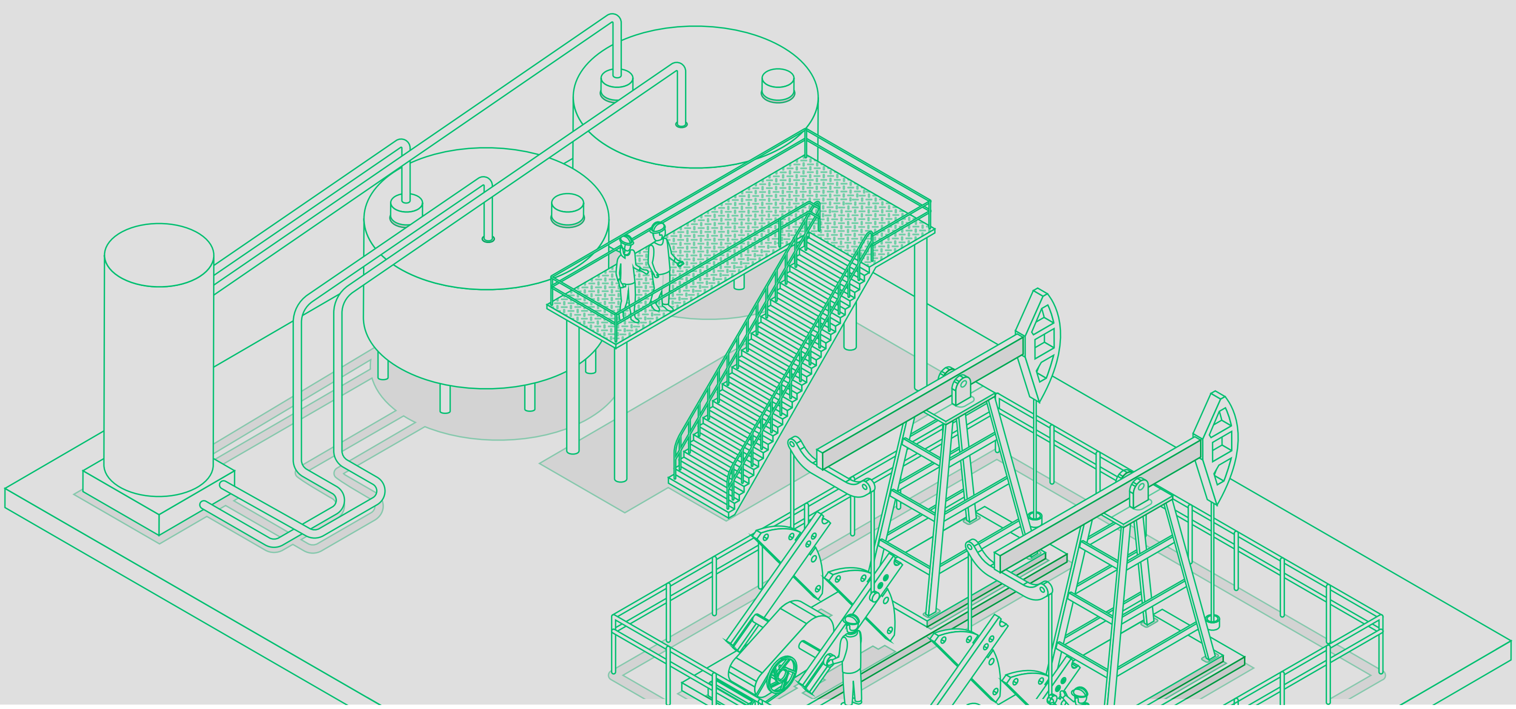
Long-Term Accuracy of Qube's Methane Sensor Calibration: A Two-Year Study

Table of Contents



Abstract

Qube has developed an innovative continuous monitoring solution specifically designed for industrial applications to detect, localize, and quantify methane emissions. Utilizing metal oxide (MOx) sensing technology, Qube's sensors offer high sensitivity to methane, predictable performance across diverse environmental conditions, and a cost-effective technology for large-scale deployment. Each sensor undergoes rigorous lab calibration to ensure accuracy within 1 PPM before it is deployed in the field. The lab calibration process characterizes the sensor's response to methane from 0 to 2,000 PPM, while compensating for environmental conditions. To maintain precision and consistency once deployed in the field, Qube has developed a patent pending auto-baselining algorithm that autonomously adjusts for sensor drift, seamlessly adapting to environmental changes and sensor aging without human intervention.

This white paper describes the lab calibration process and presents the findings from a comprehensive field study validating the prolonged accuracy of Qube's calibration methods over two years of operational use.
Key findings include:

- Qube's sensors maintain consistent calibration and performance throughout the two-year period.
- The technology effectively manages baseline drift and enables reliable, autonomous recalibrations as needed.
- The study underscores the robustness of Qube's sensing technology and calibration approach, ensuring operational integrity in challenging industrial environments.

Background

How the Qube Platform Works

The Qube platform consists of three parts: (i) an Industrial Internet of Things (IIoT) device that measures gas concentrations and environmental data and transmits it to the cloud, (ii) a cloud-based platform converts sensor data into leak locations and rates, and (iii) a web-based user dashboard that displays critical insights generated by the analytics platform.

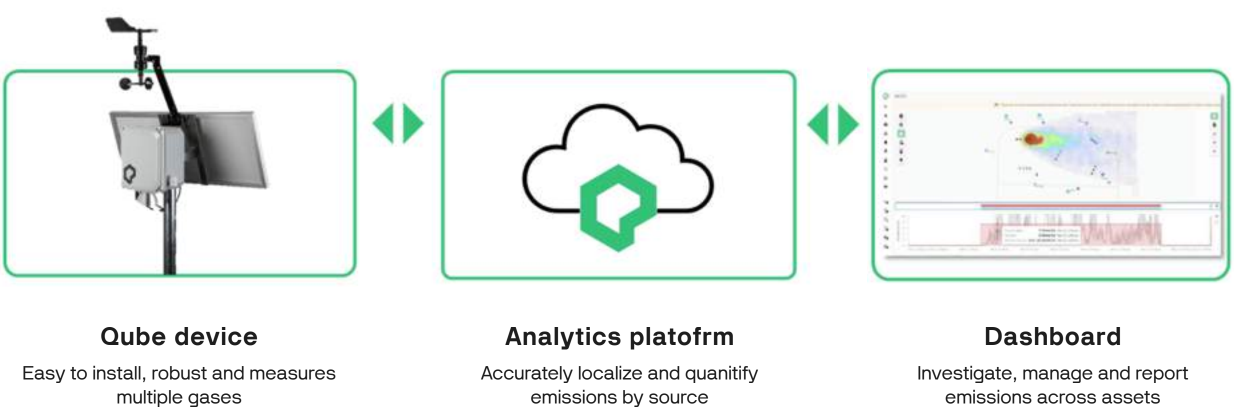


Figure 1 - Qube's three part solution

Qube's IIoT devices, have five key components: a sensor array including multiple gas sensors and environmental sensors, sensor enclosure, edge computing module, communications module, and power supply. All five components function together to capture accurate, time-synchronized emissions and environmental data without the need for costly tie-ins to direct power or communication systems.

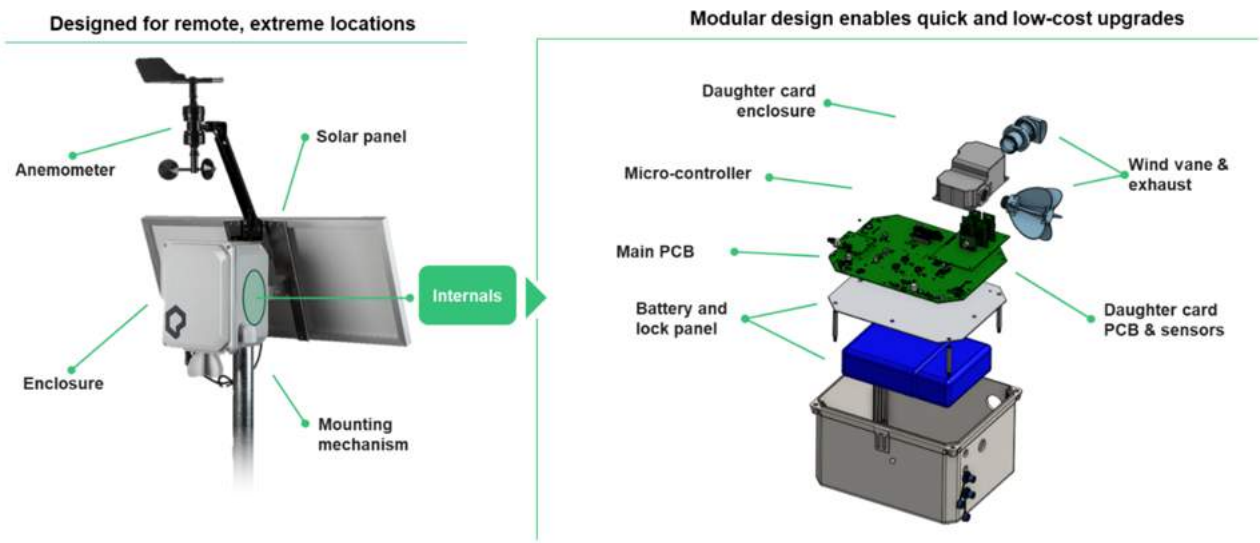


Figure 2 - Qube's IIoT devices

The system works by detecting methane that is carried by wind and atmospheric dispersion from a given point in a facility to sensors placed around the facility. The number of sensors deployed, and the placement of those sensors, is based on the facility's configuration and an automated analysis is performed using historical wind data, emission source locations and a budget of devices to optimize device placement thereby maximizing the probability of detecting emissions from the facility.

Figure 3 - Qube's deployment planning tool

Methane concentrations and environmental data captured by the sensors are uploaded to the cloud-based analytics platform where localization and quantification calculations are made. These outputs are then displayed in a web-based dashboard for operators to respond in accordance with the data.

Qube has deployed the technology in every major producing basin in North America and currently has 5,000+ devices installed globally. Customers who deploy the technology typically see 50-90% reduction in emissions through process improvements and early detection and mitigation of leaks.

Metal Oxide Sensors

Metal oxide sensors are simple semiconductor circuits that detect the presence of methane gas by showing a change in resistance or voltage drop across the sensor as the gas reacts with metal oxides on the sensor's surface. When methane molecules come into contact with the metal oxide, a chemical reaction occurs, changing the sensor's resistance or voltage output.

Metal oxide sensors are a low-cost solution that are highly sensitive to methane and highly accurate if calibrated properly, which enables operators to deploy the Qube platform at scale, achieving high accuracy for a lower cost than competing sensor technologies.

How Sensor Calibration Works

To accurately measure methane concentration, each sensor undergoes a calibration process. This involves exposing the sensor to known methane concentrations in a controlled environment and recording the corresponding voltage drop across the sensor. This data forms the ‘calibration curve,’ which relates voltage output to methane concentration.

The sensor's response is also affected by environmental variables like temperature, humidity, and air pressure. Changes in these conditions alter the calibration curve, transforming it from a simple 2-dimensional curve (voltage vs. concentration) into a multi-dimensional surface. This surface is described by a complex mathematical formula using ‘calibration coefficients’ as inputs.

To map this surface accurately, the calibration process is repeated multiple times, varying both gas concentration and the environmental conditions all independently. This results in a unique set of calibration coefficients for each sensor, allowing accurate determination of methane concentration within 1 ppm across a wide range of environmental conditions.

How Qube Calibrates its Sensors in the Lab

Qube’s proprietary calibration process involves placing a batch of sensors in an environmental chamber where they are exposed to varying methane gas concentrations while systematically changing the temperature, humidity, and pressure, and monitoring each sensor’s response. By mapping those responses to known values, the sensor’s independent calibration coefficients can be determined.

The left side of the figure below shows an example of a single sensor going through a temperature cycle in the environmental chamber while being subjected to a known concentration of gas. Similar cycles are performed for each environmental condition, at varying concentrations. The right side of the figure below shows the output of our sensor concentration after the unique calibration curve has been applied versus input gas concentration.

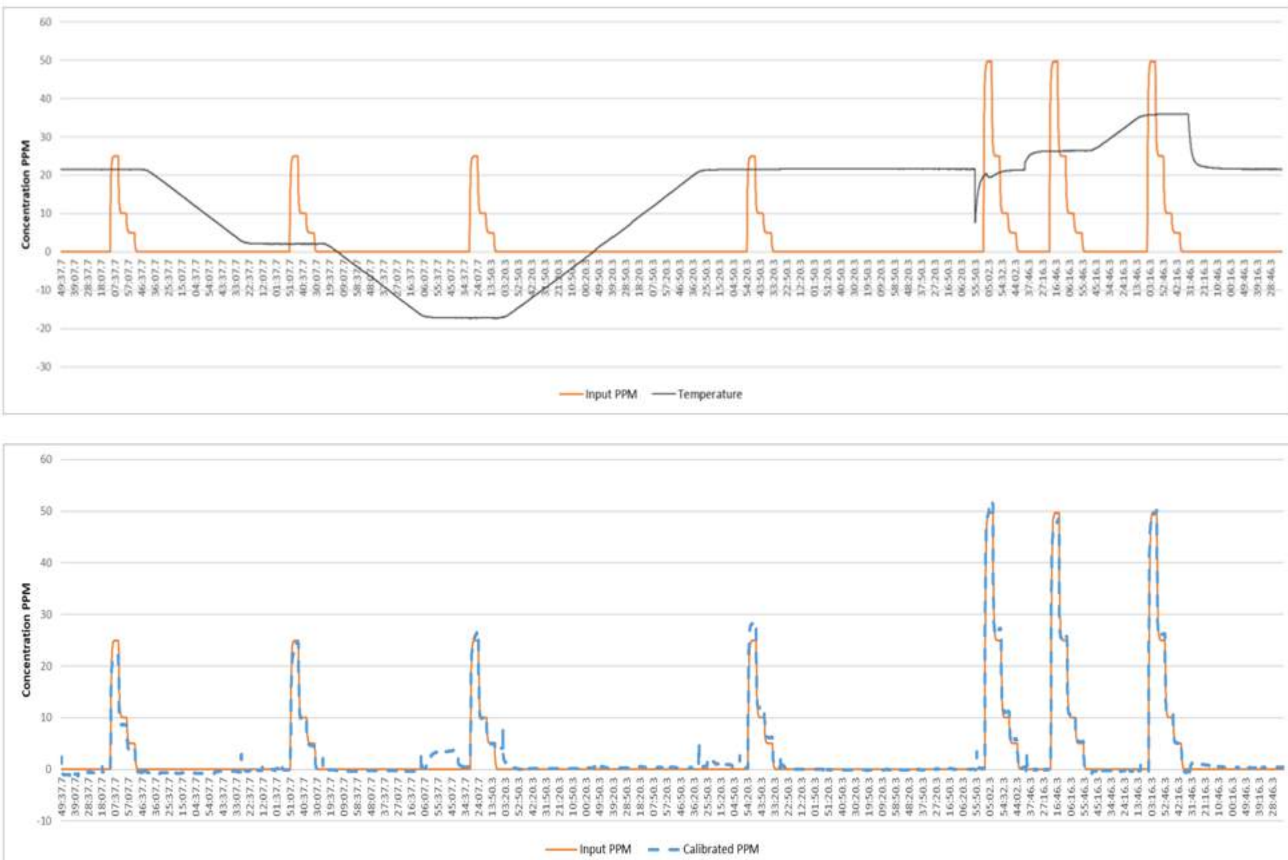


Figure 4 - Lab calibration of a single MOx sensor across a variety of methane concentrations, temperatures and humidity levels

How Qube Validates its Calibration Process

Each sensor is lab calibrated to all expected ranges of operating conditions and gas concentrations, with an accuracy of 1 ppm or 1% of reading, whichever is greater.

While the lab calibration procedure confirms the sensor’s response to highly controlled steady-state concentration values, this level of performance is periodically validated in the field, by measuring real plumes of methane at a controlled release test facility west of Calgary.

The field testing is intended to simulate an actual deployment and a typical emission profile a Qube device is expected to detect and measure. The sensors' responses are compared against a high-quality reference, a Los Gatos Gas Analyzer (LGA), which is co-located during the test release campaign.

The figure below shows an example of methane readings observed during a controlled release test with the two systems co-located:

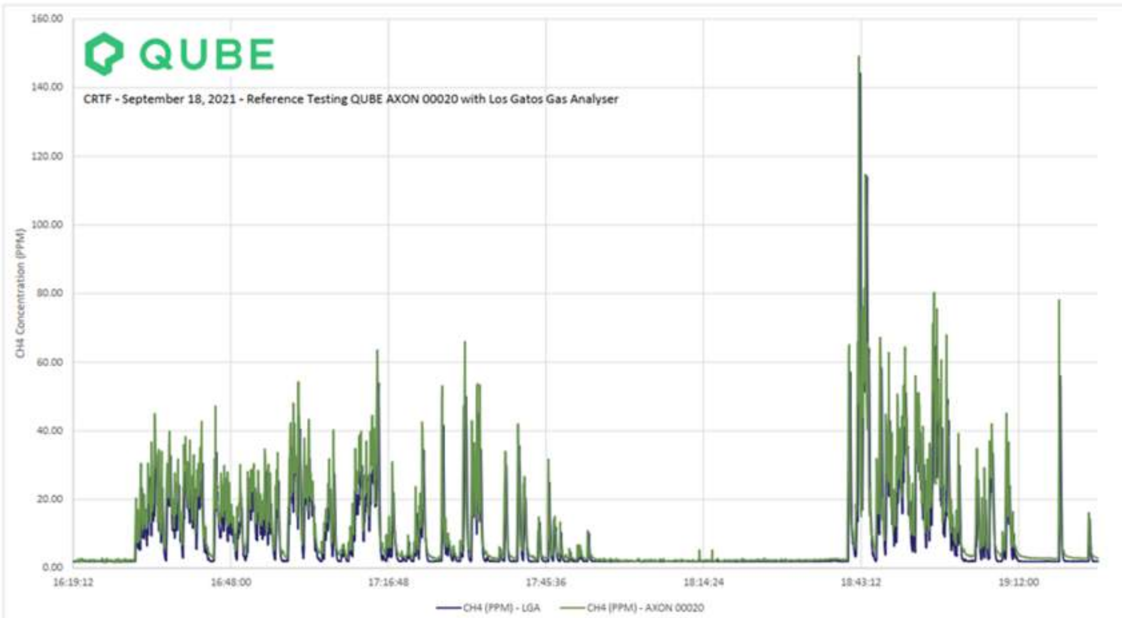


Figure 5 - Reference testing between Qube's MOx sensors and a Los Gatos gas analyzer during a controlled release test

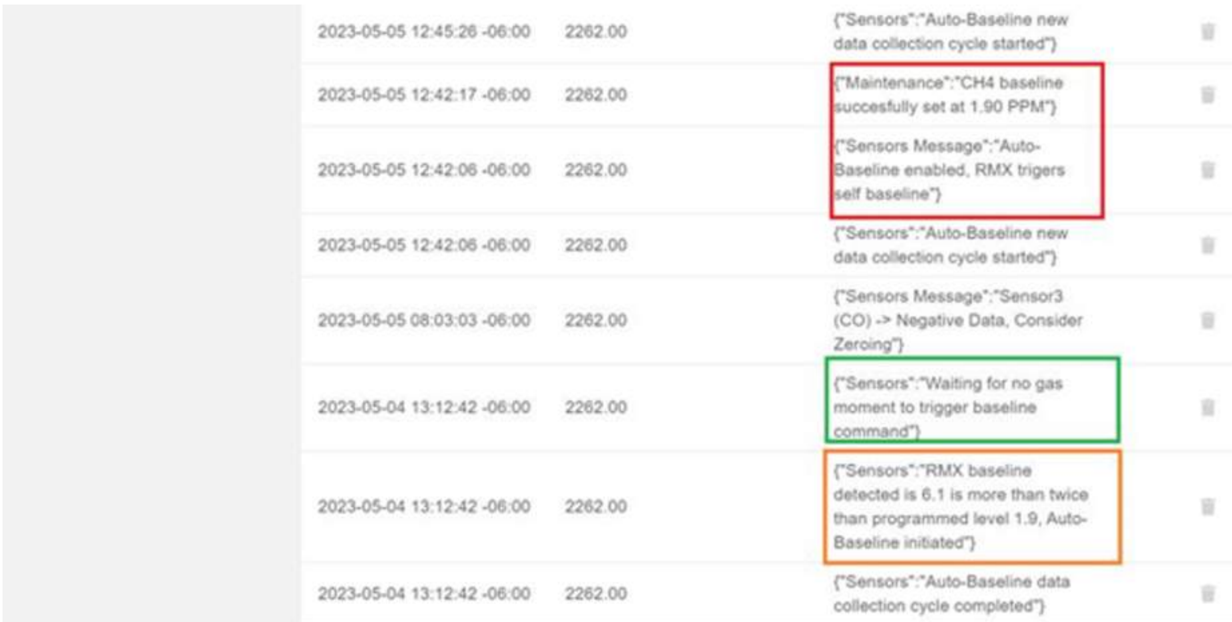
Metal Oxide Sensor Drift

Metal oxide sensors, while sensitive and reliable, can experience 'drift' as they age. This drift occurs when the sensor's response to methane deviates from its original calibration curve due to environmental impacts on the metal oxide substrate over time.

Qube has developed a patent-pending auto-baselining algorithm to address this issue. The algorithm runs continuously in the background, detecting and compensating for drift without any human intervention.

The algorithm identifies time periods when the air is clean and compares the sensor's baseline response to the expected background methane level (typically the global average value of 1.9 ppm). If the detected baseline response deviates from this expected background level, the baselining procedure is initiated. If the algorithm determines that the sensor is not in clean air, then it waits for a period when the sensor is in clean air.

Figure 6 below shows an example of the auto-baseline algorithm triggering, waiting for clean air and then triggering the baseline command successfully.



2023-05-05 12:45:26 -06:00	2262.00	{"Sensors":"Auto-Baseline new data collection cycle started"}
2023-05-05 12:42:17 -06:00	2262.00	{"Maintenance":"CH4 baseline succesfully set at 1.90 PPM"}
2023-05-05 12:42:06 -06:00	2262.00	{"Sensors Message":"Auto-Baseline enabled, RMX trigers self baseline"}
2023-05-05 12:42:06 -06:00	2262.00	{"Sensors":"Auto-Baseline new data collection cycle started"}
2023-05-05 08:03:03 -06:00	2262.00	{"Sensors Message":"Sensor3 (CO) -> Negative Data, Consider Zeroing"}
2023-05-04 13:12:42 -06:00	2262.00	{"Sensors":"Waiting for no gas moment to trigger baseline command"}
2023-05-04 13:12:42 -06:00	2262.00	{"Sensors":"RMX baseline detected is 6.1 is more than twice than programmed level 1.9, Auto-Baseline initiated"}
2023-05-04 13:12:42 -06:00	2262.00	{"Sensors":"Auto-Baseline data collection cycle completed"}

Figure 6 - Qube's auto-calibration process

The following is an example of how the algorithm performs a controlled release test, a sensor exhibiting baseline drift was compared against a high-quality reference instrument (LGA) at Qube's controlled release test facility. Initially, the Qube sensor showed drift above baseline compared to the LGA. After stopping the controlled release and allowing the air to clear, the sensor was automatically re-baselined. In the subsequent controlled release test, the re-baselined sensor demonstrated much higher accuracy when exposed to a methane plume, closely matching the LGA reference instrument.

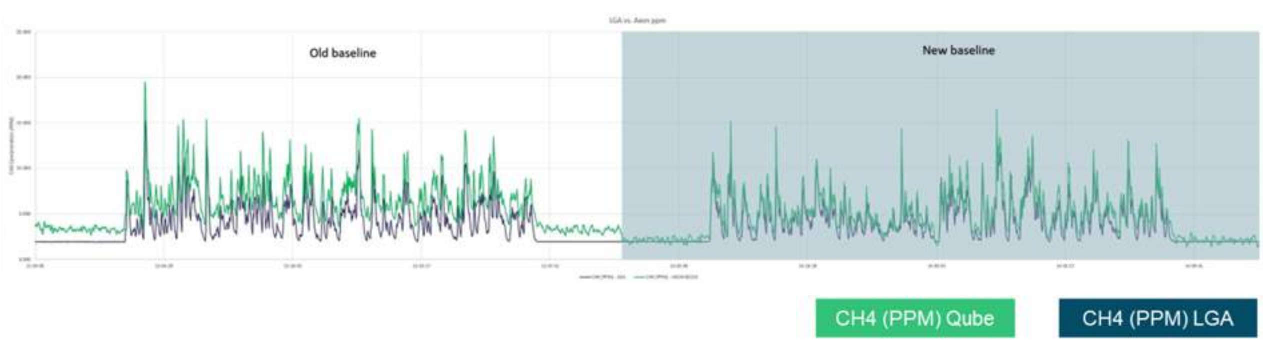


Figure 7 - Example of the auto-calibration process for a device exhibiting drift in the field

Method

The following sections of this white paper focus on testing sensors that have been deployed to the field for a period of one to two years and validating the performance of the sensors after being subjected to real-world environmental conditions.

Test Set Up

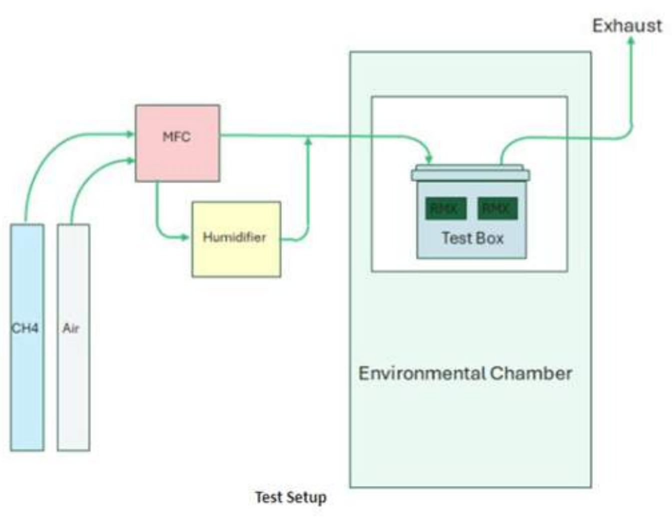
The testing methodology employed to evaluate the calibration accuracy and stability of the Qube sensors involved a two-part process: laboratory tests and controlled field release tests.

Lab Test Setup

Laboratory tests were conducted in a temperature, humidity, and pressure-controlled environmental chamber. A cohort of 26 methane sensors, previously deployed in the field for durations of 1-2 years, were selected for this evaluation. Each sensor was exposed to methane gas concentrations ranging from 0-100 ppm.
The testing procedure involved the following steps:

- The environmental chamber was flushed with “zero air”, a mixture of pure oxygen and nitrogen, for a duration of 3,600 seconds at a flow rate of 2750 standard cubic centimeters per minute (sccm) to establish a baseline.
- Subsequently, sensors were exposed to methane concentrations of 10, 20, 25, 50, and 100 ppm for a period of 3,600 seconds each.
- Between each exposure, the chamber was cleansed with zero air for 3,600 seconds to reset the environment.

The figure below shows the test setup and describes the testing methodology:



Test Setup

- Test the recovered methane sensors from the Field with exposure of 10, 20, 25, 50 and 100 ppm CH4 successively, at 2750sscm.

Test Methodology

- Run zero air inside the test for 3600s at 2750sscm
- Expose the box to 10, 20, 25, 50 and 100 ppm gas successively, at the same rate for 3600s
- Clean the chamber with zero air for 3600s

Figure 8 - Test setup to test calibration of devices deployed in the field

Controlled Release Field Test Setup

Additional testing was also conducted at Qube's controlled release test facility where the sensors were tested alongside the LGA during a campaign of test releases. At a rate of 1.4 kg/hr, with the devices located 10 meters down-wind of the of the release point, the response in the 0-100 ppm range was compared. At a rate of 6 kg/h with the devices located 5 meters down-wind of the release point, the extended range of 100-2,000 ppm was able to be compared to the LGA.

The figure 9 shows the controlled release test facility west of Calgary during a methane release, with a 'smoke bomb' simultaneously being released to visualize the plume's path and dispersion.

Figure 9 - Qube's Controlled Release Testing Facility (CRTF)

Results

Lab testing confirmed that sensors operating in the field for more than two years respond reliably within their specifications after being re-baselined. The figure below shows the response of an early Qube methane sensor deployed to operation in October 2021, recovered and tested in November 2023. The chart shows the response over time as the sensor is exposed to 10, 20, 25, 50, and three times to 100 ppm.

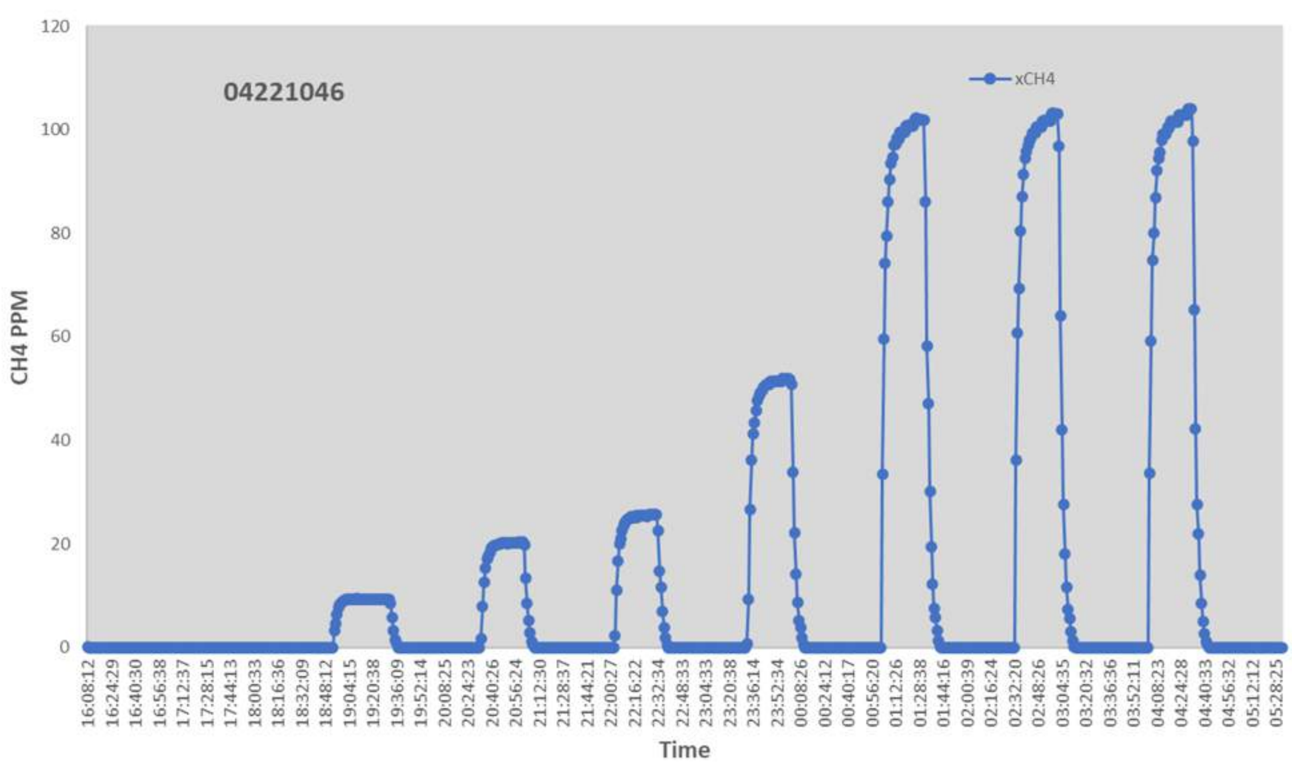


Figure 10 - Lab testing sensors deployed in the field at varying methane exposures

The following table summarizes the results of lab testing 26 sensors recovered from the field when compared against known concentrations:

Input gas concentration	Sensor response (PPM)	Error (%)
10	9.29	-0.71 PPM (-7.64%)
20	20.06	0.06 PPM (0.31%)
25	25.15	0.15 PPM (0.60%)
50	50.69	0.69 PPM (1.36%)
100	99.42	-0.57 PPM (-0.57%)

Table 1 - Performance summary of re-tested devices in the laboratory

Testing at a controlled release test facility by co-locating recovered Qube sensors with an LGA yielded similar results as those found in the lab.

The following figure shows the response comparison between a co-located Qube sensor and the LGA for the 6 kg/h release with the devices located 5 m down-wind, intended to test response to the 0 – 2,000 ppm range.

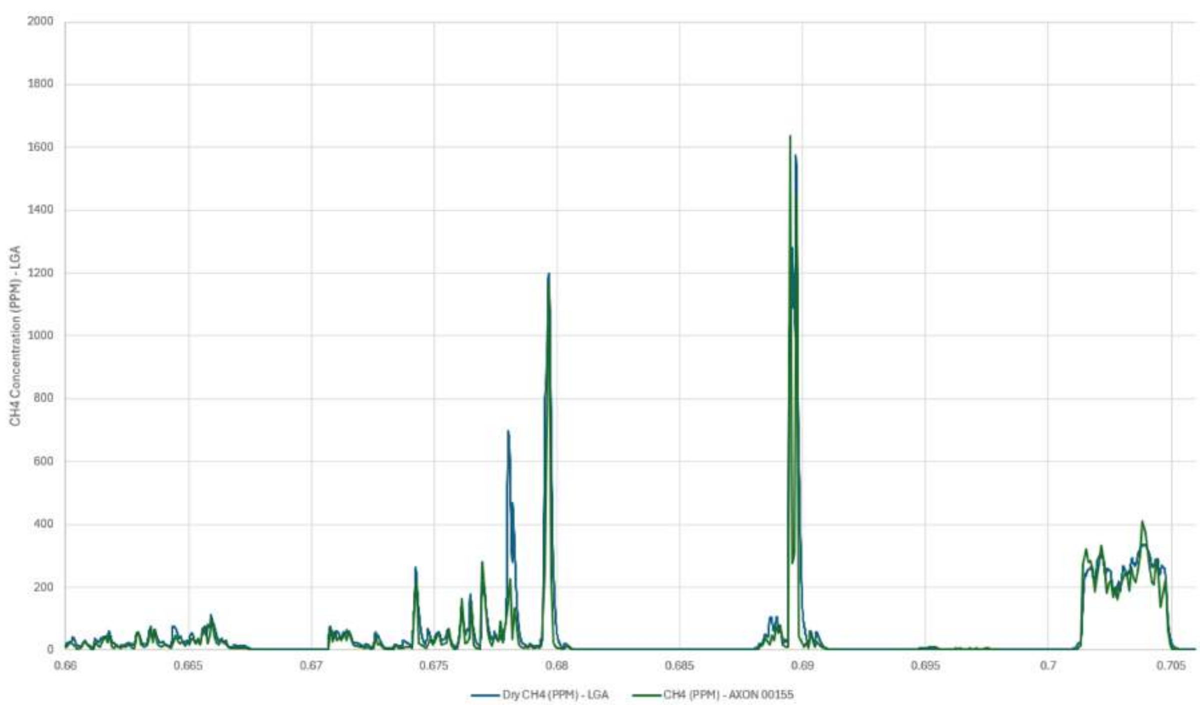


Figure 11 - Comparing a device deployed in the field against an LGA during a controlled release

Conclusion

The study demonstrates that sensors operating in the field and exposed to various environmental conditions over two years can still operate with an accuracy of 1 ppm without a full lab recalibration, by implementing Qube's auto-baselining algorithm. The findings confirm that the calibration methods have accurately identified and accounted for the aging elements which are responsible for baseline drift. The findings also confirm that Qube devices can reliably detect and compensate for baseline drift over at least two years of deployment in the field.

The study affirms a core value proposition of the Qube platform: minimal sensing hardware is needed to produce accurate measurement and quantification of methane emissions, and that the devices' capabilities remain consistent over time.

This enables primary industries oil and gas operators to cost-effectively deploy the Qube platform at scale and avoid time-consuming field maintenance to manage uncalibrated sensors.

While these test results are encouraging, we acknowledge a limitation of the study. The sensors tested have only been operating in the field for two years, not the expected five-year operational life of the sensors. Continued testing is needed to fully evaluate the calibration methods and confirm performance over the full lifespan of Qube sensors. We intend to conduct annual testing on a statistically significant subset of sensors to continue to evaluate long-term performance.