CALIFORNIA
AIR RESOURCES BOARD

Evaluation of Potential Performance Standards for Continuously Operating Emissions Detection Systems for Upstream Oil and Gas Production Sites in California

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Appendices are available in separate Adobe Acrobat files.

Acronyms

ADED – Advancing Development of Emissions Detection
AERMOD – American Meteorological Society/U.S. EPA Regulatory Model
BOARD or CARB – California Air Resources Board
CalGEM – Department of Conservation, Geologic Energy Management Division
CFR – Code of Federal Regulations
EDS – Continuously Operating Emissions Detection System
kg/h – Kilogram(s) per Hour
HARP – Hotspots Analysis and Reporting Program
HPZ – Health Protection Zone
LDAQ – Leak Detection and Quantification
LDAR – Leak Detection and Repair
LDRP – Leak Detection and Response Plan
LiDAR – Light Detection and Ranging Cameras

METEC – Methane Emissions Technology Evaluation Center

OEHHA – California Office of Health Hazard Assessment

OGI – Optical Gas Imaging Cameras

POD – Probability of Detection

QAPP – Quality Assurance Project Plan

QA/QC – Quality Assurance and Quality Control

REL – Reference Exposure Level

SB 1137 – California Senate Bill 1137, 2022

SCAQMD – South Coast Air Quality Management District

TAC – Toxic Air Contaminant

U.S. EPA – United States Environmental Protection Agency

I. Executive Summary

California Senate Bill 1137 (SB 1137) establishes a 3,200-foot health protection zone (HPZ) between oil and gas production facilities (also known as upstream facilities)[1] in California and sensitive receptors such as residences, schools, and hospitals. This legislation requires operators with a production facility or well with a wellhead within an HPZ to develop and implement leak detection and response plans (LDRP). Such plans will include the identification of a continuously operating emissions detection system (EDS) to rapidly detect target chemical constituents from leaks before emissions impact the surrounding communities. SB 1137 also requires the EDS to include an alarm system that effectively, immediately, and reliably alerts the operator when triggered. SB 1137 directs the California Air Resources Board (CARB or Board) to adopt regulations to set performance standards for the EDS.

This draft document provides the scientific and technical foundation for CARB staff's draft recommended EDS performance standards and procedures for setting site-specific alert thresholds that must be addressed in order to receive approval for the EDS in the LDRP. The recommendations outlined here aim to encourage reliable, rapid, and accurate detection of leaks before emissions impact surrounding communities, while allowing operators the flexibility to choose commercially available EDS that are suitable given facility-specific site conditions.

Technical factors evaluated by CARB staff include:

- Leak emission characteristics and frequency from California-specific and national measurement studies of oil and gas production facilities.
- Capabilities and limitations of traditional leak detection and repair (LDAR) methodologies.
- Capabilities and limitations of commercially available EDS technologies.
- Siting approaches for commercially available EDS technologies.
- Applicability and process for using air dispersion modeling to assess potential health impacts from leaks.
- Approaches for setting alert thresholds based on direct measurements of detection target constituent(s).

[1] Upstream facilities include production wells and production facilities, compared to midstream facilities such as pipeline networks, and downstream facilities such as refineries.

CARB staff's draft recommended minimum performance standards and threshold-setting procedures include:

- Continuously Operating Emissions Detection System (EDS) Definition: EDS must operate continuously (measurement resolution of one hour or less), provide automated alerts when detection targets exceed an alert threshold, and monitor meteorological conditions.
- Health Hazard Characterization: EDS can measure the toxic of highest concern, or, if circumstances allow, may measure methane as a surrogate in combination with site-specific chemical composition analysis to determine the ratio(s) of methane to the toxic of highest concern present in the natural gas in the production equipment at the facility.
- Air Dispersion Modeling of Potential Leaks: Operators must perform air dispersion modeling using the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) air dispersion model and follow California's Air Toxics "Hot Spots" Program guidance published by the California Office of Health Hazard Assessment to:
    - Calculate REL-level leak rates, which are the smallest leak rates from the production equipment monitored by the EDS that could cause the acute reference exposure level (REL) of the toxic of highest concern to be exceeded at a sensitive receptor within the HPZ;
    - Site EDS sensors or monitors; and
    - Set EDS alert thresholds.
- Alert threshold Determination: Operators may define EDS alert thresholds from air dispersion modeling results to ensure detection of leaks that could cause acute REL exceedances at sensitive receptors.
- EDS Siting: EDS must be sited to detect leaks that could impact sensitive receptors within 1 hour, based on the system's detection method. EDS meteorological sensor siting should, to the extent site-specific conditions allow, adhere to the specifications and guidelines that are specified in the United States Environmental Protection Agency (U.S. EPA) Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements.
- Establishing Baseline Conditions: EDS may consider variability in background concentrations due to meteorology, permitted emissions of the production equipment monitored by the EDS, and upwind sources so long as its sensitivity to detecting leaks is maintained.
- System Justification: LDRPs must justify EDS choice with documentation of performance capabilities, alerting capabilities, and deployment, operation, maintenance and calibration details.

- System Data Quality Assurance & Control: LDRPs must include a quality assurance project plan (QAPP). The QAPP is a formal document describing in comprehensive detail the necessary quality assurance (QA), quality control (QC), and other technical activities that must be implemented to ensure that the results of the work performed will satisfy the stated performance criteria. The QAPP components are divided into four classes: 1) Program Management, 2) Measurement/Data Acquisition, 3) Assessment and Oversight, and 4) Data Validation and Usability.

CARB staff assessed alternative regulatory options, including less stringent and more stringent alternatives. The less stringent alternative would reduce technical requirements, focusing on monitoring predominant upwind and downwind locations at facilities, without consideration of sensitive receptor locations. The more stringent alternative would require comprehensive sensor placement to ensure both direct equipment monitoring and monitoring of leak plumes transported towards sensitive receptors. The less stringent alternative was not recommended due to reduced effectiveness and diminished health protection. The more stringent alternative was not selected due to feasibility concerns, higher costs, and technological constraints.

The draft recommended performance standards in this document provide a balanced and scalable approach that is protective of community health, technically feasible with commercially available EDS, and implementable across California's diverse oil and gas production facilities and site characteristics. The recommended approach enables consistent application of monitoring requirements and improves regulatory certainty while allowing flexibility for operators and promoting innovation by EDS manufacturers.

This draft document, along with CARB staff's draft regulatory proposal for EDS performance standards and other draft technical documents, will be available at CARB's webpage, *Senate Bill 1137: Meetings, Workshops, Technical Reports, and Draft Rulemaking Documents*, for early public review and comment. After all technical, economic, and other rulemaking assessments are completed, the Board will conduct a public hearing to consider approving the regulatory proposal and supporting documents. The public hearing process includes additional opportunities for the public to provide input. In accordance with the Administrative Procedure Act, interested members of the public may present comments orally or in writing during the hearing and may provide written comments before the hearing.

II. Introduction & Background

California Senate Bill 1137 (SB 1137)[2] sets requirements for protecting public health by creating a minimum health and safety distance of 3,200 feet between sensitive receptors, which include residences, schools, childcare facilities, playgrounds, hospitals, or nursing homes, and an oil and gas production well or facility. These areas are designated HPZ. An estimated 3 million, or approximately 1 in 12 (~8%) California residents live within 3,200 feet of at least one active-producing oil and/or gas well (active oil and gas development) (Shonkoff et al., 2024; Ferrar, 2022). Compared to the overall California population, Hispanic, non-Hispanic Black, and non-Hispanic Asian communities, as well as populations of lower socioeconomic status, are more likely to live within 3,200 feet of at least one active-producing oil and/or gas well and live in areas with the highest density of oil and gas wells (Shonkoff et al., 2024; Ferrar, 2022).

SB 1137 requires that all operators with a production facility or wellhead within an HPZ to develop and submit a LDRP to the Geologic Energy Management Division (CalGEM) in the California Department of Conservation by July 1, 2028. By July 1, 2029, CalGEM, with the consultation and concurrence of CARB, must either approve the LDRP or provide notice of deficiencies. Operators must suspend all production activities on January 1, 2030, unless the approved LDRPs are fully implemented.

The statute does not mandate the use of specific monitoring technologies or detection methods. SB 1137 directs CARB to set performance standards by regulation for EDS. Operators can utilize EDS meeting the performance standards when included in an LDRP approved by CalGEM with CARB concurrence. Within the LDRP, operators must "identify the chemical constituents, such as methane and hydrogen sulfide, as well as potential toxics of highest concern in the region as identified by CARB or the local air district that will be detection targets for the EDS"[3]. SB 1137 requires the LDRP to include the identification of an EDS, selected by the operator, designed to provide for rapid detection of target chemical constituents to identify leaks before emissions impact the surrounding communities. SB 1137 also requires the EDS to include an alarm system that effectively, immediately, and reliably alerts the operator when triggered.

This draft document provides the scientific and technical foundation for CARB's recommended performance standards and procedures for setting site-specific alert thresholds for EDS at upstream oil and gas facilities. These draft recommendations are

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[2] *Senate Bill 1137 (Gonzalez, Stats. of 2022, Ch. 365; adding Public Resources Code Article 4.6 (commencing with Section 3280 to Chapter 1 of Division 3)). Legislative Counsel's Digest. Approved by the Governor: September 16, 2022. Filed with the Secretary of State: September 16, 2022. Published by the California Legislative Information: September 19, 2022. Accessed: January 22, 2025.*

[3] Public Resources Code section 3283(a)(1).

designed to make specific SB 1137's requirement for EDS to identify leaks before emissions impact the surrounding communities.

III. Objectives

The purpose of this document is to inform the development of regulatory performance standards for EDS at oil and gas production facilities or wells with wellheads subject to SB 1137. Specific objectives include:

- Identify and evaluate technical considerations relevant to the selection, deployment, and operation of EDS for leak detection;
- Identify procedures for setting alert thresholds that reflect site-specific health risks based on emission characteristics, proximity to sensitive receptors, and dispersion modeling;
- Identify minimum performance standards for EDS to allow and encourage reliable, rapid, and accurate detection of leak emissions that exceed site-specific alert thresholds;
- Identify documentation and siting requirements appropriate for a wide range of facility types and monitoring technologies;
- Evaluate alternative regulatory approaches and provide preliminary CARB staff recommendations with rationale.

IV. Technical Summary

A. Emissions to Ambient Air from Oil and Gas Production Facilities

Emissions to ambient air from oil and gas production facilities originate from a variety of sources and mechanisms. These include:

- Vented emissions, which are intentional releases that are normally permitted by a regulatory agency, from operations such as blowdowns[4], tank venting, or pneumatic controllers[5];
- Fugitive emissions,[6] which are leaks caused by faulty equipment or component failures; and

[4] Blowdowns are intentional gas emissions to depressurize equipment for maintenance or safety.

[5] Pneumatic controllers are devices used in oil and gas operations to automatically regulate process conditions (like pressure or level) using pressurized gas, often emitting gas during normal operation.

[6] The terms "leak" and "fugitive emissions" are used interchangeably in this document to describe the unintentional release of emissions.

- Combustion-related emissions, which consist of unburned hydrocarbons released from flares, compressor internal combustion engines, or other combustion sources (Lyon et al., 2016; U.S. EPA, 2009).

Storage tanks are a major contributor to both vented and fugitive emissions (Tyner et al., 2021; Ravikumar et al., 2020a). Vented emissions on uncontrolled tanks can occur through flashing losses when high-pressure fluids are transferred to atmospheric-pressure tanks, working losses during liquids transfer, and breathing losses during daily temperature and pressure fluctuations, while fugitive tank emissions may arise from malfunctioning control devices intended to prevent vented emissions or during loading and unloading operations (TCEQ, 2012).

SB 1137 requires operators to implement EDS at oil and gas production facilities located in HPZ to identify leaks before emissions impact the surrounding communities. These systems are not intended to alert operators of all emissions, as certain venting activities are permitted under facility operating conditions. Instead, EDS required by SB 1137 are specifically intended to identify leaks, which are caused by faulty equipment or component failures.

Multiple studies have measured emission rates at oil and gas production sites using bottom-up or top-down measurement methods. Bottom-up methods (Ravikumar et al., 2020a; Cusworth et al., 2021; Bell et al., 2017; Pacsi et al., 2019; Zimmerle et al., 2020a; Allen et al., 2013; Kuo et al., 2015, Eastern Research Group et al., 2011) use handheld tools like optical gas imaging (OGI) cameras, U.S. EPA Method 21 hydrocarbon analyzers, and Bacharach Hi Flow Samplers, to survey individual equipment components. These methods are effective at identifying and measuring small, localized leaks, but tend to miss or underestimate intermittent or large leaks (Xia et al., 2024a; Tyner et al., 2021; Ravikumar et al., 2020b). Additionally, it can be difficult to detect and measure emissions from elevated sources, such as tanks or flares, with hand-held detectors (Tyner, 2021). In contrast, top-down methods like those employed by Kunkel et al. (2023) and Duren et al. (2019) use aircraft or satellite-based sensors to detect emissions at the facility or regional scale. Top-down studies consistently identify large, often transient, emission events but generally have higher detection thresholds than bottom-up survey methods.

The differences between these two methods are also demonstrated by measurements at the same sites using professional handheld leak detection surveys (with OGI cameras and Bacharach Hi Flow Samplers) and aerial light detection and ranging (LiDAR) (Tyner et al., 2021). Tyner et al. (2021) compared emission detection methods at oil and gas facilities in British Columbia. Professional handheld leak detection surveys and aerial LiDAR surveys were conducted at the same sites, one year apart, to evaluate differences in detection capability and emission estimates. While handheld surveys identified many more individual emission sources – typically small leaks – they missed or underestimated elevated or large-volume emissions such as from tanks, unlit flares and compressor vent exhaust. The result was a large difference in total measured emissions: The aerial survey reported site-level methane emission rates up to 18 times higher than the handheld OGI survey at the same sites, identifying fewer but significantly larger sources.

Composite datasets of emission rates typical of upstream oil and gas production have been created by integrating measurements made by the top-down and bottom-up methods (Xia. et al., 2024a; Coburn et al., 2022). Xia et al. (2024a) developed a high-resolution methane emission rate distribution dataset by integrating top-down aerial data (with a 3 kilogram per hour (kg/h) detection limit) from Kunkel et al. (2023) across four major U.S. basins – Anadarko, Bakken, Eagle Ford, and Permian – with measurements from bottom-up studies (Ravikumar et al., 2020a; Cusworth et al., 2021; Bell et al., 2017; Pacsi et al., 2019; Zimmerle et al., 2020a; Allen et al., 2013; Kuo et al., 2015) to fill gaps in smaller emission rates. Emissions were categorized into general fugitives (small component-level leaks), tank emissions (tank-specific emissions often not detected in bottom-up surveys), and large emitters (non-tank sources with emissions exceeding 10 kg/hour(h)). Notably, tank emitters and large emitters exhibit significantly higher median emission rates than general fugitives (Table 1).

Table 1. Quartiles of methane emission rates for three emission categories (Xia et al., 2024b).

Emitter Category	25th Percentile Rate (kg/h)	Median Rate (kg/h)	75th Percentile Rate (kg/h)
General Fugitives	0.14	1.95	4.22
Tank Emitters	3.85	7.92	19.06
Large Emitters	13.10	18.11	32.02

Lyon et al. (2016) conducted aerial infrared camera surveys across more than 8,000 oil and gas well pads in seven U.S. basins (outside of California) to assess the prevalence and sources of large hydrocarbon emissions. Using imaging technology with an estimated detection limit of 4 to 11 kg/h, the study found elevated emissions at approximately 4% of sites, though this rate varied by basin. Over 90% of detected emissions originated from tank hatches and vents, identifying tanks as a dominant source of large emission events. Statistical models based on well pad and operator characteristics explained less than 15% of the variance in emission occurrence, suggesting that high-emission events are largely random and unpredictable, rather than tied to observable site attributes. The study found that the observed frequency of tank emissions was greater than the frequency expected if control systems were functioning properly.

Findings from California, though limited, follow similar trends to study results from other U.S. oil production regions. Duren et al. (2019) surveyed potential methane emitting infrastructure throughout California, including approximately 88% of oil and gas infrastructure across the state using aerial infrared imaging (detection limits of 2 to 10 kg/h) and found a heavy-tailed emission distribution, where 10% of sources were responsible for 60% of emissions. Spatially, 85% of upstream oil and gas production emission sources were in the southern San Joaquin Valley, 14% in Los Angeles and Ventura counties, and 1% in the Sacramento Valley. Many of these emission sources exhibited intermittent behavior, complicating detection with periodic inspection methods.

Community based organizations have conducted field investigations in California to identify and document emissions from oil and gas production facilities using handheld OGI cameras. Reports and video compilations from these efforts, such as those published in FracTracker Alliance's 2022 report[7] and a YouTube video playlist hosted by Earthworks[8], show emissions from active and idle wells, storage tanks, flares, and other infrastructure. These findings are often compiled into publicly available databases and submitted to local air quality agencies to support enforcement and policy discussions related to air pollution, community health, and climate impacts from oil and gas development.

California has launched a statewide satellite methane monitoring initiative funded by a $100 million state budget investment to purchase methane plume data collected by satellites, which supports detection and mitigation of large, localized methane emissions (CARB, 2025a). The program uses data from satellite-mounted sensors capable of detecting major (>100 kg/h) point-source plumes that may otherwise go undetected. Carbon Mapper, the third-party contractor for satellite data, posts any plumes they identify to their website after 30 days. CARB will share plume detection data as well as owner/operator response, if any, through its own centralized database and web portal in the future.

B. Periodic Leak Detection and Repair Methods Compared to Continuously Operating Emissions Detection Systems

Periodic manual leak detection and repair (LDAR) methods and EDS offer different strengths in detecting and managing leaks at oil and gas production sites. LDAR methods, when deployed on a periodic basis by trained operators, are effective at detecting small, component-level leaks (Zimmerle et al., 2020b; U.S. EPA, 2023). However, while these methods can detect component leaks with high probability during inspections, they may miss intermittent leaks and large leaks that occur between survey intervals. By contrast, higher-frequency monitoring with technologies that have less sensitive detection thresholds can match or exceed the overall emissions mitigation performance of periodic LDAR

[7] *FracTracker Alliance report webpage*.
[8] *Earthworks YouTube video playlist*.

surveys, due to their ability to rapidly detect large and/or intermittent leak events (U.S. EPA, 2024).

EDS are well-suited for detecting large or intermittent leaks, as they provide continuous site surveillance. For compliance with SB 1137, EDS must be capable of automatically alerting operators to the presence of leaks before leak emissions impact surrounding communities. Effective deployment of these systems requires careful consideration of site-specific factors that introduce uncertainty into rapid leak detection (NPC, 2024). These factors generally include, but are not limited to, meteorological variability, baseline process emissions from permitted operations, ambient background emissions from nearby sources such as agriculture or landfills, complex topography, and the presence of buildings or vegetation that can alter airflow (U.S. EPA, 2019; SCAQMD, 2024).

C. Commercially Available Continuously Operating Emissions Detection Systems

This section focuses on commercially available EDS suitable for continuous air monitoring at oil and gas production sites. The primary purpose of these EDS is to identify leaks near oil and gas production sites. Some systems simply measure the ambient detection target concentration (e.g., methane or total hydrocarbons) while others are also designed to estimate individual leak locations and emission rates, often referred to as leak detection and quantification (LDAQ) systems (NPC, 2024). However, confirming specific leaks still typically requires follow-up with handheld tools like OGI cameras or U.S. EPA Method 21 hydrocarbon detectors (NPC, 2024).

LDAQ EDS often quantify emissions by measuring concentrations of pollutants downwind of potential sources, where plumes have had time to develop and stabilize (NPC, 2024). These systems often use atmospheric dispersion modeling to estimate leak source locations and emission rates, but estimates have high uncertainty because modeling is complex and needs to address multiple sources of uncertainty — especially in complex terrain or near obstructions like buildings or vegetation (NPC, 2024). Compared to direct source-level measurements, LDAQ EDS emission rate estimates tend to carry greater uncertainty and may also exhibit systematic bias, meaning even long-term averaging of leak rate estimates may not yield accurate cumulative emissions estimates (NPC, 2024; Bell et al., 2023; Ilonze et al., 2024; Cheptonui et al., 2025). Such uncertainties in emission rate estimates can cause false positives (detecting leaks that are not there) or false negatives (missing actual leaks) (Bell et al., 2023; Ilonze et al., 2024; Cheptonui et al., 2025), which are particularly important in regulatory contexts such as California's SB 1137.

Non-LDAQ EDS types do not attempt to locate or quantify leak emission rates, but instead monitor for elevated concentrations of pollutants as indicators of abnormal emissions. For example, California regulations require continuous methane monitoring at underground natural gas storage sites, where alerts are triggered when concentrations exceed four times the established baseline value[9]. Similarly, fenceline monitoring systems around refinery sites in the South Coast Air Quality Management District (SCAQMD) and Bay Area Air Quality Management District include alerts that are triggered when toxic air contaminant (TAC) concentrations exceed applicable acute reference exposure levels (REL)[10].

All EDS use one or more sensors or monitors that may detect a specific hydrocarbon (e.g., methane, benzene), a broader range of hydrocarbons, and, less commonly, certain nonhydrocarbon species (NPC, 2024). These include, but are not limited to, point sensors, scanning or imaging monitors, and open-path monitors, and most systems incorporate analytical software to process measured data into actionable outputs such as alerts, emissions images, and concentration time series (NPC, 2024). While these outputs help operators decide on follow-up actions, many EDS still require human interpretation to distinguish between background variability or permitted emissions and leaks (NPC, 2024). Some systems rely on pre-established baseline conditions to distinguish leaks, while some scanning or imaging EDS may track and recognize known permitted emission patterns, and offer visual data for operator decision-making.

Despite growing availability, many of these EDS were developed within the last decade (NPC, 2024) and have undergone limited performance testing in real-world field conditions at oil and gas production sites (Day et al., 2024).

California oil and gas production sites vary widely in configuration and complexity (Figure 1). As a result, effective deployment of EDS across oil and gas production sites will likely require access to a diverse array of technologies. No single EDS design is optimal for all site types, and operators will need flexibility in selecting systems that address the unique monitoring challenges of each facility.

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[9] *California Air Resources Board Oil and Gas Methane Regulation Reporting Data and Monitoring Plans webpage*.

[10] *South Coast Air Quality Management District Rule 1180 Monitoring Plans webpage*.

Figure 1: Examples of oil and gas production sites within HPZs in California[11].

D. Standardized Performance Testing of LDAQ Continuous Monitoring Systems

Efforts to improve and standardize performance testing of LDAQ EDS have focused on developing third-party, independent testing protocols and testing facilities (Zimmerle, 2020c; METEC & TADI, 2025; Bell et al., 2021; TotalEnergies, 2025; NPC, 2024). These are important steps for ensuring unbiased evaluations of LDAQ EDS capabilities, especially given the regulatory and commercial pressures to reduce methane emissions from oil and gas production. Third-party testing – conducted by entities unaffiliated with EDS manufacturers – helps establish trust in performance claims by eliminating potential conflicts of interest.

[11] Sources: All images from Google Earth or Google Maps (2025).

The Methane Emissions Technology Evaluation Center (METEC) at Colorado State University, funded in part by the U.S. Department of Energy, has developed industry consensus-based testing protocols for continuous methane monitoring EDS[12]. METEC's original testing approach, called the Advancing Development of Emissions Detection (ADED) 1.0 protocol, used single-blind controlled release testing, in which EDS operators were unaware of the timing, location, and magnitude of releases. While rigorous, the ADED 1.0 protocol lacked certain features representative of real-world oil and gas production sites. In response, METEC, in collaboration with TotalEnergies Anomalies Detection Initiative, recently introduced the ADED 2.0 protocol (METEC & TADI, 2025) for use from 2025 onward, which incorporates a more realistic baseline emissions profile derived from METEC's Mechanistic Air Emissions Simulator model. This model simulates routine emissions, such as combustion slip and pneumatic venting, creating a more operationally realistic testing environment.

Under the ADED 2.0 protocol, EDS are typically given a two-week period to characterize the site's baseline emissions before fugitive releases are introduced over the course of an approximately three-month test. EDS vendors define their detection threshold and reporting frequency, and the test center evaluates system performance based on these parameters. Detection reports are categorized as true positives, false positives, false negatives, or true negatives, which are then used to generate probability of detection (POD) curves (probability of detection plotted against independent variables such as emission rate). Additional performance metrics include time-to-detection (i.e., how quickly does the EDS recognize a leak?) and time-to-alert (i.e., how quickly is an alert reported to the test center?), along with documentation of system installation time, uptime, maintenance needs, and sensor configurations.

Results from METEC ADED 1.0 testing through 2024 (Bell et al., 2023; Ilonze et al., 2024; Cheptonui et al., 2025) show that some EDS solutions can detect leak rates typical of general fugitive emissions at oil and gas sites (Table 1) with a 90% POD[13] (with one achieving a 0.5 kg/h 90% POD) (Table 2), while others exhibit significantly higher modeled 90% POD that exceed the scale of METEC's controlled releases (up to approximately 7 kg/h). For all EDS types, emission rate significantly affects POD, however scanning or imaging EDS were most affected, with a quasi-linear relationship between emission rate and POD. Quantification precision and bias vary widely between EDS, but all EDS have significant relative error in individual leak rate estimates (Table 2). The quickest detecting scanning or imaging EDS detected leaks more quickly than the quickest point sensor network EDS, but high performing point sensor network EDS have detected a greater proportion of smaller leaks than other EDS types. No open-path EDS have yet participated

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[12] *Colorado State University METEC webpage*.

[13] For ADED 1.0 testing, METEC suggested a definition for an EDS' method detection limit as the emission rate where 90% POD is achieved (Bell et al., 2023).

in published ADED protocol testing, although they have conducted ad-hoc testing at METEC.

Table 2. Results from best performing EDS (lowest 90% POD threshold) from ADED 1.0 Protocol Testing 2022 to 2024 (Bell et al., 2023; Ilonze et al., 2024; Cheptonui et al., 2025) by EDS type (METEC, 2024a; METEC, 2024b).

Leak Detection Metric	Point Sensor Network EDS	Scanning or Imaging EDS	Open-Path EDS
90% POD threshold	0.5 kg/h	5.5 kg/h	No Data
Percent of rate estimates within a factor of 2	75%	67%	No Data
Mean Detection Time	8.9 h	1.3 h	No Data
False Negative Rate	8%	49.4%	No Data
Percent of Leaks Located to Equipment Level	50.4%	89.5%	No Data

It is important to note that LDAQ EDS performance in active oil and gas production field settings tends to be worse than in controlled test environments like at the METEC test facility, as indicated by initial field-based controlled release studies (Day et al., 2024). As of the time of this document's writing, there is no publicly available dataset that combines EDS outputs with known emission rates from operating oil and gas production facilities. However, this is an area of active research.

E. Emissions Detection System Siting Strategies by System Type

Proper siting of EDS sensors or monitors is critical for an accurate assessment of potential emissions impacts associated with an oil and gas production facility (Day et al., 2024; U.S. EPA, 2019; SCAQMD, 2024). Common siting strategies vary depending on the EDS type, monitoring purpose, and the physical and operational constraints of the facility. In general, sensor placement is limited by site infrastructure, hazardous area classifications, and utility access (e.g., power or sunlight for solar-powered sensors) (Appendix A). Most EDS are not rated for hazardous zones and must be installed at a safe distance from production equipment (Appendix A). Additionally, roads, buildings, and other infrastructure may limit where EDS can be installed, requiring strategic planning to ensure adequate coverage and performance (Day et al., 2024; U.S. EPA, 2019).

1. Point Sensor Network EDS

Point sensor network EDS rely on wind transport to carry emissions from their source to a sensor before detection can occur. For methane leak detection at oil and gas production sites, sensor siting is typically guided by one of two strategies: optimization frameworks or empirical placement approaches (Jia et al., 2024; Metzger et al., 2024; Day et al., 2024; SCS, 2024). Optimization frameworks use historical meteorological data – often from on-site instruments or nearby weather station – combined with air dispersion modeling to simulate plume behavior and optimize sensor placement to meet performance metrics such as mean detection time (Jia et al., 2024; Metzger et al., 2024). Empirical placement approaches rely on heuristics, such as placing sensors based on prevailing wind directions and ensuring proximity to major sources (SCS, 2024) or placing sensors at the corners of a site (Day et al., 2024). Both strategies are typically intended for methane leak detection, with an emphasis on overall detection performance rather than focusing on rapid detection of leaks with potential to impact nearby communities. This emphasis on overall detection performance can cause delays in detecting leaks transported towards sensitive receptors. In contrast, a third approach – SCAQMD Rule 1180 is an example (SCAQMD, 2024) – focuses on achieving spatial coverage of plume transport from potential sources towards the surrounding community so that plumes are rapidly detected. This boundary-based strategy involves placing sensors along the facility perimeter where leak plumes may travel from the facility towards sensitive receptors. While all three strategies involve siting sensors to detect atmospheric transport of emissions, the first two are designed to support leak detection, quantification and localization without consideration of sensitive receptor locations, whereas the third is explicitly intended to rapidly detect leaks that could cause sensitive receptor impacts.

A subset of commercially available point sensor networks are designed to identify leaks at close proximity using intrinsically safe[14] sensors placed directly on or near specific equipment components, such as thief hatches on tanks (Honeywell, 2025; NevadaNano, 2025; SCS, 2025; Appendix A). CARB staff found no peer-reviewed studies that establish siting optimization frameworks for direct source measurement systems. Rather, system providers are the best resource for applicability for siting. In a typical example of a siting strategy, sensors are sited within 10m of equipment being monitored, with multiple sensors to cover different wind directions, placed roughly within the horizontal plane from which

[14] Under the Occupational Safety and Health Administration's (OSHA) adoption of the National Electrical Code, oil and gas production equipment is typically located in Class I hazardous locations where flammable hydrocarbon gases and vapors may be present. An intrinsically safe sensor meets OSHA requirements for placement in Class I locations and is designed so that under normal or fault conditions, the electrical energy is too low to ignite the flammable gases or vapors.

leaks are most likely to originate (Honeywell, 2025). These systems are advantageous at facilities where there is complex airflow or limited open space, particularly for pinpointing leaks at individual components. However, because they are typically limited to monitoring emissions at or near specific sources, they have the potential to miss leaks that travel towards sensitive receptors without being intercepted by a sensor. More individual sensors may be needed to achieve plume transport coverage from all potential leak sources on equipment. Without a broader spatial coverage strategy that accounts for offsite plume transport, these systems may not reliably detect leaks before impact to sensitive receptors. Some providers intend their close-proximity sensors to be used in combination with facility boundary sensors to aid in leak source identification (SCS, 2025).

2. Open-Path EDS

Open-path EDS operate by transmitting a laser beam across an open-air path and measuring the absorption of specific wavelengths by target gas molecules, allowing determination of the average gas concentration along the beam (U.S. EPA, 2018). These systems typically span tens to hundreds of meters and provide linear coverage across a facility rather than point-based measurements (Appendix A). While CARB staff found limited peer-reviewed literature establishing siting optimization frameworks for open-path systems, two deployment strategies are commonly used for monitoring oil and gas facilities: boundary-based coverage (e.g., fenceline monitoring) and radial plume mapping (LongPath, 2025).

In the boundary-based approach – SCAQMD Rule 1180 fenceline monitoring is an example (SCAQMD, 2024) – beam paths are placed along the facility perimeter to detect emissions transported offsite towards nearby communities. Radial plume mapping arranges multiple beam paths in intersecting geometries, often radiating from a central location, to track plume movement and estimate emission rates (U.S. EPA, 2006; LongPath, 2025). This approach typically uses one transmitter that pans between different beam paths. This approach supports leak localization within a facility but may not adequately capture offsite transport towards sensitive receptors unless combined with boundary coverage. Although open-path systems offer complete linear coverage of beam paths, they may fail to detect leaks before community impacts occur if beam placement does not ensure adequate spatial and temporal coverage of transport pathways from sources to sensitive receptors.

3. Scanning or imaging EDS

Most scanning or imaging EDS, such as fixed OGI or LiDAR cameras, are deployed to monitor broad areas of a facility rather than specific points. CARB staff found no peer-reviewed literature establishing siting-optimization frameworks for these systems. Rather, system providers are the best resource for siting approaches. Typically, they are sited to maximize visual coverage of high-priority equipment, and to be within a maximum detection distance of potential sources at a customer-specified detection threshold (Kuva, 2025;

Honeywell, 2024a; Honeywell, 2024b; SLB, 2025). Many systems can pan across multiple viewing angles, and siting strategies should consider both the number of directions scanned and the dwell time at each direction to support rapid leak detection (Appendix A). Proper deployment requires verifying that all potential emission sources fall within the line of sight and detection range of at least one camera. While scanning or imaging EDS offer greater spatial coverage than other EDS types, they still require careful siting and scan cycle consideration to ensure reliable and timely detection.

4. Meteorological Systems

SB 1137 requires that EDS include a new, or use an existing, meteorological system that is appropriately sited. The purpose of the EDS (and the meteorological system) required by SB 1137 is to provide rapid detection of leaks that could impact sensitive receptors within the HPZ. The meteorological system should thus provide meteorological data useful in detecting and locating leaks. Meteorological system siting guidance varies considerably depending on the purpose of the monitoring program and the quality objectives for the data.

U.S. EPA regulatory modeling guidance (U.S. EPA, 2000; U.S. EPA, 2008) prescribes rigorous siting standards to ensure that meteorological measurements are representative of the site and comparable between different sites, which is suitable for regulatory applications such as air dispersion modeling and compliance determinations with federal programs, including National Ambient Air Quality Standard compliance and New Source Review air quality analyses. Under U.S. EPA regulatory modeling guidance, key meteorological system siting guidance includes placement of meteorological towers at a distance at least ten times the height of the nearest obstruction, mounting wind sensors at least 10 meters above ground level, and placing temperature, pressure, and humidity sensors at standard near-surface and elevated heights with proper shielding and ventilation. Additionally, the selected meteorological system location(s) must reflect the surface roughness and land use of the monitored area and account for complex terrain, coastal, or urban microclimates, with full documentation required in a quality assurance plan.

Alternative approaches used in siting meteorological systems for commercially available EDS prioritize deployment flexibility, spatial coverage, and practical constraints over strict representativeness and comparability objectives for the measured meteorological data. The resultant data is used for leak identification rather than for regulatory modeling purposes.

Commercially available EDS often include integrated meteorological systems, particularly EDS that detect leak plumes downwind of the source (LongPath, 2025; SLB, 2025; Honeywell, 2025). Meteorological sensor siting approaches vary by EDS model. Some EDS include meteorological sensors collocated with each concentration sensor, while other EDS have one meteorological sensor for the monitored site. In general, if a commercially available EDS has an integrated meteorological system, the EDS analytics are designed to utilize the meteorological data provided by that system in performing leak source localization and quantification. Few of the meteorological systems included with commercially available EDS would meet U.S. EPA guidance (U.S. EPA, 2000; U.S. EPA, 2008), and the inclusion of an additional meteorological system compliant with U.S. EPA guidance may be infeasible at many oil and gas production facilities and may not directly improve leak localization performance of the EDS.

F. Setting Alert Thresholds

1. Alert Threshold Overview

In accordance with SB 1137, EDS deployed for compliance purposes must be capable of alerting operators before leak emissions from a production facility impact nearby communities. As described in section II of this document, SB 1137 establishes a health protective zone extending 3,200 feet from sensitive receptors and defines sensitive receptors. The leak rates at which adverse health effects could occur at sensitive receptors are highly site-specific. The proportion of toxic air contaminants (TACs) in oil and gas leak emissions varies significantly across oil and gas production facilities in California (CARB, 2025b). Two key factors drive this variability: (1) the composition of the wellstream, and (2) the type of equipment from which the emission originates (CARB, 2025b). As a result, a leak of a given magnitude may present very different health hazards depending on these variables.

Additional factors influencing health risk include proximity of sensitive receptors, the range of meteorological conditions that occur at the site, and site topography. Specific weather patterns – such as temperature inversions, low wind speeds, and shallow boundary layers – increase the likelihood of community-level exposure by limiting dispersion and trapping pollutants near the ground surface (Halliday et al., 2016; Pusede et al., 2014). These conditions are particularly common in regions like the San Joaquin Valley and South Coast Air Basin due to their geographic and atmospheric characteristics (CARB, 2018; CARB, 2024)

2. Composition of Potential Emissions from a Site

The chemical composition of fugitive emissions is a critical factor for evaluating the potential health risks of leaks from oil and gas production facilities. Methane is released from nearly all operational equipment and is commonly detected alongside non-methane volatile organic compounds and TACs. Its prevalence makes methane a potential surrogate for identifying fugitive emissions, and allowances for this were included by the California Legislature within SB 1137 (CARB, 2025b).

However, the proportion of methane to TACs can vary widely based on geography, equipment type, and site operations. For example, the weight-based methane-to-benzene ratio can differ by as much as a factor of 1,000 across components (CARB, 2025b). This variability complicates efforts to use a universal methane-to-TAC ratio in health-based monitoring and alarm systems.

To address this, the use of surrogate gases should be supported by site-specific gas composition testing of production equipment that will be monitored by the EDS (CARB, 2025b). Gas composition test results can be used to identify the toxic of highest concern at the site, and to calculate ratio(s) of methane to the toxic of highest concern (CARB, 2025b). The ratio(s) can then be used in calculating methane concentration-based alert thresholds of the EDS.

3. Air Dispersion Modeling of Leaks

Air dispersion modeling is a widely accepted tool in health risk assessments and can account for multiple variables, including emission source characteristics, local meteorology, terrain, leak locations, and sensitive receptor proximity. Addressing these variables is critical to setting appropriate alert thresholds to protect the health of sensitive receptors. Air dispersion modeling can be used to simulate TAC concentrations at sensitive receptors caused by potential leaks from specific equipment, throughout the range of meteorological conditions that occur at the site, in order to establish EDS alert thresholds that are protective of sensitive receptors. Air dispersion modeling has been widely used in California for health risk assessments under regulatory programs.

Modeling tools and guidance are publicly available through California's Air Toxics "Hot Spots" Program (Assembly Bill 2588). The California Office of Health Hazard Assessment (OEHHA) has published specific guidance for using air dispersion modeling in risk assessments, including model selection, meteorological data requirements, source characterization, receptor grid setup, and land use considerations (OEHHA, 2015). Additional modeling resources are provided by CARB and air districts, including AERMOD-ready meteorological data and terrain files for use across the state.

AERMOD[15] is commonly used to simulate pollutant dispersion from stacks, open pits, and fugitive sources, and is suitable for near-field dispersion modeling (≤50 km). AERMOD is a steady-state dispersion model and is applicable for a wide range of terrain and meteorological conditions. Guidance from U.S. EPA (40 CFR Part 51, Appendix W[16]) and OEHHA (OEHHA, 2015[17]) outlines procedures for selecting and justifying alternative models, where applicable. The Hotspots Analysis and Reporting Program[18] (HARP) is a CARB-developed modeling software suite designed to provide a publicly available air

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[15] *U.S. EPA AERMOD webpage*.

[16] *U.S. EPA Guideline on Air Quality Models*.

[17] *OEHHA Air Toxics Hot Spots Program Guidance Manual*.

[18] *CARB Hot Spots Analysis and Reporting Program*.

dispersion modeling and health risk assessment tool. Within HARP, the Air Dispersion Modeling and Risk Assessment Tool incorporates the AERMOD model.

When used in conjunction with OEHHA's acute RELs[19] for TACs identified as air toxics of highest concern[20], air dispersion modeling can support estimation of REL-level leak rates for potential leak sources. A REL-level leak rate represents the lowest leak rate that would be expected to exceed an acute REL at a sensitive receptor if the emission occurred continuously throughout the modeled time period. An acute REL is a health-protective air concentration limit developed by OEHHA to prevent noncancer health effects from short-term (one-hour) exposure to a TAC (OEHHA, 2015). The limit is set at a level below which no adverse noncancer health effects are expected to occur from infrequent one-hour exposures, even in sensitive individuals such as children, the elderly, or those with preexisting conditions (OEHHA, 2015). While OEHHA also develops 8-hour and chronic RELs for TACs, these represent the concentration at which no adverse noncancer health effects are anticipated in sensitive individuals with repeated 8-hour (e.g., workday) or continuous exposure over a significant fraction of a lifetime (OEHHA, 2015).

Air dispersion modeling results provide spatially resolved estimates of ground-level pollutant concentrations across the modeled area, which would include the monitored production site and the surrounding HPZ. These concentration values provide the concentration gradients between emission sources and sensitive receptors, offering insight into how pollutant levels attenuate with distance and terrain. By correlating EDS-measured concentrations at sensor locations with modeled concentrations at downwind sensitive receptor locations, it is possible to set concentration-based alert thresholds that will trigger when the acute REL of the toxic of highest concern may be exceeded at sensitive receptors.

4. EDS-Specific Alert Thresholds

Once REL-level leak rates and concentration gradients have been modeled, that information can be used for setting EDS alert thresholds. Alert thresholds may vary depending on the characteristics of the monitoring technology, detection method, and siting of sensors or monitors at a site.

Because of the wide variability in equipment types, detection technologies, and site layouts, a uniform or prescriptive alert threshold may not be suitable for all facilities. Thresholds could instead be based on three main factors:

- The estimated REL-level leak rates for the site,

[19] *OEHHA RELs webpage*.
[20] *CARB staff report (CARB, 2025b), Draft: Evaluation of Methane as a Surrogate to Identify Leaks and Associated Toxic Emissions from Crude Oil and Natural Gas Production Wells and Production Facilities*.

- The spatial distribution of potential ground-level concentrations across the site resulting from these leak rates, and
- The detection principles and deployment strategy of the selected EDS.

Examples of how alert thresholds are commonly defined in practice, depending on the EDS type, include:

- Scanning or Imaging EDS: These systems may use OGI or LiDAR cameras. OGI camera-based systems may use image-based analytics to estimate leak presence, concentration, or rate, and are sometimes combined with open-path or point sensors to measure concentration near the source. LiDAR cameras, by contrast, do measure concentration. Alert thresholds for these types of EDS are commonly expressed as: leak detection flags without thresholds, estimated emission rates, and measured concentration.
- Open-Path EDS: These systems measure path-averaged gas concentrations and may estimate emission rates. Alert thresholds for this type of EDS are commonly expressed as: estimated emission rates and measured concentration.
- Point Sensor Network EDS: These systems detect gas concentrations at fixed locations and may include rate estimation and leak localization algorithms. Alert thresholds for this type of EDS are commonly expressed as: estimated emission rates and measured concentration.

G. EDS Quality Assurance and Quality Control

To meet the objective of SB 1137, EDS should generate monitoring data of sufficient quality to provide rapid detection of leaks that could impact sensitive receptors within the HPZ. To ensure that the EDS continues to produce data of sufficient quality, the EDS must be implemented with quality assurance and quality control (QA/QC) measures that are appropriate for the detection technology, the monitoring environment, and the intended use of the data. The QA/QC measures should ensure that data is valid, accurate, and timely for leak detection and localization purposes.

U.S. EPA quality system requirements for regulatory monitoring (U.S. EPA, 2002; U.S. EPA, 2016) prescribe rigorous QA/QC standards to ensure that measurement data are accurate, precise, and comparable between sites and over time. These requirements are typically documented in a Quality Assurance Project Plan (QAPP) and include specifications for calibration procedures, data verification and validation processes, use of certified standards, routine performance checks, and documentation of any deviations. Regulatory-grade QA/QC requirements often include:

- Regular calibration of instruments against traceable standards at defined intervals.

- Routine audits (both performance and systems) to verify instrument operation and data quality.
- Preventative maintenance schedule to maintain instrument performance.
- Defined criteria for data completeness, with minimum data capture percentages required for compliance.
- Procedures for identifying, flagging, and replacing invalid or suspect data.
- Comprehensive documentation of QA/QC activities and corrective actions.

Commercially available EDS often incorporate automated QA/QC features and sensors or monitors designed for low maintenance with factory pre-calibration (Appendix A). These design elements can reduce the operational burden of QA/QC while helping to maintain data quality. Commercial EDS manufacturers typically integrate automated QA/QC features into their systems (LongPath, 2025; SLB, 2025; Honeywell, 2025), such as built-in calibration cells, self-diagnostic routines, connectivity and system health checks, and automated data validation algorithms. These EDS may flag anomalous readings, account for environmental interferences, and apply automated corrections in near real-time.

While commercially available EDS often integrate automated QA/QC features that can reduce operational effort and support reliable performance, these features alone are not sufficient to ensure long-term data quality. The LDRP should still define and implement comprehensive QA/QC procedures that address all aspects of data quality management, including manual oversight where appropriate. In particular, the LDRP should explicitly identify key data quality indicators, specify acceptable performance thresholds, and establish methods for tracking and documenting corrective actions to maintain confidence in leak detection results over time.

V. Draft Recommendations

A. Recommended Performance Standards for Continuous Monitoring Systems

CARB staff considered the peer-reviewed literature and other information identified in section VII References, including a review of commercially available monitoring technologies, and evaluated several alternatives before identifying the following draft recommendations for minimum performance standards for EDS to be implemented at oil and gas production facilities. These recommended requirements are designed to ensure that EDS implemented by operators have the capability to provide reliable, rapid, and accurate detection of leaks before emissions impact surrounding communities, as required by SB 1137. Further, such requirements will improve regulatory certainty for operators by identifying the minimum requirements upon which to base CalGEM and CARB review and approval criteria for LDRPs and help maintain a level playing field amongst operators and manufacturers. The recommendations are designed to be applicable across a range of technologies and site conditions, while providing a clear basis for evaluating long-term EDS effectiveness in meeting SB 1137 requirements.

CARB staff is releasing this early draft document with draft recommendations (this section) and a draft, scoping-level alternatives evaluation (section VI) to help support the solicitation of public input for additional alternatives that can ensure full compliance with SB 1137 requirements for EDS. CARB invites the public to submit questions, comments, suggestions for alternatives, and information about any of the topics discussed in this draft document, to CARB's SB 1137 Implementation email address, *SB1137implementation@arb.ca.gov*. See section VI for more information about additional assessments and opportunities to provide input before the Board considers a regulatory proposal for adoption.

Summary of Recommendations

- Continuously Operating Emissions Detection System (EDS) Definition: EDS must operate continuously (measurement resolution of one hour or less), provide automated alerts when detection targets exceed an alert threshold, and monitor meteorological conditions.
- Health Hazard Characterization: EDS can measure the site-specific toxic of highest concern determined through site-specific natural gas chemical composition analysis, or, can measure methane as a surrogate in combination with site-specific chemical composition analysis to determine the ratio(s) of methane to the toxic of highest concern.
- Air Dispersion Modeling of Potential Leaks: Operators must perform air dispersion modeling using the AERMOD air dispersion model and following California's Air Toxics "Hot Spots" Program guidance published by the California Office of Health Hazard Assessment to:
    - Calculate REL-level leak rates, which are the smallest leak rates from the production equipment monitored by the EDS that could cause the acute REL of the toxic of highest concern to be exceeded at a sensitive receptor within the HPZ;
    - Inform siting of EDS sensors or monitors; and
    - Inform EDS alert threshold determination.
- Alert Threshold Determination: Operators may define EDS alert thresholds from air dispersion modeling results to ensure detection of leaks that could cause acute REL exceedances at sensitive receptors.
- EDS Siting: EDS must be sited to detect leaks that could impact sensitive receptors within 1 hour, based on the system's detection method. EDS meteorological sensor siting should, to the extent site-specific conditions allow, adhere to the specifications

and guidelines that are specified in the U.S. EPA Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements.

- Establishing Baseline Conditions: EDS may consider variability in background concentrations due to meteorology, permitted emissions of the production equipment monitored by the EDS, and upwind sources so long as its sensitivity to detecting leaks is maintained.
- System Justification: LDRPs must justify EDS choice with documentation of performance capabilities, alerting capabilities, and deployment, operation, maintenance and calibration details.
- System Data Quality Assurance & Control: LDRPs must include a quality assurance project plan (QAPP). The QAPP is a formal document describing in comprehensive detail the necessary quality assurance (QA), quality control (QC), and other technical activities that must be implemented to ensure that the results of the work performed will satisfy the stated performance criteria. The QAPP components are divided into four classes: 1) Program Management, 2) Measurement/Data Acquisition, 3) Assessment and Oversight, and 4) Data Validation and Usability.

1. Definition of a Continuously Operating Emissions Detection System

CARB staff recommends the following definition for EDS required by SB 1137:

> A *Continuously Operating Emissions Detection System (EDS)* means a system of one or more sensors or monitors that operates automatically to detect and report the presence of target chemical constituents in ambient air from leaks or fugitive emissions of oil and gas production equipment. This definition of an EDS includes any associated hardware, software, and analytics used to detect fugitive emissions. An EDS shall be capable of continuous air monitoring (measurement resolution 1 hour or less), shall be capable of providing time-resolved measurement data, and shall include automated alerting functionality that enables rapid operator response to leak emission events. An EDS shall include an alarm system. An EDS shall be programmed to automatically trigger the alarm system and generate and send a notification as soon as technically feasible, but no later than 15 minutes after a target chemical constituent identified in the approved LDRP exceeds an applicable alert threshold. An EDS shall be programmed to automatically generate and send a notification to the operator in the event of a sensor or monitor failure. An EDS shall have sufficient sensors to continuously measure meteorological conditions at the facility including wind speed, wind direction, ambient temperature, ambient pressure, and relative humidity with the ability to continuously record measurements. An EDS shall have the ability to store at least 5 years of continuous instrument data and the ability to generate hourly, daily, weekly, monthly, and annual reports.

This definition is intended to be *technology neutral*, allowing for the use of a wide range of commercially available systems (e.g., point sensor network EDS, open-path EDS, scanning or imaging EDS), provided they meet the operational requirements described above.

2. Methods to Account for Health Hazard Potential of Leaks

CARB staff recommends that operators be required to select one or more of the following methods to account for the chemical composition of potential leaks (Figure 2):

- Deploy an EDS that measures the toxic of highest concern identified in the LDRP (e.g., benzene).
- Deploy an EDS that measures methane as a surrogate detection target. Conduct site-specific gas composition testing to establish site-specific ratios of methane to the toxic of highest concern identified in the LDRP.

CARB staff provides draft recommendations for a list of potential toxics of highest concern, gas composition testing methods, and site-specific toxic of highest concern calculation in a separate draft report (CARB, 2025b).

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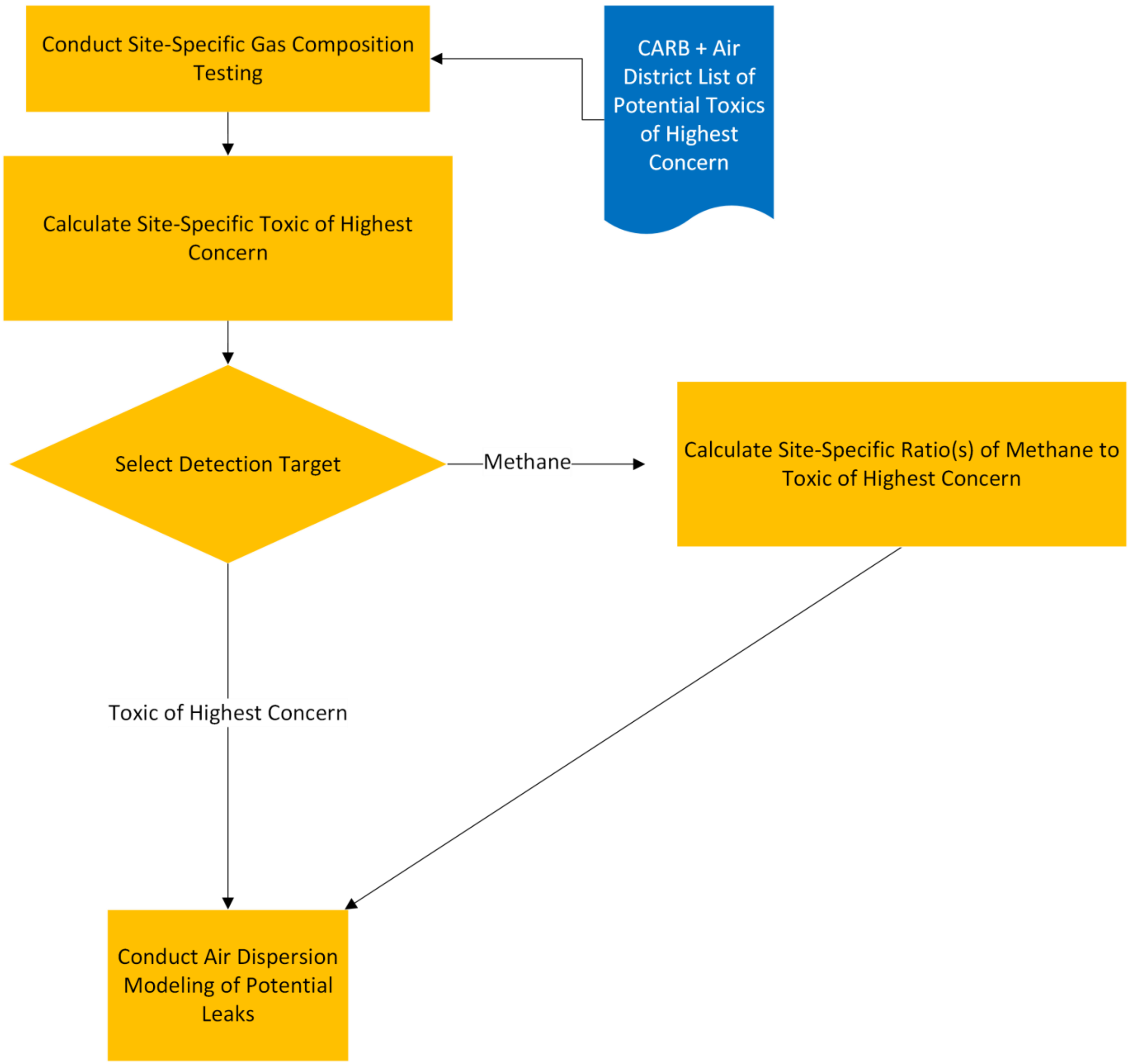
Figure 2: Flow chart outlining the two recommended methods to account for the health hazard potential of a production facility for use in air dispersion modeling.



3. Air Dispersion Modeling to Determine REL-level Leak Rates

CARB staff recommends a requirement that air dispersion modeling be used to assess the potential for leaks from the facility to impact sensitive receptors within the HPZ (Figure 3). This air dispersion modeling should:

- Calculate the REL-level leak rates, defined as the minimum leak rates from production equipment monitored by the EDS, that would result in the maximum 1-hour ground-level concentration of the toxic of highest concern identified in the LDRP exceeding its acute REL[21] at a sensitive receptor within the HPZ (acute RELs have a one-hour exposure averaging time). Modeling should account for the health hazard posed to sensitive receptors by the spatial distribution and chemical composition of all production equipment monitored by the EDS.
- Document the spatial distribution of potential ground-level concentrations across the site resulting from REL-level leak rates.
- Follow OEHHA's Hot Spots Program guidance (OEHHA, 2015).
- Use the AERMOD air dispersion model.
- Result in a modeling report that documents the modeling methods, input parameters, receptor grid configuration, source parameters and locations, meteorological data, terrain data, pollutant concentration results, and isopleth maps. Include in the report a table of the source-specific REL-level leak rates and a sensitivity analysis of the source parameters. Modeling input and output files should be retained by the operator and made available upon request from the CARB Executive Officer.

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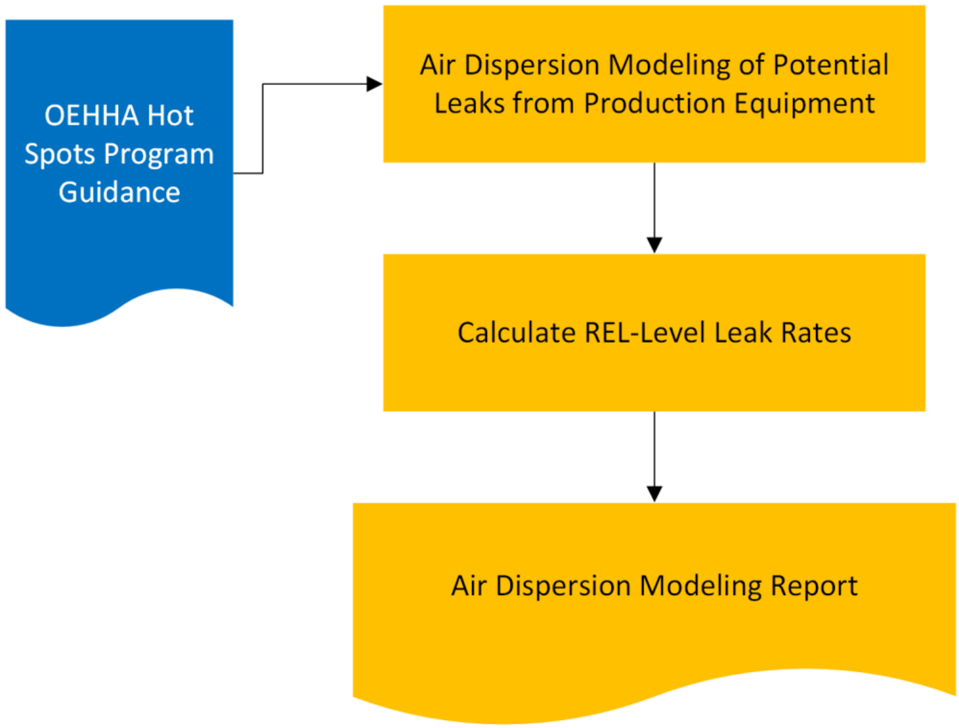
[21] See the CARB staff report, *Draft: Evaluation of Methane as a Surrogate to Identify Leaks and Associated Toxic Emissions from Crude Oil and Natural Gas Production Wells and Production Facilities*, October 14, 2025, for a detailed discussion of the use of acute RELs of toxics of highest concern.

Figure 3: Flow chart outlining the air dispersion modeling process recommended for leak detection and response plans required by SB 1137.



4. Siting of EDS

CARB staff recommends a requirement that EDS be sited so leaks that may impact sensitive receptors within the HPZ can be detected within one (1) hour (Figure 4). EDS should be sited to meet the following objectives, as applicable:

- If production equipment monitored by the EDS has the potential to leak at the REL-level leak rate(s):
  - For EDS that scan or image leaks (e.g., fixed OGI or LiDAR camera EDS), the EDS should monitor and report measurements for each piece of production equipment monitored at least once an hour.
  - For EDS that detect leak plumes downwind of a source (e.g., point sensor network EDS, open-path EDS), the EDS should be sited to achieve detection on an hourly basis of at least 90% of leaks that exceed the REL-level leak rate(s) from the production equipment monitored by the EDS that are transported in the direction of sensitive receptors within the health protection zone.
- If production equipment monitored by the EDS does not have the potential to leak at the REL-level leak rate(s):

  - The EDS should have sufficient sensors to measure upwind and downwind concentrations of the detection target throughout the facility, with at least one sensor located in a predominant upwind location and at least one sensor located in a predominant downwind location.
- For monitoring an individual well, EDS siting should include at minimum one sensor located within 10 meters of the well, positioned predominantly downwind under prevailing wind conditions, with no obstructions to airflow between the sensor and the well.

CARB staff recommends that meteorological monitoring sensor siting should, to the extent site-specific conditions allow, adhere to the specifications and guidelines that are specified in the U.S. EPA Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements (March 24, 2008).

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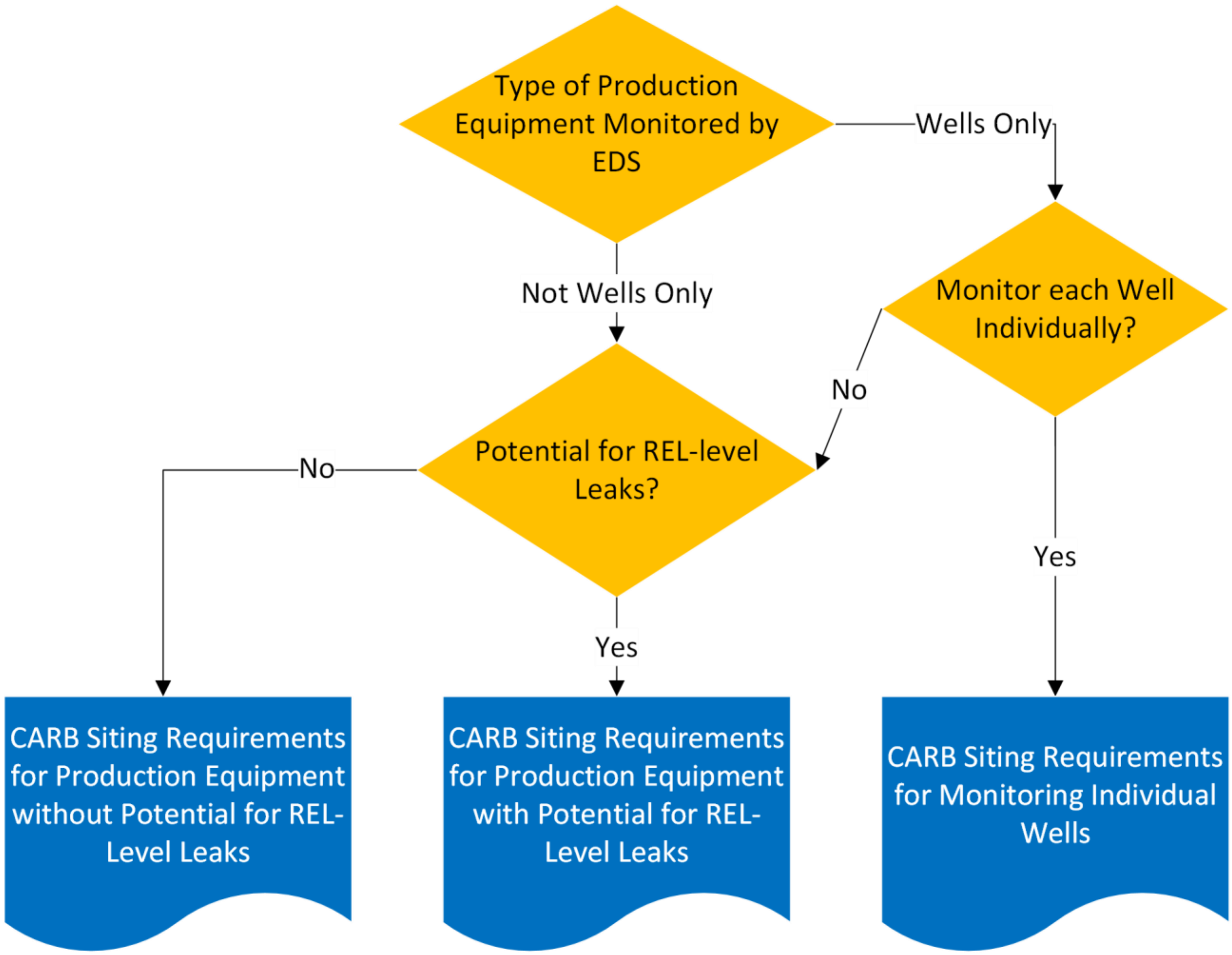
Figure 4: Flow chart outlining the EDS siting process recommended for leak detection and response plans required by SB 1137.



5. EDS Alert threshold Basis

CARB staff recommends a requirement that EDS alert thresholds be set to detect leaks that may cause an acute REL to be met at a sensitive receptor within the HPZ. alert thresholds should meet the following requirements:

- Alert threshold(s) should be defined in terms of measured concentration.
- If methane is used as a surrogate detection target, the ratios of methane to toxic of highest concern identified with site-specific gas composition testing should be used to calculate alert threshold(s) based on methane concentrations.
- Alert threshold concentration values should be quantifiably resolved from temporal variation in the baseline detection target concentration.

- Alert threshold value(s) should be set using one of the following options:
  - Set alert threshold(s) to achieve detection of leaks exceeding REL-level leak rates from production equipment monitored by the EDS using the spatial distribution of potential ground-level concentrations across the site resulting from these leak rates.
  - Set alert threshold(s) at the acute REL of the toxic of highest concern, or methane-based equivalent concentration.

CARB staff recommends that EDS be required to achieve and maintain performance characteristics necessary to accurately detect alert threshold concentrations during typical operation, including:

- Alert threshold averaging time should be one (1) hour or less.
- The EDS should account for uncertainty in measured values in determining if an alert threshold has been exceeded.
- EDS should have a minimum detection limit at least three (3) times less than the alert threshold(s).
- EDS should have a manufacturer-documented precision within ±15% at the alert threshold concentration(s).
- EDS sensor(s) or monitor(s) should be performance tested at least once per quarter to verify field precision is maintained within ±25% at the alert threshold concentration(s).

While LDAQ EDS include analytics capable of estimating emission rates, these estimates involve substantial uncertainty (Table 2). Therefore, CARB staff recommends that alert thresholds for SB 1137 leak detection be defined in terms of concentration measurements rather than solely on estimated or calculated leak rates.

6. Establishing Baseline Conditions

CARB staff recommends a requirement that EDS that detect leak plumes downwind of a source establish baseline conditions for the detection target. EDS that scan or image leaks (e.g., fixed OGI or LiDAR cameras) should be excluded from this requirement. The process used to establish baseline conditions should adhere to the following requirements:

- The EDS should collect 12 months of valid measurements before establishing baseline detection target concentration(s).
  - Measurements should be representative of normal operating conditions of the production equipment monitored by the EDS. Periods when maintenance

activities, malfunctions or leaks occur should be excluded from baseline calculation.

  - Days with incomplete data (5 or more hours of missing measurement values) should be excluded.

- An interim baseline value should be calculated on a 30-day rolling basis to include all valid hourly measurements collected to date, until baseline detection target concentrations have been established.
- Measurements should be made using the same averaging time as the EDS alert threshold(s).
- Baseline detection target concentration(s) should be calculated as the arithmetic mean of baseline measurements.
- The methodology used by the EDS to establish baseline conditions should be documented in the LDRP.

7. EDS Justification, Documentation & Standard Operating Procedures

CARB staff recommends a requirement that LDRPs include justification for the selected EDS. Supporting documentation should demonstrate the EDS's ability to detect emissions at or below the alert threshold(s) as deployed. Specifically, the justification should include:

- A description of the EDS's detection capabilities and thresholds, data resolution, detection and averaging times, spatial resolution, automatic alerting capabilities and timing, power source and backup systems, and known operational constraints (e.g., performance limitations under certain wind speeds, temperature ranges, precipitation, requirement for daylight operation, or specific maintenance intervals).
- A discussion of how the EDS is appropriate for the site-specific emission sources, meteorology, and facility layout. This discussion should include relevant performance data and validation results, where validation results may include controlled release testing results or other field-based evaluations demonstrating that the system performs as expected under operating conditions representative of oil and gas production facilities.

8. EDS Data Quality Assurance & Quality Control

CARB staff recommends a requirement that LDRPs include a QAPP covering all aspects of data QA/QC necessary to maintain EDS data integrity, including for the meteorological monitoring system. At a minimum, QAPPs should include the following elements:

- Roles and Responsibilities – identify the personnel or teams responsible for QA/QC procedure implementation.

- Methods and Procedures – specify how data will be collected, measured, or analyzed.
- Quality Objectives and Data Quality Indicators – define standards for data validity, completeness, or other measures of acceptable data quality for the EDS.
- Equipment Care – describe maintenance and calibration plans for the EDS.
- Data Handling – explain how information will be stored, verified, and updated.
- Problem Resolution – detail how errors or issues will be flagged, investigated, and corrected.
- Documentation – identify how activities, changes, and corrective actions will be recorded.

B. Purpose and Rationale for Each Recommended Performance Standard

This section describes the purpose and rationale for CARB staff's draft recommendations for performance standards for EDS used to comply with SB 1137. As described in section V.A, these recommendations are designed to ensure that EDS implemented by operators have the capability to provide reliable and rapid detection of leaks before emissions impact surrounding communities. Each requirement addresses a specific aspect of EDS performance — such as system definition, health risk evaluation, and sensor siting — to help ensure that monitoring systems are technically sound, appropriately applied, and capable of meeting SB 1137 requirements.

1. Definition of an EDS

Purpose: To establish a clear, consistent definition of what constitutes an EDS under SB 1137, with adequate specificity to ensure statute requirements are met.

Rationale: The term "continuous monitoring" is used in a variety of regulatory and technical contexts and can vary in interpretation. Due to various interpretations for the definition of continuous monitoring in existing regulations (e.g., 40 CFR 60.5417b, 17 CCR 95668(h)(4)), there may be ambiguity about which systems are appropriate for SB 1137 use. Establishing a definition will provide sufficient clarity to comply with the statutory and regulatory requirement for reliable and rapid detection of leaks before emissions impact surrounding communities. This definition is beneficial in two ways. First, it would allow operators the flexibility to select from a variety of commercially available EDS types that meet performance requirements for site-specific conditions. Second, it provides EDS manufacturers with a benchmark definition that they can consider when developing or updating their systems.

2. Methods to Account for Health Hazard Potential of Leaks

Purpose: To ensure that EDS deployed to comply with SB 1137 are capable of detecting emissions attributed to leaks before they impact surrounding communities, it is necessary to account for the chemical composition of those emissions — not just the total mass emission rate (sum of all chemical species).

Rationale: CARB staff's review of available literature (CARB, 2025b) and databases found that the chemical composition of oil and gas production facility emissions are not uniform in composition. Leak emission composition varies widely based on geography, equipment type, and site operations, and leak emissions may contain varying levels of TACs. For example, factors such as wellstream characteristics and equipment type influence the presence and concentration of TACs like benzene. The potential health impact of a leak can vary substantially depending on the site-specific and equipment-specific chemical composition of the emission. The toxicity of a leak is not always proportional to the total mass emission rate (sum of all chemical species) of the leak (CARB, 2025b), thus conducting site-specific gas composition testing or measuring TACs directly helps ensure appropriate siting and alert thresholds.

3. Air Dispersion Modeling to Determine REL-level Leak Rates

Purpose: Determine REL-level leak rates at which emissions from production equipment could exceed acute health-based thresholds at sensitive receptors within the HPZ, and model ground-level concentrations of detection targets for use in setting alert thresholds.

Rationale: REL-level leak rates are health-protective because modeling identifies the potential health hazard of leaks under the range of meteorological conditions that historically occur near the facility. Air dispersion modeling provides a scientific, data-driven method for estimating how emissions disperse and accumulate at a given location. Using air dispersion modeling, operators can model emissions from each relevant source and determine the minimum leak rates that would lead to a potential exceedance of an acute REL. An acute REL is a health-protective air concentration limit developed by OEHHA to prevent noncancer health effects from short-term (one-hour) exposure to a TAC (OEHHA, 2015). The limit is set at a level below which no adverse noncancer health effects are expected to occur from infrequent one-hour exposures, even in sensitive individuals such as children, the elderly, or those with preexisting conditions (OEHHA, 2015). Using standardized modeling approaches with established meteorological data enables consistency and transparency, such as using CARB or local air district supplied meteorological data. Modeling ground-level concentrations at each EDS detection location and preparing a modeling report to include with the LDRP provides the necessary technical information for EDS siting and alert threshold determination. This documentation also supports verification during CalGEM and CARB's LDRP review and approval process.

4. Siting of EDS

Purpose: Confirm that the EDS, as deployed, is positioned effectively to detect leak emissions before they impact sensitive receptors.

Rationale: The performance of any air monitoring system, including the EDS described in this document, is closely tied to where and how it is installed. Site-specific factors such as meteorology, terrain, obstructions, and proximity to sensitive receptors and potential leak sources all influence whether emissions will be detected before impact occurs. OEHHA acute RELs have a concentration averaging time of one (1)-hr. An acute REL is a health-protective air concentration limit developed by OEHHA to prevent noncancer health effects from short-term (one-hour) exposure to a TAC (OEHHA, 2015). The limit is set at a level below which no adverse noncancer health effects are expected to occur from infrequent one-hour exposures, even in sensitive individuals such as children, the elderly, or those with preexisting conditions (OEHHA, 2015). While OEHHA also develops 8-hour and chronic RELs for TACs, these represent the concentration at which no adverse noncancer health effects are anticipated in sensitive individuals with repeated 8-hour (e.g., workday) or continuous exposure over a significant fraction of a lifetime (OEHHA, 2015). Therefore, acute impact to sensitive receptors from a TAC present in a leak can begin with one (1)-hr and accordingly EDS must be sited to rapidly detect leaks that may cause acute impacts to sensitive receptors within one (1)-hr.

Peak pollutant concentrations caused by a leak of a given magnitude often occur during stable, low wind conditions when pollutants can build up and drift in any direction, highlighting the importance of complete or adequate spatial coverage (SCAQMD, 2024). Point sensors measure at a single point, so narrow pollutant plumes may pass between point sensors and impact sensitive receptors before detection if sensors are not sited close enough together to achieve adequate spatial coverage (SCAQMD, 2024). Open-path monitors, by contrast, can provide complete boundary coverage if sited along all boundaries between potential leak sources and sensitive receptors. Scanning or imaging monitors can achieve adequate spatial coverage of an area of a facility rather than a facility boundary because they directly identify leaks at their source.

5. EDS Alert threshold Basis

Purpose: Identify allowable approaches to setting alert thresholds that alert operators of emissions that may impact sensitive receptors within the HPZ.

Rationale: There are multiple approaches used for setting alert thresholds for the types of commercially available EDS that might be used SB 1137, which broadly include emission rate thresholds, concentration thresholds, and leak detection flags without thresholds. However, not all of these approaches are appropriate for reliably detecting leak emissions before they impact sensitive receptors within the HPZ. There are commercially available EDS

(Appendix A) designed to estimate leak emission rates in addition to identifying leaks and/or measuring detection target concentrations; however, the accuracy of these estimates is not sufficient to reliably identify when leaks are above a threshold rate, with at best 75% of estimates within a factor of 2 of the true rate in controlled release testing (Table 2). Therefore, alert thresholds should not be defined in terms of leak rates. Concentration measurements are directly comparable to concentration-based reference exposure levels (e.g., acute RELs). Using ground-level concentration results from air dispersion modeling to set alert thresholds is a health protective approach that accounts for the health hazard posed by a leak under worst-case meteorological conditions at the facility.

6. Establishing Baseline Conditions

Purpose: Identify allowable approaches to establishing the baseline conditions at the monitored facility of the detection target.

Rationale: Fluctuations in baseline detection target concentrations from meteorology, upwind sources, and permitted emissions can cause false alerts in EDS that detect leak plumes downwind of a source. Establishing baseline concentration value(s) for the EDS helps account for site-specific variability not caused by leaks. Requiring Operators to follow a standard approach to establishing baseline conditions helps ensure EDS sensitivity to leaks is maintained and facilitates LDRP review by CalGEM and CARB.

7. EDS Selection Justification and Documentation

Purpose: Provide supporting evidence that the selected EDS, as deployed, will be capable of reliably detecting leak emissions at or below the REL-level leak rates before impact to the surrounding community.

Rationale: EDS vary widely in design, detection capabilities, and environmental stability. Requiring operators to justify their choice of system, and to provide supporting documentation based on the performance standards recommended by CARB staff, demonstrates that the system is appropriate for the site's emission sources, meteorology, and facility layout. This also facilitates LDRP review by CalGEM and CARB and helps verify that the system will perform as expected given site-specific conditions.

8. EDS Quality Assurance and Quality Control

Purpose: QA/QC measures are necessary to track, maintain, and verify the quality of EDS data over time. These measures support consistent data collection, handling, and equipment performance.

Rationale: Quality control and quality assurance procedures help maintain the functionality and data quality of EDS ensuring that data are actionable and appropriate for notification and follow-up action. Data quality indicators for the EDS, including the meteorological system, routine checks, calibration, and maintenance are necessary to identify performance deviations and correct them promptly. Documentation of these procedures in the LDRP facilitates review by CalGEM and CARB.

Applying QA/QC procedures helps preserve the validity, completeness, and reliability of EDS data so that it remains suitable for rapid leak detection and reporting. Monitoring data quality indicators, including routine or automated QC checks, calibration, and equipment maintenance, enables early identification of performance issues and timely corrective actions. Documenting these procedures, indicators, and corrective processes in a QAPP within the LDRP provides a clear record for review by CalGEM and CARB and supports effective data quality management.

VI. Potential Alternatives

CARB staff considered several alternative approaches to the draft recommended EDS performance standards outlined in section V, and consolidated them into two categories for this draft, scoping-level alternatives evaluation. The less stringent alternative would reduce technical requirements, focusing on monitoring predominant upwind and downwind locations at facilities, without consideration of sensitive receptor locations. The more stringent alternative would require comprehensive sensor placement to ensure both direct equipment monitoring and monitoring of leak plumes transported towards sensitive receptors. CARB staff has not yet identified an alternative to the draft recommendations in section V that would be less burdensome and equally effective in achieving SB 1137 requirements for EDS. CARB staff is releasing this early draft document with a draft, scoping-level alternatives evaluation to help support the solicitation of public input for additional alternatives that can ensure full compliance with SB 1137 requirements for EDS. CARB staff invites the public to submit questions, comments, suggestions for alternatives, and information about any of the topics discussed in this draft document, to CARB's SB 1137 Implementation email address, *SB1137implementation@arb.ca.gov*.

CARB staff will conduct an additional evaluation of alternatives as part of the formal rulemaking process that will include alternatives suggested by the public, along with an analysis of cost impacts and health benefits of each alternative. The draft recommendations and scoping-level alternatives described herein are subject to change based on the results of the alternatives evaluation conducted for the rulemaking. After all technical, economic, and other rulemaking assessments are completed, the Board will conduct a public hearing to consider approving the regulatory proposal and supporting documents. The public hearing process includes additional opportunities for the public to provide input. In accordance with the Administrative Procedure Act, interested members of the public may present comments orally or in writing during the hearing and may provide written comments before the hearing.

A. Less Stringent Alternative

Under a less stringent approach, the primary difference would be that EDS can achieve adequate spatial coverage of a facility by including at least one sensor in a predominant upwind location and at least one sensor in a predominant downwind location in relation to the facility, with all sensors capable of continuously recording detection target concentration measurements within the ambient concentration range. This arrangement is intended to provide a basic comparison of air quality conditions entering and leaving the facility and does not require consideration of sensitive receptor locations.

B. More Stringent Alternative

This more stringent approach requires comprehensive sensor placement to ensure both direct equipment monitoring and monitoring of leak plumes transported towards sensitive receptors. Sensors must be installed on each piece of production equipment, as well as in locations that provide adequate spatial coverage along boundaries between the equipment and sensitive receptor areas to detect leaks transport towards sensitive receptors within 1-hr. This configuration is intended to maximize spatial coverage to rapidly detect all leaks at the facility.

The equipment-mounted sensors have alert thresholds set to rapidly identify leaks that exceed the leak thresholds specified in the California Oil and Gas Methane Regulation (COGMR) or applicable air district LDAR rules. These thresholds ensure prompt detection of leaks that trigger repair requirements regardless of the health hazard posed to sensitive receptors.

Boundary coverage sensors are set to alert if 1-hr average measured detection target concentrations indicate an exceedance of the acute REL for the TAC of highest concern at the site. This requirement provides a health-protective trigger designed to safeguard sensitive receptors, regardless of whether the leak is detected by equipment-mounted sensors.

C. Rationale for Not Recommending These Alternatives

CARB staff does not recommend adoption of either the less or more stringent alternatives to the recommended EDS performance standards under SB 1137.

The *less stringent alternative* reduces spatial coverage of potential leak plumes, increasing the likelihood of missed or delayed detection. With a minimum requirement for one upwind and one downwind sensor, the system may not capture leaks during variable wind conditions, complex terrain flows, or stable conditions with low or no wind: situations in which plumes can drift in any direction. The alternative also does not directly account for the location of sensitive receptors, which may experience elevated TAC concentrations even when sensors do not register an alert threshold exceedance.

The *more stringent alternative* maximizes spatial coverage by requiring sensors on every piece of production equipment and along boundaries between facilities and sensitive receptors, ensuring that all leaks are rapidly detected, including those that may not pose a direct health hazard to sensitive receptors. Direct equipment monitoring allows rapid identification of leaks exceeding COGMR or applicable air district LDAR thresholds, while boundary sensors provide additional protection by alerting at concentrations above the acute REL for the toxic of highest concern. However, the requirement to monitor the boundary may be infeasible at many facilities due to site layout or access limitations. This approach does not allow for site-specific selection of an appropriate EDS, and it entails higher costs for equipment, installation, and maintenance.

The draft recommended performance standards in section V provide a balanced and scalable approach that is protective of community health, technically feasible with commercially available technologies, and implementable across California's diverse oil and gas production facilities and site characteristics. The recommended approach enables consistent application of monitoring requirements and improves regulatory certainty while allowing flexibility for operators and promoting innovation by EDS manufacturers.

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VIII. Appendices

Appendix A – Review of Commercially Available Continuously Operating Emissions Detection System Technologies Designed for us at Oil and Gas Production Sites

Appendix B – Review of Existing Oil and Gas Related Rules and Regulations with Continuous Monitoring and/or Leak Detection and Repair Requirements

Appendices are available in separate Adobe Acrobat files.