
Max leak rate (g/s)	10,000
Natural repair dealy (NRd, days)	365

Table 6: Clean Connect program level parameters

Regulatory OGI Program Parameters	
Methods	[M_OGI]
Program name	P_Regulatory_OGI
Weather file	ERA5_2019_2020_CO.nc
Weather is hourly	True
Site samples	500
Repair delay (days)	30
Leak rate distribution (LRD)	See Table 4
Leak distribution type	Lognormal
Leak production rate (LPR)	See Table 4
Max leak rate (g/s)	10,000
Natural repair dealy (NRd, days)	365

Table 7: Regulatory OGI program level parameters used in simulations

No LDAR "Program" Parameters	
Methods	[]
Program name	P_nonel
Weather file	ERA5_2019_2020_CO.nc
Weather is hourly	True
Site samples	500
Repair delay (days)	30
Leak rate distribution (LRD)	See Table 4
Leak distribution type	Lognormal
Leak production rate (LPR)	See Table 4
Max leak rate (g/s)	10,000
Natural repair dealy (NRd, days)	365

Table 8: No LDAR program level parameters

Methods: A list of the methods deployed in each program. The Clean Connect program has two methods: the Clean Connect monitoring system and an annual OGI survey.

Program name: User defined program name.

Weather file: Colorado historical weather data, forms the basis of daily weather during simulation.

Weather is hourly: Setting to TRUE establishes that weather data uses hourly values as opposed to daily averages.

Site samples: The number of sites used in simulations. Each simulation is performed on a random sample of 500 from the “infrastructure file”, a CSV file which contains the locations of 121,355 Colorado facilities.

Consider weather: Set to TRUE to establish if the methods used by the program can be affected by the weather as per those method’s weather envelopes (Section 8.e.iii).

Repair delay: How long it takes to repair a leak. Regulation 7 timeline of 30 days is used.

Leak distribution parameters: Describes the shape and values of the distribution from which randomly generated leak emission rates are assigned. See Section 8.d.

Leak distribution type: Specifies the distribution shape that will be fit to the parameters passed to the leak distribution parameters parameter. Lognormal is exclusively used.

LPR: Leak production rate. The probability that a leak will arise at a given site on a given day. Adapted from 2020 Colorado LDAR report.

Max leak rate: The maximum possible leak rate that can be sampled from a distribution. 100,000 g/s is the default value and is approximately representative of an “extreme” upper limit in natural gas operations but is extremely rare.

NRd: Natural repair delay. The time within which a leak will be “naturally” discovered and repaired (found by operators conducting random AVO inspections, or retrofits,, for example) should it not be found by any other method. Limited data exists to inform this parameter, so one year is used.

8.e.iii. Method level parameters

The Clean Connect method represents the entirety of the Clean Connect monitoring system, in that, the properties of the Clean Connect OGI camera and the Clean Connect detection algorithm are accounted for. The Clean Connect program also has an annual handheld OGI inspection, represented by the Clean Connect OGI method (M_OGI_CleanConnect). This annual OGI inspection practice entails the Operator conducting/facilitating a facility-wide handheld OGI inspection as they typically would as per Regulation 7. As such, this is the responsibility of the Operator. Regardless of facility type this only has to be done annually (as opposed to potentially monthly as per Regulation 7). The goal of this handheld OGI survey is to "sweep up" any very small leaks that could be missed by the Clean Connect system. In addition, the results of this handheld survey could inform adjustments to the Clean Connect monitoring path.

The regulatory OGI method represents regulatory OGI methods at a predefined frequency. Aside from survey frequency, the regulatory OGI and annual Clean Connect OGI survey behave the same parameterization.

Frequently, alternative monitoring technologies will incorporate necessary OGI follow-up into their work practices. As per the Clean Connect monitoring work practice described in Section 7.b.ii, a handheld OGI or Method 21 follow-up could be facilitated if necessary, as part of the Clean Connect program. However, as the Clean Connect monitoring system is based around OGI technology, the Operator is frequently capable of performing “follow-up” investigations through live Clean Connect OGI video footage. To date, no handheld OGI follow-up surveys have been required at a site with an actively monitoring Clean Connect Monitoring System. As such, OGI follow-up is not modeled as it is extremely rare. Parameters and descriptions follow.

Clean Connect Monitoring System Method	
Label	M_CleanConnect
Consider daylight	False
Spatial coverage	0.9
Temporal coverage	0.9
Deployment type	Stationary
Is follow-up	FALSE
Max workday (hours)	24
Measurement scale	component
Reporting delay (hours)	3
Sensor type	default
Sensor MDL	5 kg/hr
Precipitation constraints	[0.0, 10]
Temperature constraints	[-40.0, 40.0]
Wind constraints	[0.0, 15.0]

Table 9: Clean Connect monitoring system method parameters

Clean Connect Annual OGI Method	
Label	M_OGI_CleanConnect
Consider daylight	True
Spatial coverage	0.7
Temporal coverage	0.7
Deployment type	mobile
Is follow-up	FALSE
Max workday (hours)	8
Time between sites (minutes, average)	30
Survey frequency (per year)	1
number of crews	3
Measurement scale	component
Reporting delay (hours)	3
Sensor type	default
Sensor MDL	5 kg/hr
Precipitation constraints	[0.0, 10]
Temperature constraints	[-40.0, 40.0]
Wind constraints	[0.0, 15.0]

Table 10: Clean Connect Annual OGI method parameters

Regulatory and Routine OGI Methods	
Label	M_OGI
Consider daylight	True
Spatial coverage	0.7
Temporal coverage	0.7
Deployment type	mobile
Is follow-up	FALSE

Max workday (hours)	8
Time between sites (minutes, average)	30
Survey frequency (per year)	1
number of crews	3, or 10 in monthly simulation tiers
Measurement scale	component
Reporting delay (hours)	3
Sensor type	OGI_Zimmerle
Sensor MDL	PoD informed by Zimerle, et al. 2020
Precipitation constraints	[0.0, 10]
Temperature constraints	[-40.0, 40.0]
Wind constraints	[0.0, 15.0]

Table 11: Regulatory OGI method parameters

Label: The Label which will be displayed in outputs.

Consider daylight: Determines if the method requires daylight to operate.

- Clean Connect: set to FALSE as the Clean Connect monitoring system does not require daylight to operate.
- All OGI methods: set to TRUE as the methods involve crews operating handheld OGI cameras, so daylight is required.

Spatial coverage: A representation of the average proportion of a site the method can effectively survey. A value of 0.7 indicates that the technology will find a leak 100% of the time in 70% of the site.

- Clean Connect: set to a value of 0.9 as occurrences where emission plumes are totally obscured are very rare.
- All OGI methods: set to 0.7 due to situations where potential leaking components are inaccessible to OGI crews (e.g., tops of tanks).

Temporal coverage: The probability the method will detect a leak in a single survey. This parameter is mainly intended for OGI based methods.

- Clean Connect: set to a value of 0.9 to account for rare cases where facility power or internet connectivity may drop.
- All OGI methods: set to 0.7 to account for human error and variable fugitive emission sources (inexperience, overwork, and laziness).

Spatial and temporal coverage additional information: There are many factors that dictate the real world effectiveness of a monitoring technology, such as technology malfunctions or reporting errors, accessibility of equipment requiring monitoring, and, most notably with handheld OGI methods, human factors such as experience and fatigue. These factors are difficult to quantify within the realm of a method's minimum detection limit.

Spatial and temporal coverage are important parameters intended to more accurately represent the real-world use of monitoring technology in the simulation. As these parameters are difficult to empirically quantify, they are heavily informed by literature review and discussion with industry/technology experts. These parameters are prone to change over time as additional research emerges and the general understanding of these technologies evolves.

OGI coverage parameters, like the OGI minimum detection limits used in this investigation, are based partly on work found in Zimmerle, et al. 2020, which describes the often difficult nature of successfully detecting emissions with an OGI inspection in real world conditions.

Deployment type: One of a selection of method technology types.

- Clean Connect is a stationary method.
- The OGI methods are mobile as they entail "crews" moving from site to site.

Is follow-up: Defines if the method being parameterized is triggered through a prior method. As they are exceedingly rare, OGI follow-up surveys have not been modelled.

Survey frequency: The number of times each survey in the simulation must be surveyed by the method in question. Only applies to OGI methods as Clean Connect is a stationary method (continuous monitoring).

Number of crews: The number of distinct crews for mobile methods (in this case, OGI methods) which "move" from site to site conducting surveys. In most cases, 3 crews are sufficient to ensure all facilities are surveyed to their required amount (survey frequency parameter). However, when monthly surveying is required, 10 crews are used to avoid a "labor shortage", a situation where there are not enough crews to attend to all required site surveys. Requiring more crews for a group of facilities which require higher survey frequency is representative of real-world crew demands.

Survey time (minutes): The time it takes for a mobile method to conduct an entire site survey. An average of 2 hours is used for OGI methods.

Measurement scale: The level of granularity the method can localize a leak source to. The Clean Connect scale is set to component as this represents the ability of the *Operator* to localize a leak using Clean Connect OGI footage and subsequent SCADA and field investigations. Component scale is used for modeling, in its current iteration, the

Clean Connect monitoring scale can localize down to the equipment level. As "component scale" is used to represent the Operator localizing down to the component scale with the assistance of the Clean Connect system, a larger-than-default reporting delay parameter (see below) is used to represent this investigation/decision making process.

Reporting delay: The number of days that pass between when a site is flagged and when the duty holder is informed. The default value of 0 used for the camera methods represents that reporting is accomplished on the day of the survey. The Clean Connect method is set to three days to account for the time in which the Operator deliberates as to the nature of the detected emission (fugitive vs. scheduled release).

Sensor – type: "Default" is used for all non-OGI sensor types.

- Although the Clean Connect method employs an OGI device, default is used as the system being modeled represents the OGI camera and the detection algorithm.

- The OGI methods use a sensor logic informed by Zimmerle, et al. 2020[2]. The parameters used dictate handheld OGI behaviour detection capability typical of an "average" OGI operator.

Sensor – MDL: Minimum Detection Limit. Can be a simple emission rate (any leak larger than this emission rate is detected) or a probability curve/surface.

- Clean Connect: A conservative value of 5 kg/hr, based on testing of the detection algorithm, is used.
- All OGI methods: Parameters represent the behaviour of an average OGI operator, as per Zimmerle, et al. 2020. These parameters inform a probability of detection curve. Emission rates of leaks in the simulation are compared against this probability of detection curve, should a given leak rate, according to the curve, have a 70% chance of detection by an "average" operator, a "weighted coin" is flipped such that there is 70% the simulated operator will successfully detect the leak.

Time between sites: Only applies to mobile, OGI methods. An approximation of 30 minutes is used. This 30 minute value is an approximation of Colorado travel times, with travel times in areas of high site densities (DJ basin) being very quick, thus affecting the average.

Operational weather envelope: If the meteorological conditions, randomly generated from the weather file, are outside the weather envelopes for each method, their operation will halt. Values used are approximations of the operating condition ranges of handheld OGI surveys. The Clean Connect monitoring system assumes the same operational envelope as a handheld OGI camera. This is likely a conservative estimate, as the stationary, non-human operated aspect of the Clean Connect OGI camera will likely increase operational efficacy in more extreme weather conditions such as high winds.

- **Precipitation Constraints**: The range of precipitation accumulation (mm) in one hour permissible by the method.
- **Temperature constraints**: The range of average hourly temperatures (°C) between which the method will work.
- **Wind constraints**: The bounding range of maximum average hourly wind speed (m/s at 10m) between which the method will work.

8.f. Simulation results

8.f.i. Annual survey frequency requirement tier - well production facilities

The results of comparing LDAR programs within a virtual world populated by facilities indicative of Colorado well production facilities which require annual AIMM surveys (P_Regulatory_OGI has an annual OGI survey method) follow. The Clean Connect program, with modeled emissions reductions of 23.2% (emissions of 1.1 ± 0.009 kg/site/day, 95% confidence interval) exceeds equivalence with the regulatory OGI program, which has modeled emissions reductions of 19.9% (emissions of 1.2 ± 0.008 kg/site/day, 95% confidence interval).

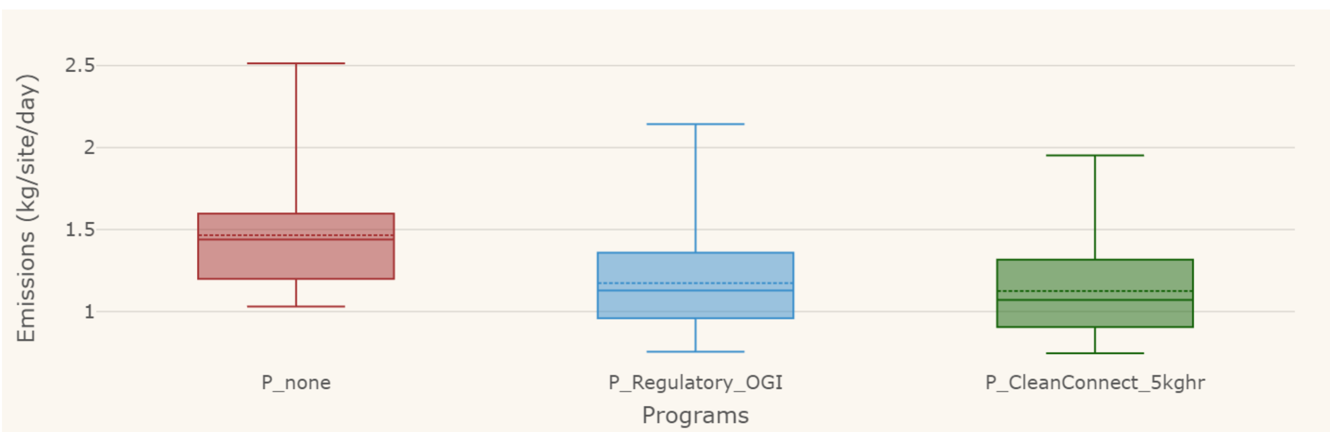


Figure 18: Box Plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require annual AIMM surveys.

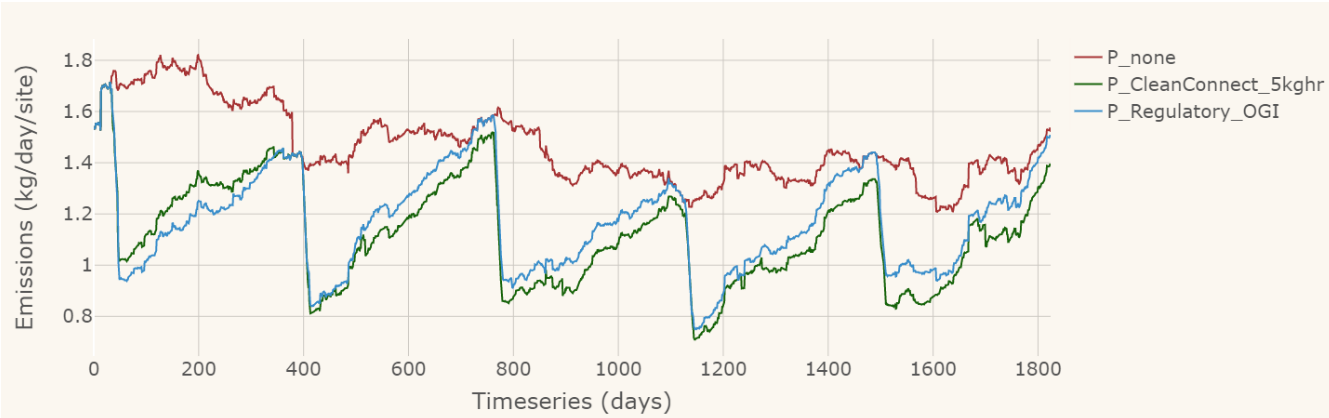


Figure 19: Time series of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require annual AIMM surveys.

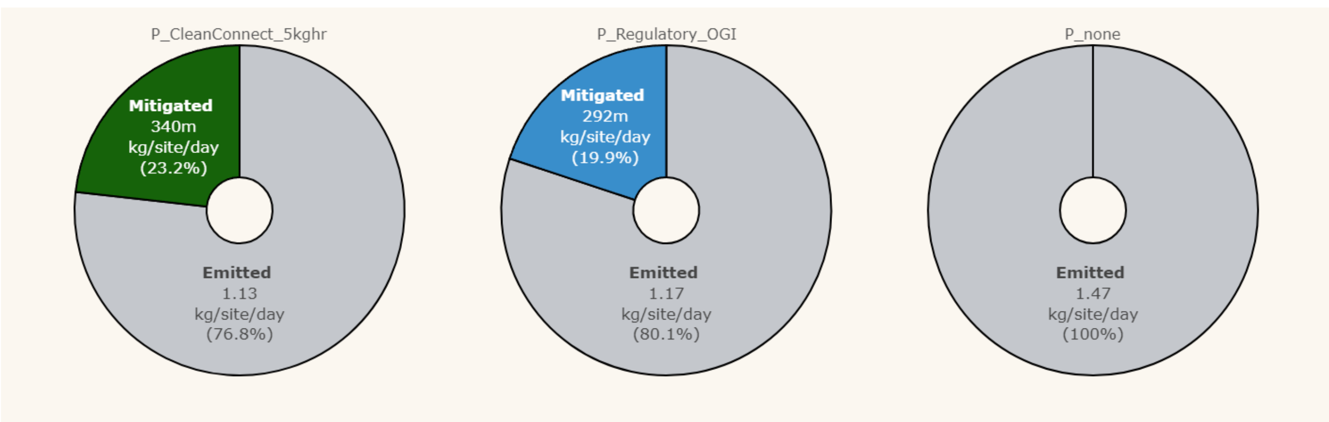


Figure 20: Donut Plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require annual AIMM surveys.

The cyclicity present in the time series is related to OGI survey frequency. In this simulation, the regulatory OGI program is based on an annual survey an, the Clean Connect program has an annual handheld OGI survey method, intended to “sweep up” any small leaks which may have been missed by the Clean Connect monitoring system method (a possibility due to the smaller detection limit of a handheld OGI survey compared to the Clean Connect method). This tracking of the Clean Connect and Regulatory programs emissions time series is due to both programs' annual OGI survey occurring simultaneously.

As the emissions time series rise, randomly generated leaks across the facilities are accumulating, then, the fall of the emissions corresponds to the annual OGI survey which identifies and instigates the repair of these leaks. These cycles correspond to 365 days.

The annual OGI survey method of the Clean Connect program appears to have such a large impact on overall emissions because of the leak rate distribution used. The leak rate distribution chosen for this annual tier simulation is one which very rarely results in randomly generated leaks which are larger than the Clean Connect minimum detection limit of 5 kg/hr. Therefore, many of the leaks randomly generated are too small to be detected by the Clean Connect method. A notable exception to this occurs at ~day 480, where the Clean Connect and Regulatory program time series deviate. This deviation is assumed to be caused by the Clean Connect monitoring system immediately detecting a leak larger than 5 kg/hr, leading to its repair. This leak, in the regulatory program, will not be detected until the next annual survey.

When observing the total mitigation (Figure 20) keep in mind it is based on the entire simulation (500 sites). This logic continues when discussing program mitigation in the other simulation tiers.

8.f.ii. Semi-annual survey frequency requirement tier - well production facilities

The results of comparing LDAR programs within a virtual world populated by facilities indicative of Colorado well production facilities which require semi-annual AIMM surveys (P_Regulatory_OGI has a semi-annual OGI survey method) follows . The Clean Connect program, with modeled emissions reductions of 41.7% (emissions of 8.7 ± 0.08 kg/day, 95% confidence interval) exceeds equivalence with the regulatory OGI program, which has modeled emissions reductions of 37% (emissions of 9.4 ± 0.07 kg/day, 95% confidence interval).

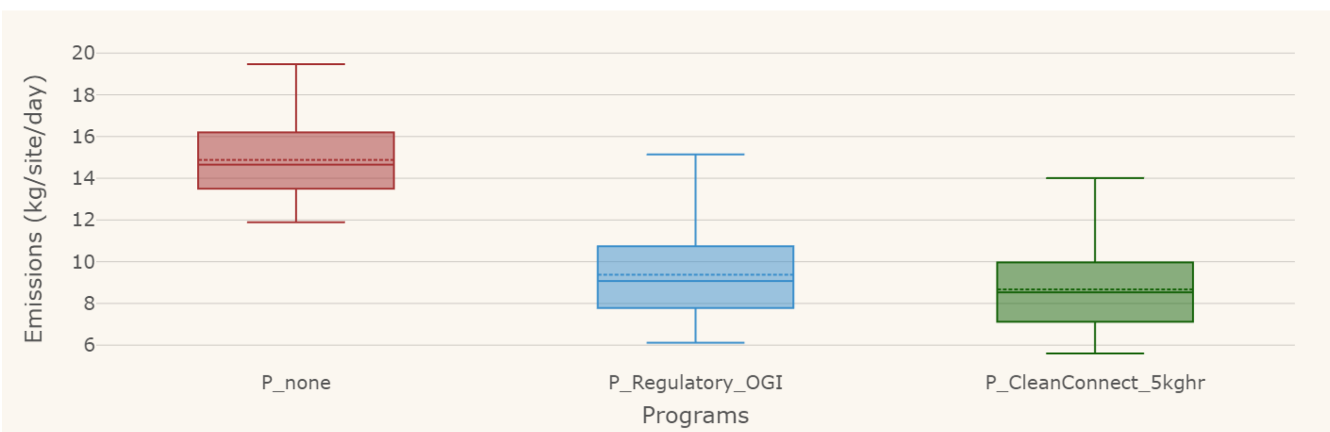


Figure 21: Box Plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require semi-annual AIMM surveys.

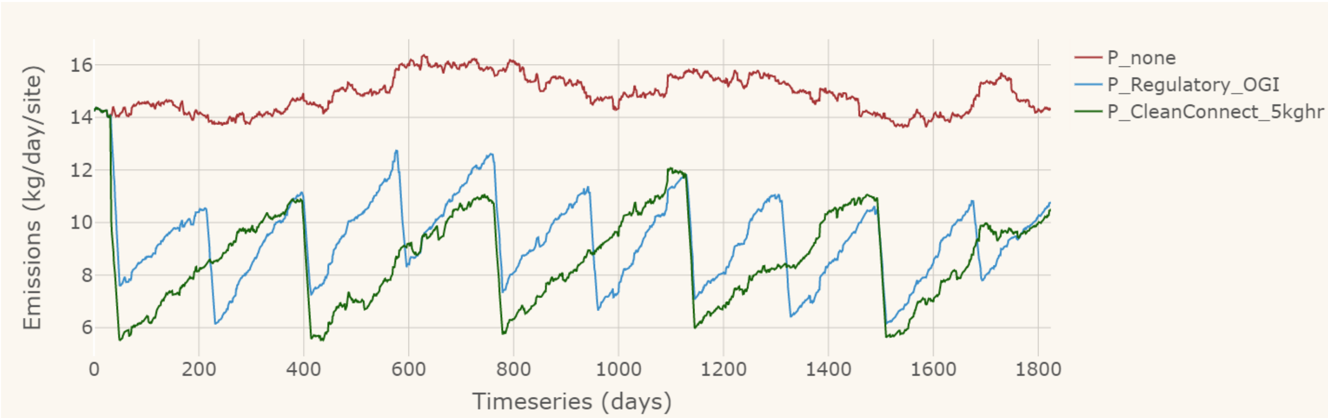


Figure 22: Time series of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require semi-annual AIMM surveys.

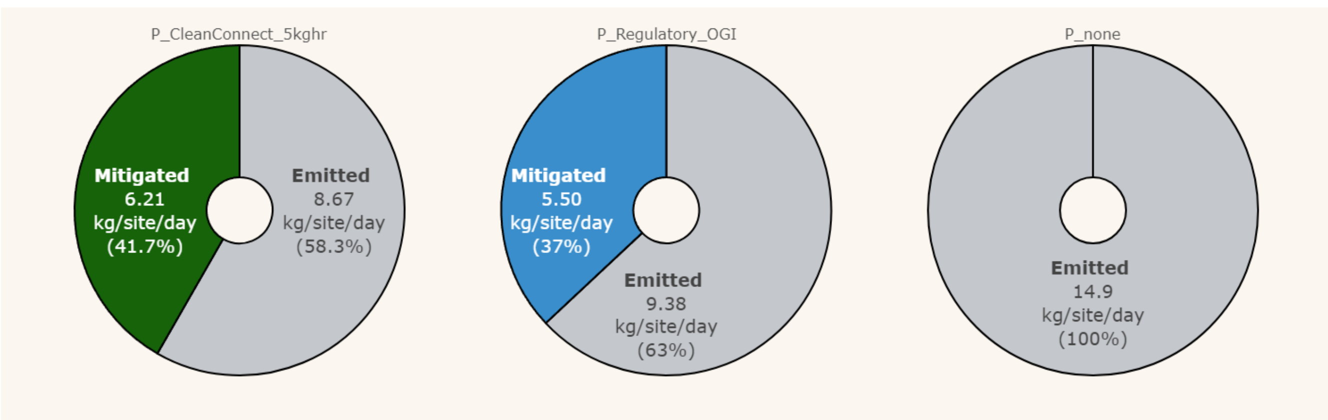


Figure 23: Donut Plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require semi-annual AIMM surveys.

The cyclicity of the regulatory OGI time series is now based on two surveys per year while the cyclicity of the Clean Connect program is still based on an annual survey. This behaviour is explained in Section 8.f.i.

Total program mitigation of the Clean Connect program (figure 23) in this semi-annual survey tier is larger than the total program mitigation (Figure 20) of the annual survey tier. This is due to the different leak rate distribution used. The leak rate distribution used for the semi-annual tier is more prone to larger leaks, therefore, a larger proportion of leaks which are large enough to be detected and repaired by the Clean Connect monitoring system are created. This trend of increasing mitigation, due to increasingly large-leak-prone leak rate distribution, continues in the following tiers.

8.f.iii. Quarterly/bi-monthly survey frequency requirement tier - well production facilities

The results of comparing LDAR programs within a virtual world populated by facilities indicative of Colorado well production which require quarterly or bi-monthly AIMM surveys (P_Regulatory_OGI has a quarterly OGI survey method) follows . The Clean Connect program, with modeled emissions reductions of 65.6% (26.6 ± 0.5 kg/site/day, 95% confidence interval) exceeds equivalence with the regulatory OGI program, which has modeled emissions reductions of 51.5% (37.5 ± 0.5 kg/site/day, 95% confidence interval).

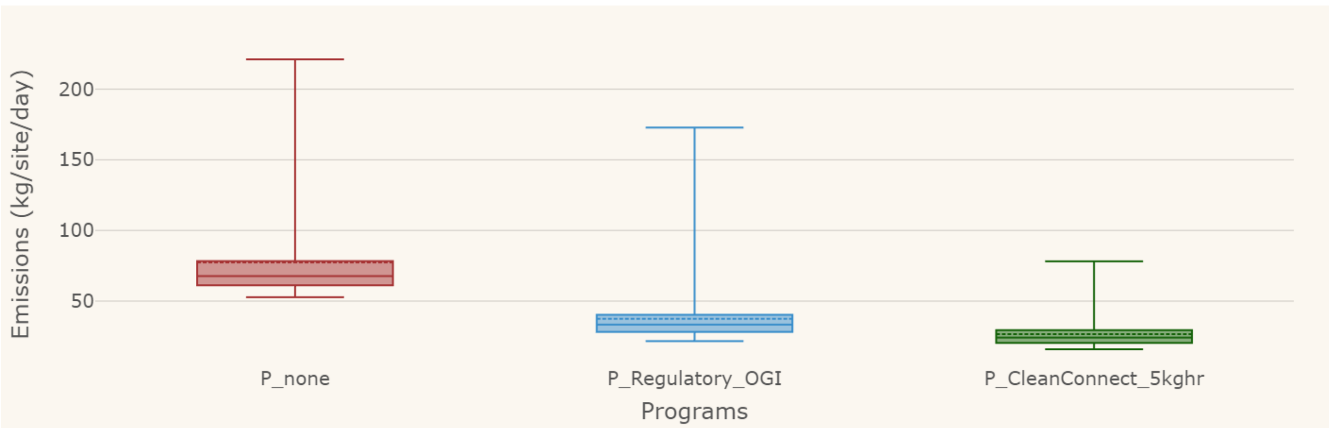


Figure 24: Box Plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require quarterly AIMM surveys.

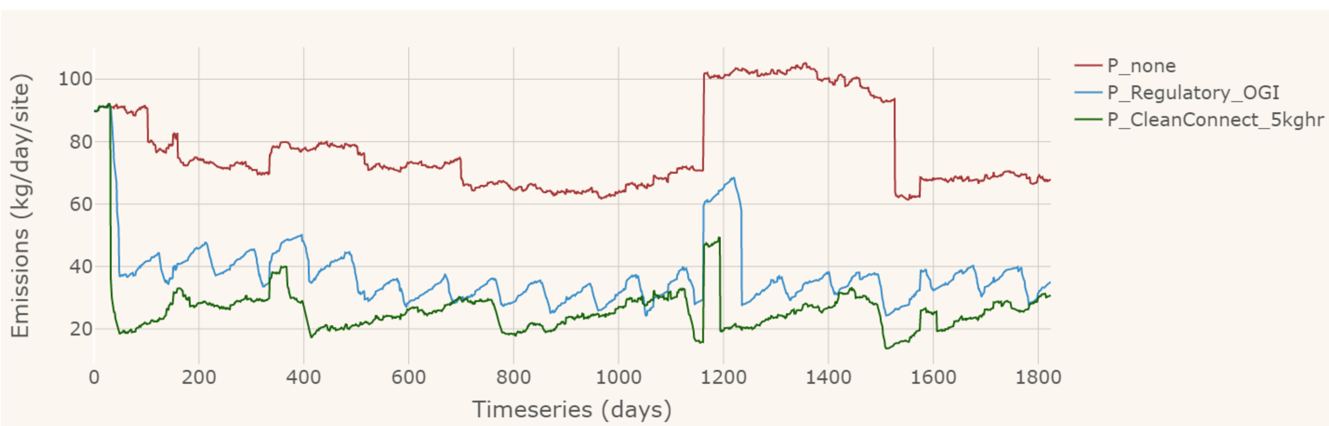


Figure 25: Time series of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require quarterly AIMM surveys.

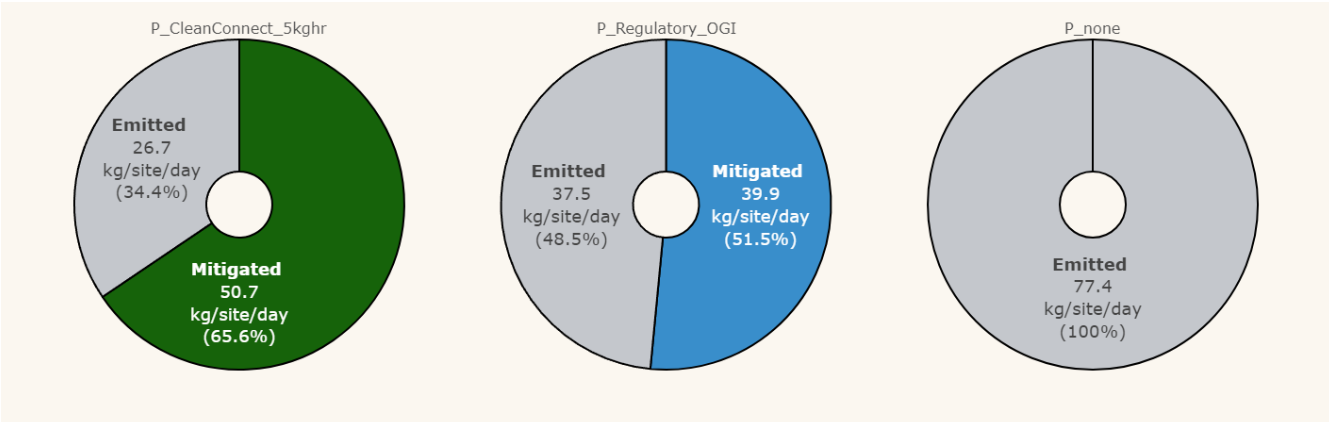


Figure 26: Time series of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require quarterly AIMM surveys.

8.f.iv. Quarterly/bi-monthly survey frequency requirement tier - compressor stations

The results of comparing LDAR programs within a virtual world populated by facilities indicative of Colorado compressor stations which require quarterly or bi-monthly AIMM surveys (P_Rregulatory_OGI has a quarterly OGI survey method) follow. The Clean Connect program, with modeled emissions reductions of 82.8% (1,401.6 ± 11.3 kg/site/day, 95% confidence interval) exceeds equivalence with the regulatory OGI program, which has modeled emissions reductions of 52.1% (502.3 ± 14 kg/site/day, 95% confidence interval)

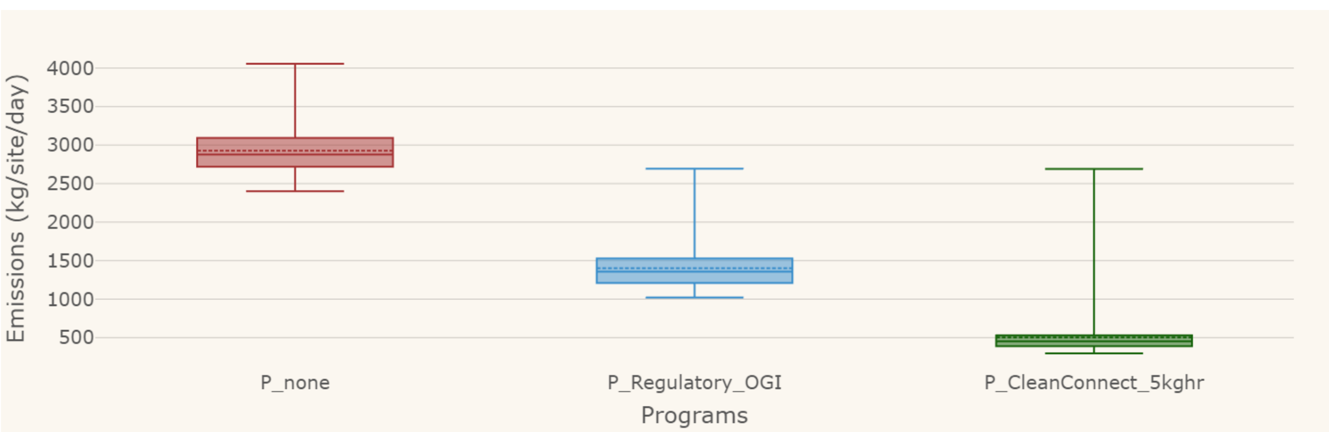


Figure 27: Box Plot of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado natural gas compressor stations which require quarterly AIMM surveys.

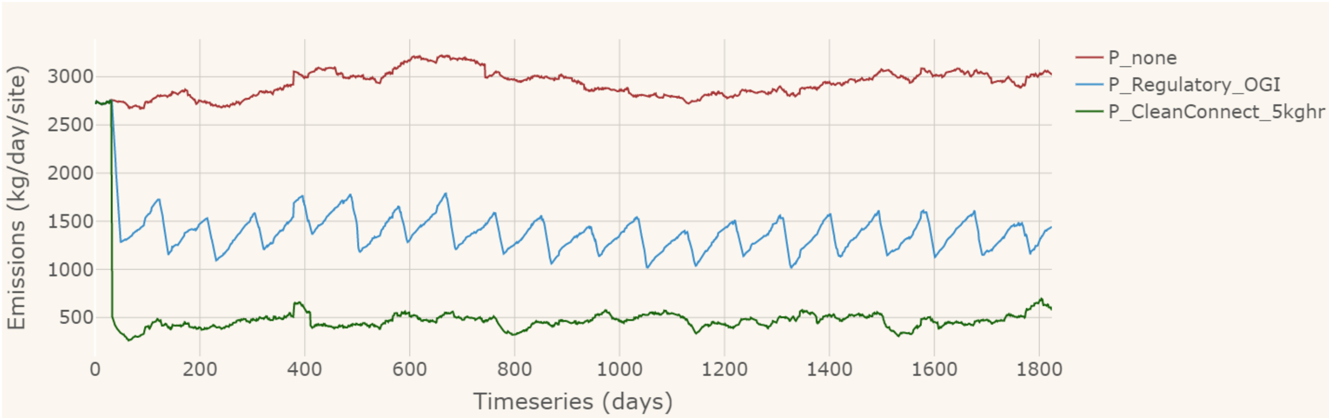


Figure 28: Time series of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado natural gas compressor stations which require quarterly AIMM surveys.

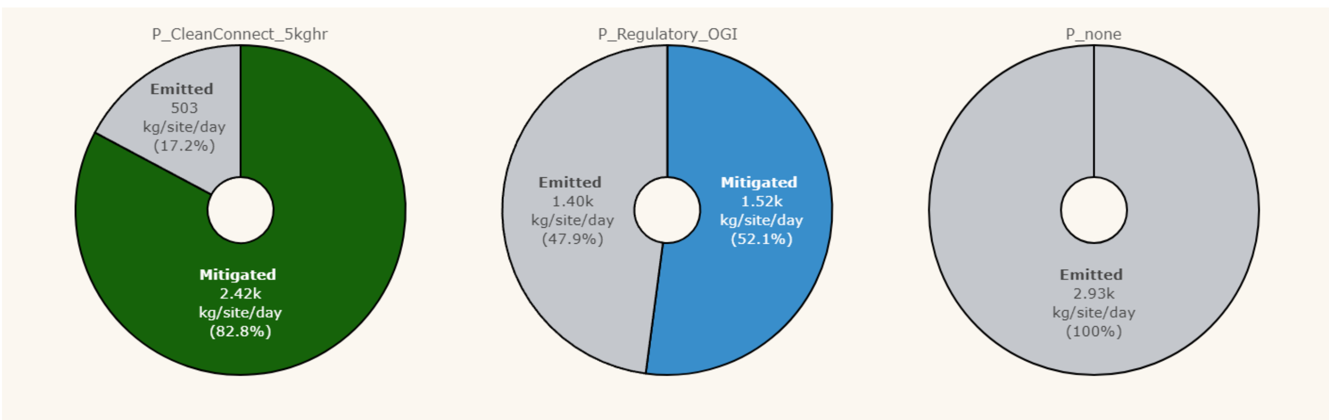


Figure 29: Donut plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado natural gas compressor stations which require quarterly AIMM surveys.

8.f.v. Monthly survey frequency requirement tier - well production facilities

The results of comparing LDAR programs within a virtual world populated by facilities indicative of Colorado well production facilities which require monthly AIMM surveys (P_Rregulatory_OGI has a monthly OGI survey method) follow. The Clean Connect program, with modeled emissions reductions of 66.4% (131.8 ± 2 kg/site/day, 95% confidence interval) exceeds equivalence with the regulatory OGI program, which has modeled emissions reductions of 61.3% (151.8 ± 1.8 kg/site/day, 95% confidence interval).

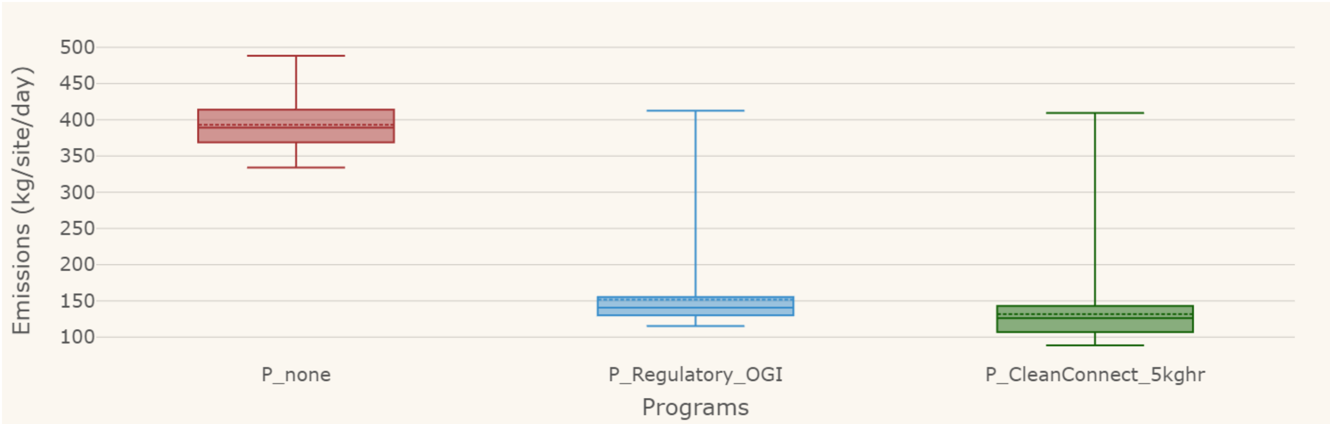


Figure 30: Box plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require monthly AIMM surveys.

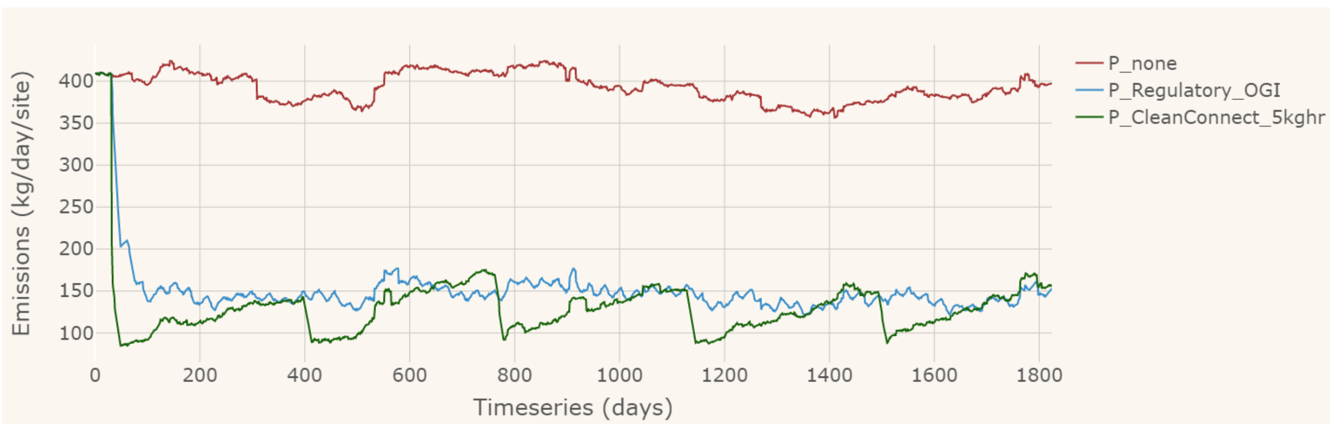


Figure 31: Time series of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require monthly AIMM surveys.

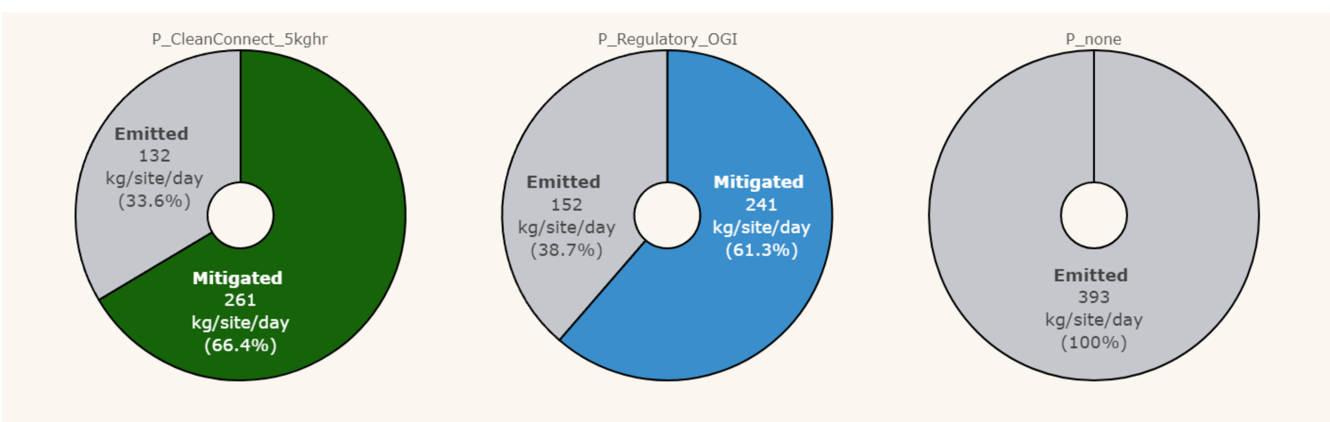


Figure 32: Donut plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado well production facilities which require monthly AIMM surveys.

8.f.vi. Monthly survey frequency requirement tier - compressor stations

The results of comparing LDAR programs within a virtual world populated by facilities indicative of Colorado compressor stations which require monthly AIMM surveys (P_Regulatory_OGI has a monthly OGI survey method) follow. The Clean Connect program, with modeled emissions reductions of 66.4% (2,507.2 ± 75.7 kg/site/day, 95% confidence interval) exceeds equivalence with the regulatory OGI program, which has modeled emissions reductions of 61.3% (5,461.8 ± 63.7 kg/site/day, 95% confidence interval).

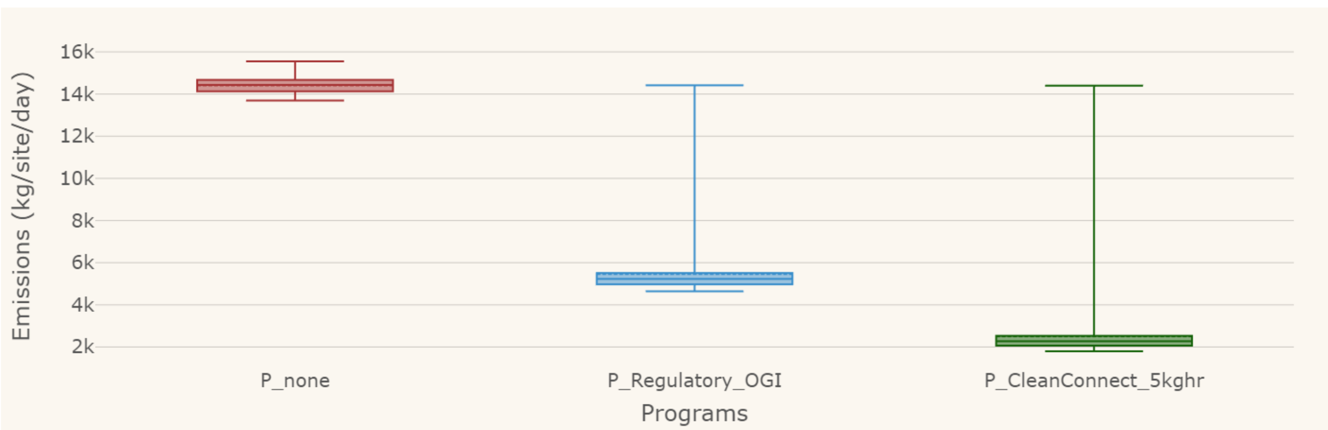


Figure 33: Box plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado natural gas compressor stations which require monthly AIMM surveys.

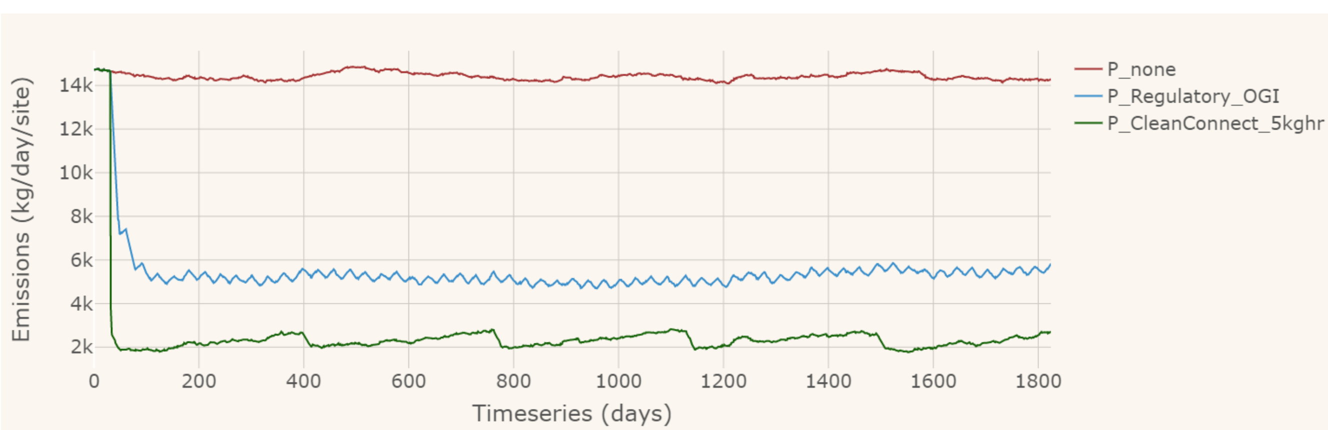


Figure 34: Time series of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program)

and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado natural gas compressor stations which require monthly AIMM surveys.

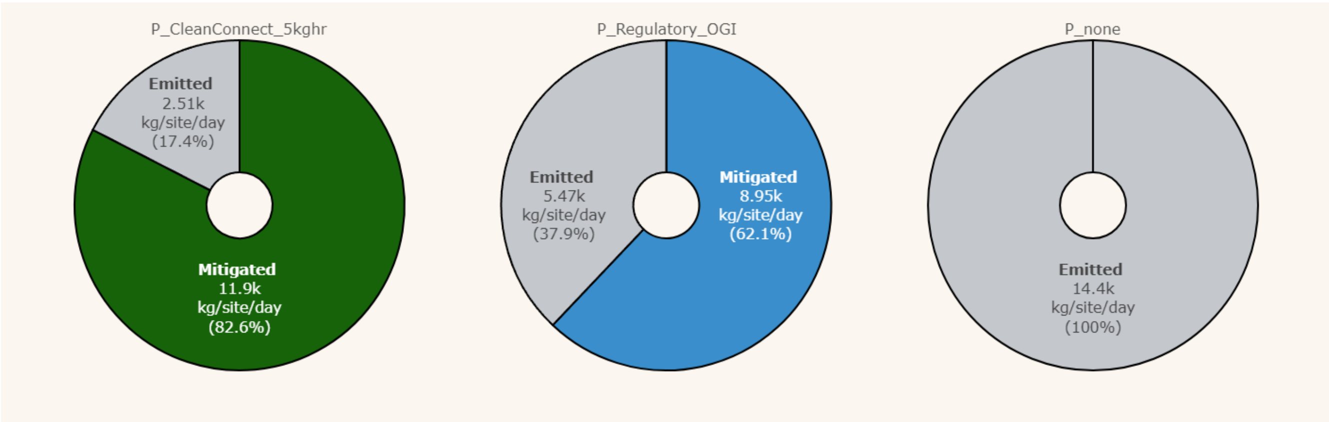


Figure 35: Donut plots of average emissions in kg/site/day under the following programs: P_CleanConnect (the Clean Connect monitoring system-based program), P_Regulatory (the regulatory based, routine handheld OGI inspection-based program) and P_none (a program devoid of any LDAR). These programs are applied to a virtual world consisting of oil and gas facilities designed to replicate Colorado natural gas compressor stations which require monthly AIMM surveys.

The monthly compressor station simulation is run with the largest leak rate distribution and leak production rate of all tiers. The rapid drop in daily emissions seen on the time series of this simulation due to the Clean Connect program detecting and instigating repair on the leaks existing at the start of the simulation. This rapid initial mitigation of existing leaks allows the Clean Connect program to maintain a lower baseline as it is a continuous monitoring program, when compared to the time series of the monthly OGI based program where we monthly cyclicity but never is able to reach such rapid initial mitigation due to the non-continuous nature of the program.

8.f.vii. Overall interpretation

It is helpful to consider the leak rate distribution in the context of its relationship to a method's minimum detection limit (MDL). The Clean Connect MDL used in all simulation tiers is 5 kg/hr, therefore, any randomly generated leak larger than 5kg/hr will be detected by the Clean Connect monitoring system method and ultimately repaired. The leak rate distribution used in the annual tier simulation rarely results in leaks greater than 5 kg/hr being randomly created. Therefore, the annual Clean Connect handheld OGI method component of the program detects more leaks, but the Clean Connect method acts as an important “safety net”, ready to catch any large leaks should they arise (as is seen around day 450 of the annual time series, Figure 19). By comparison, the leak rate distribution used in the simulations which represent compressor stations results in a much more frequent generation of larger leaks (frequently larger than 5kg/hr). In these compressor station specific simulations, the Clean Connect method will rapidly detect almost all leaks being randomly generated, as they are frequently large enough to exceed the Clean Connect method detection limit. As each simulation tier employs a distribution more prone to large leaks and a leak production rate more prone to frequent leaks than the last, this relationship between leak rate distribution, leak production rate and MDL is why the mitigation ratio of the Clean Connect program improves from the annual tier to the monthly tier simulations for both well production facilities and compressor stations.

From an equivalency perspective, the most difficult simulation tier for Clean Connect to achieve equivalency within is the monthly well production facility tier. Here, Clean Connect is compared against a monthly OGI based program with a much more sensitive MDL and the simulation leak behaviour is not always prone to large leaks (as it would be in the monthly compressor station simulation tier). Despite this, Clean Connect achieves an improvement in mitigation over the regulatory, OGI based program of 5.1%.

8.g. Sensitivity Analysis

8.g.i. Overview

Some LDAR-sim parameters can have a large impact on the overall outcome of a simulation. A high-level sensitivity analysis on two key parameters was conducted to better understand their effect on emissions mitigation. The two parameters investigated are natural repair delay (NRd: the time which will elapse before which an Operator will detect a leak left undetected by other methods) and leak production rate (LPR: the probability that a leak will arise in a day). For simplicity, sensitivity analysis was only performed on the Clean Connect program and all other parameters are held constant. The sensitivity analysis concluded that altering these parameters does have an effect on the outcome of the simulation, but the Clean Connect program is robust against the inherent uncertainty of these parameters as emissions mitigation still consistently exceeds the regulatory OGI program.

8.g.ii. Natural repair delay

To compare with the natural repair delay of 365 days, a simulation was run with programs with natural repair delays of one quarter of a year, one half of a year, and one and a half years (90, 180 and 548 days). The overall program emission values are shown in Figure 31.

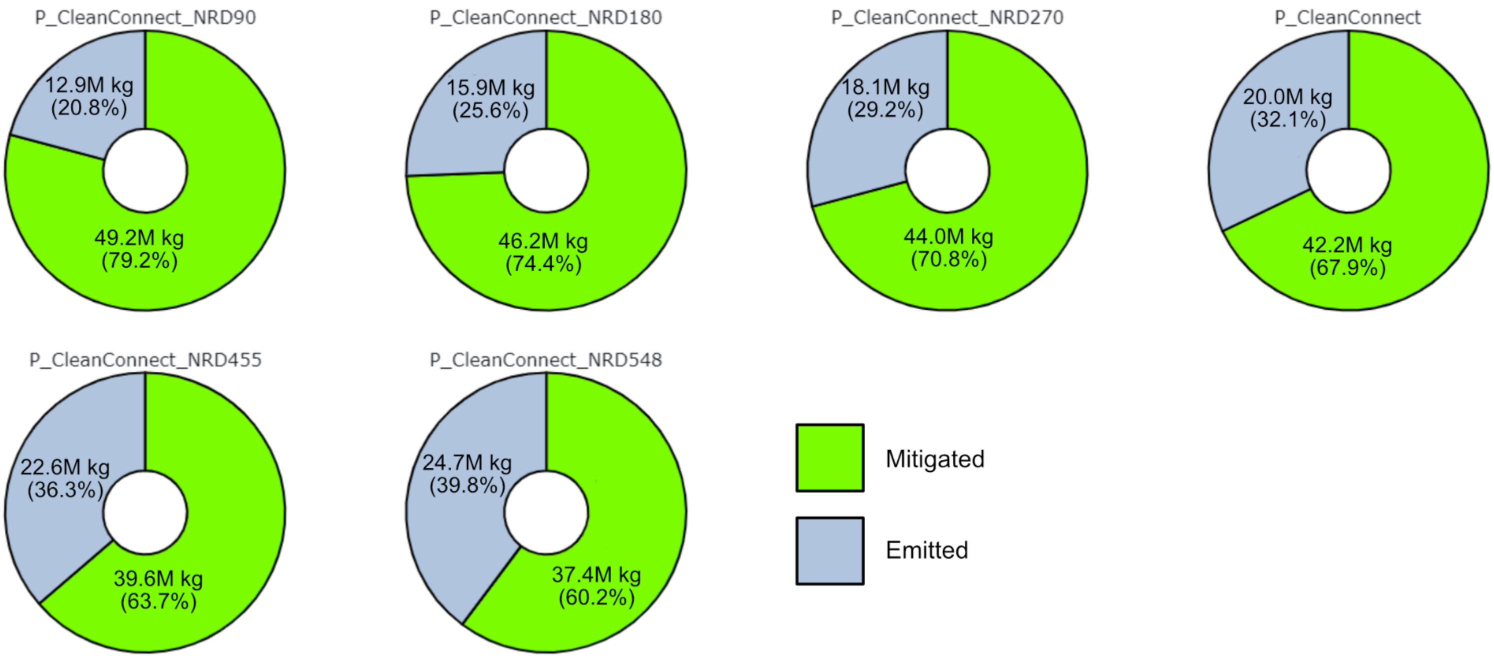


Figure 31: Natural repair delay sensitivity analysis

As per Figure 31, there is an average increase in emissions of 3.8% for each 90 days added to the natural repair delay parameter. If we assume the highest NRD tested (1.5 years, 548 days) the mitigation is still greater than that of the regulatory program (52.9%, Figure 24).

8.g.iii. Leak production rate

To compare with the leak production rate of 0.005 used in the quarterly simulation tier, a simulation was run with programs with leak production rates of 0.0025, 0.01, and 0.04. The overall program emission values are shown in Figure 32.

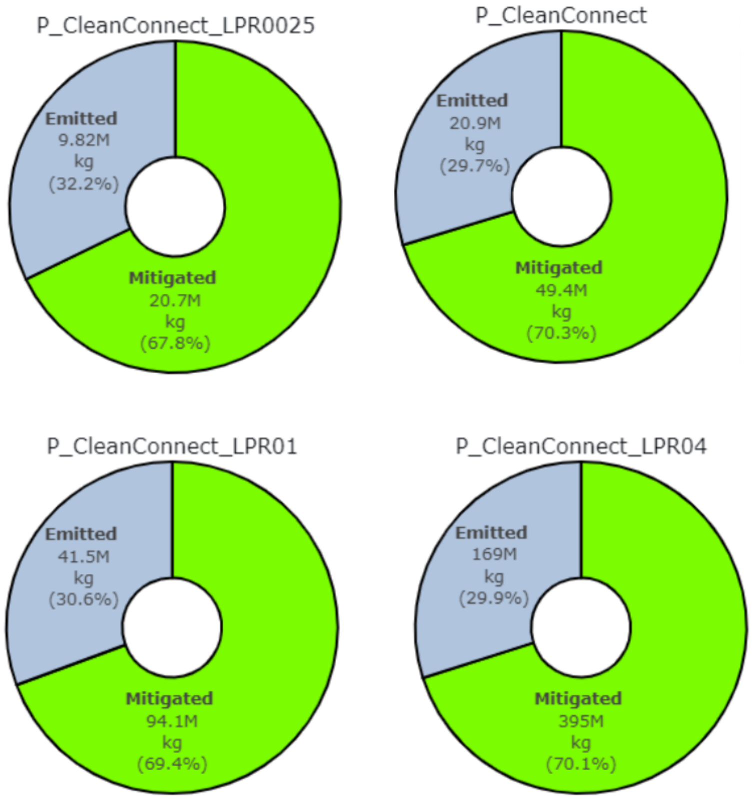


Figure 32: Natural repair delay sensitivity analysis

Increasing the leak production rate does not have an effect on the mitigation ratio of the Clean Connect program as the temporal duration of leaks mitigated by the program is held constant (Clean Connect is catching leaks in the same time span), only now there are more leaks in the system. The plot however does emphasize the importance of the leak production rate, which when doubled effectively doubles the amount of emissions in the simulation.

9. Appendix A: Example record keeping format

All data is uploaded to the secure cloud-based platform. The Operator can retrieve a tabular time series of data from the platform for submission to the Regulator. An example of these records, autonomously created by the Clean Connect monitoring system, which can be retrieved by the Operator and circulated follows.

The hypothetical deployment scenario which would generate the following table sees a single Clean Connect camera observing an entire facility in 10 tour stops, observing the equipment groups which require monitoring at each for 3 minutes. The system has kept track of two possible events, one of which has been elevated to a detection event as it has been persistent for more than 4 hours (Figure 4). As soon as an emission is classified as a possible event, it has a unique emission ID assigned to it.

Timestamp	Camera View (°)	% of Pixels Impacted	Contrast	Persistence (s)	Wavelength 1	Wavelength 2	Possible Event?	Detection Event?	Unique Emission ID	Missing Data Code
2022-03-01 14:03:00	0-36	30	3	0	2	6	0	0	NA	NA
2022-03-01 14:06:00	36-72	60	4	22	2	7	1	0	0002	NA
2022-03-01 14:09:00	72-108	50	3	0	2	6	0	0	NA	NA
2022-03-01 14:12:00	108-144	40	3	0	2	6	0	0	NA	NA
2022-03-01 14:15:00	144-180	110	8	14521	8	9	1	1	0001	NA
2022-03-01 14:18:00	180-216	20	2	0	1	5	0	0	NA	NA
2022-03-01 14:21:00	216-252	30	3	0	2	6	0	0	NA	NA
2022-03-01 14:24:00	252-288	20	2	0	2	6	0	0	NA	NA
2022-03-01 14:27:00	288-324	40	8	0	2	4	0	0	NA	NA
2022-03-01 14:30:00	324-360	null	null	null	null	null	null	null	null	power loss

Appendix A Table 1: Proposed record keeping time series tabular format

10. Appendix B: Blind, on-site testing, April 2022, full results

The following table contains the results of all controlled release testing carried out on April 22, 2022.

Leak ID	Tower Height	Distance to leak	Wind-Speed	Leak Rate scf/h	Detected	Camera	Video
Leak 1	30ft	30 yards	0 mph	1950	Y	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/13/13_59_52_ptz_22_out.mp4
Leak 2	30ft	30 yards	0 mph	1000	Y	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/14/14_03_20_ptz_22_out.mp4

Leak 3	30ft	30 yards	0 mph	500	Y	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/14/14_06_28_ptz_22_out.mp4
Leak 4	30ft	30 yards	0 mph	150	Y	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/14/14_20_15_ptz_22_out.mp4
Leak 5	30ft	30 yards	0 mph	15	Y	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/14/14_44_18_ptz_22_out.mp4
Leak 6	30ft	30 yards	0 mph	10	Y	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/14/14_54_15_ptz_22_out.mp4
Leak 7	30ft	100 yards	1 mph	10	N	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/15/15_08_43_ptz_35_out.mp4
Leak 8	30ft	100 yards	1 mph	50	N	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/15/15_16_20_ptz_35_out.mp4
Leak 9	30ft	100 yards	1 mph	250	Y	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/15/15_23_11_ptz_35_out.mp4
Leak 10	30ft	100 yards	1 mph	150	Y	FLIR G300a	https://storage.googleapis.com/gas_detection/pdc_chalkseeley/2022/04/22/15/15_28_32_ptz_35_out.mp4
Leak 11	30ft	80 yards	7mph	250	Y	Ventus OGI	https://storage.googleapis.com/gas_detection/pdc_ridge/2022/04/22/16/16_25_28_ptz_18_out.mp4
Leak 12	30ft	80 yards	2mph	150	Y	Ventus OGI	https://storage.googleapis.com/gas_detection/pdc_ridge/2022/04/22/16/16_32_55_ptz_18_out.mp4
Leak 13	30ft	80 yards	0mph	50	N	Ventus OGI	
Leak 14	30ft	40 yards	0mph	50	N	Ventus OGI	
Leak 15	30ft	40 yards	5mph	50	N	Ventus OGI	
Leak 16	30ft	40 yards	6mph	150	Y	Ventus OGI	https://storage.googleapis.com/gas_detection/pdc_ridge/2022/04/22/17/17_01_22_ptz_18_out.mp4

11. Appendix D: Blind, on-site testing to establish performance at greater distances, November 2022, full results

The following images are of the PDF testing forms recorded by the Operator conducting controlled release testing of the Clean Connect Monitoring System during November 2022 blind testing and sent to CDPHE. Forms are captioned by distance of the release point to the Clean Connect Camera System.

Period # (Key)	Release or Non-release	Distance (m)	Period Start (YYYY-MM-DD_00:00)	Period End (YYYY-MM-DD_00:00)	Wind Speed (m/s)	Clean Connect detection/alert received*	Correct Result**
1	Release	40	2022-10-20_8:56AM	2022-10-20_8:59AM	0	1	1
2	Non-Release	40	2022-10-20_9:00AM	2022-10-20_9:05AM	0	0	1
3	Release	40	2022-10-20_9:06AM	2022-10-20_9:08AM	1.788	1	1
4	Non-Release	40	2022-10-20_9:09AM	2022-10-20_9:14AM	1.56	0	1
5	Release	40	2022-10-20_9:15AM	2022-10-20_9:17AM	0.89	1	1
6	Non-Release	40	2022-10-20_9:19AM	2022-10-20_9:24AM	0.357	0	1
7	Release	40	2022-10-20_9:25AM	2022-10-20_9:27AM	0.76	1	1
8	Non-Release	40	2022-10-20_9:29AM	2022-10-20_9:34AM	0.1	0	1
9	Release	40	2022-10-20_9:34AM	2022-10-20_ 9:37AM	0.9	1	1
10	Non-release	40	2022-10-20_9:39AM	2022-10-20_9:44AM	0.6	0	1
11	Release	40	2022-10-20_9:44AM	2022-10-20_9:47AM	1.4	1	1
12	Non-Release	40	2022-10-20_9:47AM	2022-10-20_9:52AM	1.2	0	1
13	Release	40	2022-10-20_9:52AM	2022-10-20_9:56AM	1.3	1	1
14	Non-Release	40	2022-10-20_9:56AM	2022-10-20_10:01AM	3.2	0	1
15	Release	40	2022-10-20_10:01AM	2022-10-20_10:02AM	0.8	1	1
16	Non-Release	40	2022-10-20_10:04AM	2022-10-20_10:09AM	1.9	0	1
17	Release	40	2022-10-20_10:09AM	2022-10-20_10:13AM	2.5	1	1
18	Non-Release	40	2022-10-20_10:13AM	2022-10-20_10:18AM	1.9	0	1
19	Release	40	2022-10-20_10:19AM	2022-10-20_10:23AM	1.3	1	1
20	Non-Release	40	2022-10-20_10:23AM	2022-10-20_10:28	1.2	0	1
21	Release	40	2022-10-20_ 10:28AM	2022-10-20_10:32AM	0.6	1	1
22	Non-Release	40	2022-10-20_10:32AM	2022-10-20_10:37AM	0.9	0	1
23	Release	40	2022-10-20_10:37AM	2022-10-20_10:41AM	1.3	1	1
24	Non-Release	40	2022-10-20_10:41AM	2022-10-20_10:46AM	0	0	1
25	Release	40	2022-10-20_10:47AM	2022-10-20_10:51AM	1.5	1	1
26	Non-Release	40	2022-10-20_10:51AM	2022-10-20_10:56AM	1.6	0	1
27	Release	40	2022-10-20_10:57AM	2022-10-20_11:01AM	1.2	0 (Model Caught Leak, bug in communication)	0
28	Non-Release	40	2022-10-20_11:06AM	2022-10-20_11:11AM	0.4	0	1
29	Release	40	2022-10-20_11:11AM	2022-10-20_11:16AM	0	1	1
30	Non-Release	40	2022-10-20_11:16AM	2022-10-20_11:21AM	1.2	0	1

*Detection / alert received values: 1 = alert received, 0 = no alert received

** Result Values: 1 = True positive (alert received for a release) or true negative (no alert received for a non-release), 0 = false negative (no alert received for a release) or false positive (alert received for a non-release)

Controlled release, blind testing results filled in by the Operator and sent directly to CDPHE. Distance of the Clean Connect Camera System to the release point: 40m

Period # (Key)	Release or Non-release	Distance (m)	Period Start (YYYY-MM-DD_00:00)	Period End (YYYY-MM-DD_00:00)	Wind Speed (m/s)	Clean Connect detection/ alert received*	Correct Result**
1	Release	60	2022-10-20_11:37AM	2022-10-20_11:40AM	1.0	1	1
2	Non-Release	60	2022-10-20_11:41AM	2022-10-20_11:46AM	1.5	0	1
3	Release	60	2022-10-20_11:47AM	2022-10-20_11:52AM	1.9	1	1
4	Non-Release	60	2022-10-20_11:53AM	2022-10-20_11:58AM	1.7	0	1
5	Release	60	2022-10-20_11:58AM	2022-10-20_12:03PM	2.9	1	1
6	Non-Release	60	2022-10-20_12:40PM	2022-10-20_12:45PM	1.7	0	1
7	Release	60	2022-10-20_12:45	2022-10-20_12:47PM	1.6	1	1
8	Non-Release	60	2022-10-20_12:49PM	2022-10-20_12:54PM	0.8	0	1
9	Release	60	2022-10-20_12:54PM	2022-10-20_12:56PM	2.0	1	1
10	Non-release	60	2022-10-20_12:58PM	2022-10-20_1:03PM	2.6	0	1
11	Release	60	2022-10-20_1:03PM	2022-10-20_1:08PM	0.8	1	1
12	Non-Release	60	2022-10-20_1:08PM	2022-10-20_1:13PM	2.3	0	1
13	Release	60	2022-10-20_1:14	2022-10-20_1:17PM	3.8	1	1
14	Non-Release	60	2022-10-20_1:17PM	2022-10-20_1:22PM	2.4	0	1
15	Release	60	2022-10-20_1:23PM	2022-10-20_1:27PM	2.6	1	1
16	Non-Release	60	2022-10-20_1:27PM	2022-10-20_1:32PM	1.9	0	1
17	Release	60	2022-10-20_1:32PM	2022-10-20_1:35PM	2.5	1	1
18	Non-Release	60	2022-10-20_1:36PM	2022-10-20_1:41PM	2.7	0	1
19	Release	60	2022-10-20_1:41PM	2022-10-20_1:45PM	3.6	1	1
20	Non-Release	60	2022-10-20_1:45PM	2022-10-20_1:50PM	1.8	0	1
21	Release	60	2022-10-20_1:50PM	2022-10-20_1:53PM	4.0	1	1
22	Non-Release	60	2022-10-20_1:54PM	2022-10-20_1:59PM	2.2	0	1
23	Release	60	2022-10-20_1:59PM	2022-10-20_2:02PM	3.6	1	1
24	Non-Release	60	2022-10-20_2:02PM	2022-10-20_2:07PM	3.0	0	1
25	Release	60	2022-10-20_2:08PM	2022-10-20_2:13PM	3.1	1	1
26	Non-Release	60	2022-10-20_2:11PM	2022-10-20_2:16PM	1.9	0	1
27	Release	60	2022-10-20_2:16PM	2022-10-20_2:20PM	3.2	1	1
28	Non-Release	60	2022-10-20_2:20PM	2022-10-20_2:25PM	1.4	0	1
29	Release	60	2022-10-20_2:25PM	2022-10-20_2:29PM	2.4	1	1
30	Non-Release	60	2022-10-20_2:29PM	2022-10-20_2:34PM	2.6	0	1

*Detection / alert received values: 1 = alert received, 0 = no alert received

** Result Values: 1 = True positive (alert received for a release) or true negative (no alert received for a non-release), 0 = false negative (no alert received for a release) or false positive (alert received for a non-release)

Controlled release, blind testing results filled in by the Operator and sent directly to CDPHE. Distance of the Clean Connect Camera System to the release point: 60m

Period # (Key)	Release or Non-release	Distance (m)	Period Start (YYYY-MM-DD_00:00)	Period End (YYYY-MM-DD_00:00)	Wind Speed (m/s)	Clean Connect detection/ alert received*	Correct Result**
1	Release	80	2022-10-20_2:50PM	2022-10-20_2:54PM	0.9	1	1
2	Non-Release	80	2022-10-20_2:54PM	2022-10-20_2:59PM	3.6	0	1
3	Release	80	2022-10-20_2:59PM	2022-10-20_3:03PM	1.1	1	1
4	Non-Release	80	2022-10-20_3:03PM	2022-10-20_3:08PM	4.7	0	1
5	Release	80	2022-10-20_3:08PM	2022-10-20_3:12PM	2.1	1	1
6	Non-Release	80	2022-10-20_3:12PM	2022-10-20_3:17PM	3.4	0	1
7	Release	80	2022-10-20_3:18PM	2022-10-20_3:22PM	2.1	1	1
8	Non-Release	80	2022-10-20_3:22PM	2022-10-20_3:27PM	3.1	0	1
9	Release	80	2022-10-20_3:27PM	2022-10-20_3:31PM	1.9	1	1
10	Non-release	80	2022-10-20_3:31PM	2022-10-20_3:36PM	1.8	0	1
11	Release	80	2022-10-20_3:37PM	2022-10-20_3:40PM	1.6	1	1
12	Non-Release	80	2022-10-20_3:40PM	2022-10-20_3:45PM	1.9	0	1
13	Release	80	2022-10-20_3:46PM	2022-10-20_3:49PM	0.9	1	1
14	Non-Release	80	2022-10-20_3:49PM	2022-10-20_3:54PM	1.6	0	1
15	Release	80	2022-10-20_3:54PM	2022-10-20_3:58PM	3.9	1	1
16	Non-Release	80	2022-10-20_3:59PM	2022-10-20_4:04PM	1.3	0	1
17	Release	80	2022-10-20_4:04PM	2022-10-20_4:09PM	2.0	1	1
18	Non-Release	80	2022-10-20_4:09PM	2022-10-20_4:14PM	1.5	0	1
19	Release	80	2022-10-20_4:14PM	2022-10-20_4:17PM	0.7	1	1
20	Non-Release	80	2022-10-20_4:17PM	2022-10-20_4:22PM	0.5	0	1
21	Release	80	2022-10-20_4:22PM	2022-10-20_4:27PM	1.3	1	1
22	Non-Release	80	2022-10-20_4:27PM	2022-10-20_4:32PM	2.2	0	1
23	Release	80	2022-10-20_4:32PM	2022-10-20_4:36PM	1.7	1	1
24	Non-Release	80	2022-10-20_4:36PM	2022-10-20_4:41PM	0.7	0	1
25	Release	80	2022-10-20_4:41PM	2022-10-20_4:45PM	1.8	1	1
26	Non-Release	80	2022-10-20_4:45PM	2022-10-20_4:50PM	2.8	0	1
27	Release	80	2022-10-20_4:50PM	2022-10-20_4:54PM	2.9	1	1
28	Non-Release	80	2022-10-20_4:54PM	2022-10-20_4:59PM	3.2	0	1
29	Release	80	2022-10-20_4:59PM	2022-10-20_5:03PM	0.6	1	1
30	Non-Release	80	2022-10-20_5:03PM	2022-10-20_5:08PM	0.8	0	1

*Detection / alert received values: 1 = alert received, 0 = no alert received

** Result Values: 1 = True positive (alert received for a release) or true negative (no alert received for a non-release), 0 = false negative (no alert received for a release) or false positive (alert received for a non-release)

Controlled release, blind testing results filled in by the Operator and sent directly to CDPHE. Distance of the Clean Connect Camera System to the release point: 80m

Period # (Key)	Release or Non-release	Distance (m)	Period Start (YYYY-MM-DD_00:00)	Period End (YYYY-MM-DD_00:00)	Wind Speed (m/s)	Clean Connect detection/ alert received*	Correct Result**
1	Release	100	2022-10-21_7:25AM	2022-10-21_7:29	0.8	1	1
2	Non-Release	100	2022-10-21_7:32AM	2022-10-21_7:37AM	1.1	0	1
3	Release	100	2022-10-21_7:37AM	2022-10-21_7:42AM	0	1	1
4	Non-Release	100	2022-10-21_7:44AM	2022-10-21_7:49AM	0	0	1
5	Release	100	2022-10-21_7:53AM	2022-10-21_7:57AM	1.5	1	1
6	Non-Release	100	2022-10-21_7:57AM	2022-10-21_8:02AM	1.9	0	1
7	Release	100	2022-10-21_8:02AM	2022-10-21_8:05AM	1.4	1	1
8	Non-Release	100	2022-10-21_8:07AM	2022-10-21_8:12AM	1.9	0	1
9	Release	100	2022-10-21_8:12AM	2022-10-21_8:15AM	0.9	1	1
10	Non-release	100	2022-10-21_8:16AM	2022-10-21_8:21AM	1.5	0	1
11	Release	100	2022-10-21_8::22AM	2022-10-21_8:25AM	0.6	1	1
12	Non-Release	100	2022-10-21_8:26AM	2022-10-21_8:31AM	1.9	0	1
13	Release	100	2022-10-21_8:31AM	2022-10-21_8:34AM	1.7	1	1
14	Non-Release	100	2022-10-21_8:35AM	2022-10-21_8:40AM	0	0	1
15	Release	100	2022-10-21_8:40AM	2022-10-21_8:43AM	1	1	1
16	Non-Release	100	2022-10-21_8:44AM	2022-10-21_8:49AM	0.8	0	1
17	Release	100	2022-10-21_8:50AM	2022-10-21_8:53AM	1.8	1	1
18	Non-Release	100	2022-10-21_8:54AM	2022-10-21_8:59AM	1.7	0	1
19	Release	100	2022-10-21_8:59AM	2022-10-21_9:02AM	1.9	1	1
20	Non-Release	100	2022-10-21_9:02AM	2022-10-21_9:07AM	3.4	0	1

*Detection / alert received values: 1 = alert received, 0 = no alert received

** Result Values: 1 = True positive (alert received for a release) or true negative (no alert received for a non-release), 0 = false negative (no alert received for a release) or false positive (alert received for a non-release)

Controlled release, blind testing results filled in by the Operator and sent directly to CDPHE. Distance of the Clean Connect Camera System to the release point: 100m

Period # (Key)	Release or Non-release	Distance (m)	Period Start (YYYY-MM-DD_00:00)	Period End (YYYY-MM-DD_00:00)	Wind Speed (m/s)	Clean Connect detection/ alert received*	Correct Result**
1	Release	120	2022-10-21_9:15AM	2022-10-21_9:17AM	2.0	1	1
2	Non-Release	120	2022-10-21_9:19AM	2022-10-21_9:24AM	4.1	0	1
3	Release	120	2022-10-21_9:24AM	2022-10-21_9:27AM	1.7	1	1
4	Non-Release	120	2022-10-21_9:28AM	2022-10-21_9:33AM	2.4	0	1
5	Release	120	2022-10-21_9:33AM	2022-10-21_9:36AM	3.3	1	1
6	Non-Release	120	2022-10-21_9:37AM	2022-10-21_9:42AM	3.1	0	1
7	Release	120	2022-10-21_9:43AM	2022-10-21_9:46AM	1.8	1	1
8	Non-Release	120	2022-10-21_9:48AM	2022-10-21_9:53AM	3.1	0	1
9	Release	120	2022-10-21_9:53AM	2022-10-21_9:57AM	3.7	1	1
10	Non-release	120	2022-10-21_9:59AM	2022-10-21_10:04AM	2.3	0	1
11	Release	120	2022-10-21_10:05AM	2022-10-21_10:09AM	2.4	1	1
12	Non-Release	120	2022-10-21_10:09AM	2022-10-21_10:14AM	0.6	0	1
13	Release	120	2022-10-21_10:14AM	2022-10-21_10:18AM	0.6	1	1
14	Non-Release	120	2022-10-21_10:18AM	2022-10-21_10:23AM	1.3	0	1
15	Release	120	2022-10-21_10:23AM	2022-10-21_10:27AM	1.5	1	1
16	Non-Release	120	2022-10-21_10:28AM	2022-10-21_10:33AM	0.7	0	1

*Detection / alert received values: 1 = alert received, 0 = no alert received

** Result Values: 1 = True positive (alert received for a release) or true negative (no alert received for a non-release), 0 = false negative (no alert received for a release) or false positive (alert received for a non-release)

Controlled release, blind testing results filled in by the Operator and sent directly to CDPHE. Distance of the Clean Connect Camera System to the release point: 120m

12. Appendix C: LDAR-Sim simulation update/sensitivity analysis

The following appendix presents an investigation into two key parameters of the LDAR-Sim simulation modelling described in Section 8: Leak Production Rate (LPR) and Leak Rate Distribution (LRD). The modelling in Section 8 was carried out with the assumption that Colorado facilities which required more frequent surveys are prone to more frequent *and* larger leaks. In simulation, this was represented by having each simulation representing a survey frequency tier having a unique LPR (sourced from CDPHE LDAR surveys, Table 3) and LRD (sourced from empirical leak rate distribution studies, Figure 16). These LPRs and LRDs are summarized in Table 4.

The following sensitivity analysis assumes that LPR does increase relative to the survey frequency of a given facility (facilities which require more OGI surveys per year are more prone to more frequent leaks), however, the LRD is consistent across all survey frequency tiers for a given facility type (individual leak emission rate is relatively consistent regardless of facility). In other words, facilities which require more OGI surveys are more prone to larger total emissions as they are more prone to more frequent leaks, not that those individual leaks have markedly larger emission rates. To represent this in simulation, it is assumed that the Zavala-Araiza (2015) well production distribution is representative of all well production facilities.

The assumption around consistent emission rates is for a given facility type, and it *is* assumed that compressor stations are more prone to larger emission rates for individual leaks than well production facilities. Compressor stations can require either quarterly/bi-monthly surveys or monthly surveys (depending on various factors described in Table 2). As such, compressor stations are modeled using the Zavala-Araiza (2015) compressor station distribution.

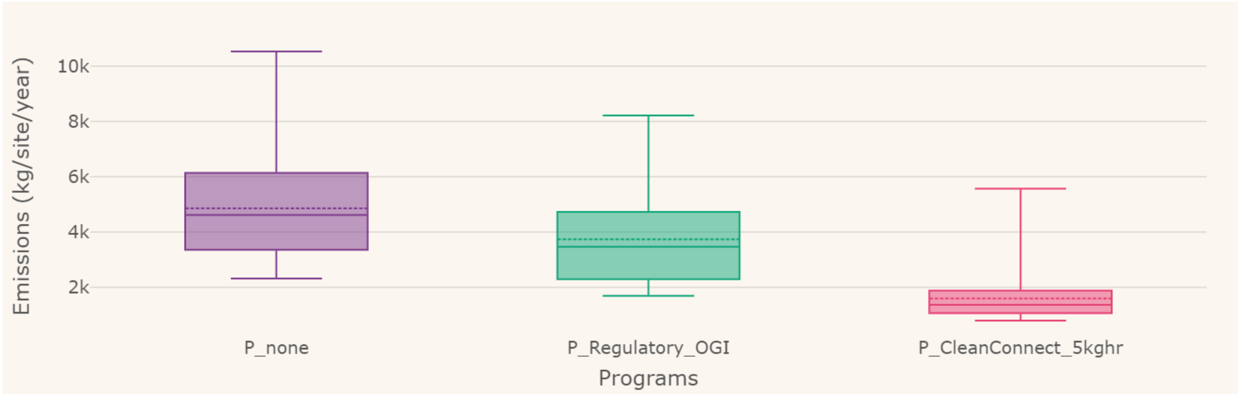
The Clean Connect program is represented as "P_CleanConnect_5kghr". Although Clean Connect has proven performance down to 2.86 kg/hr (Figure 12), simulations show that this conservative MDL of 5 kg/hr achieves equivalency when compared to the various regulatory OGI based programs. All parameterization of the Clean Connect program is consistent with Section 8.

Appendix C Table 1 summarizes the results of this sensitivity analysis while the following figures Appendix C, Figures 1-18, provide additional detail.

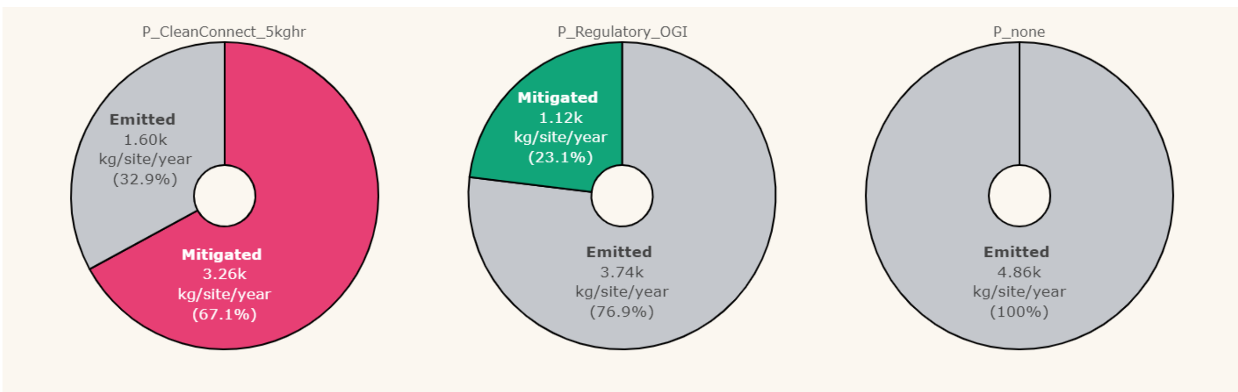
Appendix C, Table 1: Sensitivity analysis simulation results summary

Leak Rate Distribution	Leak Production Rate	Regulatory OGI Survey Frequency	Baseline (P_none) *Emissions* (kg/site/year)	Regulatory OGI program (P_Regulatory_OGI) *Mitigation* (kg/site/year)	Clean Connect Program (P_CleanConnect_5kghr) *Mitigation* (kg/site/year)
Zavala-Araiza Production	0.00093	1x	4.86	1.12	3.26
Zavala-Araiza Production	0.0018	2x	10.25	4.11	6.69
Zavala-Araiza Production	0.0051	4x	2.82×10^4	1.46×10^4	1.85×10^4
Zavala-Araiza Compressors	0.0051	4x	1.07×10^6	5.56×10^5	8.85×10^5
Zavala-Araiza Production	0.026	12x	1.44×10^5	88.01×10^4	95.3×10^4
Zavala-Araiza Compressors	0.026	12x	5.26×10^6	3.27×10^6	4.34×10^6

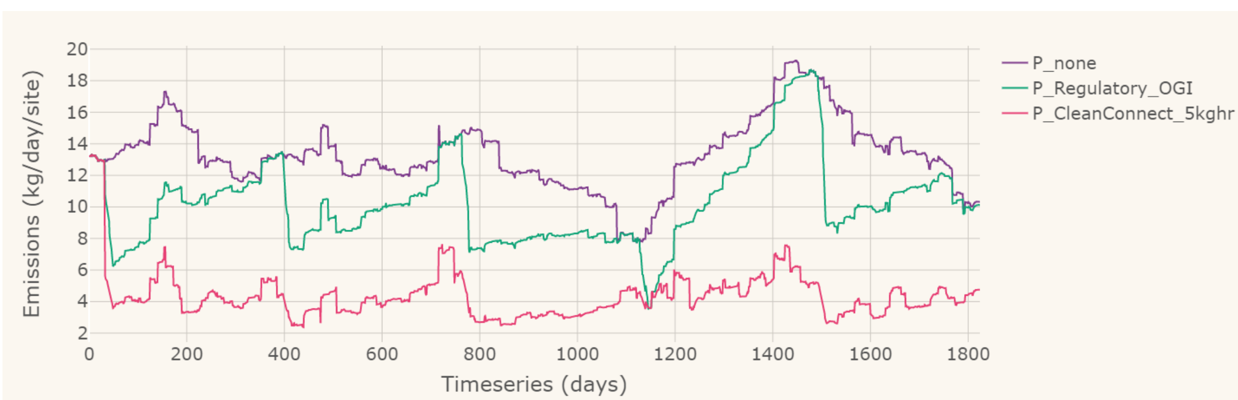
As we can see, when assuming a consistent LRD of either Zavala-Araiza production or compressor depending on the facility type being simulated, the Clean Connect program conservatively parameterized with a 5 kg/hr MDL achieves and surpasses emissions reduction equivalency with a regulatory OGI program.



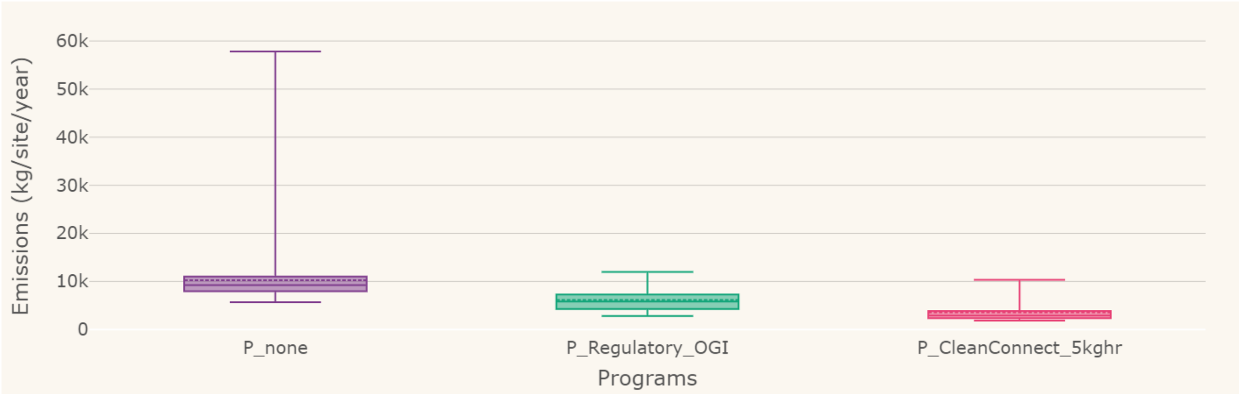
Appendix C, Figure 1: Zavala-Araiza (2015) production distribution (well production facilities modeled), 1x per year regulatory OGI, annual LPR (0.00093), box plot



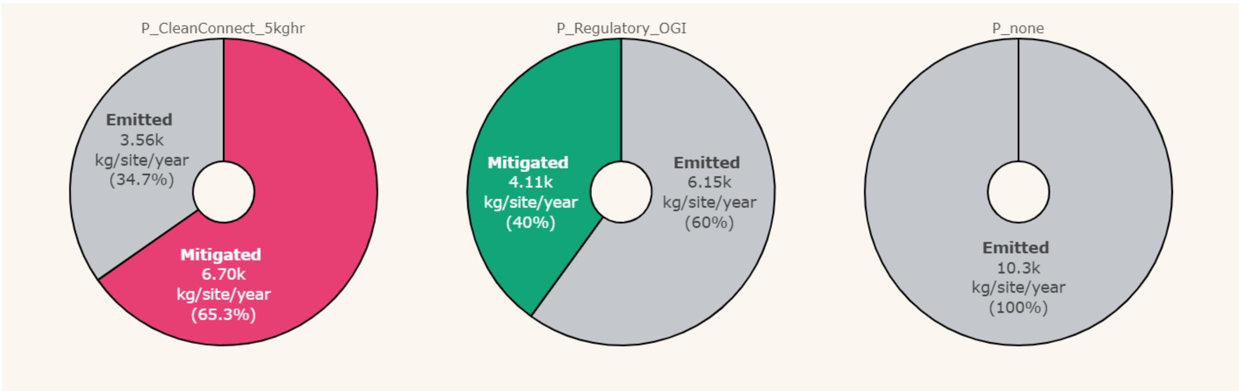
Appendix C, Figure 2: Zavala-Araiza (2015) production distribution (well production facilities modeled), 1x per year regulatory OGI, annual LPR (0.00093), donut plot



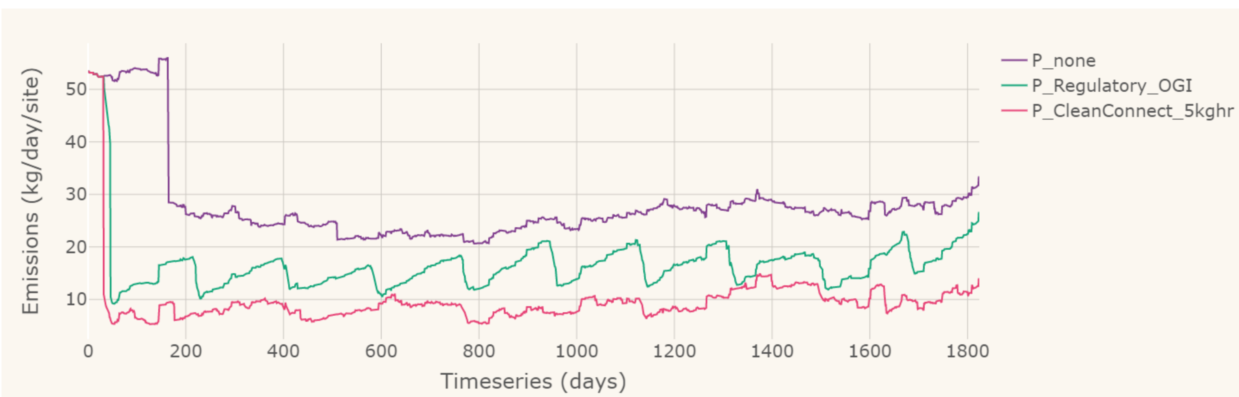
Appendix C, Figure 3: Zavala-Araiza (2015) production distribution (well production facilities modeled), 1x per year regulatory OGI, annual LPR (0.00093), time series



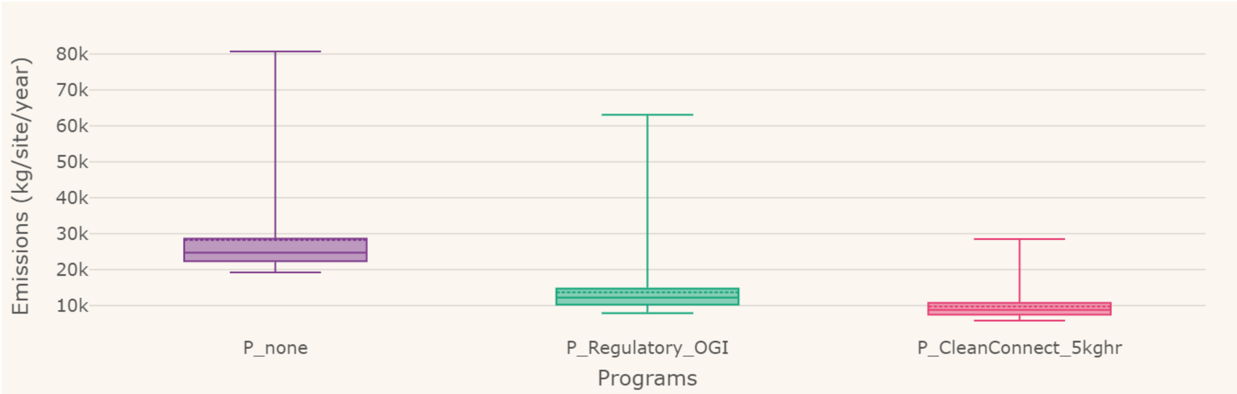
Appendix C, Figure 4: Zavala-Araiza (2015) production distribution (well production facilities modeled), 2x per year regulatory OGI, semi-annual LPR (0.0018), box plot



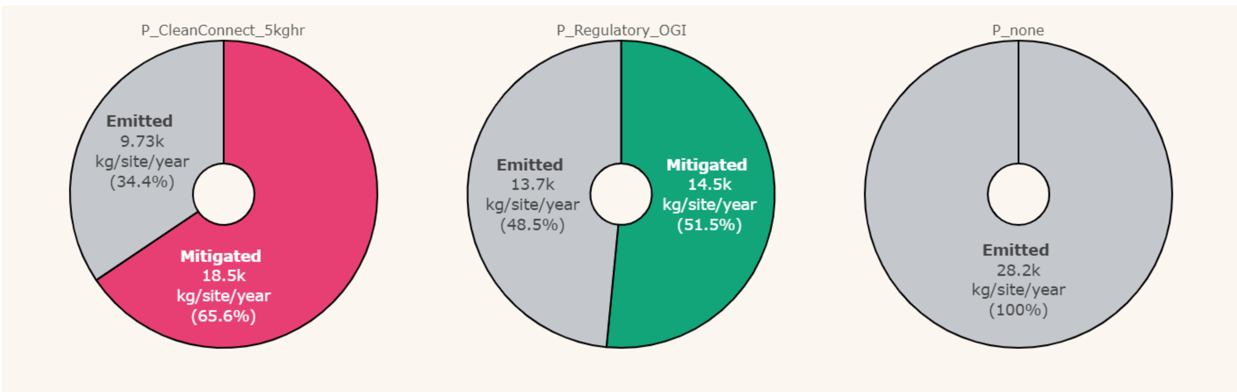
Appendix C, Figure 5: Zavala-Araiza (2015) production distribution (well production facilities modeled), 2x per year regulatory OGI, semi-annual LPR (0.0018), donut plot



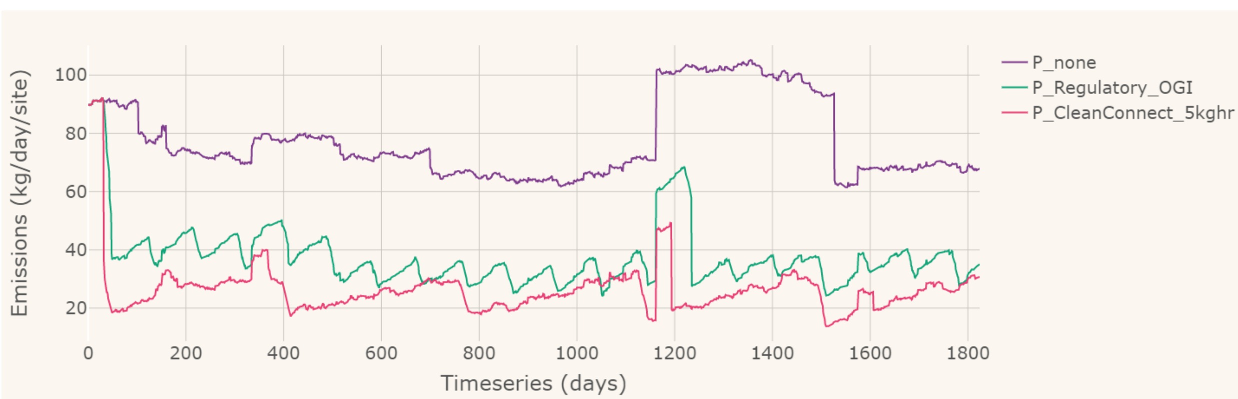
Appendix C, Figure 6: Zavala-Araiza (2015) production distribution (well production facilities modeled), 2x per year regulatory OGI, semi-annual LPR (0.0018), time series



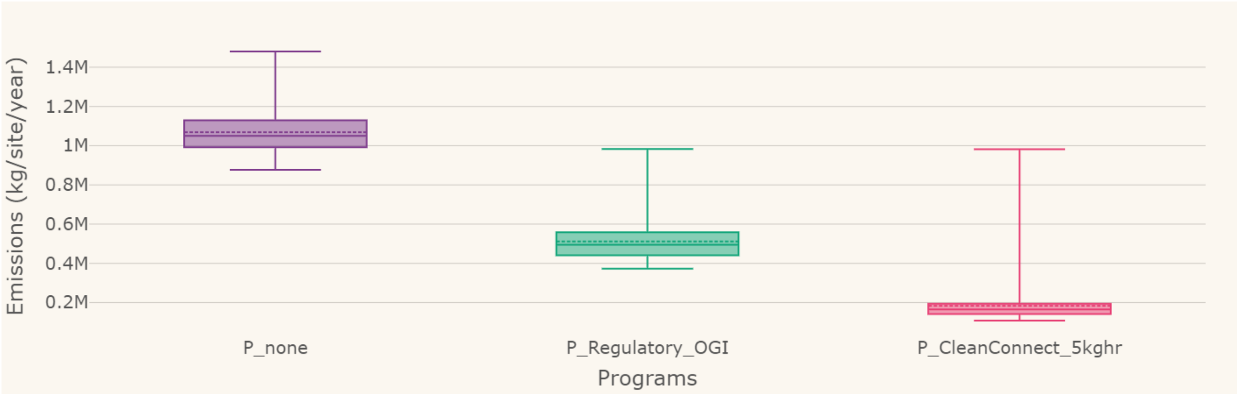
Appendix C, Figure 7: Zavala-Araiza (2015) production distribution (well production facilities modeled), 4x per year regulatory OGI, quarterly LPR (0.0051), box plot



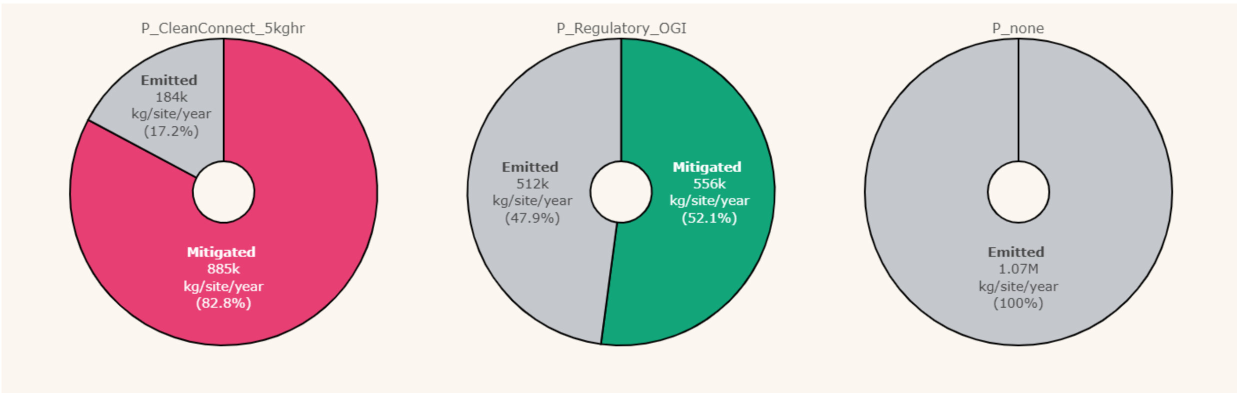
Appendix C, Figure 8: Zavala-Araiza (2015) production distribution (well production facilities modeled), 4x per year regulatory OGI, quarterly LPR (0.0051), donut plot



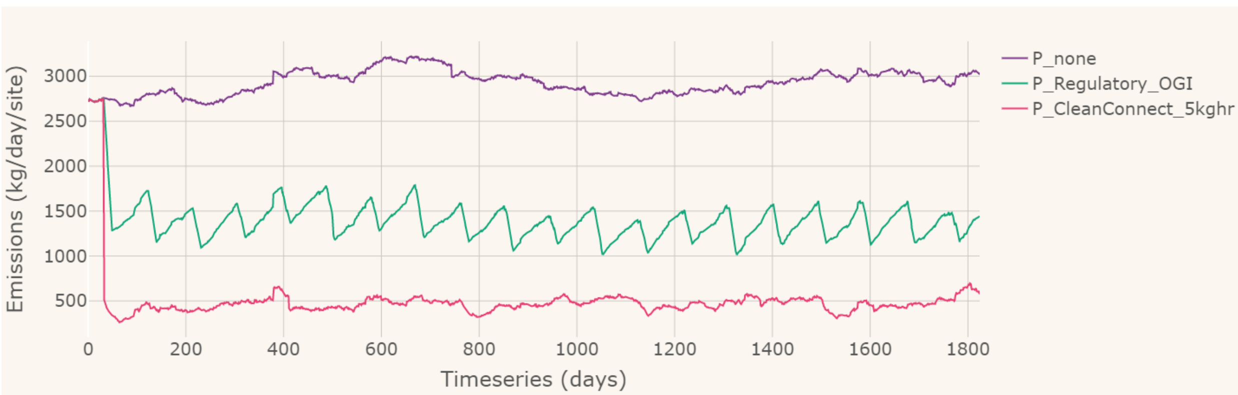
Appendix C, Figure 9: Zavala-Araiza (2015) production distribution (well production facilities modeled), 4x per year regulatory OGI, quarterly LPR (0.0051), time series



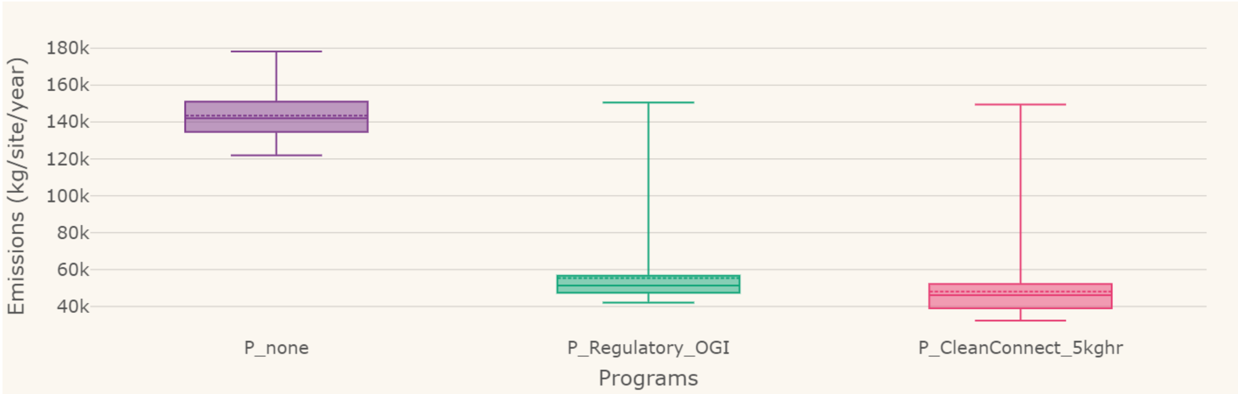
Appendix C, Figure 10: Zavala-Araiza (2015) compressor distribution (compressor stations modeled), 4x per year regulatory OGI, quarterly LPR (0.0051), box plot



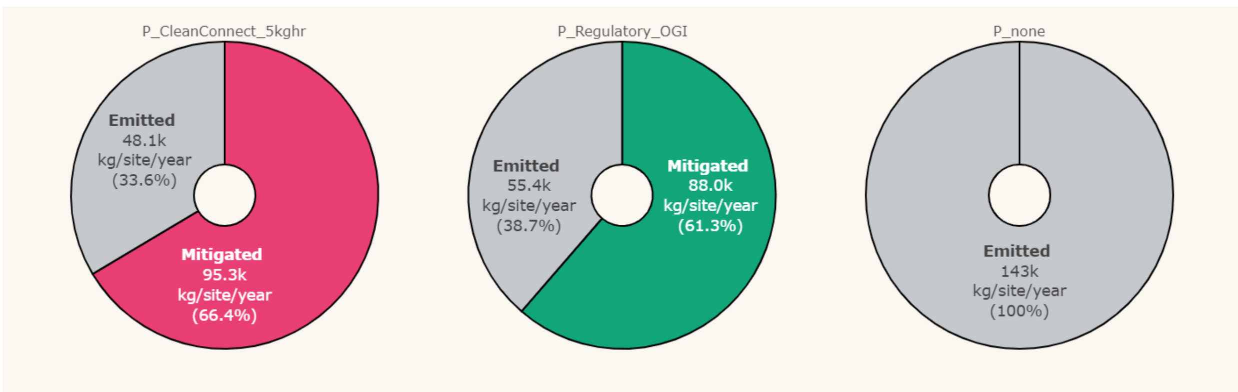
Appendix C, Figure 11: Zavala-Araiza (2015) compressor distribution (compressor stations modeled), 4x per year regulatory OGI, quarterly LPR (0.0051), donut plot



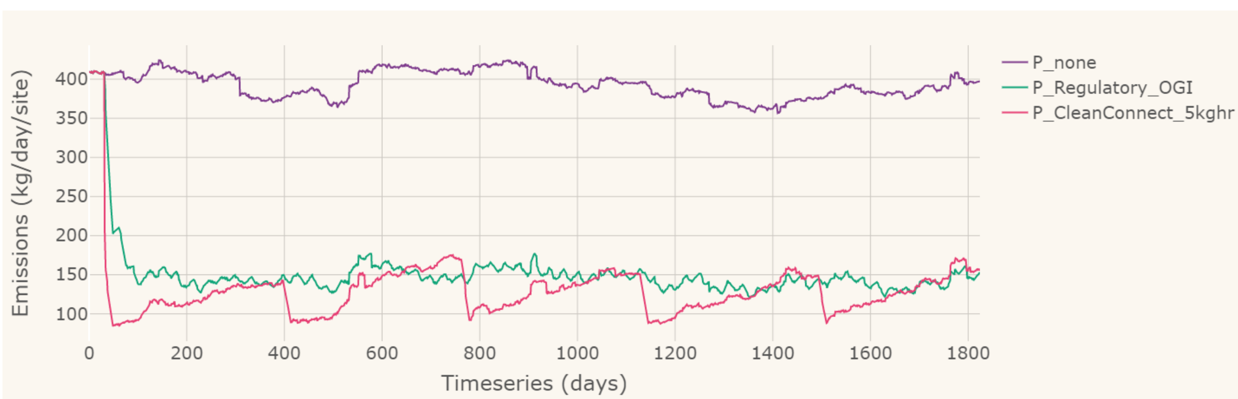
Appendix C, Figure 12: Zavala-Araiza (2015) compressor distribution (compressor stations modeled), 4x per year regulatory OGI, quarterly LPR (0.0051), time series



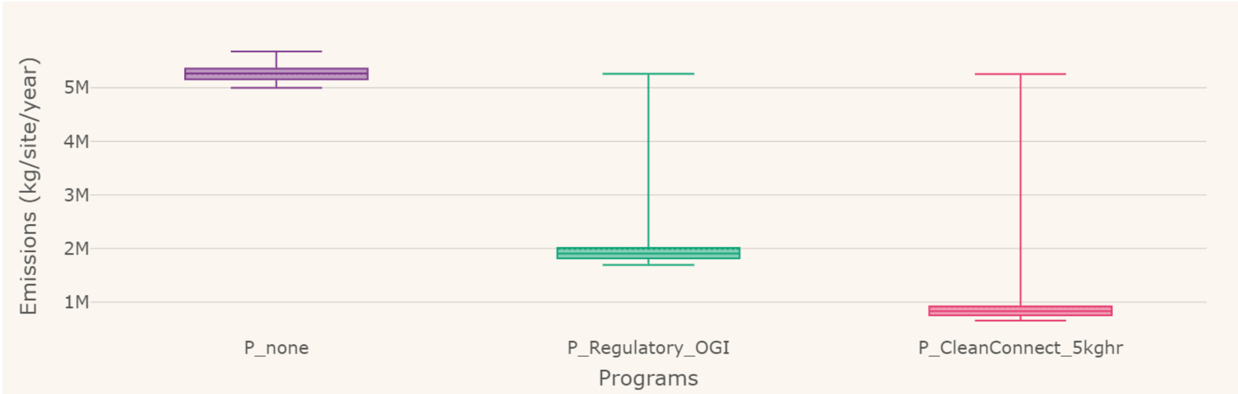
Appendix C, Figure 13: Zavala-Araiza (2015) production distribution (well production facilities modeled), 12x per year regulatory OGI, monthly LPR (0.026), box plot



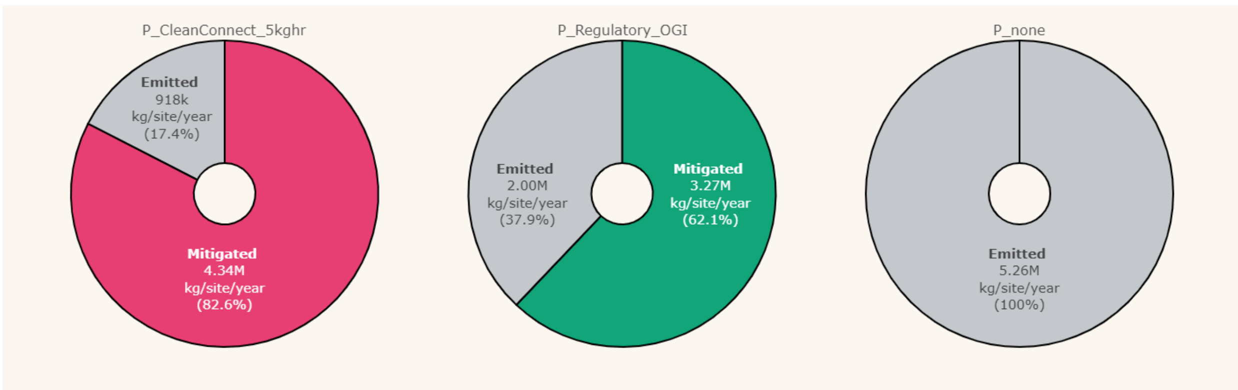
Appendix C, Figure 14: Zavala-Araiza (2015) production distribution (well production facilities modeled), 12x per year regulatory OGI, monthly LPR (0.026), donut plot



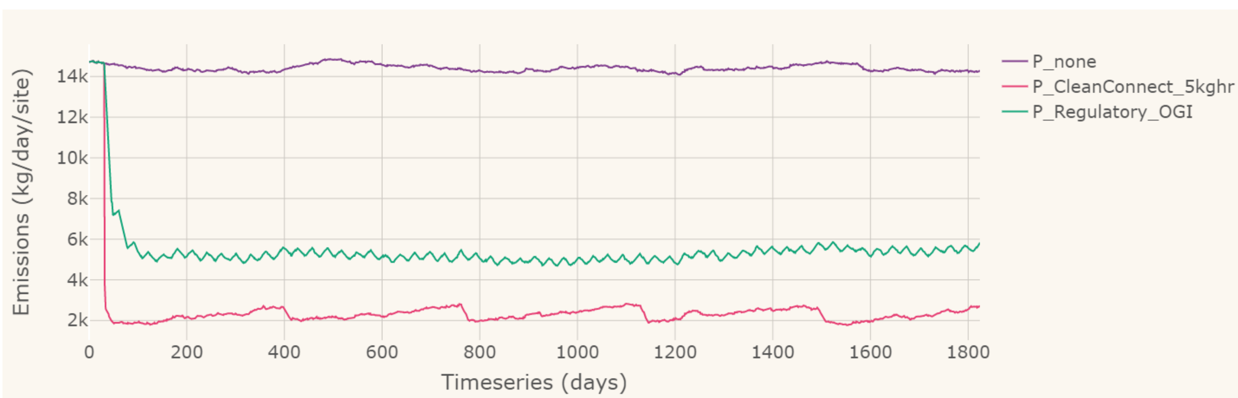
Appendix C, Figure 15: Zavala-Araiza (2015) production distribution (well production facilities modeled), 12x per year regulatory OGI, monthly LPR (0.026), time series



Appendix C, Figure 16: Zavala-Araiza (2015) compressor distribution (compressor stations modeled), 12x per year regulatory OGI, monthly LPR (0.026), box plot



Appendix C, Figure 17: Zavala-Araiza (2015) compressor distribution (compressor stations modeled), 12x per year regulatory OGI, monthly LPR (0.026), donut plot



Appendix C, Figure 18: Zavala-Araiza (2015) compressor distribution (compressor stations modeled), 12x per year regulatory OGI, monthly LPR (0.026), time series

The simulation, which assumes a LRD based on Zavala-Araiza's compressor distribution and a LPR based on monthly OGI requirements, sees the most total emissions in the system. This is to be expected as this simulation is intended to represent compressor stations which require 12x per year OGI inspections.

When considering the simulations intended to represent well production facilities, we see that the Clean Connect program consistently achieves ~66% mitigation, however, the amount of emissions which this 66% represents varies according to the LPR. This consistency in mitigation % is due to the consistent LRD while the changing amount of emissions associated with this 66% mitigation is due to the modified LPR. In other words, regardless of the number of leaks generated with sizes based on the Zavala-Araiza production distribution, the Clean Connect program will consistently be capable of detecting ~66% of them. This trend repeats with the compressor station simulations, both of which see the Clean Connect program achieve ~83% emissions mitigation. A trend is more difficult to observe when considering the regulatory OGI program as the survey frequency as well as the LPR change based on the facility tier being simulated.

A large factor in the performance of the Clean Connect program is its lack of follow-up requirements. As the Clean Connect program inherently allows for follow-up via the OGI video, the model was parameterized without the need for OGI follow-up, a realistic scenario based on anecdotal Clean Connect field deployments. Removing the need for OGI follow-ups in simulation also removes some stochasticity in which leaks could be "missed".

These simulations show the robustness of a Clean Connect program conservatively parameterized with a 5 kg/hr MDL when compared to a regulatory OGI program of varying survey frequency.

13. Glossary

A **technology** is a gas sensing instrument, optionally configured with a deployment platform and/or ancillary instruments (e.g., anemometers, positioning), that can be used to gather data on emissions.

A **work practice** describes how a technology is used to collect information about emissions. It should include operating procedures (e.g., distance from source, measurement time) and any restrictions on use (e.g., environmental envelopes, production segments, etc.)

A **method** combines a technology, a work practice, and analytics for use in an LDAR program.

An **LDAR program** is the systematic implementation of one or more methods across a collection of assets. The program describes the method, or combination of methods, to be used for each facility, along with survey frequency, repair response, and reporting standards. Ultimately, it is the LDAR program that results in emissions mitigation, not the technologies of methods in isolation.

14. References

1. Brandt, A.R., Heath, G.A. and Cooley, D. (2016). Methane Leaks from Natural Gas Systems Follow Extreme Distributions. *Environmental Science & Technology*, 50(22), pp.12512–12520.
2. Zimmerle, D., Vaughn, T., Bell, C., Bennett, K., Deshmukh, P. and Thoma, E. (2020). Detection Limits of Optical Gas Imaging for Natural Gas Leak Detection in Realistic Controlled Conditions. Environmental Science & Technology, 54(18), pp.11506–11514