White Paper

Qube Technologies Continuous Monitoring Probability of Detection

Highwood Emissions Management

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Technical white paper

Qube Technologies Continuous Monitoring Probability of Detection:
Results from independent single-blind controlled release testing

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Executive Summary

Continuous monitoring (CM) is emerging as a promising solution for rapid detection of methane leaks (i.e., fugitive emissions) at oil and natural gas facilities. Despite rapid innovation in recent years, each CM solution is unique and requires independent verification of performance in the field. We report on independent single-blind controlled release testing performed to evaluate the detection performance of the Qube Technologies Emission Platform.

Highwood Emissions Management (Highwood), an independent consultant, administered 306 controlled releases at emission rates ranging from 0.1 to 1.38 kg/h at a controlled release testing facility in Alberta, Canada. Releases were conducted for sensors positioned at 50, 75, and 100 m from the emission source and under a broad range of temperatures, wind speeds, and wind directions. Qube was blind to timing of releases and emission rates. All results were submitted autonomously by email to Highwood.

Results show that, under average wind conditions, the Qube Solution detects > 50% of 1 kg/hr releases within 40 minutes at up to 75 m distance. Our analysis predicts detection probabilities of > 90% at all distances for emission rates of 2 kg/h. Our analysis suggests that both wind direction and speed can have a marked impact on detection performance, and that this impact is amplified at larger distances.

Our findings suggest that the Qube Solution should detect > 90% of emissions in high-emitting basins, based on typical site-level emission rates common in the peer-reviewed literature. This study highlights the effectiveness of the Qube Solution in immediately (< 40 minutes) detecting medium and large sized leaks with a high degree of certainty. Future work will evaluate localization and quantification performance.

Introduction

Natural gas is an important transition fuel due to its economic viability compared to emerging renewable technologies and its reduced net atmospheric impact compared to other fossil fuels.[1] However, the primary constituent of natural gas is methane, a potent greenhouse gas that accounts for approximately 20% of global climate forcing.[2] As reliance on natural gas increases, so has an awareness of the methane emissions associated with its production in the oil and gas industry. Unintentional leaks, or fugitive emissions, are a prominent source of methane emissions and can be difficult to locate and quantify. Emerging fugitive emissions regulations are leading to a surge in innovation in methane detection and quantification technologies.[3]

Until recently, the primary means of monitoring for fugitive methane emissions has been handheld technologies such as Optical Gas Imaging (OGI) cameras.[4] When used correctly, OGI cameras have low detection thresholds and are intuitive for technicians to use.[5] Handheld Leak Detection and Repair (LDAR) methods are administered periodically. Typically, depending on the regulations, these inspections are separated by at least a month, but more commonly a quarter to a full year. On average, as survey frequency declines, leaks emit for longer and pose a greater concern for safety, climate, and revenue from natural gas sales. Continuous monitoring (CM) has therefore emerged to detect leaks more quickly.

Dozens of CM solutions have emerged to offer LDAR services. However, as a novel approach, the performance of each CM solution must be rigorously evaluated using independent, single blind controlled release testing. Only by developing an understanding of the performance capabilities of CM systems can industry and regulators have confidence in them as a complement to close-range OGI. To date, this understanding has remained very limited, and each CM solution differs considerably.

Here, we report on the independent evaluation of the detection performance of the Qube Solution. From February to May 2022, Highwood Emissions Management administered a series of blinded controlled releases with the goal of defining the probability of detection of the Qube Solution. The testing accounted for wind speed and direction, emission rate, and distance from source to sensor. Results highlight the capabilities of the Qube Solution and the role it can play in methane emissions monitoring

Methodology

The Qube Solution

The Qube Solution is a network of fixed sensors designed to detect, locate, and quantify methane emissions in real-time. The technology consists of three components; (i) an Industrial Internet of Things (IIoT) device that measures gas concentration and environmental data and transmits it to the cloud (henceforth, 'Qube Devices'), (ii) a cloud-based platform that records and analyzes data received by the IIoT device, and (iii) a web-based user dashboard that aggregates critical insights generated by the analytics platform and identifies the remedial actions that need to take place by repair teams.

The technology provides continuous measurement of multiple gas concentrations and local meteorological conditions at each sensor node. The data from each sensor at a particular facility is unified in a cloud-based dashboard providing early detection of leaks through continuous monitoring.

A typical deployment at a facility involves installing three to five devices around the perimeter of the facility. As the technology relies on wind to transport the gas to the sensors, an analysis is performed to determine the optimal device placement at each facility. This involves scraping wind data from nearby municipal weather stations and identifying potential emissions sources at the facility to understand where gas is likely to disperse. Devices are then placed in these emissions hotspots ensuring adequate coverage around the facility.

Algorithms have been developed which use gas concentration and wind data collected by an anemometer at each sensor location to locate and quantify emissions in real-time. The algorithms use data from each of the fixed sensors deployed at the site in a two-step process whereby emissions sources are first located and then quantified. By deploying sensors around the facility and measuring wind at each location the algorithm accounts for emissions which originate onsite versus those that originate from offsite.

Testing facility setup

Experiments were performed at the Qube Technologies Controlled Release Testing Facility (CRTF) located in Bighorn No. 8 (Alberta, Canada), a district located between Calgary and Banff National Park. Fifteen Qube Devices were installed at the facility at 50m, 75m and 100m "steps" away from the release source with five devices deployed at each distance. Empirical CRTF wind data were used to establish a prevailing wind direction and guide the placement of Qube Devices on the downwind side of CRTF as illustrated in **Figure 1**. Emissions source and Qube Devices were set up approximately 2m above ground level.

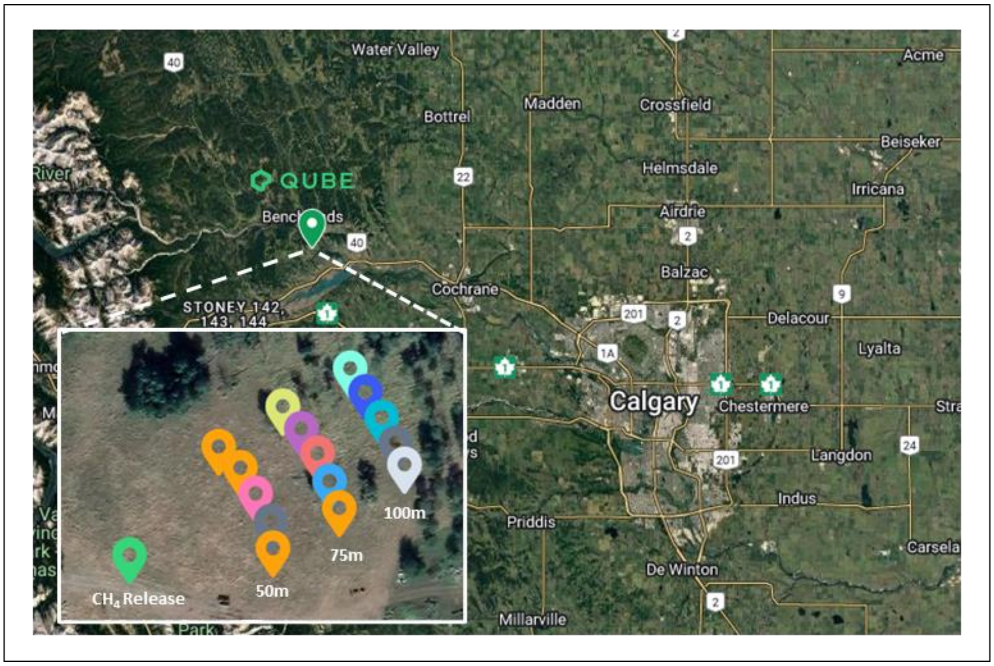

Figure 1 - Qube Technologies CRTF location (Bighorn No. 8, AB). Inset shows the release source (green) and sensors arrangement at 50m, 75m and 100m from it.

All releases were performed using one of three remote controlled mass flow controllers (MFCs) at a single release point. Controlled releases were performed from 24 February to 10 May 2022 with a total of 29 days of active measurement. Qube Technologies set up the devices and Highwood Emissions Management designed the methane release schedule and the controlled release rates and initiated the releases remotely. Qube Devices autonomously push data to the cloud and issued hourly detection reports to Highwood via email.

Experiment design

Testing protocols were developed to guarantee that release occurrence, timing, emission rate, and environmental conditions were only known by Highwood and not by Qube Technologies staff. Highwood remotely activated all controlled releases. Highwood also compiled testing results by processing automated alert data (received via an email system) and ancillary data (wind speed and direction data pulled from the Qube Solution cloud-based platform).

Probability of detection was calculated as a function of emission rate, distance from source to sensor, wind speed, and wind direction. Emission rates ranged from 0.10 kg/h up to 1.38 kg/h. Each release consisted of 40 minutes of steady-state methane discharge fixed at the release rate being tested, followed by 20 minutes of “non-release” to ensure the air was clear for the following release. We refer to the 1-hour period of release and non-release as the release window. A detection at any point within the release window was considered a true positive. Typically, 15-20 release windows were set off in succession around timed MFC auto-shutoffs implemented at CRTF for safety purposes.

A total of 306 releases were performed across all tested conditions. An overview of the tested release rates and the count of releases at each rate is provided in **Table 1**.

Table 1 - Releases overview

Release Rate (kg/h)	Number of Releases
1.38	75
1.00	47
0.50	71
0.20	60
0.10	53

Performance at different distances was evaluated using the email alerting system. For each release window an email alert classifying the release window as detected or not was sent to Highwood for each distance (50m, 75m and 100m). Each Qube Device was fitted with an anemometer which uploaded wind speed and direction data to the cloud over the course of the study. Because wind direction can only be averaged over very short time spans due to the 0-360° degrees nature of the data, a wind favourability index was used to characterize wind direction as a single data point for each release window. The wind favourability index, ranging from 0 to 1, is the "directness" of the methane plumes path towards the Qube Devices. **Figure 2** illustrates the directions and their associated wind favourability scores, each individual wind direction measurement from the anemometer is assigned a wind index score. For each release window, wind speed and wind favourability index were averaged for the first 40 min, which was the period that methane was being released. Averaging across the first 40 minutes, as opposed to the whole hour, was chosen because all true positive detections occurred within the first 40 minutes of the release window. Releases were performed with wind speeds ranging from 1 to 19 m/s and ambient temperature ranging from -14°C to 13°C.

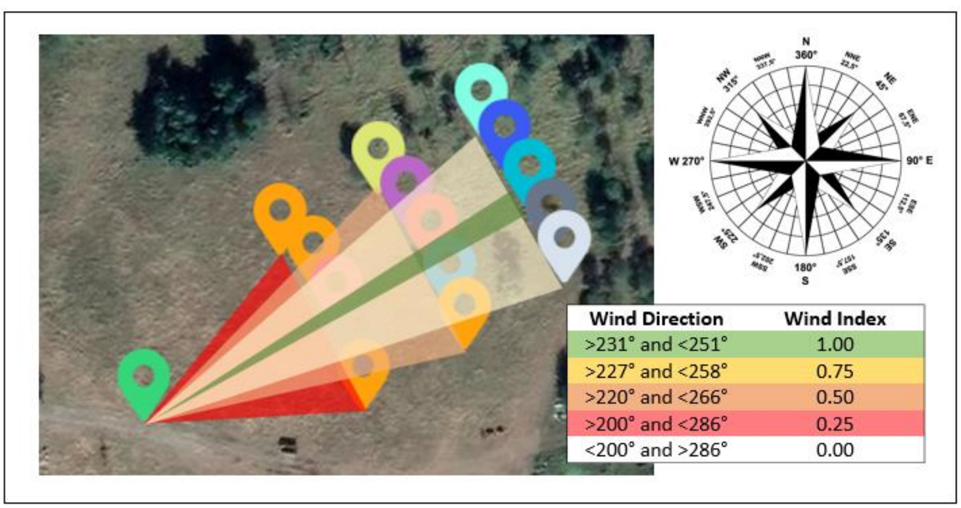

Figure 2 - Wind favourability index

Results

Probability of detection

Probability of detection is often depicted as a function of emission rate and other predictor variables with a probability ‘curve’ or a ‘surface’. The S-shaped Sigmoid curve is the most common approach. At very low emission rates that are well below the sensitivity of a given solution, the probability of detection approach 0 (left tail of the S). The other side of the S should approach 1, meaning that detection is almost certain.

To create a probability of detection curve, a logistic regression model was constructed using all independent variables: release rate, distance, wind speed, and wind index (represented as a wind favourability index value). Although distance could be thought of as a categorical variable (one of 50m, 75m or 100m) it was incorporated into the model as a continuous variable.

The logistic regression model was created using Python and the scikit-learn library. Interaction terms and higher order polynomial terms were not incorporated into the final model as their inclusion reduces model interpretability and was found to result in only minimal model performance improvement. The model can be represented by the Sigmoid function:

$$p(detect) = \frac{1}{1 + e^{-(\beta_0 + \beta_{Wi} \cdot X_{Wi} + \beta_{Ws} \cdot X_{Ws} + \beta_{RR} \cdot X_{RR} + \beta_d \cdot X_d)}}$$

Where:

X_{Wi} = Wind favourability index

X_{Ws} = Wind speed (m/s)

X_{RR} = Release rate (kg/hr)

X_d = Distance (m)

Populating the β coefficient terms with values extracted from the final logistic regression model produces the Sigmoid function:

$$p(detect) = \frac{1}{1 + e^{-(1.189 + 2.314 \cdot X_{Wi} - 0.257 \cdot X_{Ws} + 3.465 \cdot X_{RR} - 0.037 \cdot X_d)}}$$

Due to the inherent challenges with visualizing a probability of detection surface based on 4 dimensions (features), wind speed and wind index values representative of “moderately favourable / average conditions” were assigned to their respective values in the sigmoid function. This allows for a visualization of three, 1-dimensional probability of detection curves for each tested distance with release rate as the only manipulated variable.

Determining the representative wind values for moderately favourable conditions was done by qualitatively assessing cross-scatter plots of wind speed and wind favourability index at the largest release rate of 1.38 kg/hr. The largest release rate was used as detections at this rate are the most likely, and as such the impact of the wind speed and direction can be more easily assessed. The cross-scatter plots are shown in **Figure 3**.

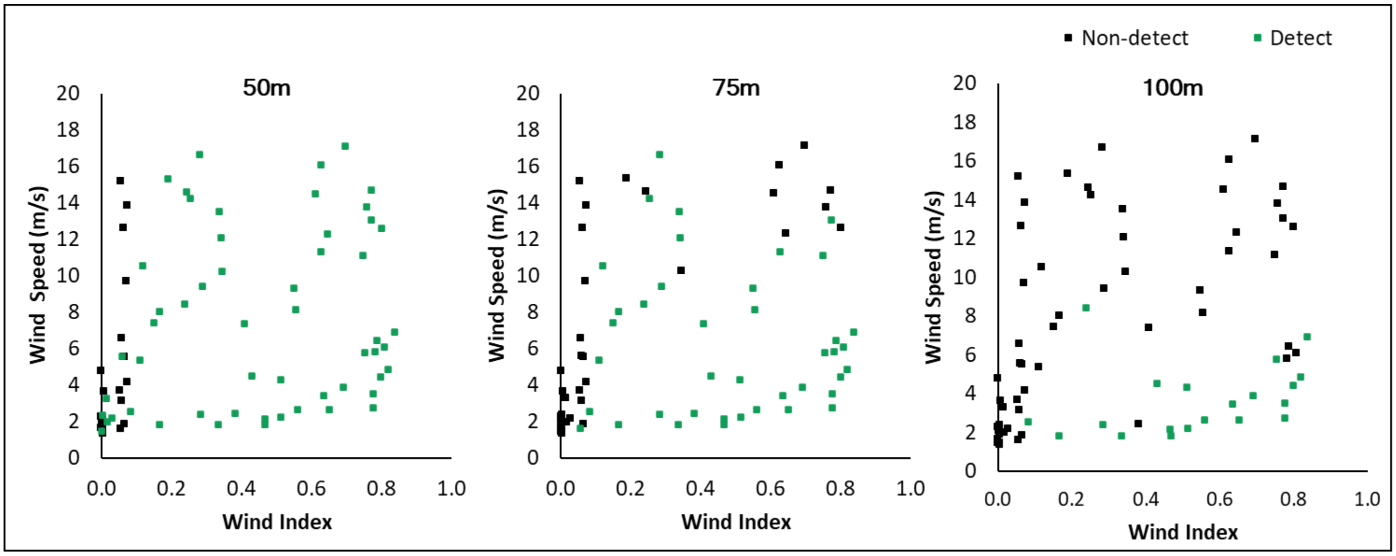

Figure 3 - Scatterplots correlating wind speed and favourability index with detection performance. Plots were constructed using 1.38 kg/hr under the assumption that at the higher release rates the winds effects on performance can be more easily identified.

At 50m, only when the wind index is extremely poor are releases not detected, wind speed does not appear to be a factor. At 75m, some releases under faster wind speeds are now being missed. This trend becomes clearer at 100m where all releases during wind speeds greater than 6 m/s were not detected. The role of wind index is less clear, however, at the 100m distance, 15 releases were detected when the wind index was greater than 0.4 while only 5 were detected when the wind index was less than 0.4.

We conclude that for the range of releases and distances evaluated, a wind index of approximately 0.4 and wind speeds between 2 m/s and 6 m/s represent the window of "average" conditions required for successful emission detection. "Ideal" conditions would see wind index values near 1.0.

The probability of detection curves shown in **Figure 4** were created by passing values of 0.4 and 6 m/s to the wind favourability and wind speed parameters respectively in the sigmoid function, allowing an investigation into only distance and release rate. Probability of detection values were calculated by passing a range of release rates from 0 to 4 kg/hr to the releases rate parameter.

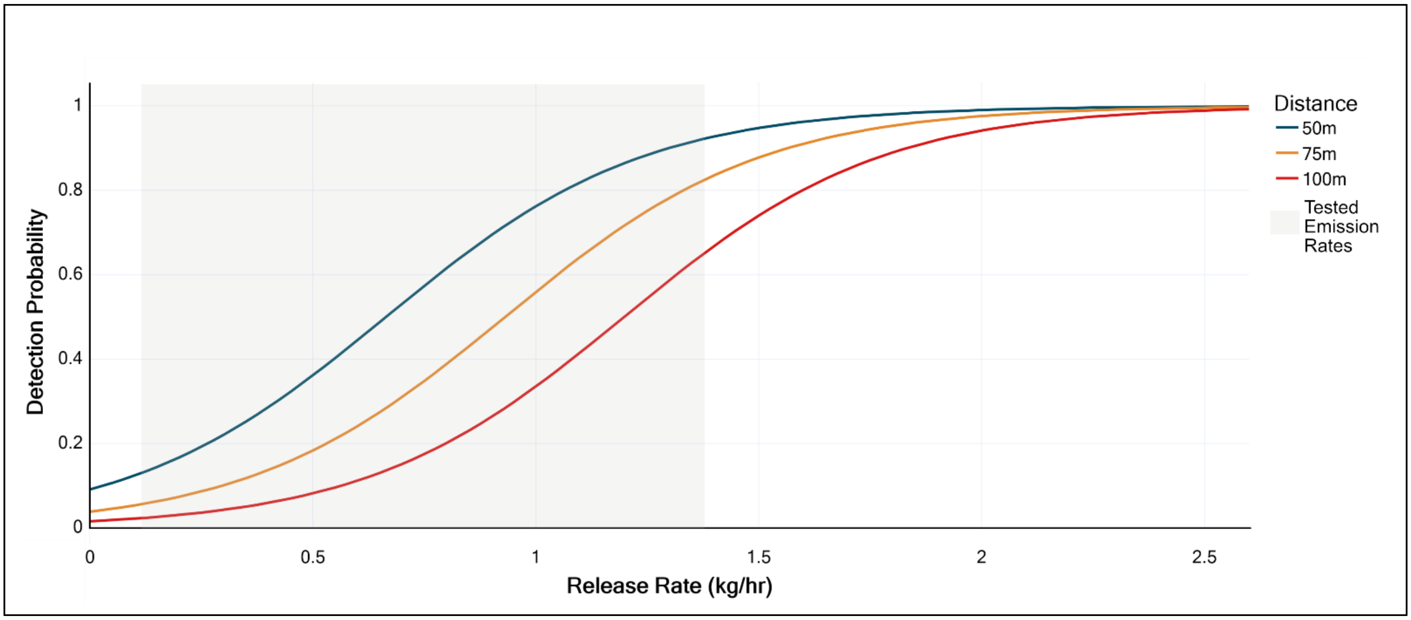

Figure 4 - Probability of detection of the Qube Solution at variable distance based on emission rate assuming favourable wind conditions

Based on the probability of detection curve, under average wind conditions, the probability of detection of a 1.0 kg/hr release rate for the Qube Solution is approximately 37% at 100m, 58% at 75m and 78% at 50m for a 40-minute release window.

Detection counts

Overall detection results which informed probability of detection curve construction are presented in **Figure 5**. Under all conditions, the Qube Solution successfully detected 116 of the 306 releases, which represents a successful detection rate of 38%. The count of successfully detected emissions decreases when the distance of Qube Devices to the source increases and the release rate decreases. It is important to note that 0.10 kg/hr was successfully detected at 100m, though not very often. This could have more to do with wind suitability than sensitivity, as a further away sensor is a more difficult target to hit for a plume.

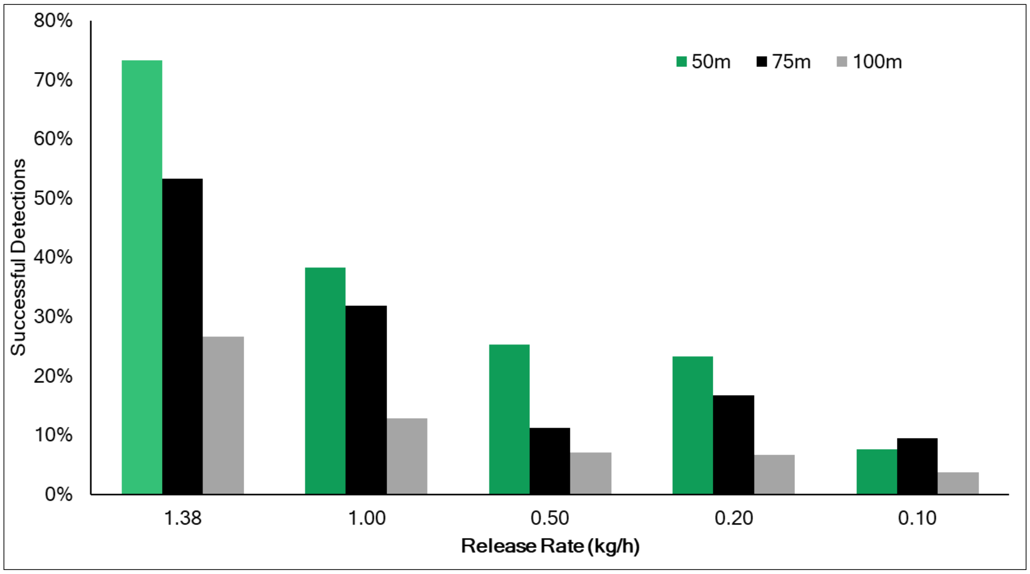

Figure 5 - Overview of detection performance at multiple release rates

Discussion

Under the current understanding of emissions distributions in key oil and gas basins, the probability of detection derived in this experiment suggests that the Qube Solution can consistently detect the leaks responsible for the majority of total emissions.

Efforts made to understand leak rate distributions have identified a repeatable trend in which a small proportion of the total leaks (~5%) are responsible for a large proportion of total emissions (~51%).[6] Simply put, addressing the largest leaks quickly will have a marked impact on overall emissions reductions.

The works of Omara et al., Zavala Araiza et al. and Cusworth et al. recorded empirical leak rates in the Marcellus Shale (Pennsylvania and West Virginia), Barnett Shale (Texas) and Permian Basin (Texas and New Mexico), respectively. This empirical data was used to construct the cumulative density functions in **Figure 6**, which corroborates this heavy skew of total emissions in relation to leak size.[7,8,9]

We note that testing was not performed at distances greater than 100 m or less that 50 m. In general, detection probabilities should increase when closer to the source, unless the source is elevated, and the plume is passing above the Qube Device.

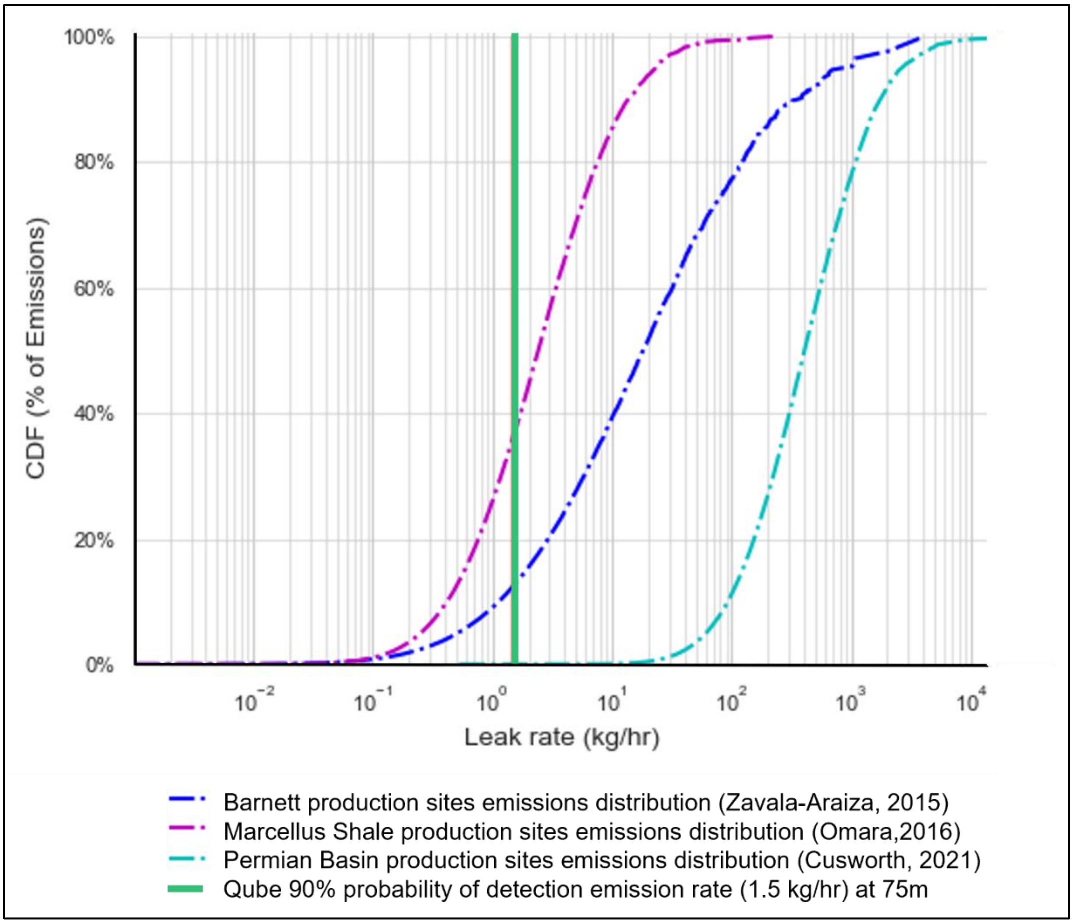

Figure 6 - Cumulative distribution function of total emissions based on individual leak size of production sites in Marcellus Shale Basin (Omara,2016), Barnett Shale (Zavala Araiza, 2015) and Permian Basin (Cusworth, 2021). Given these empirical emissions distributions, the Qube Solution should be able to detect ~60-99% of total methane emissions within 60 minutes at a 90% probability of detection.

At 75m, the Qube Solution has a 90% probability of detecting a 1.5 kg/hr emission. **Figure 6** shows that leaks of 1.5 kg/hr and larger account for 65% of total emissions in the Marcellus Shale, 87% of emissions in the Barnett, and 99% of emissions in the Permian Basin (based on three distinct studies of different sites using different methods). These results emphasize the share of emissions that the Qube Solution could detect – and potentially mitigate – based on the probability of detection derived in this experiment.

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