Emissions Measurement Center
Oil and Natural Gas Advanced Methane Technology Program
CleanConnect LeakFinder System Periodic Screening Methane Alternative Test Method (MATM)

1. Scope and Application

This method outlines the procedure for using the CleanConnect LeakFinder Periodic Screening Methane Alternative Test Method (MATM) to comply with 40 CFR §60.5398b requirements. The CleanConnect LeakFinder system is an alternative method to the current Best System of Emission Reductions (BSER), and it applies to fugitive monitoring and inspection and monitoring of covers and closed vent systems under 40 CFR part 60 subparts OOOOa, OOOOb, and OOOOc.

The CleanConnect LeakFinder MATM carries out stationary, remote monitoring using an automated optical gas imaging (OGI) camera-based system to monitor methane. The CleanConnect LeakFinder camera is housed in the Minerva Platform. The CleanConnect LeakFinder system is OGI camera agnostic so long as the OGI camera meets the requirements laid out in 40 CFR part 60 §60.5397b. Therefore, the OGI camera used by the CleanConnect LeakFinder system operates under the same principles as those used for handheld inspections to meet the requirements of 40 CFR part 60 §60.5397b.

The deployment of the CleanConnect LeakFinder system, as described in this protocol, will achieve a 90% probability of detecting an emission source emitting methane at a rate of 5 kg/hr. This sensitivity has been validated via single-blind testing. The CleanConnect LeakFinder system achieved greater than 90% detection of controlled releases of 2 kg/hr (98.8 scf/hr) at distances of 40m to 120m from the CleanConnect Minerva Platform OGI camera to the controlled release point.

The method performance can be affected by factors such as obstructions in the line of sight of the OGI camera, and high wind speeds. Therefore, the periodic screening window of the system is 24 hours, to ensure performance requirements are met, such as wind direction shifting such that methane emissions are visible (blown within the line of sight) by the Minerva Platform OGI.

The CleanConnect LeakFinder system Period Screening MATM does not apply to equipment located inside buildings. Therefore, if a site is being monitored using the CleanConnect LeakFinder system MATM and has equipment which requires monitoring located inside buildings, those will be inspected with OGI or EPA Method 21 at the applicable inspection frequency for the given site.

2. Summary of Method

The CleanConnect LeakFinder system is used to screen for leaks at oil and gas sites requiring leak detection and repair (LDAR). OGI video footage is collected using a permanently installed, autonomous OGI camera housed in the Minerva Platform. 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.

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 all equipment prone to leaks can be effectively monitored. 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. Tours are completed during the periodic screening window, a 24 hour block of time during which the CleanConnect LeakFinder system autonomously and continuously screens for emissions.

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 are changing 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 emission, will classify all flagged emissions as either a leak or allowable process emission. Operator classification will be logged either via the CleanConnect dashboard, or the operator's internal reporting software, depending on the operator's work practice.

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, only 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.

3. Definitions of Method

Periodic Screening Window: A 24 hour window of time during which the CleanConnect LeakFinder system autonomously and continuously screens the site. 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% probability of detection:

- 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.

Tour: When the CleanConnect LeakFinder OGI Camera has rotated the entire 360° in its 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 its presence. In addition, after the 24 hour screening window, the operator receives 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.

Trained and qualified: A definition related to the operator classification of detention events. 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: A definition related to the operator classification of detention events. This refers to data used when classifying detection events and 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: A definition related to the operator classification of detention events. This refers to data used when classifying detection events and includes 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 may be necessary in cases where the OGI footage of a detection event shows the emission plume but not the source.

4. Interferences

4.1. Line of Sight Obstructions

The CleanConnect LeakFinder system requires direct line of sight to a methane emission in order to “see” it and flag it as a potential event and ultimately 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 fugitive emissions source). These obstructions are minimized through strategic placement of the CleanConnect Minerva Platform, including installation of multiple Minerva Platforms if necessary.

4.2. False Positives

Movement not related to methane plumes, cloud cover, sunlight reflections, etc. in the OGI video footage can be originally mis-interpreted 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 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.

5. Safety

The CleanConnect LeakFinder system MATM is a fully automated system that does not require regular on-site personnel, minimizing the safety risks typically associated with standard field operations for emissions monitoring. The two main safety risks related to this method are the installation and system maintenance of the Minerva Platform and its mounting system. The sections below describe the safety risks associated with both.

5.1. Minerva Platform Installation

The presence of Minerva Platform and elevated mounting tower installed on the site can introduce a few safety risks, such as:

- Traffic obstruction
- Structural Hazards
- Electrical Hazards
- Visibility and Operational Safety

The Minerva Platform installation at a given site is carried out collaboratively by the operator and CleanConnect. The location is decided on a site-by-site basis informed by local conditions and operational and safety constraints. For each installation, the operator and CleanConnect work together to ensure that the camera is placed at a safe location and that the individual fields of view at each tour stop are set up in a way that they are sufficient to address the requirements of use. Physical installation is conducted by CleanConnect staff, operators, or third parties trained in proper installation by CleanConnect staff.

5.2. Field Operations (maintenance)

Installation procedures and rare on-site maintenance procedures, including swapping out the Minerva Platform if required, carry the same safety risks as any oil and gas facility activity. These risks include exposure to hazardous gasses such as methane and other toxic substances. Following all safety protocols during installation and maintenance activities will mitigate these risks. This begins with thorough hazard assessments before starting any field work. Ensuring all personnel are equipped with appropriate personal protective equipment (PPE) is also essential. This includes gas detectors, fire-resistant clothing, hard hats, safety glasses, steel toed boots, and gloves. By adhering to stringent safety measures, the risks associated with installation and maintenance activities in oil and gas facilities can be significantly reduced, ensuring the safety and well-being of all personnel involved.

6. Equipment and Supplies

The CleanConect LeakFinder system hardware components consist of the following elements:

- *Minerva Sensor-FusionTM Platform (Minverva Platform)*: The Minverva platform is CleanConnect's proprietary hardware which houses an Optical Gas Imaging (OGI) camera, a pan and tilt device, and edge computing devices ("Intelligent Edge" data

center). The Minerva Platform is attached to an elevated platform via a mounting bracket. Figures 1 and 2 show the external and internal view of the Minerva Platform respectively, while the following provide further details on the associated components:

- *OGI camera and IP67 Enclosure:* The CleanConnect LeakFinder system is OGI camera agnostic so long as the camera meets the requirements laid out 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.

- *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.

- *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

- *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 additional IR cameras are used in these other offerings.

- *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 the Minerva Platform. Figure 2 provides an internal view of the Minerva platform, showing the location of the edge computing devices.

Figure 1. External view of the Minerva Platform, the primary physical component of the CleanConnect LeakFinder system.

Figure 2. Internal view of the Minerva Platform showing the location of up to 4 edge computing devices.

- *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” fugitive emissions. The algorithm is applied to OGI video footage at the intelligent edge data center.
- *Meteorological station*: Often the site requiring monitoring will have a pre-existing meteorological station on site which is used alongside CleanConnect LeakFinder. 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, temp, humidity, etc.).
- *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.

7. Reagents and Standards

This method is executed using instrumentation that does not require laboratory reagents or standards.

8. Sample Collection, Preservation and Storage

This method does not require the collection of laboratory samples. Therefore, discussing sample collection, preservation, and storage procedures is unnecessary. Section 11 of this document describes the procedures necessary to acquire data by this protocol.

9. Quality Control

9.1. Camera system

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 6 of this document. 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 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.

9.2. Weather Conditions

Extremely adverse weather conditions (very high winds, heavy precipitation) may impact the CleanConnect detection algorithms ability to correctly identify emissions, however, in field deployments this has proven to be rare. The CleanConnect periodic screening window is 24 hours to ensure there is a window of time to account for favorable weather conditions.

9.3. Data

The CleanConnect LeakFinder detection algorithm has been extensively trained to filter out potential false positives in the analyzed OGI video footage. However, the work practice culminates in the operator classifying each detection event of the system as either a leak, allowable process emission, or false positive.

10. Calibration and Standardization

The OGI camera housed in the Minerva Platform requires neither field calibration or baseline data collection and can begin monitoring shortly after installation. The Minerva Platform's tour path to be followed during the periodic screening window is agreed upon between the operator and CleanConnect prior to the commencement of periodic screening.

11. Procedure

The CleanConnect LeakFinder periodic screening MATM consists of four main procedures:

- Installation and set-up (pre-screening)
- Data collection
- Data processing
- Data documentation and reporting

11.1. Installation and set-up

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 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 which require monitoring are adequately monitored with the CleanConnect Leak Finder system ultimately falls to the operator.

- Ensure the CleanConnect LeakFinder systems autonomously begins 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) has access to the cloud for proper algorithm function and record keeping.
- Maintain a database of all installed camera systems, the facilities they are installed at and their specific install 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.

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 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 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 3 is a screenshot of the DigitalTwin software.

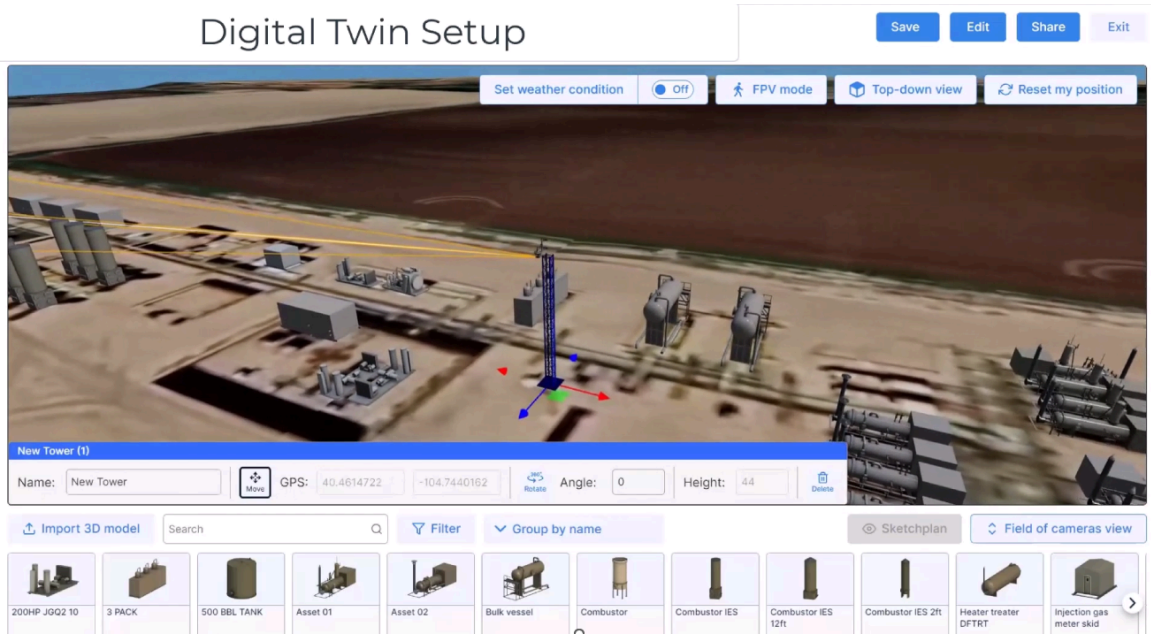

Figure 3. The CleanConnect Digital Twin software. The DigitalTwin software creates a to-scale 3D representation of the site requiring screening so CleanConnect can explore optimal placement of the OGI camera tower(s). Here, we see a possible OGI camera tower placement, and the associated lines of sight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

11.2. Data Collection

The data collection stage occurs during the periodic screening window, a 24 hour window of time where the CleanConnect LeakFinder system continuously and autonomously screens for emissions.

During the periodic screening window, the CleanConnect LeakFinder system first autonomously scans for potential events. A potential event is any emission identified by the CleanConnect LeakFinder system which has persisted for more than 20 seconds (no longer than 20 seconds elapse between detection of the potential event during a given tour stop). Each potential event is tracked by the CleanConnect LeakFinder system.

The CleanConnect LeakFinder system will automatically elevate a potential event to a detection event if the potential event surpasses the 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 events require further investigation which is described in Section 11.3 of this document.

The periodic screening window culminates in a screening summary report being sent to the operator, the screening report can also be sent to CleanConnect for ongoing system improvement at the discretion of the operator (it is not required). The screening summary 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 populated upon completing the Emissions Classification Work Practice (Section 11.3) including the classification of emissions associated with detection events, and details of Follow-up OGI information if necessary. Alternatively, operators can use the screening summary report in combination with internal tracking systems to meet 40 CFR 60.5424b reporting requirements.

During the periodic screening window, all time stamped OGI video footage and associated wind speed data (via weather APIs) collected by the CleanConnect LeakFinder system is automatically uploaded to the CleanConnect dashboard. In addition, potential events and detection events are flagged as such within the dashboard and can be observed at a later time by the operator.

11.3. Data Documentation and Reporting

Data documentation and reporting is broken down into two work practices, the Emissions Classification work practice which is followed by the Leak Localization work practice.

Emissions Classification Work Practice

The CleanConnect LeakFinder system is not capable of classifying detection events as either an allowable emission or a leak, a trained and qualified operator expertise is required to perform this classification. The operator performing this classification must be trained and qualified in that they must be trained in both interpreting CleanConnect LeakFinder OGI footage and associated data as well as qualified to understand all routine operations at the site being monitored by the CleanConnect LeakFinder system. 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.

When classifying detection events, the operator will begin by reviewing existing data. Existing data refers to the CleanConnect LeakFinder OGI footage, SCADA data if available, knowledge of known allowable process emissions or emissions from regulated sources (e.g., blowdowns), etc. Past CleanConnect LeakFinder system deployments have shown that, 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 to classify an emission as a leak or a known allowable emission.

If the operator cannot classify the detection event using existing data, they will acquire additional data. Additional data refers to 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 allows the operator to manually position the OGI camera via the CleanConnect dashboard to better diagnose the emission associated with the detection event.

If the operator classifies the detection event as an allowed process emission, the operator will log the detection event as such in either internal tracking / reporting software, or via the CleanConnect dashboard depending on their reporting work practice.

If the operator classifies the detection as a leak, the leak localization process commences. If the operator is unsure of the nature of the detection event, it is assumed to be a leak.

Leak Localization Work Practice

The leak localization work practice begins after the periodic screening window has elapsed and after the operator has classified a detection event during the screening window as a leak, or, was unable to ascertain the source of emissions. The work practice details the localization of leaks so they can be repaired.

The operator will use both existing and additional data to attempt to pinpoint the leak. This could include the OGI video footage collected during the periodic screening window, new, live footage viewed when using the CleanConnect LiveLook feature, or any other form of data available on site.

If the operator cannot localize the leak such that repairs can be carried out, a close range inspection following the procedure outlined in EPA CFR 60.5397b, and 60.5398b(b)(5)(iv) is conducted (a handheld OGI or Method 21 survey is conducted).

Once the leak is localized, it is repaired following procedures outlined in EPA CFR 60.5397b(h).

12. Data Analysis and Calculations

The core data analysis and calculations of the CleanConnect LeakFinder system MATM occur in The CleanConnect LeakFinder detection algorithm. The CleanConnect LeakFinder detection algorithm is a combination of neural networks (both a-priori and developed internally by CleanConnect) which operate in tandem to autonomously detect methane emissions in OGI video footage.

There are two input data sources, sensor data and video 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.
- *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. Details of the pixels which inform the vectorization include the color (RGB value) and how rapidly this color changes from frame to frame. This is the key concept of the CleanConnect LeakFinder detection algorithm: It “looks” for emissions in the video data by assessing the numeric values of the video’s pixels, and the nature of how these numeric values change from frame to frame.

Four models are applied to these input data:

- *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.

The results models all operate simultaneously, “using” each other's results to ultimately detect methane emissions. Where the models interact is referred to as the nonlinear function:

- *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.

13. Method Performance

Method performance was evaluated across 3 rounds of controlled release testing.

- *Controlled Release Testing 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. Highwood Emissions Management (Highwood), uploaded OGI video files to the website at a time unknown to CleanConnect (CleanConnect was also unaware of the source of OGI video footage). The uploaded OGI video footage was then passed through the Clean Connect detection algorithm. After analyzing the OGI video, the user who uploaded it was automatically sent a reporting email which states if the uploaded video contained an emission. The OGI video footage was sourced from (Wang et al 2022)[1] and (Wang et al 2020)[2].
    - Results: 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.

[1] 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

[2] 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,

- *Controlled Release Testing 2*:
    - Methodology: 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. Releases were set off by an operator on site. A combination of emission rates and distances of the CleanConnect LeakFinder OGI camera to the emission source were tested. 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 with the notable exception that autonomous reporting went to Highwood and the operator in charge of testing prior to CleanConnect. The operator signed off on all testing results.
    - Results: 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*:
    - Methodology: Testing occurred at a centralized production facility in the Denver Julesburg basin. The goal of the testing was to evaluate detection capabilities at distances further than those testied in controlled release testing 1 and 2 and was conducted during the Alternative Approved Instrument Monitoring Method application process with The Colorado Department of Health and Environment (CDPHE). 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. 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. All testing result forms were signed off by the operator conducting testing and sent directly to CDPHE, afterwards, results were sent to Highwood and CleanConnect.

- Results: 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.

14. Pollution Prevention

The method does not require a specific pollution prevention protocol. No physical samples are collected, which avoids generating waste. Additionally, the method reduces regular site visits, reducing transportation-related emissions compared to traditional methods.

15. Waste Management

No physical samples or waste are generated in this procedure.