Description of Technology

The Environmental Protection Agency

Emission Measurement Center

https://www.epa.gov/emc/oil-and-gas-alternative-test-methods

LongPath Technologies

https://www.longpathtech.com

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This document describes and documents how the LongPath Technologies LongPath Emissions Sensing Network™ technology works, from first principles through the calculated Emission Rate Reading product. In this document, detailed descriptions of how the technology and modeling work are provided to form the basis for the technology and inversion algorithm approval.

1. Description of the Measurement Technology

Per §60.5398b(d)(3)(iii), this section describes the candidate measurement technology, including a description of the scientific theory, the physical components, the type of measurement and application, and the known limitations of the system and application(s).

The LongPath Emissions Sensing Network™ monitoring system is a continuous open-path laser sensor system. The LongPath Emissions Sensing Network™ system is capable of continuously monitoring one to multiple facilities (monitored areas) via a single installation of a centralized tower. The system operates under the following general architecture (further details are provided in the following paragraph and sections): the light from a laser spectrometer is directed via an optical transceiver towards retroreflectors (mirrors) installed around the monitored area in a configuration that enables determining methane emission rates from targeted portions of the monitored area. Sites and facilities within roughly a 20 square mile area around the central node may be eligible monitored areas and approximately 20-30 sites can be monitored per central node. The laser spectrometer light that is returned via the mirrors to the detector is analyzed for methane concentration. An anemometer collocated with the laser spectrometer measures atmospheric parameters needed for plume model calculations. The methane concentration data and the atmospheric data are then used in an atmospheric inversion for methane emissions estimates from the monitored area(s). The LongPath Emissions Sensing Network™ employs a rigorous system of quality control checks to ensure incoming data is valid. With this data, the LongPath Emissions Sensing Network™ is capable of accurately quantifying emission rates. Quantification accuracy of individual Emission Rate Readings is ±20-40%. The overall bias in the quantification accuracy of Emission Rate Readings over time is less than 10%.

1.a. Scientific Theory

Per §60.5398b(d)(3)(iii)(A), this section describes the scientific theory and appropriate references outlining the underlying technology (e.g., reference material, literature review).

1.a.i. Laser Spectroscopy

The fundamental laser sensor is based on the principle of laser absorption spectroscopy, which is a technique for accurately and sensitively measuring gas properties that has been demonstrated and utilized for numerous scientific applications ranging from satellite systems [1] to point sensors[2] to open-path measurements[3][4]. In laser absorption spectroscopy, gas

[1] Veefkind, J. P., Aben, I., McMullan, K., et al., 2012. TROPOMI on the ESA Sentinal-5 precursor: a GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications. Remote Sensing of the Environment, 120, 70-83. https://doi.org/10.1016/j.rse.2011.09.027
[2] Washenfelder, R., A., Wagner, N. L., Dube, W. P., and Brown, S. S., 2011. Measurement of atmospheric ozone by cavity ring-down spectroscopy. Environ. Sci. Technol., 45(7), 2938-2944. https://doi.org/10.1021/es103340u
[3] Rieker, G. B., Giorgetta, F. R., Swann, W. C., et al., (2014). Frequency-comb-based remote sensing of greenhouse gases over kilometer air paths. Optica, 1, 290-298. https://doi.org/10.1364/OPTICA.1.000290
[4] Coddington, I., Newbury, N., and Swann, W. (2016). Dual-comb spectroscopy. Optica, 3, 414-426. https://doi.org/10.1364/OPTICA.3.000414

properties in a sample are determined by processing laser light after passing it through the sample. Light is absorbed by molecules at specific wavelengths that are resonant with vibrational-rotational transitions (for near infrared light sources) of the specific molecules that interact with those laser light wavelengths. The absorbance signals are unique for different molecular species. This enables specificity for distinguishing between molecules – e.g., methane vs. water vs. carbon dioxide. The absorbance signals are also directly related to the number of molecules interacting with the laser light (i.e., the gas concentration in the sample).

The measured absorbance signals are fitted against modeled signals to determine the gas properties of interest. The modeled signals are generated using data from spectroscopic databases which contain the information needed to understand how molecules interact with light. We utilize data from the HITRAN database[5], which is well-established and widely used method for making spectroscopic measurements of methane – particularly at atmospherically relevant temperatures and pressures[6][7][8]. In the LongPath Emissions Sensing Network™ measurement system, the modeled data parameters are constrained by directly measured (known) variables of pathlength, temperature, and pressure. By constraining these known variables, the concentration of methane becomes the only fitted (unknown) quantity, thus greatly reducing the degrees of freedom and increasing the confidence in the fitting process. Because the measurement is equally sensitive to all methane molecules interacting with the laser light along the laser beam path, the determined quantities (e.g., concentration) represent path-integrated values, or the average concentration of methane along the laser beam path.

The LongPath Emissions Sensing Network™ system uses commercial semiconductor lasers, a mature technology used in mass production by the telecommunications industry. As such, the lasers have a long lifetime without degradation in performance and are robust to the broad range of environmental conditions experienced by our systems. Unlike electrochemical sensors that are known to degrade with time, the LongPath laser sensor experiences no loss in sensitivity over time and does not require standardization, baseline adjustment, initial instrument calibration, regular calibration, or on-site calibrations. The technique of absorption spectroscopy is inherently calibration-free but does require an initial characterization of the laser performance, which is conducted in the manufacturing process.

Some sensor systems have data inconsistencies due to water vapor or other gas molecule interferences or degradation. The LongPath Emissions Sensing Network™ measurement system does not, because the CH_4 absorption transitions targeted by the LongPath Emissions Sensing Network™ systems are spectrally separated from neighboring CO_2 and H_2O transitions,

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[5] Gordon, I. E., Rothman, L. S., Hargreaves, R. J., et al. (2022). The HITRAN2020 molecular spectroscopic database. Journal of quantitative spectroscopy and radiative transfer, 277, 107949. https://doi.org/10.1016/j.jqsrt.2021.107949

[6] Buzan, E. M., Beale, C. A., Boone., C. D., and Bernath, P. F., 2016. Global stratospheric measurements of the isotopologues of methane from the atmospheric chemistry experiment Fourier transform spectrometer. Atmos. Meas. Tech., 9(3) 1095-1111. https://doi.org/10.5194/amt-9-1095-2016

[7] Thompson, D. R., Bovensmann, H., Eastwood, M., et al., 2015. Real-time remote detection and measurement for airborne imaging spectroscopy: a case study with methane. Atmos. Meas. Tech., 8(10), 4383-4397. https://doi.org/10.5194/amt-8-4383-2015

[8] Crosson., E. R., 2008. A cavity ring-down analyzer for measuring atmospheric levels of methane, carbon dioxide, and water vapor. Applied Physics B, 92, 203-408. https://doi.org/10.1007/s00340-008-3135-y

making the LongPath Emissions Sensing Network™ insensitive to interference from these gases. This is important due to the rapid and potentially extreme fluctuations of water vapor that can occur in the atmosphere.

For these open-path, laser-based measurements, the laser precision (which ultimately drives the laser detection sensitivity) is specified in units of mixing ratio * pathlength (ppm*m). The instrument/system precision is related to the amount of laser signal collected during a given measurement, so can be variable through time. Laboratory measurements through static methane-filled optical cells using the LongPath laser systems yield a minimum precision value in the range of <2 ppm*m. That value equates to 2 ppb over a 1 km pathlength, or 1 ppb over a 2 km pathlength, and so on. Heavy turbulence encountered in the field (which negatively impacts signal collection) can increase the ppm*m precision metric to roughly 10, leading to a 10 ppb precision over a 1 km path, or 5 ppb over a 2 km path, and so on. The maximum precision value derived from the laboratory testing occurs with the raw laser signal (i.e., no averaging) at the highest data rate. The raw laser signal is also tracked during normal operation of the LongPath system and this metric is used to assess the laser performance on a measurement-by-measurement basis by comparing the retrieve signal response to value derived from the laboratory tests.

The length of the beam cutting through the atmosphere is typically between 50 m and 5000 m (5 km) long, and the beam can be roughly 0.05 - 0.2 m in diameter (depending upon distance from the light source), collectively giving rise to the effective dimensions of the system as a horizontally oriented integrated column.

1.a.ii. [Content Reserved for CBI]

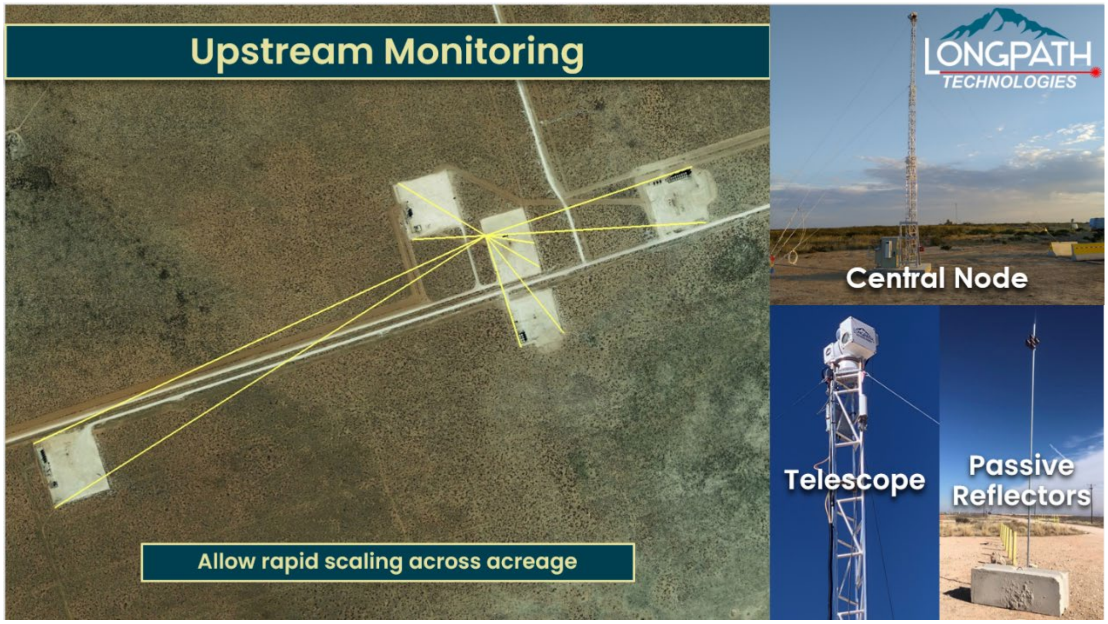
1.b. Physical Instrumentation

Per §60.5398b(d)(3)(iii)(B), this section describes the physical instrumentation as well as the characterization of instrument precision.

1.b.i. Hardware and Instrumentation

LongPath is headquartered in Boulder, Colorado. All laser hardware is manufactured in-house either at the Boulder office or the manufacturing facility in Mead, CO by LongPath personnel.

The LongPath Emissions Sensing Network™ system consists of 3 primary components: 1) the central node; 2) the array of retroreflectors; and 3) a wind sensor. The central node is composed of a retractable tower on a small base pedestal with the integrated laser transceiver mounted on a gimbal placed at the top of the tower. Systems typically operate using solar power, so that the central node additionally includes a solar panel array, battery pack, and charge controlling device. The laser spectrometer and computing/control systems devices are typically located within the laser transceiver, however on older systems they are housed in a climate-controlled cabinet at the base. The configuration of components and power source for the system do not affect the Emission Rate Readings. Each hardware component will be described in more detail below.



A central node is shown in the center of the starburst pattern in the left-hand panel. Yellow lines indicate the geometry of eye-safe, invisible laser light that travels between the telescope (at the central node location) and retroreflective mirrors ("passive reflectors") located near monitored areas.

Central Node: The location where the tower, controls, computing, transceiver, and anemometer are located. Located at the center of yellow "starburst" in the left-hand panel.

Transceiver: The optical componentry that sends eye-safe and invisible laser light through the atmosphere to a retroreflector and then receives the reflected laser light for processing.

Laser Spectrometer: The device that generates the laser light and signals required to perform laser absorption spectroscopy. This additionally includes the laser control computer and fundamental hardware for converting the raw laser data to methane concentrations and generating base-level QAQC metrics for the concentration/laser data.

Gimbal: A device that rotates about two orthogonal axes enabling the controlled pointing of the laser transceiver towards the retroreflector targets. This device is controlled through direct serial communications with LongPath Emissions Sensing Network™ custom control software.

Retroreflectors: Small, specialized mirrors that return light directly back along the incident path. These are placed either atop a small post or mounted to existing infrastructure at or near specific areas being monitored. For reference, the retroreflectors would be located at the end of each yellow line in left-hand panel of the above figure. These are passive devices that do not require power or communications. They are interchangeably called mirrors, retros, reflectors, or retroreflectors. They do not require cleaning.

Tower, Guy Wires, Bin Blocks: The tower is a commercial product constructed of aluminum with a maximum height of 50' – 75'. The tower is supplied with support cabling (i.e., guy wires) and the necessary hardware components to secure the cabling both to the tower and to the anchoring infrastructure. For anchoring, cement blocks (bin blocks) are used at each of the cabling termination points at ground level.

Anemometer: A commercial wind sensor, which is an acoustic device that measures the wind speed along different axes. The measurements additionally determine the wind direction and ambient temperature.

Power Source: Systems are powered using commercial solar panels, batteries, and a charge controlling device. Some systems may be line or generator powered.

1.b.ii. [Content Reserved for CBI]

1.c. Type of Measurement and Application

Per §60.5398b(d)(3)(iii)(C), this section describes the type of measurement and application (e.g., remote or in-situ measurements, mobile, airborne).

The LongPath Emissions Sensing Network™ system is a fixed, ground-based, remote emissions sensing system that uses an open-path laser spectrometer in tandem with atmospheric inversion modeling for determining trace gas emissions. The system is capable of detection and localization of emissions as required by the Periodic Screening protocols.

The desired application of the candidate measurement system is "Broadly Applicable Across Sector". As will be described in the limitations section, this technology is suitable across site types, due to the inherent flexibility in the monitoring system parameters.

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