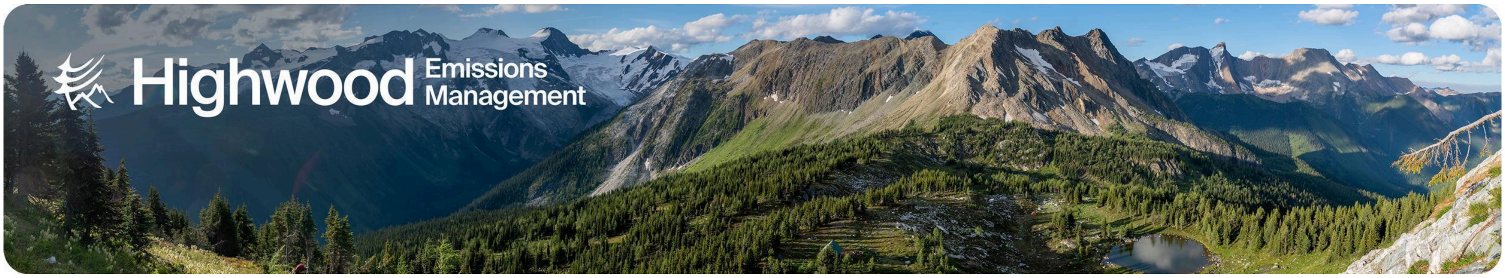


CleanConnect LeakFinder System EPA Alternative Test Method Application: Description of Technology

Focus

This document is part of the CleanConnect LeakFinder system application package for regulatory approval as a periodic screening alternative test method as per NSPS OOOO Rules Section §60.5398b(d).

CleanConnect.ai

Seeing is Believing

1. Alternative Test Method Desired Approval Details

CleanConnect is seeking approval of the CleanConnect LeakFinder system as an alternative test method with the details outlined in Table 1:

Table 1: CleanConnect LeakFinder system ATM desired approval details

Application Category	Desired Approval Detail
Company Name	CleanConnect.ai
Product Name	CleanConnect LeakFinder
Applicability	Broadly applicable
Work Practice	Periodic Screening
Measurement Type	Stationary Remote Sensor
Emission Rate Threshold	≤5 kg/hr
Spatial Resolution	Component-level

Table 1. Desired application details

2. CleanConnect LeakFinder Description

2.1. Overview of the Technology

The CleanConnect LeakFinder system is used to screen for leaks at oil and gas sites requiring leak detection and repair (LDAR). Optical gas imaging (OGI) video footage is collected using a permanently installed, autonomous OGI camera. The OGI footage is then passed through a detection algorithm consisting of a proprietary, gas leak detection model, and a-priori auxiliary models. The detection algorithm and all supporting models leverage deep learning / neural networks to “see” emissions in the autonomous OGI camera’s footage and isolate these emissions from potential false positives (crew operations, other operational procedures, vehicles, cloud cover, etc.). As the central hardware in the system is an OGI camera, the system operates on the same, well understood sensing principles as traditional and regulatorily approved handheld OGI LDAR methods. Further details on the core components of the CleanConnect LeakFinder system are:

1. **Minerva Sensor-Fusion™ Platform (Minverva platform)**: The Minverva platform is CleanConnect’s proprietary hardware which houses an Optical Gas Imaging (OGI) camera and edge computing devices (“Intelligent Edge” data center):

    a. **Optical Gas Imaging (OGI) Camera Installation**: An OGI camera mounted at an elevated position that screens the site requiring periodic screening via a panoramic “tour” through the use of a pan and tilt device. The CleanConnect Leak Finder system is OGI camera agnostic so long as the OGI camera meets the requirements defined in EPA OOOOb CFR § 60.5397b. So long as these requirements are met, the resultant OGI video footage can effectively be used by the CleanConnect detection algorithm.

b. **The "Intelligent Edge" Data Center (Edge Computer)**: An on-site computing system integrated with the OGI camera housing. An Nvidia-powered edge device designed to efficiently run deep learning computer vision models is used. It is at the edge computer that the CleanConnect detection algorithm is applied to incoming OGI video footage to "look" for methane leaks.

2. **The CleanConnect detection algorithm**: A novel, proprietary deep learning image processing model that uses videos captured by the OGI camera and support models to detect methane leaks. The detection algorithm can effectively "see" methane emissions. The algorithm is applied to OGI video footage at the intelligent edge data center.

3. **Meteorological station**: Often the site requiring monitoring will have a pre-existing meteorological station on site which is used alongside the CleanConnect LeakFinder by having the data uploaded to the edge computing devices. In the instances where no meteorological station is present, CleanConnect will get meteorological data from https://openweathermap.org/. CleanConnect sends exact GPS coordinates via API and OpenWeatherMap.org returns accurate weather data (wind, temperature, humidity, etc.).

4. **The CleanConnect cloud-based platform (dashboard)**: Where OGI footage of detection events is uploaded. Operators and CleanConnect can access OGI footage of detection events via the cloud-based platform. Figure 1 is a screenshot of the CleanConnect dashboard.

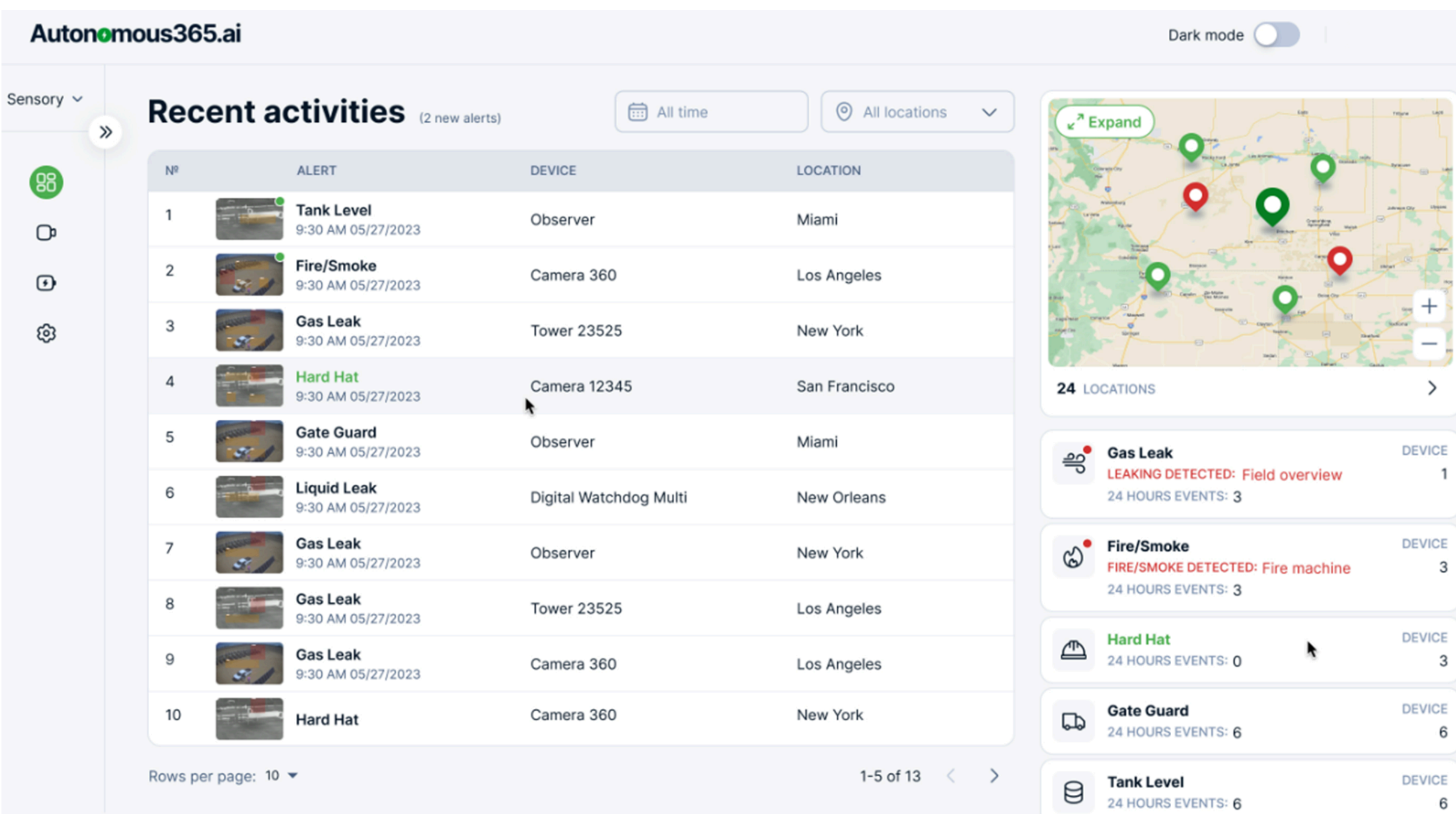


Figure 1. The CleanConnect Dashboard showing the LeakFinder view (other CleanConnect service offerings can be accessed by the dashboard)

2.2 Underlying Scientific Theory

The OGI camera component of the Minerva platform and larger CleanConnect LeakFinder system will be installed around the site requiring screening at elevated positions such that they can effectively monitor all equipment prone to leaks. The Minerva platform OGI camera installation allows for 365 degrees of visibility. The number of required cameras is dependent on the amount of equipment and the size of the site being monitored.

The OGI camera screens the site in a rotational “tour,” stopping and recording OGI video footage at predefined “tour stops.” Tour stops are decided collaboratively between CleanConnect and the operator such that all equipment requiring LDAR is sufficiently monitored. Incoming OGI video footage is sent to the intelligent edge data center (also located within the Minerva platform). There, the OGI video footage is passed through the CleanConnect detection algorithm in real-time.

The CleanConnect detection algorithm is a proprietary “computer vision” algorithm, meaning the algorithm has been trained to “see” certain characteristics of incoming OGI 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 change from one frame to the next. CleanConnect has trained the model with more than 1,000,000 hours of OGI video, ensuring that the algorithm has “learned” which patterns of pixel behavior are indicative of methane emissions. However, in its current form, the detection algorithm will identify targeted emissions, and the operator, through their expertise of the site and knowledge of scheduled or allowed emissions, will classify all flagged emissions as either a leak or allowable process emission.

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

As the primary data product collected by the CleanConnect LeakFinder system is OGI video footage, the system operates on the same sensing principle as traditional, regulatorily approved, handheld OGI surveys. Briefly, OGI cameras are infrared (thermal) cameras which can visualize methane and various other organic gasses which are inherently invisible to the human eye. The CleanConnect LeakFinder system leverages the same OGI footage a traditional OGI operator would, but instead of a human operator interpreting the footage, the CleanConnect LeakFinder system employs an autonomous detection algorithm.

From the intelligent edge data center, all OGI video and metadata are uploaded to the CleanConnect cloud-based platform. It is through this platform that CleanConnect will store and distribute OGI video and metadata to the operator via a dashboard. If a detectable emission is present, CleanConnect Leak Finder can detect it, log relevant data, and notify the Operator in less than 5 minutes. Figure 2 is a high-level overview of the CleanConnect LeakFinder system (note, for this application, “Additional sensors” in Figure 2 refers to weather stations).

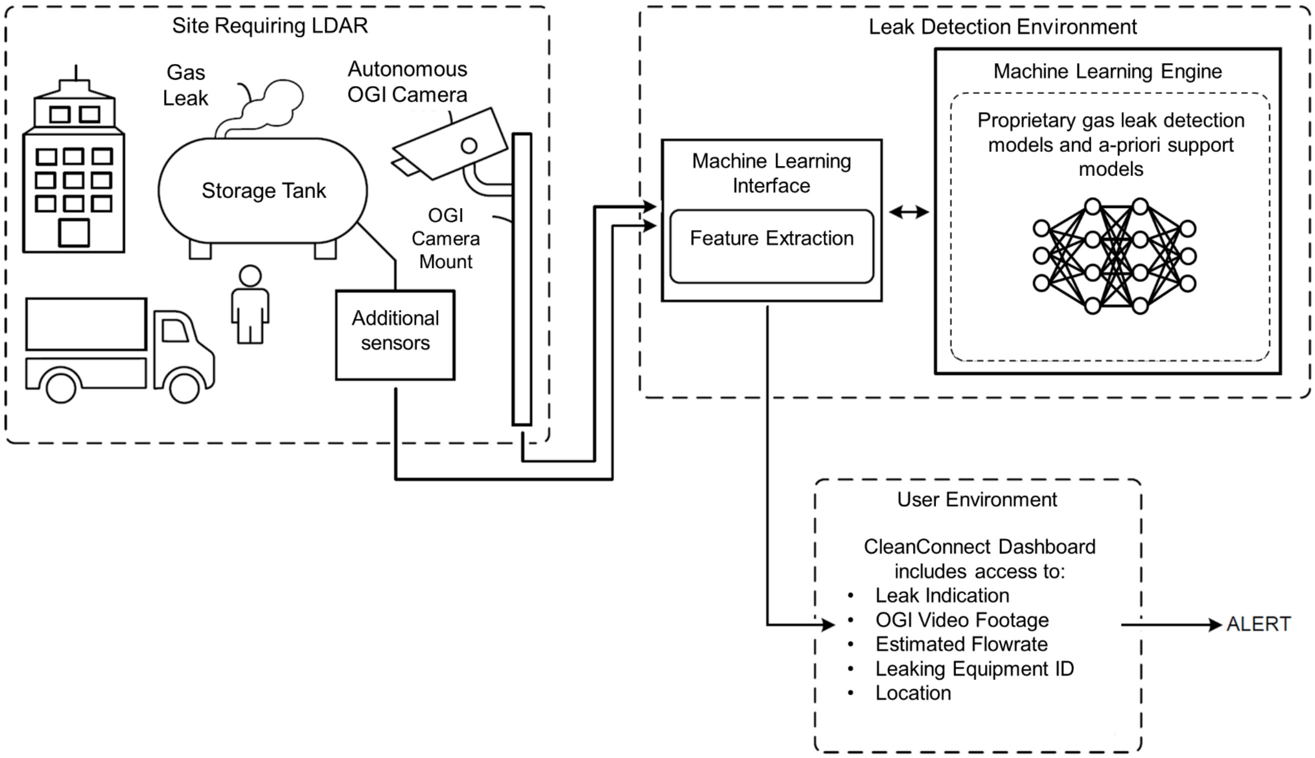


Figure 2. CleanConnect LeakFinder System overview[1]

2.3 Description of Physical Instrumentation

The physical instrumentation of the CleanConnect LeakFinder system is all contained within the Minerva platform. Figure 3 depicts the subcomponents of the Minverva platform from an external view, and Figure 4 provides an internal view of the Minverva platform.

[1] 2023-04-20 334.0001 Patent Application (*CleanConnect patent application, Supporting Information 02*)

Figure 3. External view of the Minerva Platform, the primary physical component of the CleanConnect LeakFinder system.

A description of the subcomponents of the Minerva platform follows:

A. **OGI camera and IP67 Enclosure:** The CleanConnect LeakFinder system is agnostic as long as the camera meets the requirements in 40 CFR part 60 §60.5397b. Specifically, the camera must be capable of imaging a gas that is half methane, half propane at a concentration of 10,000 ppm at a flow rate of ≤60 g/hr from a quarter inch diameter orifice. CleanConnect has, and will continue to, ensure deployed OGI cameras meet this requirement. The IP67 Enclosure is a weatherproof enclosure which ensures operation in adverse meteorological conditions.

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 degrees and the tilt is capable of 180 degrees of vertical movement.

C. **Mounting Bracket:** 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 (often, the site's communication tower can be used), however, in the absence of an adequate structure, additional equipment (i.e., mast) may be required

D. **Optical Cameras:** CleanConnect has a suite of autonomous monitoring offerings in addition to LeakFinder, which fall outside the scope of this application. The optical and IR cameras are used in these other offerings.

E. **Edge Device Enclosure:** The on-site computing system which is where the detection algorithm is applied to incoming OGI video footage. An Nvidia-powered edge device designed to efficiently run deep learning computer vision models is used. It is at the edge computer that the CleanConnect detection algorithm is applied to incoming OGI video footage to “look” for methane leaks. In early deployments, the edge computer(s) were installed at ground level, however, current and future deployments contain hardware which sees the edge computer(s) installed in a single device which also contains the OGI camera. Figure 4 provides an internal view of the Minerva platform, showing the location of the edge computing devices.

Figure 4. Internal view of the Minerva Platform showing the location of up to 4 edge computing devices

2.4 Best Practices

2.4.1 Training, certification and user competence

Operator training for use of the CleanConnect LeakFinder device to complete periodic screening inspections is completed in a few hours. CleanConnect will provide Operators with a document describing the work practice (Section 5) so that an Operator is aware of what entails a detection event.

2.4.2 Calibration and Maintenance

The OGI camera will be swapped out every 8,000 hours. When the camera is swapped out, CleanConnect will perform a maintenance check of all other components listed in Section 2.3. The IP67 rated weather-proof enclosure provides effective protection against potential accelerated lens degradation (faster than the 8,000 hour swap-out window).

All Minerva platform subcomponents are monitored autonomously by the intelligent edge data center. The data center, via the detection algorithm, monitors:

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

CleanConnect 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, CleanConnect will attempt to remedy the situation remotely but will make site visits to carry out calibration/maintenance if required.

2.4.3 Known Limitations

- Visual obstructions: The CleanConnect LeakFinder system requires a direct line of sight to methane emissions in order to “see” it and flag it as a potential event and, ultimately, a detection event. A number of obstructions can exist including crew members, vehicles on site, existing site infrastructure, or other emissions sources (for example, an allowable emissions source may obscure the plume of a leak). These obstructions are minimized through strategic placement of the CleanConnect Minerva Platform, including the installation of multiple Minerva Platforms if necessary.

- False positives: Movement not related to methane plumes, cloud cover, sunlight reflections, etc., in the OGI video footage can be originally misinterpreted as emissions by the CleanConnect LeakFinder detection algorithm. The CleanConnect LeakFinder detection algorithm has been extensively trained to filter out these potential false positives. However, in the rare case that a false positive is assigned a detection event, the operator can flag it as such via the CleanConnect dashboard or their internal tracking software, depending on their reporting work practice.

3. Complete Visual Workflow

Figure 5 is a visual workflow of the complete CleanConnect LeakFinder System process.

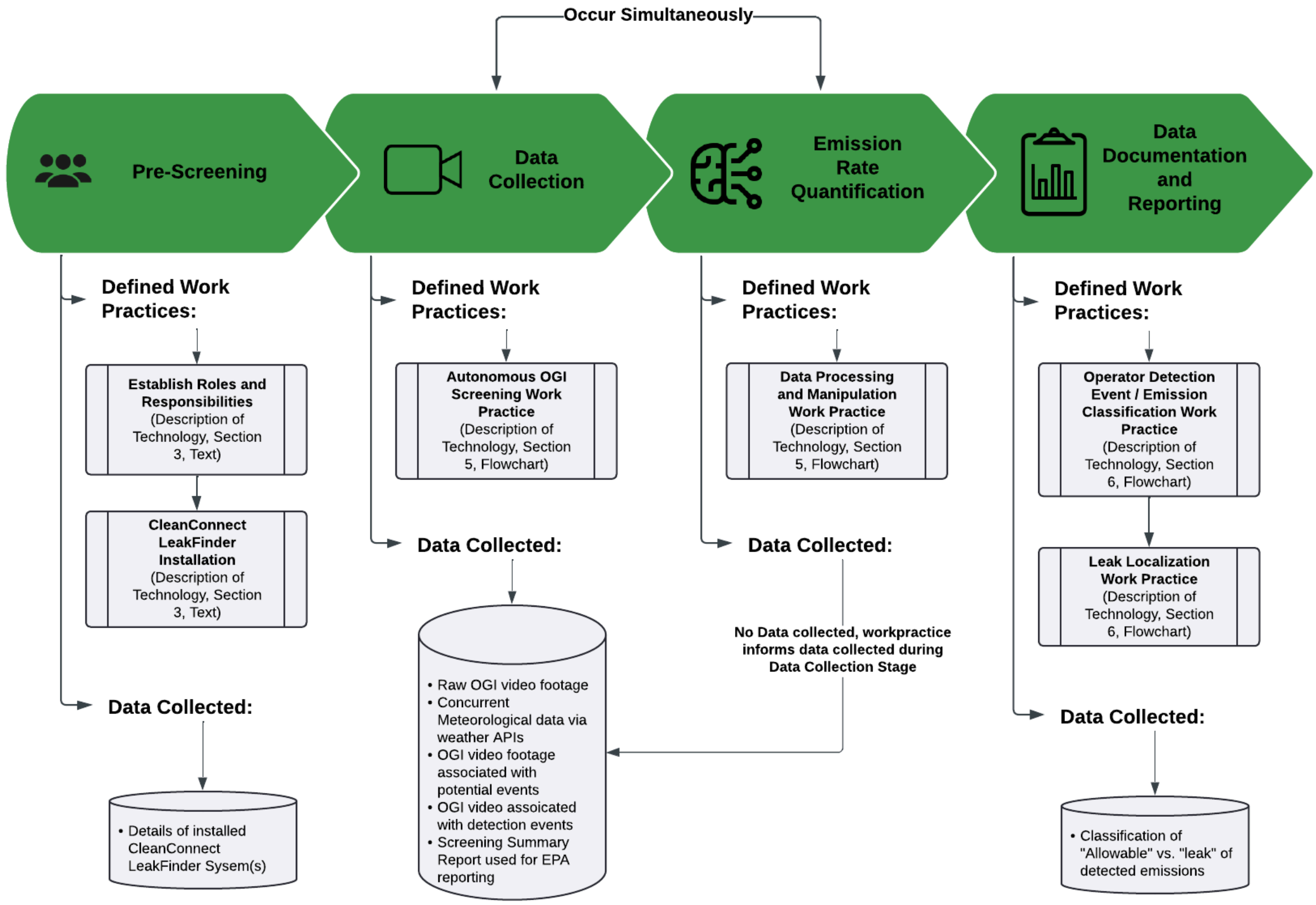


Figure 5. Visual workflow of the complete CleanConnect LeakFinder system process. References to other work practices are detailed in the following sections.

4. Pre-Screening Work Practice

This section will detail the required work practice prior to commencing the proposed periodic screening.

4.1 Roles and Responsibilities

Prior to installation of the physical components of the CleanConnect LeakFinder System (Minerva platform, mounting pole if required) and commencement of periodic screening, roles and responsibilities are established. Parties with responsibilities in the proposed CleanConnet LeakFinder alternative test method are CleanConnect and the owner/operator of the site at which the CleanConnect LeakFinder system is installed (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:

CleanConnect:

- Work collaboratively with the operator to identify the ideal number and location of CleanConnect Minerva Platform installations as well as the number and location of tour stops (the operator has the ability to name tour stops for tracking purposes once they have been established) on a per-site basis. Collaboration is necessary as the logistics of site monitoring (number of Minerva Platforms, Minerva Platform locations, number of tour stops, etc.) are highly variable across different sites, and operator expertise on their site is required. Although a collaborative process, the responsibility of ensuring all equipment and components that require monitoring are adequately monitored with the CleanConnect Leak Finder system ultimately falls to the operator.
- Ensure the CleanConnect LeakFinder systems autonomously begin the 24 hour periodic screening window at the cadence required by the site being monitored.
- Continuously monitor incoming data for quality assurance and quality control during the periodic screening window.
- 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.
- Perform an inspection of system components during camera swap-outs to guarantee functionality.
- Notify the operator when an emission is detected (detection event) during the periodic screening window via cellular and/or SCADA networks and the CleanConnect dashboard.
- Ensure all the intelligent edge data center(s) have access to the cloud for proper algorithm function and record keeping.
- Maintain a database of all installed camera systems, the facilities where they are installed, and their specific installation locations.

Operator:

- Work collaboratively with CleanConnect to ensure the CleanConnect LeakFinder system installation contains a sufficient number of Minerva platforms and tour stops.
- Facilitate CleanConnect site visits to install and maintain the LeakFinder system.
- Ensure CleanConnect data can be uploaded to the cloud-based platform.
- Perform preventative maintenance to minimize leaks.
- Classify detection events as either leaks or allowed process emissions once the CleanConnect LeakFinder system has been installed.

4.2 CleanConnect LeakFinder Installation

The CleanConnect Minerva platform(s) is installed at an elevated position(s) around the site to be periodically screened. The setup process varies from site-to-site and is highly collaborative between CleanConnect and the operator. It is crucial that the CleanConnect Minerva platform is installed at an elevated position. Being able to “look down” on the equipment requiring screening from an elevated vantage point allows the system to have optimal line-of-sight on equipment regardless of wind direction (in some rare cases, due to obstructions, wind must be from a certain direction for the emission to be visible, however, the 24 hour periodic screening in combination with typical methane emissions plume dispersion provides sufficient time for favorable wind direction). Typically, CleanConnect will install a tower, the top of which is affixed with the Minerva platform, however, existing elevated site infrastructure can be used if possible. The number of required Minerva Platforms is dependent on the layout of equipment (potential line of sight obstructions) and the size of the facility being monitored. To date, all upstream oil and gas facilities in Colorado have been sufficiently monitored with a single Minerva Platform / OGI camera.

A key tool when installing the Minerva Platform is the use of CleanConnect DigitalTwin software. DigitalTwin creates a 3D representation of the site which is to be screened by the CleanConnect LeakFinder system. Using digital twin, CleanConnect can model lines of sight of the OGI camera and choose optimal installation locations. Figure 6 is a screenshot of the DigitalTwin software.

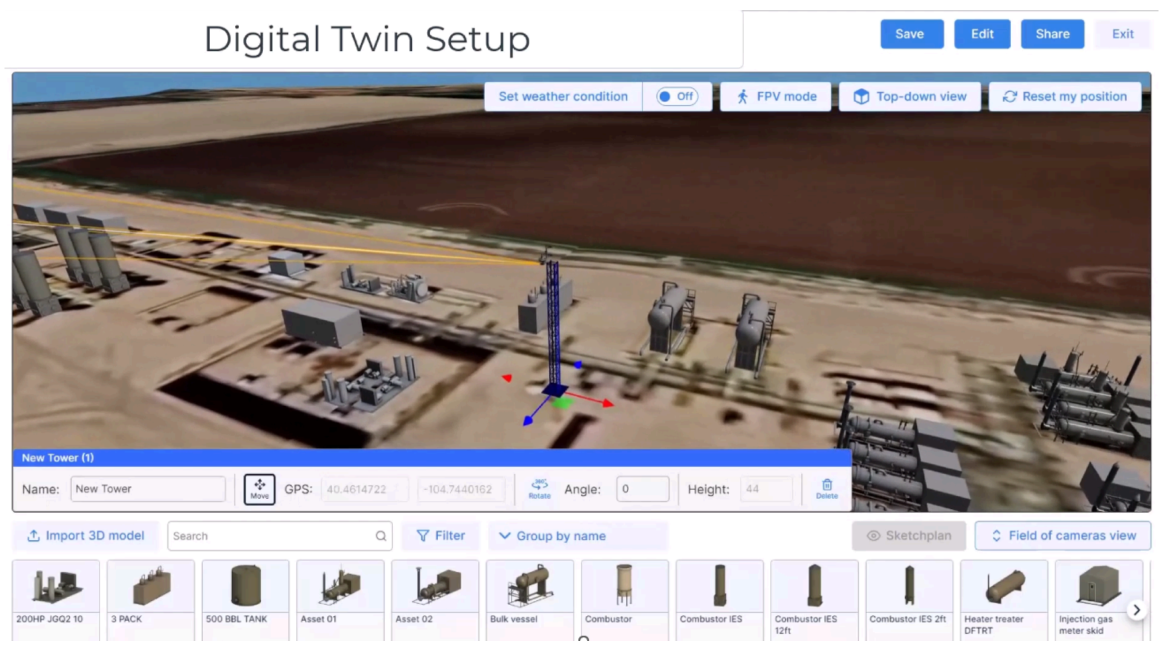


Figure 6. The CleanConnect Digtial Twin software. The DigitalTwin software creates a to-scale 3D representation of the site requiring screening so CleanConnect can explore optimal placement of the OGI camera tower(s). Here, we see a possible OGI camera tower placement, and the associated lines of sight (orange lines).

The following is considered prior to CleanConnect LeakFinder system installation:

- **Site type**: The CleanConnect LeakFinder system can be used for periodic screening for leaks from fugitive components, covers and closed vent systems under 40 CFR part 60 subparts OOOOa, OOOOb and OOOOc. The system can be used at both open and closed sites, however, at closed sites (such as those with sound barriers present), obstructed lines of sight could lead to necessary installation of additional CleanConnect Minerva platforms.
- **Number of devices and coverage**: Field deployment experience has shown that most sites are effectively monitored with 1 elevated Minerva platform. The larger the site and the more equipment requiring monitoring, the more likely additional platforms will be required. The number of stops for a given camera's tour will also be influenced by the area requiring monitoring. The Minerva platform will be mounted 20-30 feet above ground level to ensure that

the OGI camera 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**: As they are housed in the same platform, the OGI camera and the intelligent edge data center are in constant communication 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 a wired connection, however, ultimately it is the responsibility of the operator to ensure the CleanConnect data can be uploaded, 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 the 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 OGI camera component of the Minerva platform, even in high winds which would lead to accelerated plume dispersion, the LeakFinder system is often able to pinpoint the source of the emission. If extreme wind speeds prevent detection, CleanConnect 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 CleanConnect detection algorithm. Finally, a periodic screening window of 24 hours was chosen to ensure favorable wind is present during screening.
- **Cloud coverage / sunlight**: The CleanConnect LeakFinder 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.

5. Data Collection (Periodic Screening Work Practice)

CleanConnect LeakFinder periodic screening takes place during what is from here on referred to as “the periodic screening window”. The periodic screening window is a 24 hour window where the CleanConnect LeakFinder system continuously and autonomously screens all equipment requiring monitoring at a site for leaks. 24 hours was chosen as it is an ample window of time for environmental conditions, like wind and temperature, to be favorable when screening for emissions.

The 24 hour screening window begins on the 1st day of the periodic screening interval defined by the site type and the CleanConnect LeakFinder’s 5 kg/hr 90% PoD (Section 8). The annual occurrences of the periodic screening windows for the site types in scope of the CleanConnect LeakFinder alternative test method are:

- Single Wellhead Only: At the start of each quarter.
- Multi Wellhead Only Sites: At the start of each quarter.
- Small Well Sites: At the start of each quarter.
- Compressor Stations: At the start of each month.
- Major Well Sites or Centralized Production Facilities: At the start of each month.

Figure 7 is a flowchart showing the CleanConnect LeakFinder autonomous OGI screening work practice during the 24 hour screening window. Note that the work practice is designed such that a Screening Summary Report is provided to the operator upon completion of the screening window (defined in Figure 7), however, all CleanConnect LeakFinder data and OGI video feed can be monitored live during the periodic screening window via the CleanConnect operator dashboard if the operator desires.

Definitions:

Tour: When the CleanConnect LeakFinder OGI Camera has rotated the entire 360° in it's observational path and completed all planned observations, it has completed a tour.

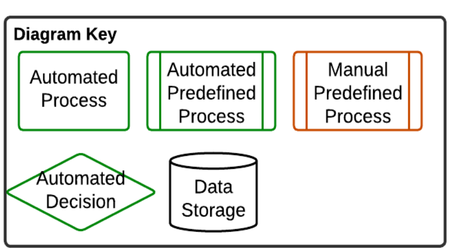
Tour Stop: Each tour is composed of a certain number of tour stops. A tour stop is the process of the CleanConnect LeakFinder OGI Camera observing a predefined field of view for a set duration of time (a minimum of 2 minutes).

Potential Event: Any visual emission event the CleanConnect LeakFinder system has identified and has persisted for more than 20 seconds (no longer than 20 seconds elapse between detection during a given tour stop).

Threshold: The threshold is surpassed when a potential event has been persistently observed for 4 hours with no more than 1 break in observation (if the CleanConnect LeakFinder system passes through two consecutive tours without "seeing" a potential detection, it is no longer a potential event).

Detection Event: A potential event that surpasses the threshold (referred to as a "confirmed detection" in 40 CFR 60.5398b). Once a potential event is elevated to a detection event the operator and CleanConnect are alerted via email to it's presence. In addition, after the 24 hour screening window, the operator and CleanConnect receive a summarized report of all detection events encountered which can be used for EPA reporting requirements. Detection Events are also logged and accessible through the CleanConnect LeakFinder dashboard.

Screening Summary Report: A report automatically provided to CleanConnect and the operator. The report will contain all data necessary for the operator to fulfill the reporting requirements of 40 CFR 60.5424b. Including: Date of screening, results (Detection events, emitting equipment group, etc.), and method and technology used. Fields will be present in the report which can be easily filled in upon completing the Emissions Classification Work Practice (See *Operator Detection Event / Emission Classification Work Practice* flowchart) including the classification of emissions associated with detection events, and details of Follow-up OGI information. Alternatively, operators can use the screening summary report in combination with internal tracking systems to meet 40 CFR 60.5424b reporting requirements.



Clean Connect LeakFinder Periodic Screening: Autonomous OGI Screening Work Practice

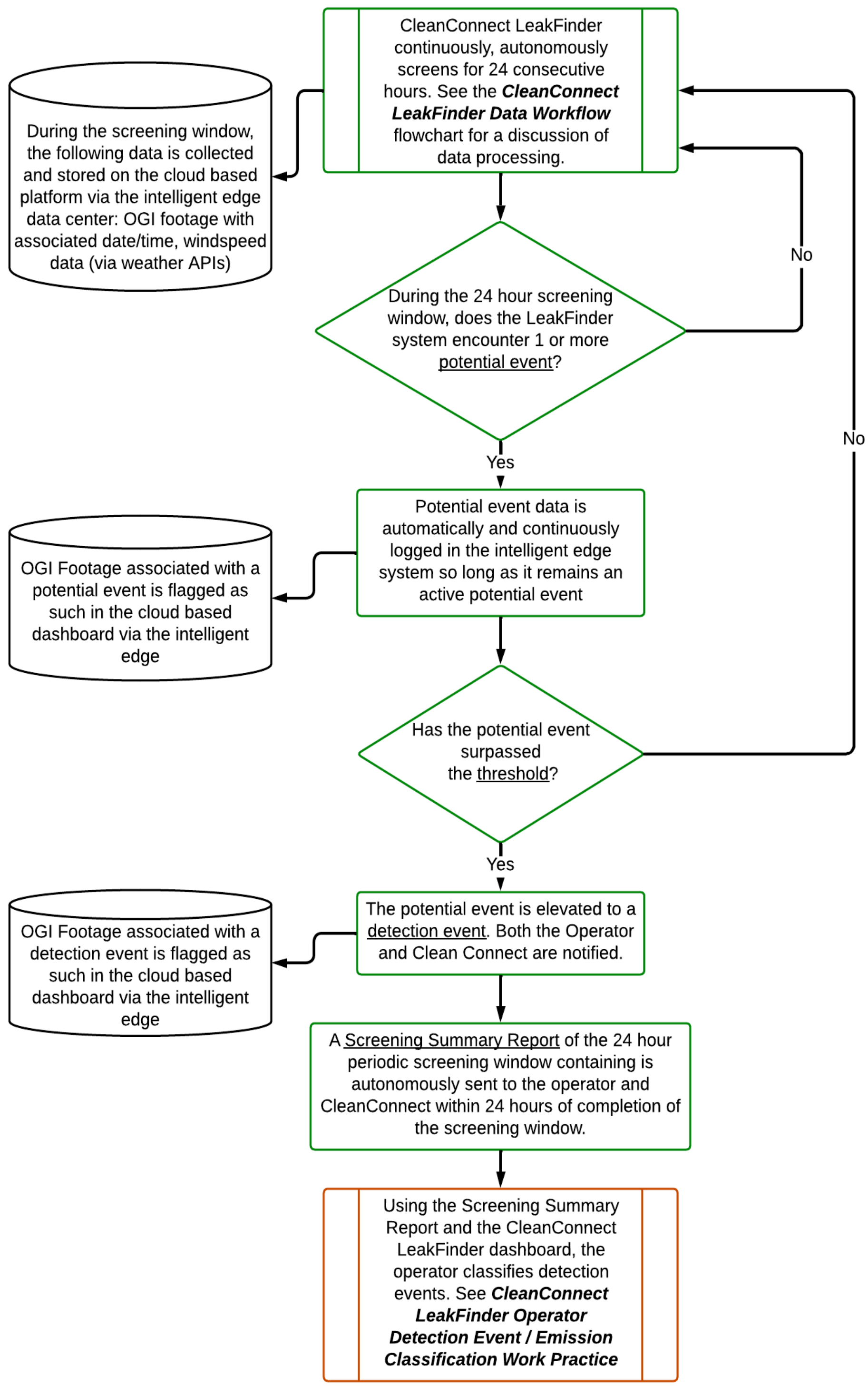


Figure 7. The CleanConnect LeakFinder Periodic Screening Autonomous OGI Screening work practice.

6. Data Processing and Manipulation (Detection and Quantification Algorithms)

The following section is a detailed description of the data processing and manipulation necessary to allow the CleanConnect LeakFinder system to detect emissions and calculate mass emissions rate using OGI video footage. This section first presents a visual workflow of the CleanConnect LeakFinder detection algorithm (Section 6.1), and provides further background on CleanConnect's proprietary gas leak detection model (Section 6.2).

6.1 CleanConnect LeakFinder Detection and Quantification Algorithms: Visual Workflow

This Section presents a visual data workflow (Figure 8) and associated description of the processes involved in the conversion from input data by the CleanConnect LeakFinder system to calculated mass emission rate. The content presented here are slightly edited versions of the CleanConnect patent, which is attached in full as supporting information[2]. These edits focus on ensuring consistent terminology with the rest of this document, and streamlining the visual and text-based components of the patent.

[2] 2023-04-20 334.0001 Patent Application (*CleanConnect patent application, Supporting Information 02*)

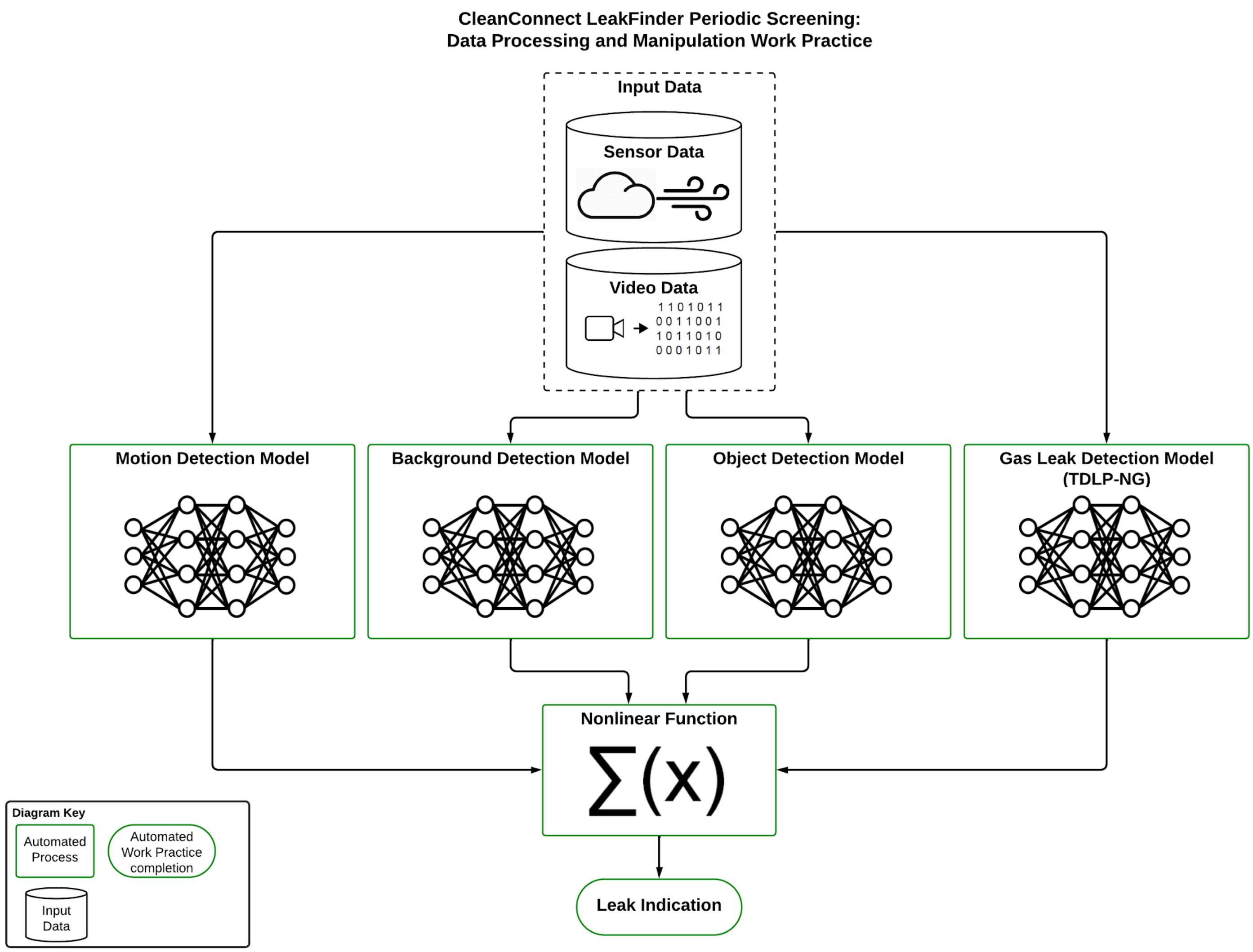


Figure 8. The CleanConnect LeakFinder system data workflow.

Further details of the data streams and processes shown in Figure 8 follow:

- **Input Data - Sensor Data**: Sensor data includes environmental telemetry data like temperature, pressure, wind speed, wind direction, clouds, visibility, humidity, dew point, and the like. The environmental telemetry metrics improve machine learning model performance and help the machine learning model better understand the condition of environments during gas leaks. Sensor data is collected from telemetry devices already present on oil and gas sites.

- **Input Data - Video Data**: The video data is a numerical representation of infrared or optical video data that depicts a natural gas extraction and/or storage environment. The intelligent edge computer vectorizes the infrared or optical video data to generate feature vectors. For example, the computing device may numerically represent the pixels in the image frames that comprise the infrared video data and form the feature vectors using the numeric representations.

- **Motion Detection Model**: A machine learning model trained to ingest video data inputs and identify motion in the infrared or optical video data. The motion detection model determines regions of the infrared or optical video data that depict motion, including motion representing a gas leak in the infrared or optical video data. For example, the motion detection model may compare corresponding pixels in sequential video frames of the infrared or optical video data to identify changes between the corresponding pixels (e.g., changes in color). The motion detection model may then classify the identified changes in the pixels as motion depicted in the infrared or optical video data. The motion detection model is an a-priori model in that its underlying functionality was not written by CleanConnect, however it has been applied to the holistic leak detection process.

- **Background Detection Model**: A machine learning model trained to ingest video input data and identify the background environment in the infrared or optical video data allowing other features depicted in the infrared or optical video data to potentially be classified as background environment. Examples of background environments include the sky, the ground, plant and animal life, equipment not associated with gas extraction (e.g., an automobile), buildings, and the like. The background detection model determines regions of the infrared or optical video data that depict the background environment. For example, the background detection model may compare corresponding pixels in sequential video frames of the infrared or optical video data to identify regions of the infrared or optical video data that are relatively unchanging to identify the background environment. The background detection model may perform long-term and short-term background detection. Long-term background detection may comprise a background detection process using 500 frames of infrared or optical video data. The short-term background detection may comprise a background detection process using 30 frames of infrared or optical video data. The background detection model may combine short and long-term background detection analysis to fully identify the background environment depicted in the infrared or optical video data. The background detection model is an a-priori model in that its underlying functionality was not written by CleanConnect, however it has been applied to the holistic leak detection process.

- **Object Detection Model**: A machine learning model trained to ingest input data and segment the image in the infrared or optical video data to identify and classify natural gas storage, extraction, and or transfer equipment.The object detection model ingests the feature vectors that represent the infrared or optical video data and segments parts of the frames that correspond to a known object in the field of view of the camera. Using object detection helps reduce gas leak detection false positives and relates each leak with some probability to an actual device in the field. Understanding which device is causing the leak helps to better manage and focus on design and deployment of different devices. The object detection model generates an output that indicates regions of the infrared or optical video data that comprise natural gas extraction, storage, and transfer equipment. The object detection model is an a-priori model in that its underlying functionality was not written by CleanConnect, however it has been applied to the holistic leak detection process.

- **Gas Leak Detection Model (TDLP-NG)**: A machine learning model trained to ingest feature input data and identify gas leaks in the infrared or optical video data. The gas leak detection model ingests the feature vectors that represent the OGI video data and identifies the movement in the video data that is corresponding to a leak. The gas leak detection model detects a segment of an image in a series of images as a leak based on the similarity of movement to a gas. The gas leak detection model may calculate the flowrate of the gas leak based on distance of the camera to the leak, speed of leak movement in the video, pixel resolution of the video, and environmental conditions like wind speed and direction. The gas leak detection model is the focal point of methane emission identification and is a proprietary model written by CleanConnect. It is defined in further detail in Section 6.2.

- **Nonlinear Function**: At a high-level, the nonlinear function is the step where the individual models (motion, object, background, and gas leak detection) interact through a process referred to as model fusion. For example, the gas leak detection model may originally classify video footage of an operator as an emission, but during model fusion as the models interact, the object detection model would then remove this incorrect classification of an emission, thus avoiding a false positive.

  In greater detail, the nonlinear function operates through a series of "subtractions". The nonlinear function subtracts the portions of the infrared or optical video data identified as background environment from the portions of the infrared or optical video data identified as depicting motion to identify all regions of the video data that depict motion that is not part of the background environment. For example, this may subtract portions of the video data that depict the motion of clouds. Background detection model outputs may be subtracted from motion detection model outputs.The nonlinear function then subtracts regions of the infrared or optical video depicting equipment from the remainder resulting from the background subtraction to identify all regions of the video data that depict both motion and natural gas equipment. The nonlinear function then compares the remainder of the image resulting from the equipment subtraction and the background subtraction to the region of the video data identified by the gas leak detection model as a possible gas leak. When the remainder of the video data resulting from the subtractions overlaps with the region of the video data identified by the gas leak detection model as a possible gas leak, the nonlinear function confirms the presence of a gas leak.Generally, motion depicted by the infrared or optical video data that is not part of the background environment, that is co-located with a piece of natural gas equipment, and that has been identified as a possible gas leak by the gas leak detection model may be classified as a gas leak. By performing multiple image subtractions, the nonlinear function inhibits false-positives of the gas leak detection model. The nonlinear function outputs an indication as to whether a gas leak has been detected in the infrared or optical video data. The indication may comprise a probability/confidence metric regarding the existence of the gas leak. If there is an 85% probability associated with the potential emission, it is deemed an emission. The indication may comprise a gas flow rate estimate for the detected gas leak and equipment identification numbers to indicate the location of the gas leak.

6.2 CleanConnect LeakFinder Detection and Quantification Algorithms: Gas Leak Detection Model Additional Details

The gas leak detection model described in Section 6.1, while supported by auxiliary models, is the focal point of the CleanConnect LeakFinder detection algorithm and was developed internally by CleanConnect. This section presents background on the underlying principles of deep learning, and neural networks, which are employed by the gas leak detection model. This Section references, and expands upon, Temporal Deep Learning Image Processing Model[3] attached as supporting information in full.

6.2.1 Automated OGI Interpretation via Deep Learning: Background

Traditional methods for processing OGI data rely heavily on manual interpretation, and therefore operator expertise and time. This has led to a significant interest in automated systems that enhance the efficacy and accuracy of the leak detection process (Kemp et al., 2016[4]). Deep learning, a subset of machine learning that utilizes neural networks with multiple layers, has shown promise in complex image recognition tasks and is being increasingly applied for environmental monitoring applications (Cusworth et al., 2021[5]).

As the concepts surrounding deep learning are central to the operation of the gas detection model and the CleanConnect LeakFinder system, this Section aims to provide a primer on necessary terminology.

Neural Networks

Neural Networks are a type of machine learning model that leverage a decision-making architecture modeled after the human brain to rapidly classify and cluster data. Part of what makes neural networks so powerful in the field of machine learning is their capacity for extensive fine-tuning for a specific use case via training data to help improve their accuracy. Neural Networks are classification models, like logistic regression which is often used when understanding methane detection technologies probability of detection, albeit more sophisticated. Neural Networks can capture incredibly complex relationships at the cost of being significantly more difficult to architect and train, as well as requiring more computing power.

Neural Networks are primarily built from a construct called neurons. These neurons can be thought of as a single, complex mathematical calculation. Many neurons are connected to other neurons in sequence or parallel to form the structure of a neural network. Figure 9 shows a simplistic neural network.

[3] Mehdi Korjani, M., Conley, D., Smith, M., (2024) Temporal Deep Learning Image Processing Model for Natural Gas Leak Detection Using OGI Camera *(Temporal Deep Learning Image Processing Model for Natural Gas Leak Detection Using OGI Camera, Supporting Information 03)*

[4] Kemp, C. E., Ravikumar ,A. P., Brandt, A. R., (2016) Comparing natural gas leakage detection technologies using an open-source virtual gas field simulator, Environmental Science & Technology 50 (8) 4546–4553.

[5] Cusworth, D.H., Duren, R.M., Thorpe, A.K., Olson-Duvall, W., Heckler, J., Chapman, J.W., Eastwood, M.L., Helmlinger, M.C., Green, R.O., Asner, G.P. and Dennison, P.E., 2021. Intermittency of large methane emitters in the Permian Basin. Environmental Science & Technology Letters, 8(7), pp.567-573.

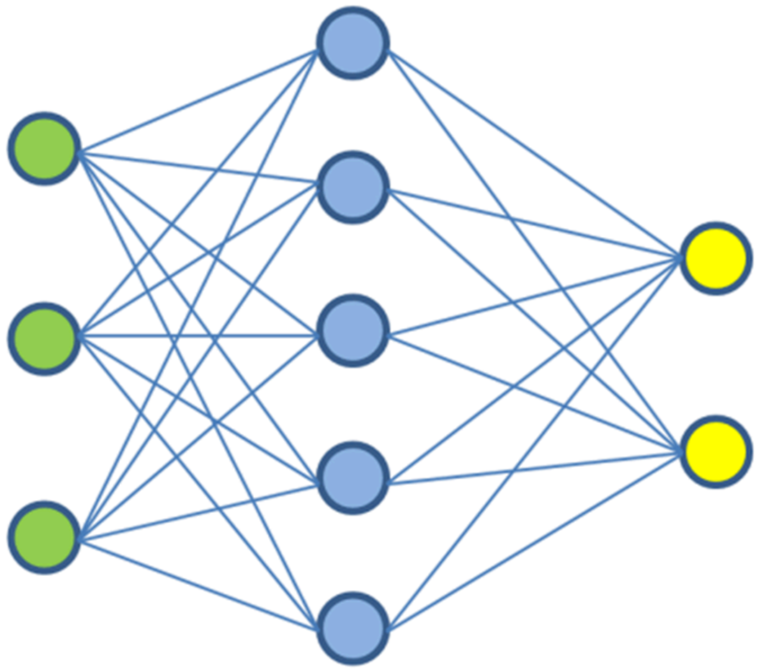


Figure 9. Sample Simplistic Neural Network Architecture[6].

Neurons are grouped into "layers" (See Figure 9, where neurons are grouped into layers by color). Neurons in each layer take the output from the neurons in the previous layer, perform a complex mathematical calculation on it and output it to neurons in the following layer. This output to input connection between neurons is called an edge. Edges in neural networks are given weights, which can be thought of as tuning knobs, that increase or decrease the impact of that relationship between neurons. The weights of edges are what is changed during the training of a neural network.

In general terms, neural networks train through a process resembling guided trial and error where they produce predicted results and compare them to the "true" or desired result, repeating this process while trying to get the predicted results as close as possible to the desired results by adjusting edge weights. The main requirements for this process are computing power and a sizable supply of training data.

Training

Training is critical to the performance of neural networks. Typically, neural networks are trained via supervised learning, a process where a machine learning model will be trained with manually labeled training data, to help teach it to identify patterns in the relevant types of data. Labeled training data consists of a set of sample inputs correctly labeled with desired outputs that the model should produce. An example of training data could be image files of dogs and cats correctly labeled as "dog" or "cat", or image files of potentially emitting oil and gas equipment correctly labeled as "emission" or "no_emission". To train itself, a neural network will take in the training "inputs" and propagate it through its neurons to ultimately predict outputs. These predicted outputs are then compared to the correct outputs (again, recorded in the labels of the training data) through a mathematical relationship called a loss function. Generally, the greater the average loss, the worse the performance of the neural network.

[6] Danilov, Mikhail & Karpov, Arkadi. (2018). A classification of meteor radio echoes based on artificial neural networks. Open Astronomy. 27. 318-325. 10.1515/astro-2018-0037

The neural network will then proceed to adjust the weights of each edge in order minimize the average loss, at which point it is considered trained.

With modern neural networks, this process can be incredibly complex. Vast amounts of unique training data is often required to enable the neural network to reach a point where it has determined the definite “best” edge weights. Performance can also be improved during or after training through architectural adjustments to the neural network such as changing the number of neurons and/or layers present in the neural network.

Convolutional Neural Networks (CNNs)

Convolutional Neural Networks (CNNs) are a special variant of neural networks optimized for performance in processing inputs like images (the typical CNN use case), speech, or audio signals. CNNs will take an input such as an image or speech and classify it, categorizing the input in some way. For example, in the case of an image this can take the form of identifying what is shown in the image, such as identifying that an image is showing a dog, a building, a tree, etc.

At a high level, CNNs function by breaking down their input into numerical values, so that mathematical patterns can be identified and interpreted. During image processing, CNNs break images down into numerical values by leveraging how computers represent images: a basic color image on a computer can be represented by a three-dimensional matrix of values which define pixel position and color (Figure 10).

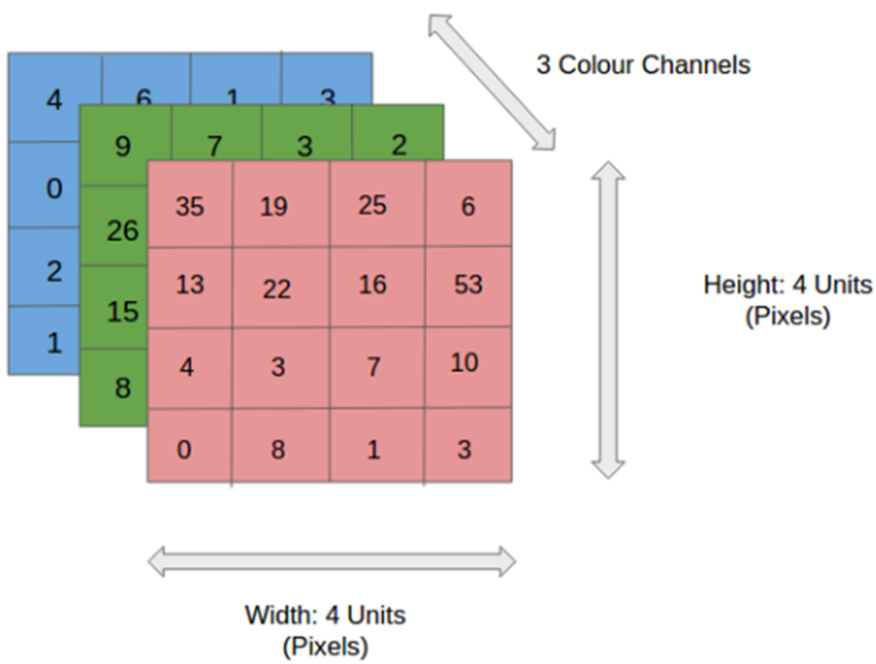


Figure 10. Example Red Green Blue (RBG) input image for a CNN. “A Comprehensive Guide to Convolutional Neural Networks — the ELI5 Way | by Sumit Saha | Towards Data Science.”

By "seeing" images as a matrix of pixel values, CNNs can break down the overall image into smaller pieces through a mathematical process called convolution before looking for patterns to simplify the task.

One of the key advantages CNNs provide over other image classification algorithms is that they require significantly less preprocessing and are overall more flexible in the range of images they can process.

Recurrent Neural Networks (RNNs) and Long Short-Term Memory units (LSTMs)

Recurrent Neural Networks (RNNs) are a type of neural network that differs from “typical” neural networks by using information from previous inputs to the model and previous decisions made by the model to help inform decision making for future inputs. This means RNNs have “memory” that helps them make informed decisions based on relevant information they have consumed prior to their current task. Basic RNNs have a limited memory and can only leverage information from the recent past. Long Short-Term Memory units (LSTMs) are a powerful and popular subset of RNNs that can identify patterns over much longer periods of time than typical RNNs.

Typically, RNNs and by extension LSTMs are applied to problems involving the use of temporal data as inputs, as they make great use of time series data to identify and interpret patterns in the dataset(s) over time. The ability to leverage data over time provides RNNs and LSTMs a significant advantage over traditional neural networks as they can better leverage this additional context via data collected over time. For example, consider predicting the temperature. If asked to predict the temperature outside for the upcoming hour, a person would typically check the temperature for the previous hour and predict a slightly warmer or colder temperature based on other conditions. This is a form of prediction that is impossible for traditional neural networks to perform as they treat each input independently. In the temperature analogy, a traditional neural network has never “knows” what the previous temperatures were when asked to predict the current temperature.

6.2.2 The CleanConnect LeakFinder Temporal Deep Learning Image Processing Model (TDLP-NG) / gas leak detection model

Model Fundamentals

The Clean Connect Temporal Deep Learning Image Processing Model (TDLP-NG) is an innovative deep learning architecture that combines two different neural network architectures, CNNs and LSTMs to leverage their respective strengths in conjunction to solve the problem of methane emissions detection and quantification using OGI video data. This is done by splitting out the problem of analyzing the OGI video data into 2 parts.

First, the video is split up by separating the video into individual frames. A frame is essentially an image that represents a snapshot in time from a video. These frames or images are then fed into the CNN component of TDLP-NG, which performs image processing on each frame independently. This process results in an intermediate output of a series of numerical data extracted from each image that is ordered chronologically.

Next, the intermediate output data from the CNN component of TDLP-NG is then fed into the LSTM component, which analyzes patterns across the temporal sequence of the vectorized image data to predict the presence and characteristics of methane emissions over time. This produces an end-result where the model can identify methane emissions from OGI video footage. Following the identification of methane emissions, rate estimation can be performed using the video footage and characteristics predicted by the model.

An important note is that while typical CNN models will include the final step of performing classification of provided images, the CNN component of TDLP-NG stops just before this step, to allow for classification to be performed by the LSTM component of TDLP-NG instead. The LSTM serves a critical role in the model architecture. Using only a CNN, hundreds of detections could be triggered from footage of a single emission, and the model would have no way to know that they were all from the same emission as each frame would be processed as a separate entity. Additionally, the ability of the LSTM to leverage information temporally “backwards” across the video footage instead of evaluating each frame individually drastically improves the model accuracy as error from factors such as sudden gusts of wind that may impact a few frames of the video can be minimalized.

Quantification

Once methane plumes have been identified by TDLP-NG, an optical flow-based model can be applied to the OGI video footage of the methane plume to estimate the leak rate of the gas based on estimating the movement of the gas in pixels of the video and converting that information into leak rate estimates.

First, an algorithm is applied to determine the movement of pixels in the video footage identified as being part of the emissions plume. Following this, by taking into account various environmental factors not inferable from video footage, such as weather, the properties of the plume captured by the OGI cameras, the distance of the camera to the lens and lens angle of the camera, the model can convert the movements of the gas pixels into gas flow rates using machine learning models.

Training and accuracy

TDLP-NG has been trained on over 10, 000 short OGI videos from real oil and gas infrastructure. Additionally, further training has been performed using simulated data with known controlled has release rates under various weather conditions. Training using variations of the base training data generated using transformation techniques such as rotation, translation, and scaling was also performed. Training on transformed data serves to help reduce potential model bias. It also allows the model to become invariant to properties of the data not correlated with the presence of methane emissions. Empirical validation has demonstrated TDPL-NG boasts a 98% true positive rate and a 100% true negative rate in emissions detection. The algorithm applied for estimating leak rates demonstrates an accuracy exceeding 78%.

7. Data Reporting and Documentation (Operator reporting and involvement)

This section described the data products provided to the end user (the operator) and how the operator leverages these data products to complete requirements of the overall CleanConnect LeakFinder alternative test method work practice.

7.1 Emissions Classification

While currently under development, the CleanConnect LeakFinder system cannot autonomously differentiate between leaks and allowable process emissions. Here, operator insight is crucial. Figure 11 describes how the CleanConnect LeakFinder data products are used to support operators in classifying emissions encountered during the periodic screening window.

Definitions:

Trained and qualified: The operator(s) conducting the emission classification must be trained in both interpreting CleanConnect LeakFinder OGI footage and associated data as well as qualified to understand all routine operations at the monitored site. CleanConnect and the operator will work collaboratively to ensure there is an established trained and qualified operator who takes ownership of emissions classification after the 24 hour screening window has concluded.

Existing data: This includes the CleanConnect LeakFinder OGI footage, SCADA data if available, knowledge of known allowed process emissions or emissions from regulated sources (e.g., blowdowns), etc. Often, the operator can classify the emission associated with a detection event with only existing data. Furthermore, the Clean Connect OGI footage alone is often sufficient material for an operator classifying an emission as a leak or a known allowable emission.

Additional data: Data collected by the operator to aid in emission event classification. This could include an investigation into activities at the facility the operator is not immediately aware of (e.g., vacuum/pumping truck operations). This can also include the use of the CleanConnect LiveLook feature which will allow the operator to manually position the OGI camera to better diagnose the emission associated with the detection event.

Close Range Survey: An OGI or Method 21 inspection following EPA CFR 60.5397b. A close range inspection my be necessary in cases where the OGI footage of a detection event shows the emission plume but not the source.

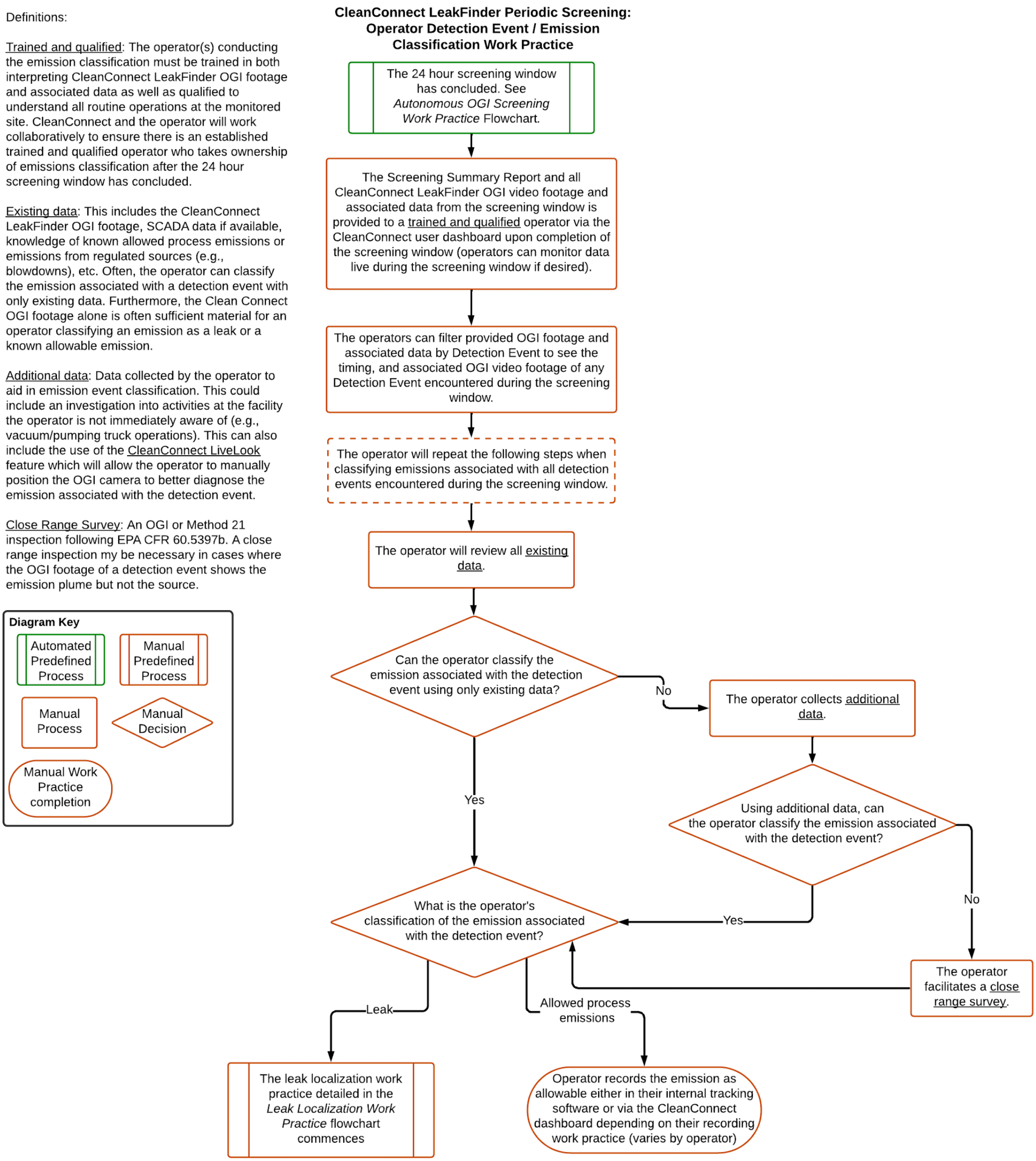


Figure 11. The CleanConnect LeakFinder Operator Detection Event / Emission Classification Work Practice

Figure 12 describes the use of LiveLook in classifying emissions events. Figure 11 is a screenshot of the LiveLook functionality.

Figure 12. A screenshot of the CleanConnect LiveLook software which allows operators to adjust the viewing angle of the OGI camera live, as shown by the directional arrows as well as the “Pan” and “Tilt” fields, both of which can be used to reposition the OGI camera. This functionality is incredibly useful when classifying emissions.

7.2 Leak Localization

The LeakFinder system in combination with operator expertise is used to localize, and ultimately repair, leaks found during the periodic screening window. Figure 13 describes the work practice employed by the operator to localize leaks detected by the CleanConnect LeakFinder system.

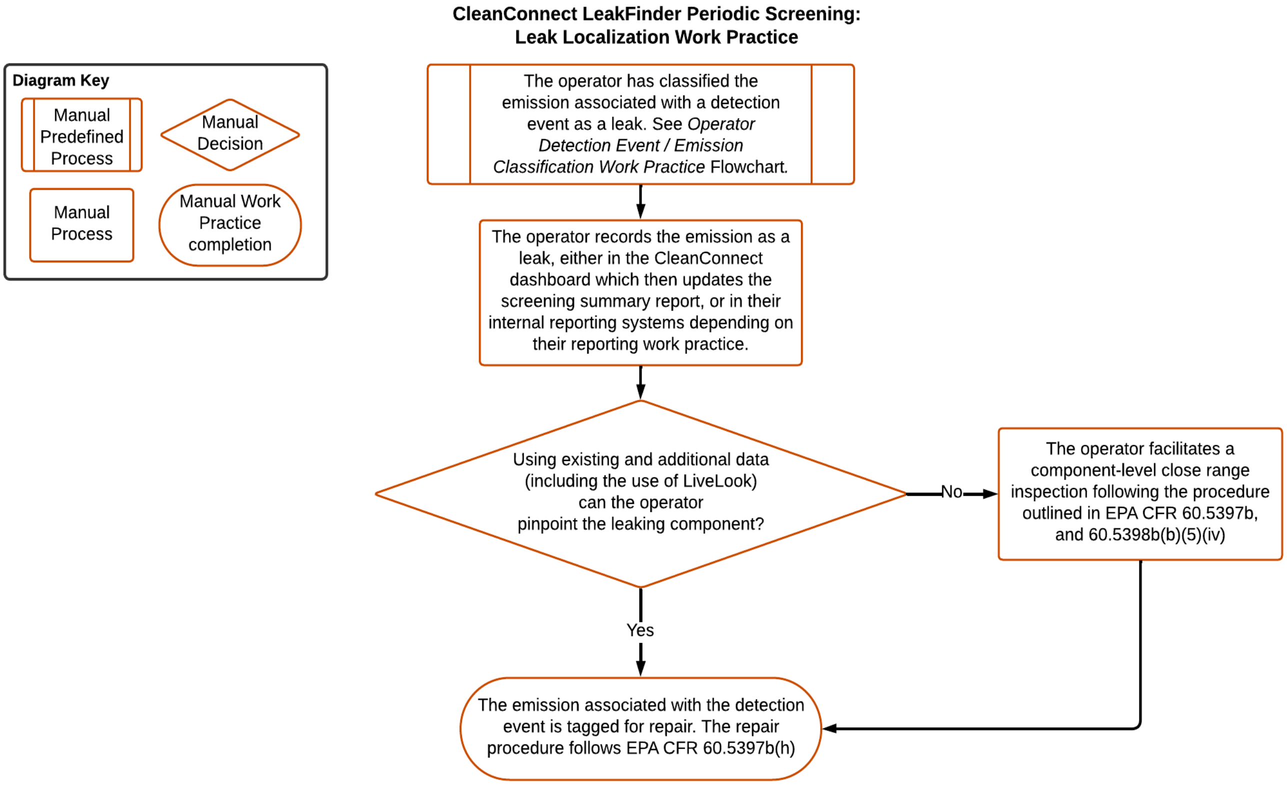


Figure 13. The CleanConnect LeakFinder leak localization work practice.

One of the key processes of note in Figure 13 is that the CleanConnect LeakFinder system can be used to localize leaks down to the component level. If this is accomplished successfully, the operator is not required to facilitate a traditional, handheld OGI or Method 21 survey. As the CleanConnect OGI camera is required to meet the requirements of 40 CFR part 60 §60.5397b, and the operator has access to LiveLook functionality, the CleanConnect LeakFinder system can be used effectively in place of a handheld OGI inspection.

8. Aggregate Detection Threshold

CleanConnect has participated in multiple validation studies to demonstrate the efficacy of the LeakFinder system and establish its aggregate threshold under standard work practices. These studies are controlled release experiments at operating facilities in Colorado. This section will summarize these controlled release investigations. Full results of all studies discussed here will be included in the application as supporting information.

All testing detailed here was conducted for the Colorado Alternative Approved Instrument Monitoring Method Application (CO-AAIMM), which is attached in full as supplemental information[7]. As such, this testing has undergone independent evaluation by the Colorado Department of Health and Environment

[7] (*CleanConnect Alternative Approved Instrument Monitoring Method (AAIMM) Application, Supporting Information 01*)

as part of the CO-AAIMM review process. Some text from the CO-AAIMM application document has been updated here, to reflect updated terminology ("LeakFinder" was not yet the accepted product name during the time of the CO-AAIMM application process).

8.1 Controlled Release Testing 1 (January and February 2022): Archival OGI Footage

Highwood and CleanConnect developed a controlled release testing methodology to investigate the performance of the LeakFinder detection algorithm in pursuit of obtaining CO-AAIMM approval. This testing involved the use of archival, publicly available OGI footage which was submitted remotely to the CleanConnect LeakFinder detection algorithm by Highwood.

8.1.1 Methodology

The CleanConnect LeakFinder 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 detection algorithm with pre-recorded OGI video, the detection algorithm can be effectively tested.

To test the system using archival OGI footage, CleanConnect developed a website to host the CleanConnect LeakFinder detection algorithm. OGI video files can be uploaded to the website, which are 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, shown in Figure 14:

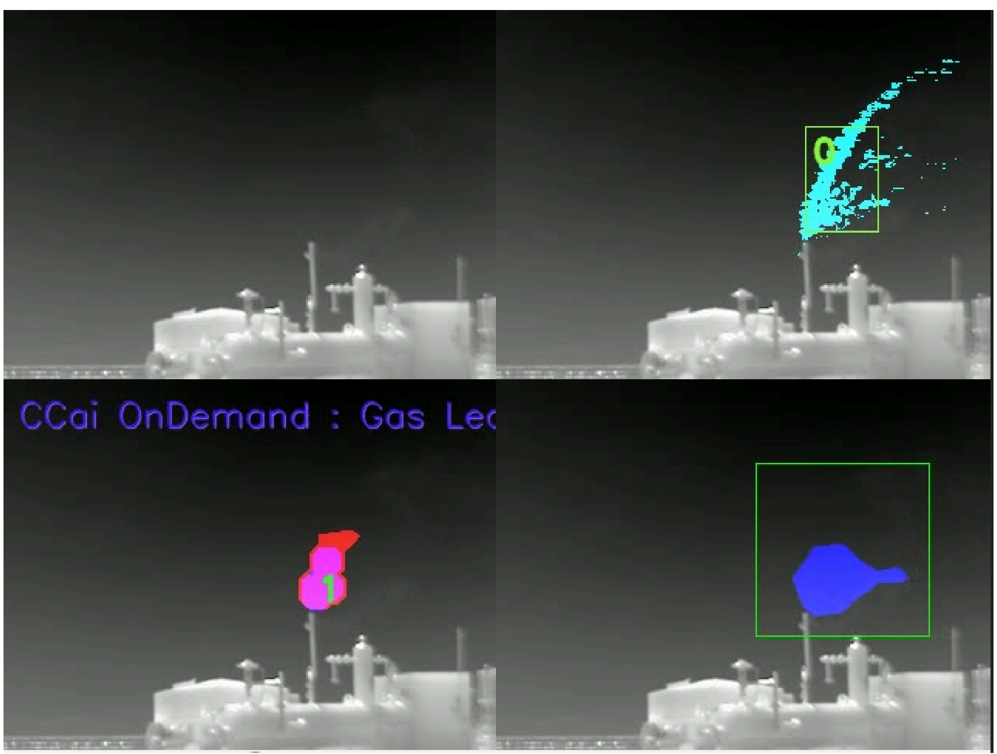


Figure 14. A still from the OGI video footage passed to the CleanConnect detection algorithm hosted website and returned to Highwood Emissions Management with CleanConnect detection algorithm annotations.

A description of the 4 panels of Figure 14, are:

- Upper left panel: The raw OGI video which was submitted to the website for testing. Other panes show the visual output of the CleanConnect LeakFinder detection algorithm.
- Upper right panel: Shows the suspected plume traced by blue pixels.
- Lower and upper right panel: A green square is annotated automatically by the CleanConnect LeakFinder detection algorithm encompassing what is the estimated emitting component.
- Lower left panel: Outputs of the LeakFinder quantification algorithm.

Note: the 4 panel format and associated annotations of Figure 14 have been updated since the controlled release testing occurred and no longer reflect the video product CleanConnect LeakFinder provides to operators.

Regarding annotated CleanConnect pixel color of Figure 14, light blue pixels indicate an emission probability of > 50%, dark blue pixels > 80%, and red/pink > 90%.

To ensure testing was single blind, Highwood sourced OGI video footage to be used for testing independently, not informing CleanConnect 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 CleanConnect of when uploads took place. Highwood then assessed the results prior to notifying CleanConnect the testing was completed.

8.1.2 Sourced OGI Footage

The OGI video used was recorded to serve as key data in (Wang et al 2022)[8] and (Wang et al 2020)[9]. 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 the Methane Emissions Technology Evaluation Center (METEC) at Colorado State University using a tripod mounted FLIR GF-320. All recorded emissions are controlled releases of methane 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 methane 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 of the CleanConnect LeakFinder detection algorithm by Highwood 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 g/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

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[8] Wang, J., Ji, J., Ravikumar, A.P., Savarese, S., Brandt, A.R. (2022) VideoGasNet: Deep learning for natural gas methane leak classification using an infrared camera

[9] Wang, J., Tchapmi, L.P., Ravikumar, A.P., McGuire, M., Bell, C,S., Zimmerle, D., Savarese, S., Brandt, A.R. (2020) Machine vision for natural gas methane emissions detection using an infrared camera, Applied Energy, Volume 257, 113998,ISSN 0306-2619,

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. The OGI video used was 320 X 240 pixels.

8.1.3 Results

A full accounting of the testing results is attached as supporting information[10]. The key takeaways Highwood found in this testing of submitting OGI video to the CleanConnect LeakFinder detection algorithm via the testing website are as follows:

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 15-17 are stills of correctly assigned detection events, provided to Highwood via email autonomously from the testing website:

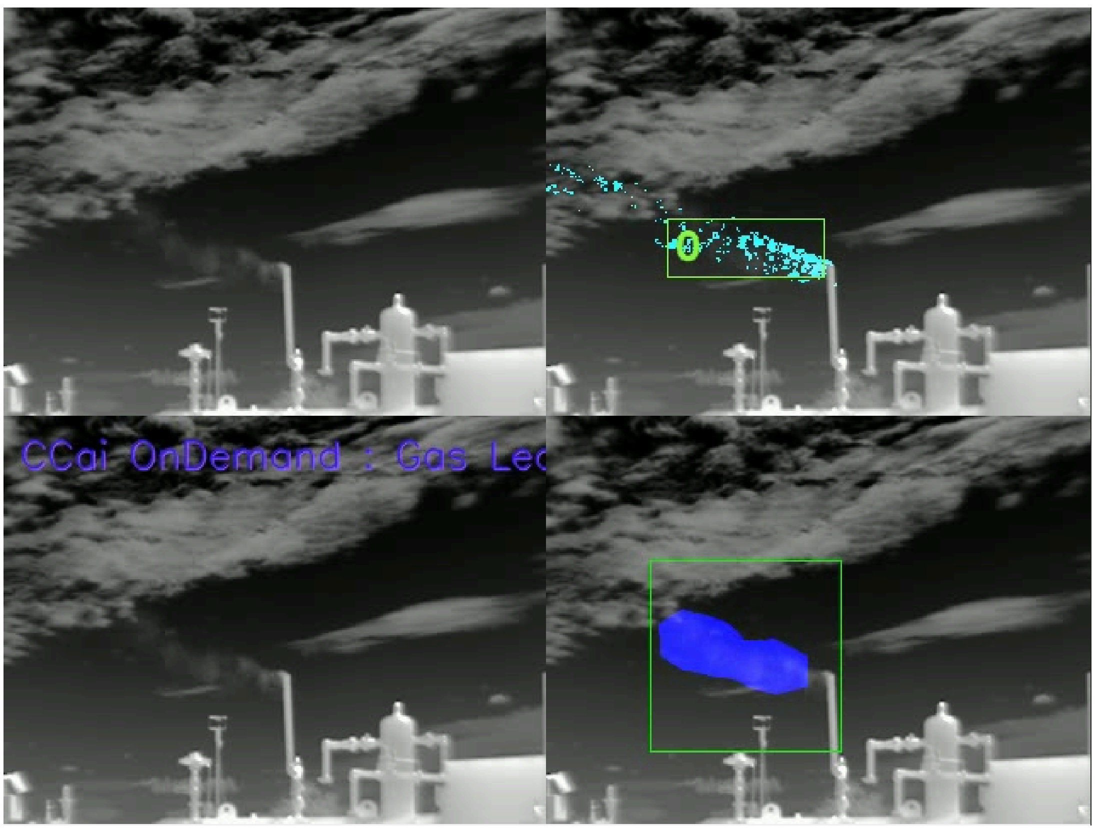

Figure 15: Processed footage of a correct detect. Distance: 15.6m, emission rate: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr)

[10] *Controlled Release Testing 1 Full results, Supporting Information 04*

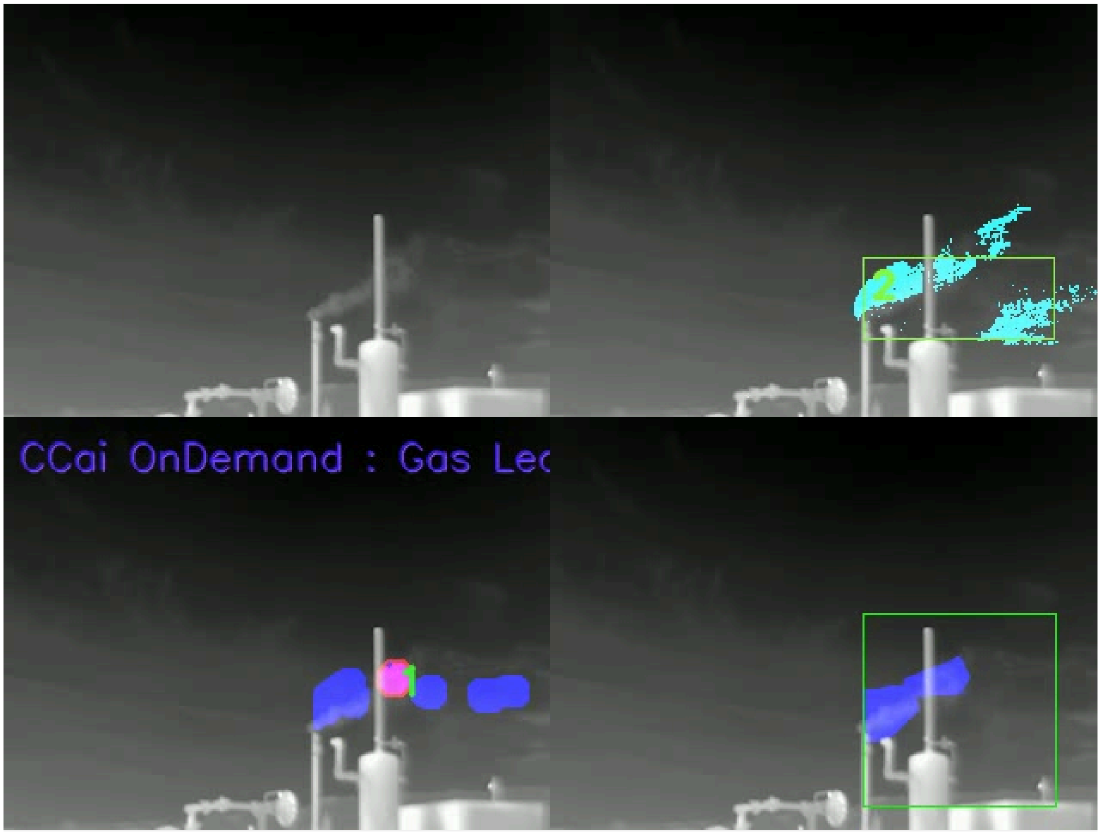

Figure 16: Processed footage of a correct detect. Distance: 15.6m, emission rate: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr)

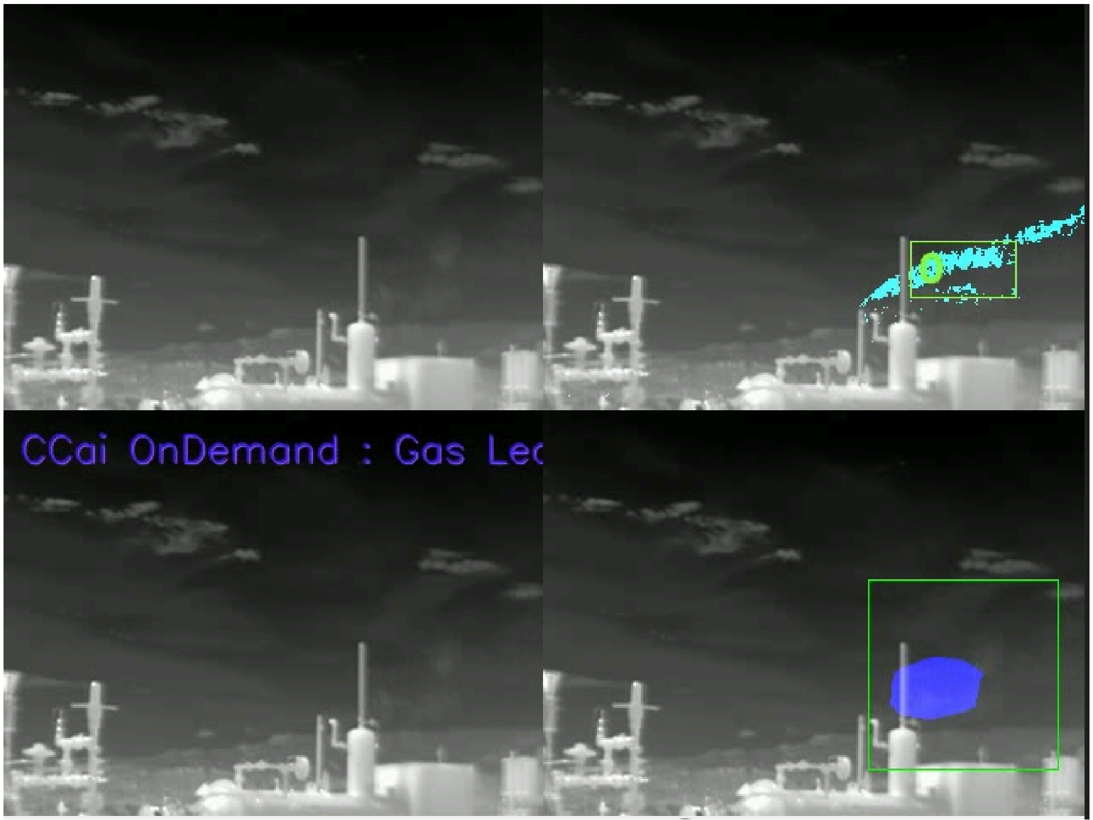

Figure 17: Processed footage of a correct detect. Distance: 18.6m, emission rate: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr)

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.

8.1.4 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 18 and 19 are stills from misclassifications (a known emission was not correctly identified as such).

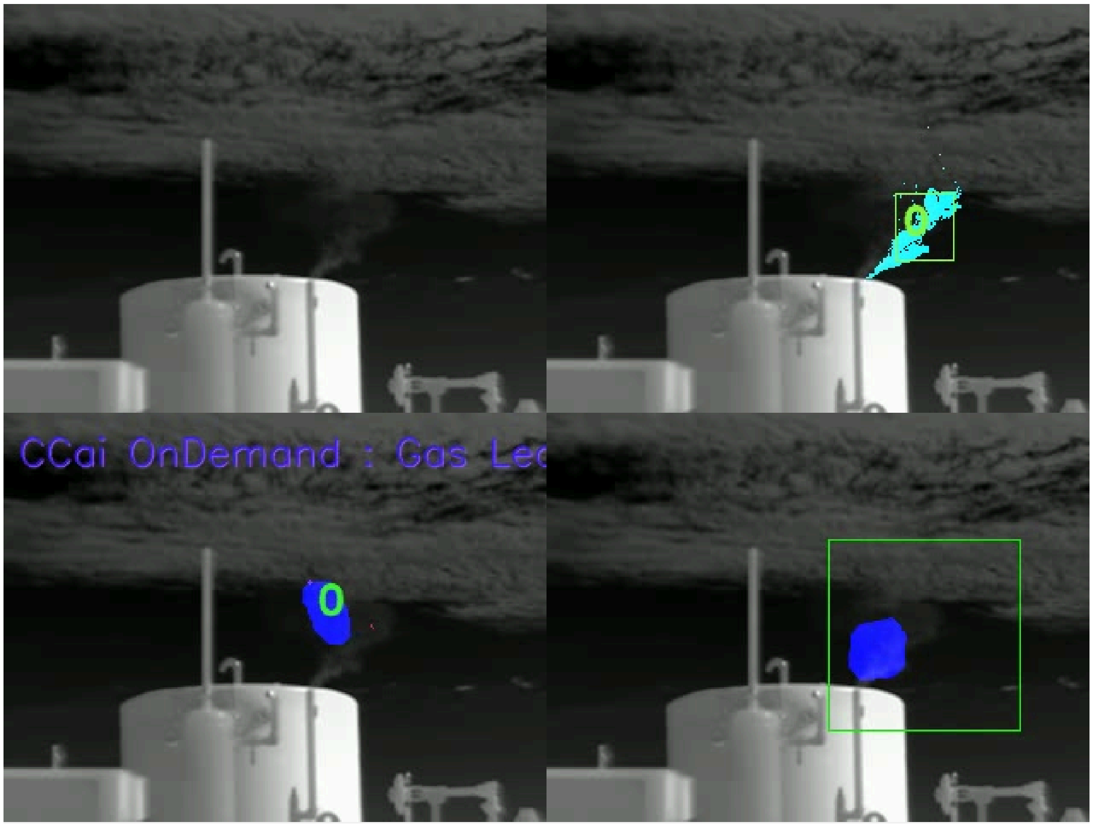

Figure 18: Processed footage of a missed detection. Distance: 9.8m, emission rate: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr)

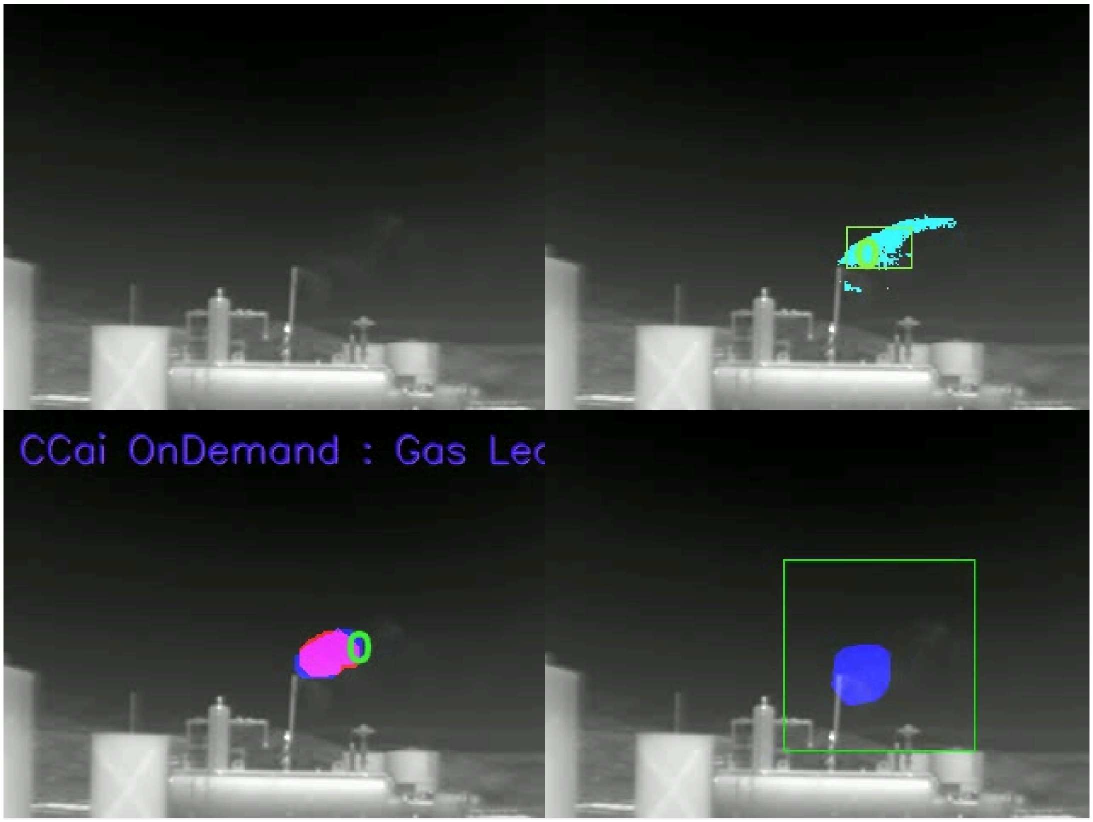

Figure 19: Processed footage of a missed detection. Distance: 18.6m, emission rate: 109.5 ± 2.5 scf/hr (1806.1 ± 41.4 g/hr)

The green square around the plume and suspected emitting equipment in Figures 18 and 19 indicate the algorithm has correctly identified emissions, however, the reporting emails failed to indicate a detection event was present.

8.2 Controlled Release Testing 2 (April 2022): CDPHE Approved Production Facility

On April 22, 2022, CleanConnect conducted blinded controlled release testing on two separate production facilities in Weld County. During testing, a fuel gas line was used as the methane emission source and flow rate was confirmed using a dual chamber flow meter. This testing leveraged full installation of the CleanConnect LeakFinder system at the test facility.

8.2.1 Methodology

A combination of emission rates and distances of the CleanConnect LeakFinder OGI camera to the emission source were tested. All distances, emission rates and wind speeds were recorded and are attached as supplemental information[11]. Facility operators were in charge of the controlled releases, the timing and emission rate of which were blinded to CleanConnect. The average time of each emission (a given emission rate at a given distance) was 2 minutes.

The CleanConnect LeakFinder system operated as it normally would during the testing window (Sections 5, 6, and 7 of this document) with the notable exception that autonomous reporting went to

[11] *Controlled Release Testing 2 Full results, Supporting Information 05*

Highwood and the operator in charge of testing prior to CleanConnect. The operator signed off on all testing results.

8.2.2 Results

A full accounting of the results of this testing is attached as supporting information[12]. A 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.

8.3 Controlled Release Testing 3 (October 2022): Denver Julesburg Facility

On October 20th and 21st 2022, the CleanConnect LeakFinder 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 CleanConnect LeakFinder system at distances greater than those available in the testing described in Sections 8.1 and 8.2 of this document.

8.3.1 Methodology: Overview

The CleanConnect OGI camera component of the LeakFinder system was installed in a fixed position at the test site. Multiple controlled natural gas release points were used throughout testing, the distance of these points from the CleanConnect OGI camera incrementally increasing (the CleanConnect OGI camera 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 CleanConnect OGI camera. The release rate was kept consistent at 2 kg methane / 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 the OGI video of the detection event, if one was present. 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), CleanConnect alarm package received (1 or 0), Correct result (1 or 0), and Link to OGI video. All testing result forms were signed off by the operator conducting testing and sent directly to CDPHE.

8.3.2 Methodology: Maintaining blindness

[12] *Controlled Release Testing 2 Full results, Supporting Information 05*

CleanConnect 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 CleanConnect LeakFinder 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.

Highwood contributed to the testing design, including drafting the testing result template, but was also blinded to the testing results once the testing result template was agreed upon between Highwood, CDPHE, and CleanConnect.

8.3.3 Results

Testing saw a total of 63 releases and 63 non-releases. The CleanConnect LeakFinder 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). Table 2 is 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 as supporting information[13].

Table 2: Controlled Release Testing 3 Results

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

Table 2. Results of blind controlled release testing at a Colorado based well production facility

It is encouraged that the methane alternative test method review team (MATMR) watch the sample OGI video linked in Table 2. Items of note when reviewing the linked OGI video:

- There are 4 "panels" within each video. The lower left panel 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 panel indicating a probability of 85% or higher of an emission. If the detection algorithm has deemed the image has an 85% of containing an emission (i.e., red pixels are present) it is flagged as such. At a high level, the average consistent duration of this

[13] *Controlled Release Testing 3 Full results, Supporting Information 06*

red pixelation is what will decide if what the detection algorithm 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 vary slightly from the wind speed values annotated in the linked OGI video footage. The CleanConenct LeakFinder system video is displaying local weather API data while the wind speed recorded in the testing result forms was measured directly at the testing site.

8.4 Summary of Aggregate Detection Threshold Derived from Controlled Release Testing

The controlled release testing can be interpreted as a simplified detection threshold, and as a probability of detection curve based on the methane emission rate.

8.4.1 Detection Threshold

A simplified detection threshold was constructed which considered the smallest tested emission rate detected at each testing distance. The following results from the controlled release testing discussed in Sections 8.1-8.3 are considered:

- **Controlled Release Testing 1**: The CleanConnect 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.
- **Controlled Release Testing 2**: At 27.4m (30 yards) the smallest emission successfully detected by the CleanConnect LeakFinder 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 CleanConnect LeakFinder system was 2.86 kg/hr (150 scf/hr).
- **Controlled Release Testing 3**: Greater than 90% detection of controlled releases of 2 kg/hr (98.8 scf/hr) at distances of 40m to 120m from the CleanConnect OGI camera to the controlled release point.

The results of Controlled Release Testing 2 and 3 illustrate that the CleanConnect LeakFinder 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 8.1 - 8.3 into account, are summarized in Figure 20. The spacing of the concentric circles is to scale.

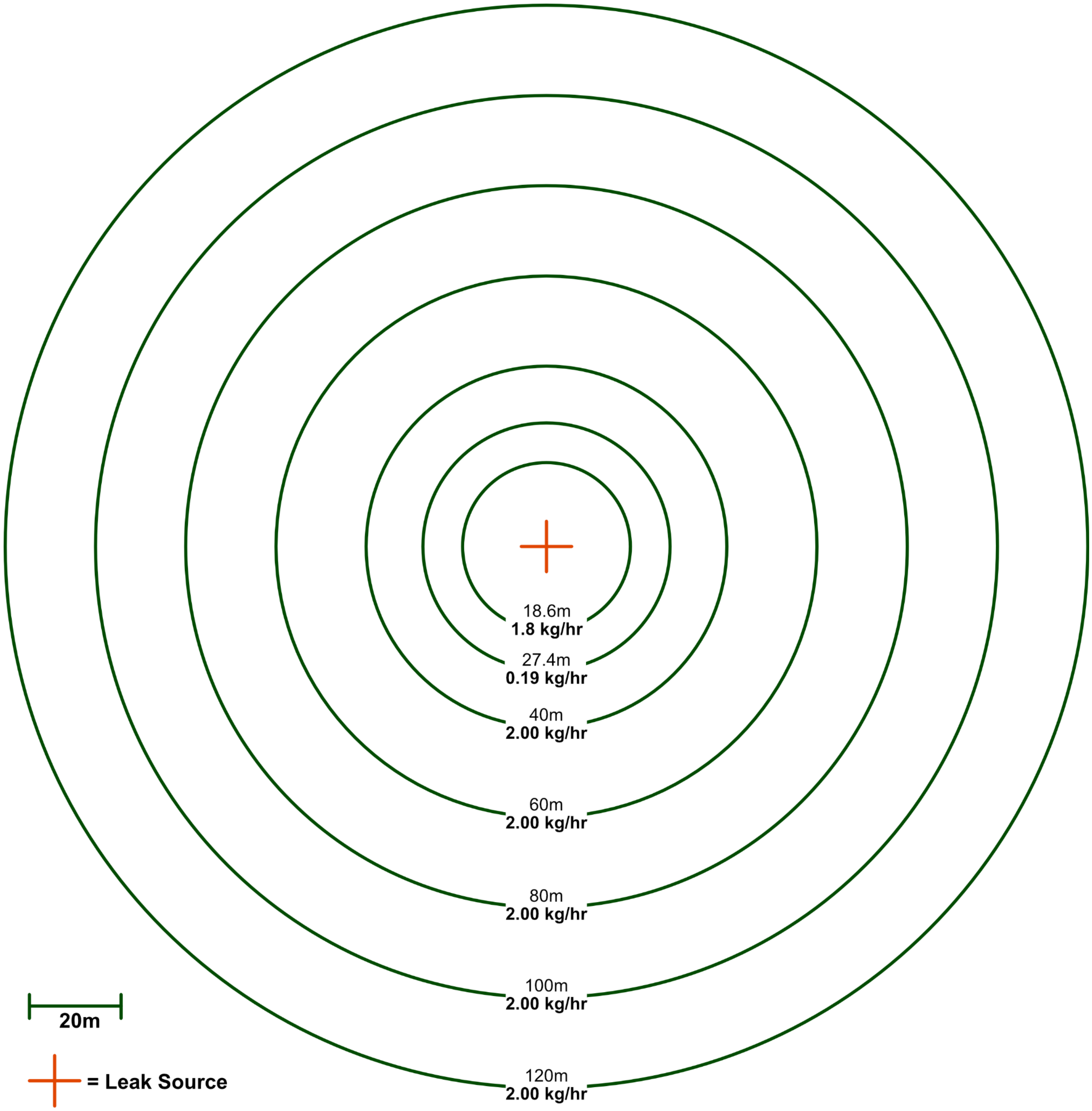

Figure 20: Minimum detected methane emission rate at varying distances from blind, controlled release testing

8.4.2 Probability of Detection

Probability of detection is typically represented as a curve or surface which visually represents the probability a given emission rate will be detected. While the detection capability of the CleanConnect LeakFinder system is dependent on many factors like wind speed, proximity of OGI camera system to emission source, and emission rate (all of which were considered during the controlled release testing described in Sections 8.1-8.3), here, we present a simple probability of detection curve which considers methane emission rate as the single variable.

Figure 21 shows the CleanConnect LeakFinder system probability of detection curve based on all controlled release testing results.

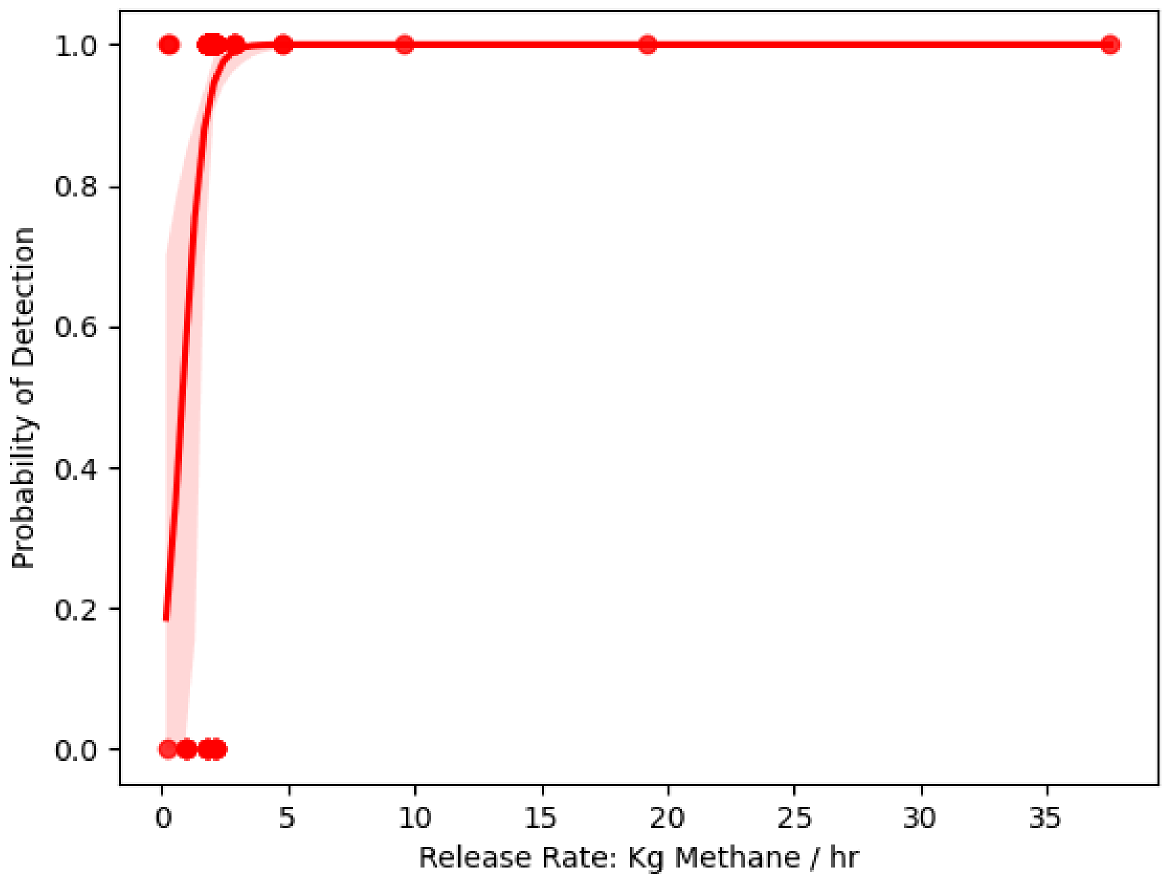

Figure 21. CleanConnect LeakFinder probability of detection assuming only emission rate as the independent variable.

9. Spatial Resolution

The CleanConnect LeakFinder system is seeking alternative test method approval as a system with component-level spatial resolution. The independently reviewed supporting information used to establish component scale spatial resolution is the CO-AAIMM application package[14], namely, the results of Controlled Release Testing 3 (Section 8.3 of this document).

Controlled Release Testing 3 produced CleanConnect LeakFinder annotated OGI video footage of all test emissions. Illustrative examples from these videos will be referenced to illustrate the CleanConnect LeakFinder's component scale spatial resolution. All testing results (including all videos) are attached in full as supporting information, but in this section we will highlight a selection of OGI footage across the range of distances and release rates tested which best illustrate component-level spatial resolution.

[14] (*CleanConnect Alternative Approved Instrument Monitoring Method (AAIMM) Application, Supporting Information 01*)

The following are selected examples from Controlled Release Testing 3 which best illustrate the CleanConnect LeakFinder systems spatial-level resolution. For each distance, a screenshot of the illustrative video and a link to the 2 minute from which it is sourced from is provided. Screenshots are captioned with the time they occur in the associated linked full video. In all cases, the release point was a ½” ball valve.

9.1 Controlled Release Testing 3: 40m Example

The following example is from the 12th controlled release at 40m. [Link to full video](). The screenshot example occurs at 00:11 into the video.

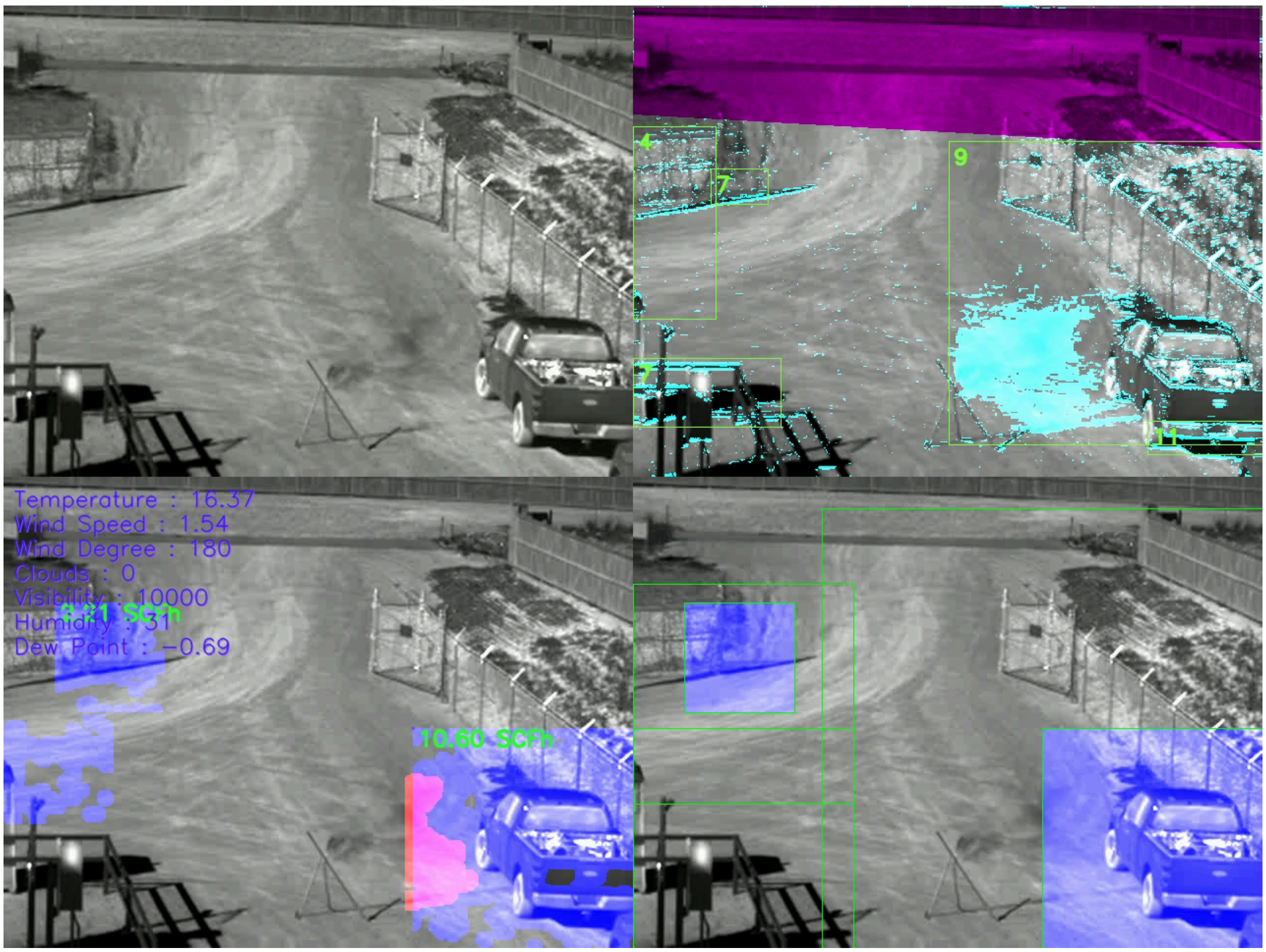

Figure 22. Controlled release testing 3 OGI video footage of the 40m test showing the CleanConnect LeakFinder’s ability to localize an emission down to a component scale.

9.2 Controlled Release Testing 3: 60m Example

The following example is from the 1st controlled release at 60m. [Link to full video](). The screenshot example occurs at 00:54 into the video.

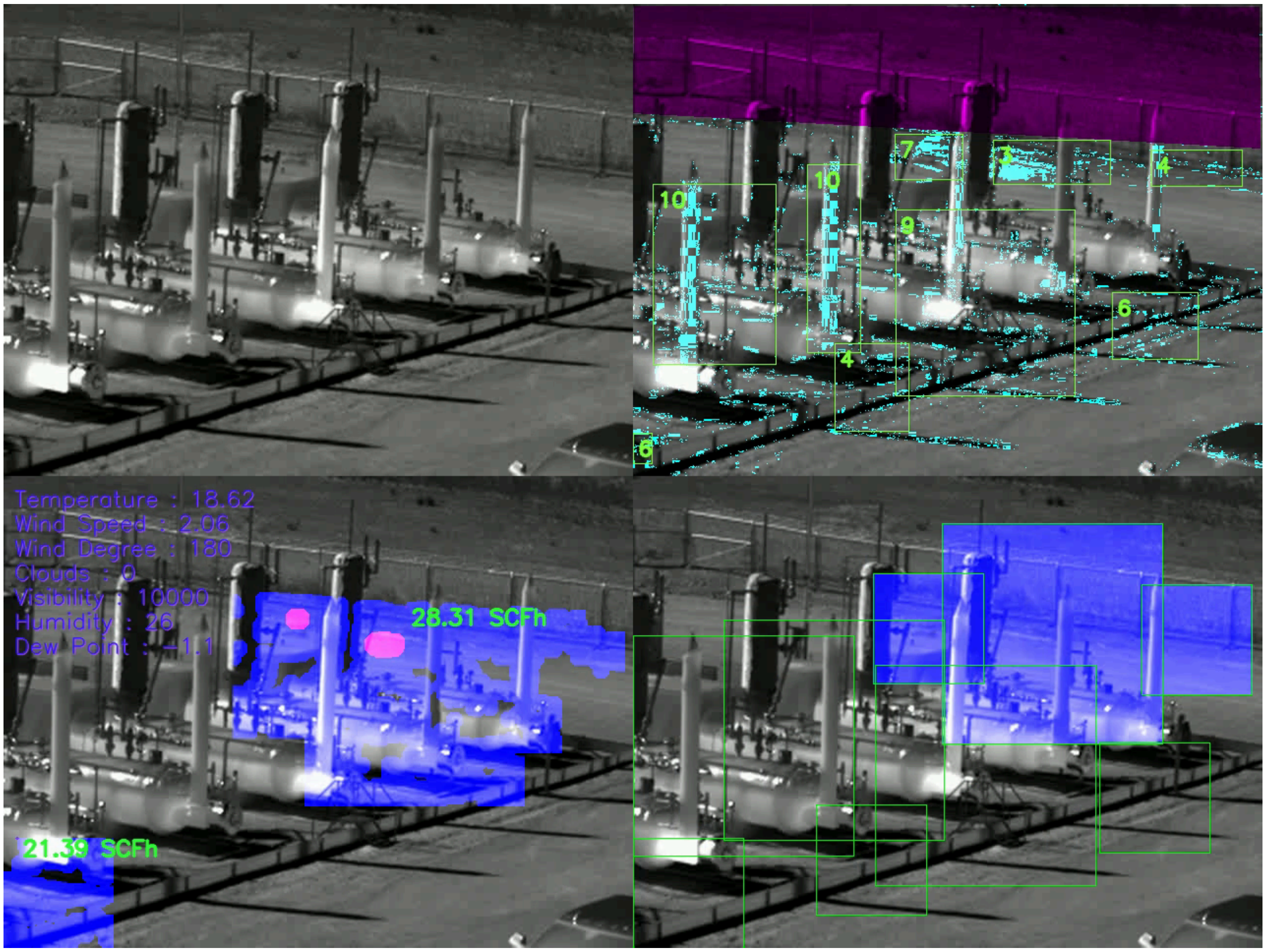

Figure 23. Controlled release testing 3 OGI video footage of the 60m test showing the CleanConnect LeakFinder's ability to localize an emission down to a component scale.

9.3 Controlled Release Testing 3: 80m Example

The following example is from the 1st controlled release at 80m. [Link to full video](). The screenshot example occurs at 00:27 into the video.

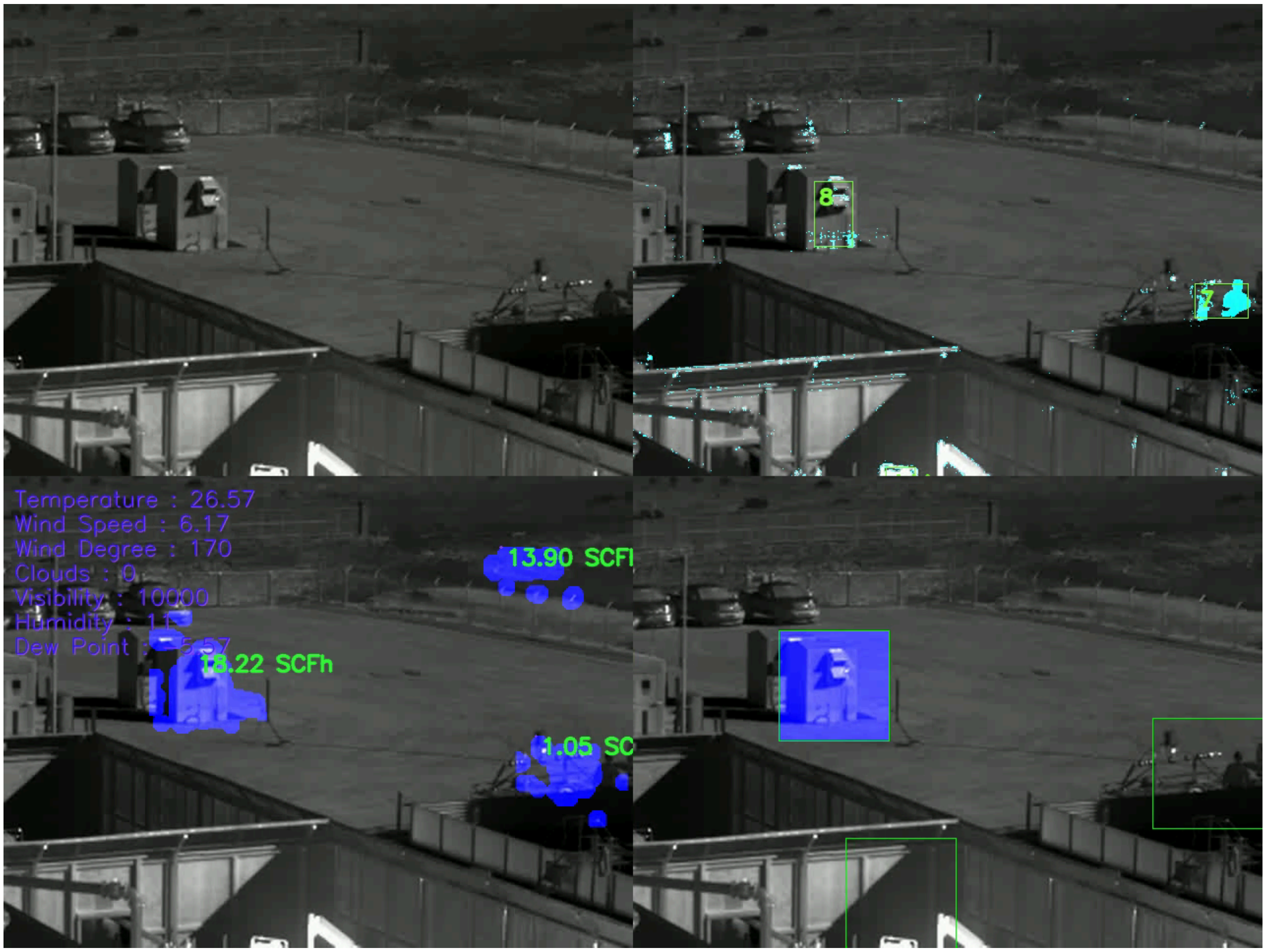

Figure 24. Controlled release testing 3 OGI video footage of the 80m test showing the CleanConnect LeakFinder's ability to localize an emission down to a component scale.