Testing of Methane Detection Technologies

FINAL REPORT

January 26, 2018 Revision

SwRI® Project No. 18.22985

Prepared for:

Environmental Defense Fund
1875 Connecticut Ave., NW
Washington, DC 20009

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SOUTHWEST RESEARCH INSTITUTE®

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EXECUTIVE SUMMARY

The Environmental Defense Fund (EDF) and Schlumberger collaborated to test a variety of technologies for the application of detecting methane leaks from equipment in the upstream oil and gas sector. The technologies fell into two general categories:

- Stationary technologies that are relatively low-cost solutions for monitoring sites such as well pads and small gathering sites that do not regularly have personnel on site.
- Handheld technologies that could be used to locate a leak at a site in which it is known there is a leak source and/or be used for determining compliance to various air emission regulations.

A set of tests was performed at Southwest Research Institute (SwRI) in San Antonio, Texas. Six stationary and nine handheld sensors were tested in the program. These technologies covered a range of commercial readiness from early developmental technologies to technologies currently on the market.

The objectives at the outset of the testing project were:

- Assess the technology readiness level of various methane leak detection technologies.
- Determine if any of the tested devices are suited for commercial deployment and/or have minor gaps that would need to be closed prior to further use.
- Provide data from realistic tests back to the technology developers to allow for continued development of the systems.

The key conclusions from the testing are:

Stationary Technologies

- There are two open-path stationary technologies that are largely ready for commercial deployment. These technology sensors are powered by solar panels and upload their data automatically to a cloud. Such technologies could, therefore, be installed at sites not having significant existing infrastructure.
- One of the point sensors tested is largely ready for commercial deployment.
- Even for the technologies that are largely ready for commercial deployment, the development of robust algorithms that can factor in a dynamic background environment are still needed in order to have unattended operation of such equipment in a real-world environment.

Handheld Technologies

- There are multiple handheld devices that could be used for compliance purposes (e.g., 40 CFR Part 60), but none provide benefits over existing Method 21 devices.
- While portable, open-path sensors provide the possibility of using such devices for narrowing down the location of a leak source, the testing conducted did not demonstrate the commercial readiness of any such technologies in upstream or midstream applications.

1. INTRODUCTION

1.1 Background

The Environmental Defense Fund (EDF) initiated the Methane Detectors Challenge (MDC) in 2014 as a means of catalyzing the development of new-to-market technologies for detecting methane leaks. EDF's efforts directly led to the development of new technologies, as well as the increase in developmental readiness of existing technologies. While the MDC was successful in generating more than one technology that was moved into industry pilots, the program was never intended to be the final assessment of such technologies. Instead, one of the key tenets of the MDC was to generate interest within the oil and gas industry to provide a larger market for such technologies, resulting in additional technologies coming to fruition. In the few years following the original MDC efforts, the methane leak technology market has continued to evolve. EDF and its partners continue to push for further refinement of such technologies.

As a means of capturing the current state of technologies, EDF and Schlumberger collaborated to test a variety of technologies for the application of detecting methane leaks from equipment in the upstream oil and gas sector. The technologies fell into two general categories:

- Stationary technologies that are relatively low-cost solutions for monitoring sites such as well pads and small gathering sites that do not regularly have personnel on site.
- Handheld technologies that could be used to locate a leak at a site in which it is known there is a leak source and/or be used for determining compliance to various air emission regulations.

There is also industry interest in both terrestrial and aerial mobile solutions, but those were not included in this particular project.

A set of tests was performed at Southwest Research Institute (SwRI) in San Antonio, Texas. While the testing had many similarities to EDF's efforts in the MDC, this testing program was a new and independent effort. Six stationary and nine handheld sensors were tested in the program. These technologies covered a range of commercial readiness from early developmental technologies to technologies currently on the market.

1.2 Objectives

The work had several objectives:

- Assess the technology readiness level of various methane leak detection technologies.
- Determine if any of the tested devices are suited for commercial deployment and/or have minor gaps that would need to be closed prior to further use.
- Provide data from realistic tests back to the technology developers to allow for continued development of the systems.

1.3 Report Overview

This report provides an overall description of the testing and an assessment of the performance of the two classes of technologies. It is not intended to be an evaluation of any one specific company's technology. Thus, this report does not disclose specific company information.

2. STATIONARY MONITOR TESTING

The stationary monitor testing aimed to investigate the sensor level performance of various technologies that may be deployed as permanent monitoring units. A stationary device may be installed at a remote site, such as a well pad, in which there may not be personnel continuously onsite. The technology could then monitor the site for leaks and dispatch an inspection team if a leak is determined to be likely.

The testing generally mimicked the program undertaken in the MDC during the summer of 2015 in which methane leaks were generated at known rates and locations and system readings were recorded and compared against a reference measurement. The results of the testing demonstrate the ongoing maturation and growth of this technology field since the original MDC program. Similar to the MDC, the emphasis of the testing was placed on sensor level performance with a secondary focus on system level performance (peripheral system design, ruggedness, communications, etc.). Data interpretation (alarm determination) and scalability were not considered since these elements were largely absent from the tested systems.

2.1 Technology Overview

There were six stationary technologies tested, each at different stages of development ranging from commercially available, environmentally ruggedized systems down to lab-scale sensors. None of the offerings were provided with fully scaled, algorithmically robust solutions.

- Four of these technologies were point sensors that must physically ingest gas in order to measure the methane concentration. Each of these technologies required grid power and ranged from lab-scale instruments to partially ruggedized systems.
- Two of the technologies were open-path systems that utilized a tunable diode laser spectroscopy (TDLAS) measurement technique where a retroreflector returned the laser signal. The monitored lengths for the systems were 75 ft and 130 ft. Both systems were solar-powered and designed for full environmental exposure. Once the units were set up, no adjustments to the hardware were required during the course of testing.

2.2 Test Setup

In general, testing involved generating methane leaks upwind of the installed systems and monitoring the response of the systems. Systems were installed and generally located in the same area to allow all systems to be exposed to the same methane plume (although spatial and temporal variation was expected). The test system measurements were compared against the reference measurement to assess a system's accuracy, noise levels, temperature dependence, and other factors of interest.

2.2.1 Facility

The testing was conducted at SwRI's Metering Research Facility (MRF), which is shown in Figure 2.1. The MRF is comprised of two recirculating natural gas flow loops used for flow meter calibrations and a variety of flow measurement research. The gas in the loops is transmission-grade natural gas with nominally 93% methane content, 4% ethane, and the balance consisting of other gases. This facility afforded both the space and realistic setting for this style of open release testing. It should be noted that the intentional releases for this project were conducted utilizing compressed gas cylinders of pure methane gas.

Figure 2.1. Metering Research Facility
This natural gas flow meter testing site at SwRI was utilized for this work.

There was a location within the facility where an unintended leak was present. This leak was not part of the test setup and emitted the transmission-quality natural gas from the pressurized flow lines of the MRF throughout much of the testing. This leak provided a leak source that also included ethane, as opposed to the compressed methane used for the intentional releases. Since one of the point sensors was able to detect gasses other than just methane, this unintentional facility leak provided additional data.

2.2.2 Installation

The technologies required either a one-time, “permanent” installation prior to all testing activities or a repeated, temporary installation prior to each day of testing. Three of the systems were permanently installed and configured and the remaining three required daily installation and setup. Instruments were largely installed inside the “horse shoe” of the MRF (one included a path length that extended beyond this boundary) and were practically collocated. The installation layout and dimensions are shown below in Figure 2.2. The stationary devices were largely set up and configured within one day by the technology developers.

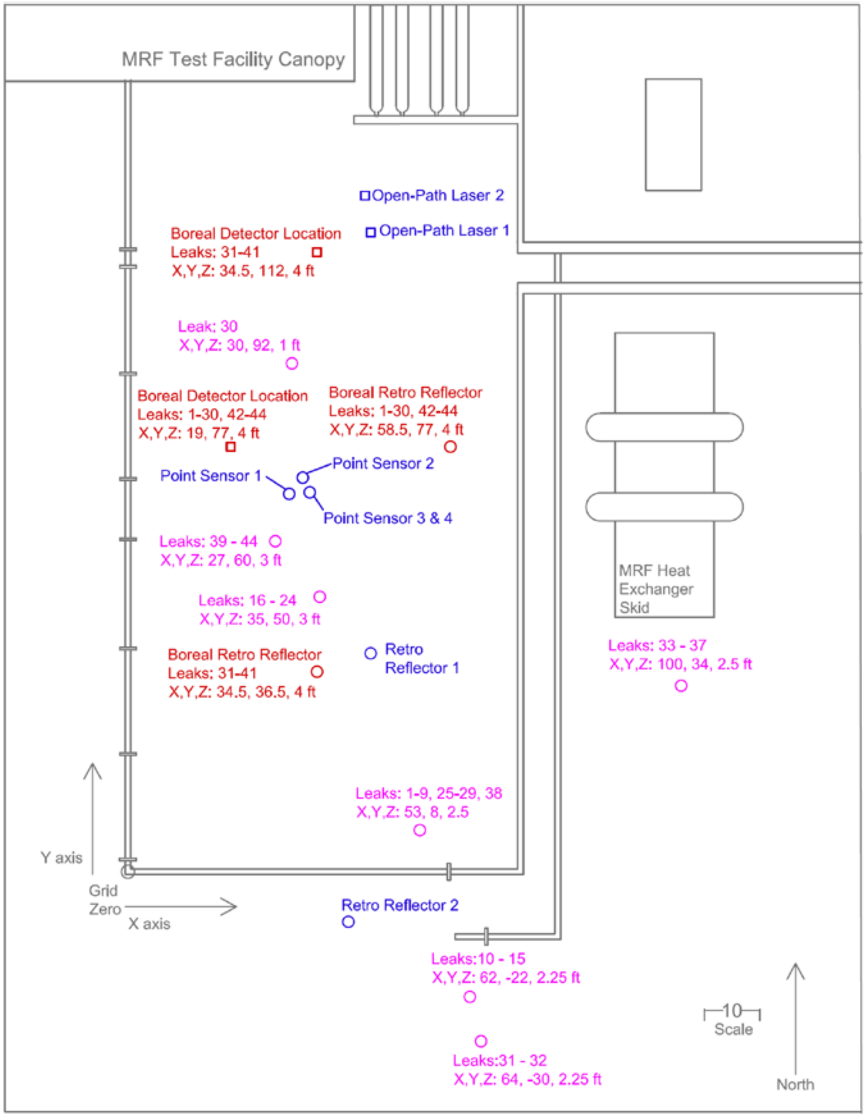

Figure 2.2. Stationary Monitor Leak Locations

During the stationary monitor testing, the leak location was moved. The figure shows the coordinates of each set of gas releases. The Boreal was the reference instrument for this testing. In general, the prevailing winds were out of the southeast in the range of 3-7 mph.

2.2.3 Release Rig

A Coriolis flow meter run was used to meter and measure the mass flux of methane. A process and instrumentation diagram (P&ID) of the meter run is shown in Figure 2.3. A compressed gas cylinder was used as the source of the methane and the upstream system pressure was set using a pressure regulator. The mass flux was controlled using a needle valve and could be monitored using the flow meter's local display. A long, flexible hose connected the meter run to the leak point.

2.2.4 Technology Developer Data Collection

Technology developer data streams were captured through either cloud or local access. Data consisted of a timestamped series of various measurements of which methane concentration was of principle interest. All clock times were adjusted to within a few seconds of local, internet time (Central Daylight Time, -5 UTC) during post-processing.

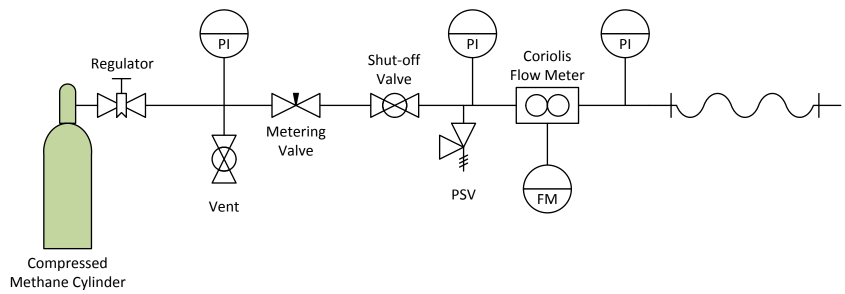

Figure 2.3. P&ID of the Flow Meter Run Used to Control Methane Mass Flux
An operator manually controlled the flux using a needle valve and monitored the value using a local flow meter display.

2.2.5 Instrumentation

The plume concentration was measured utilizing a Boreal Laser GasFinder2 gas analyzer. This device is an open-path gas detector, which uses tunable diode laser absorption spectroscopy (TDLAS) to integrate methane concentration over its path length. Laser light emitted from the transceiver travels through the air to the reflector and back to a photo-diode. The methane concentration is determined based on the absorption of near-infrared laser light by methane along the path length. The analyzer can be used to measure concentration along path lengths up to 2,500 ft, although path lengths were limited to approximately 40 ft and 76 ft during testing. Two different orientations and path lengths were used during testing, as illustrated in Figure 2.2.

Methane mass flux was measured using an Emerson CMFS010M Coriolis flow meter with the accuracy chart shown in Figure 2.4. A NovaLynx 200-WS-23 cup-and-vane anemometer was used to measure wind speed and direction in the test area (speed accuracy was ±3% of reading, direction accuracy ±3°). These instruments, along with the Boreal concentration measurement, were sampled using a LabVIEW analog signal recorder and a custom data-logging application. The data were recorded at a rate of 2 Hz for all of the testing.

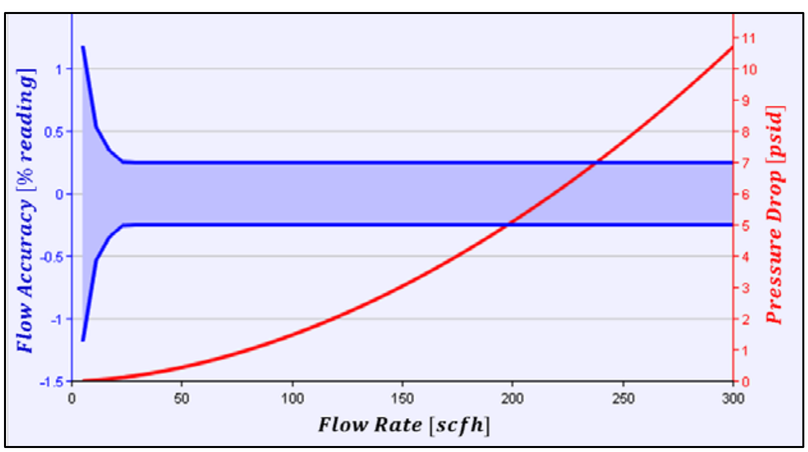

Figure 2.4. Accuracy Chart for the Emerson CMFS010M Coriolis Flow Meter (blue)
The mass flux accuracy did not exceed ±1% of reading during testing. For most test points, the mass flux accuracy was ±0.25 % of reading.

2.3 Test Matrix

This testing investigated leak conditions relevant to those that may be found in the field. The science team from EDF recommended flow rates in the range of 5-300 scfh. The low end of this range would be indicative of a fugitive emission from a seal such as a flange pair, while the upper end of this range would suggest larger leaks such as a valve or tank hatch not being fully closed. All tests were run during the day, which is notable because of the high ambient air temperatures in the range of 95-100°F. Tests ranged anywhere from 10 to 30 minutes in duration with most leaks lasting for about 10 minutes. The distance from leak was less systematically explored, but could generally be categorized as on the order of 30 ft, 70 ft, or 100 ft. Figure 2.5 contains graphics that summarize the number of tests conducted at different flow rates, times of day, duration, and range; the full matrix for the stationary monitor testing is given in Appendix A of this report.

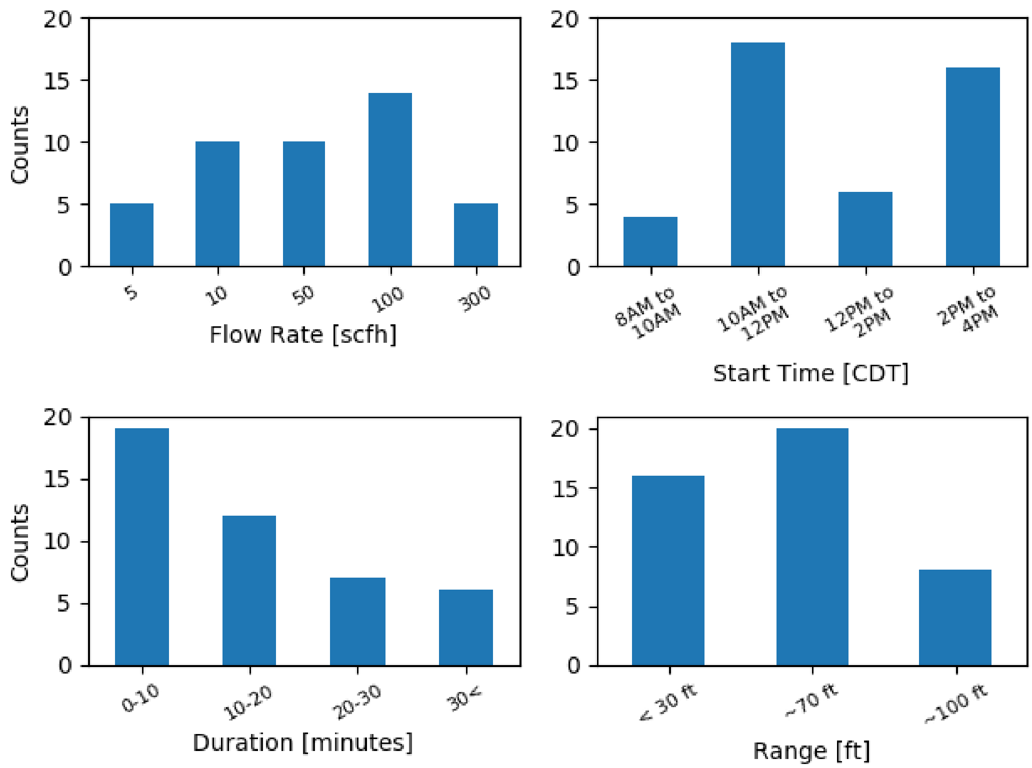

Figure 2.5 Summary Bar Charts of all Tests Conducted Sorted by Flow Rate (top left), Start Time (top right), Duration of Leak (bottom left), and Leak Range (bottom right)
A full test matrix may be found in Appendix A of this report.

2.4 Data Processing

Three of the tested technologies posted data to a cloud, which SwRI could then access remotely. In each of these cases, data streams could be viewed in real time to determine system performance or overall health. The remaining systems stored data locally either using on-board memory or a peripheral laptop.

After testing, data files from each party (all technology developers and SwRI reference data) were cleaned and standardized using scripts written in Python (version 3.6). It was at this point that time stamps were adjusted and localized to US Central time (CDT, -5 UTC). Most systems provided a number of measurements and indicators. Measurements of interest, such as methane concentration, ethane concentration, and ambient temperature, were parsed from the raw files and agglomerated into a standardized format. For open-path measurements, the path integration in ppm-m was converted to an average methane concentration in ppm by dividing the integrated measurement by the system's path length. All data streams were reduced to 1 Hz and aligned on a common time index. Three of the systems were in developmental mode, so their data are not included in this report.

2.5 Results

2.5.1 General Data Overview

The data presented in this section were selected to help "tell the story" of the results. This report is not intended to be a comprehensive technical document, so not all of the collected data are included (this information was shared with the technology developers and with Schlumberger). The remaining portions of this section contain data from three units: one point sensor (named Point Sensor) and the two open-path devices (named Open-Path #1 and Open-Path #2). Open-Path #2 had a path length that intersected with an existing leak source, so there was more resulting signal inherent in the readings from that device.

Prior to going into details on specific tests, it is worth providing a general overview of the quality of the data provided by the three units. The following four images (Figure 2.6 through Figure 2.9) show example data over the course of one afternoon. The blue bands represent periods in which leak tests occurred. In general, the Point Sensor and Open-Path #1 correlated well with the reference data. Due to its positioning, Open-Path #2 detected both intended and unintended leaks.

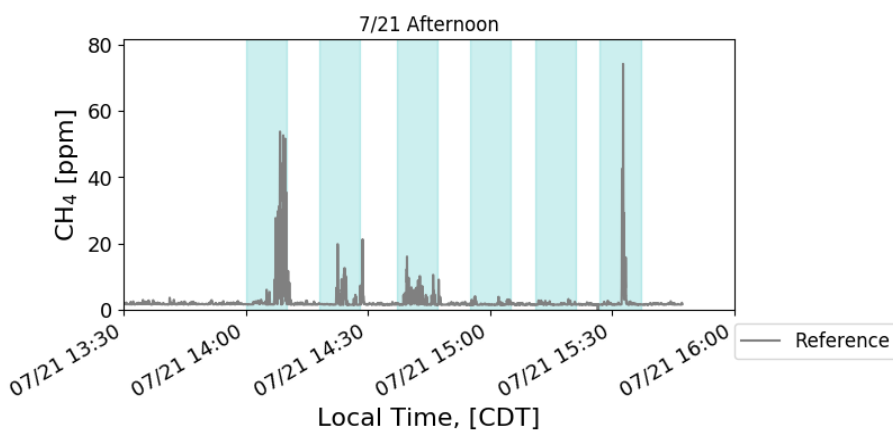

Figure 2.6. Readings from Reference Instrumentation

The following three figures are from the technology-specific datasets that align with this chart.

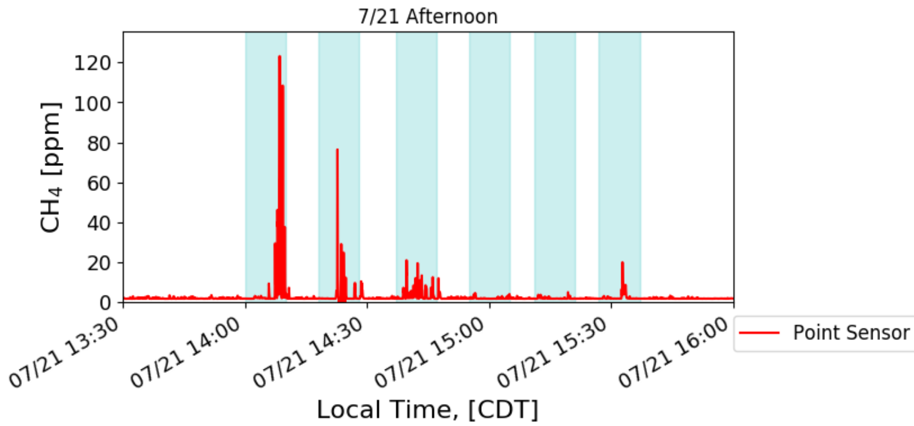

Figure 2.7. Readings from the Point Sensor Over the Course of One Afternoon
The blue bars represent periods in which leak tests occurred.

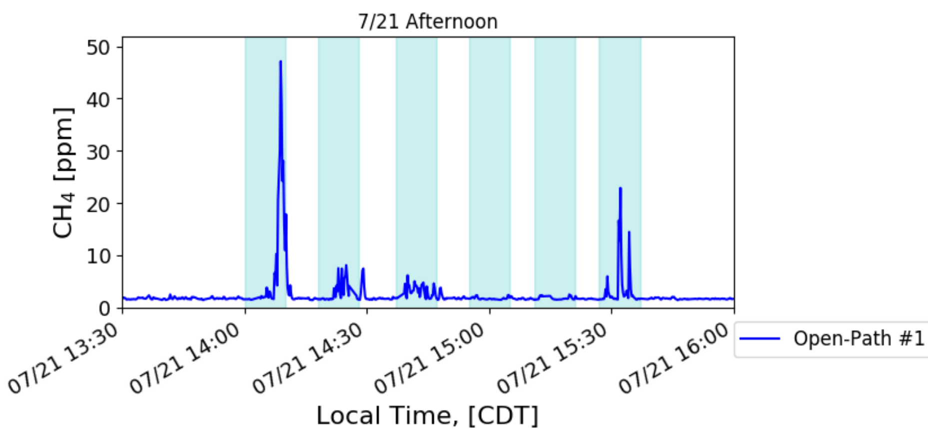

Figure 2.8 Readings from Open-Path #1 Over the Course of One Afternoon
The blue bars represent periods in which leak tests occurred.

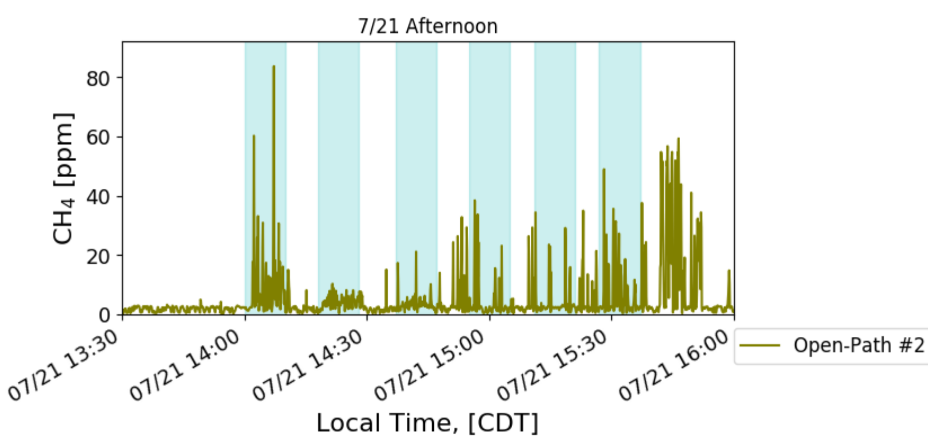

Figure 2.9 Readings from Open-Path #2 Over the Course of One Afternoon
The blue bars represent periods in which leak tests occurred.

An improved picture of performance can be assessed by reviewing the data of any particular test. For this example, data were pulled from the first test point in Figure 2.7 through Figure 2.9. This test was a 300-scfh leak from the location shown in the Figure 2.10. The data for the three sensors are given in Figure 2.11 through Figure 2.13. The green bands in these figures indicate the times in which the wind was "favorable" in that it generally blew the released gas towards the sensor. It should be noted that since the three technologies were situated at different locations from the leak source, these green bars are technology-specific and will differ from one chart to the next. A few general conclusions can be made from this information:

- The technologies largely missed leaks in which the wind blew the released gas away from the monitored path or point. This result was expected.
- The Point Sensor was very responsive to the leaks and largely mirrored the reference instrument.
- Open-Path #1 only detected methane when the wind direction was favorable. There is some level of dampening present as the technology did not respond as quickly to brief changes in concentration.
- Open-Path #2 provided less distinction between the test leaks and background than Open-Path #1, particularly in periods when the wind was not favorable. It should be noted that the path lengths for these two devices were not the same; that could have an impact in either direction on the results. Additionally, Open-Path #2 was physically closer to an existing leak source.

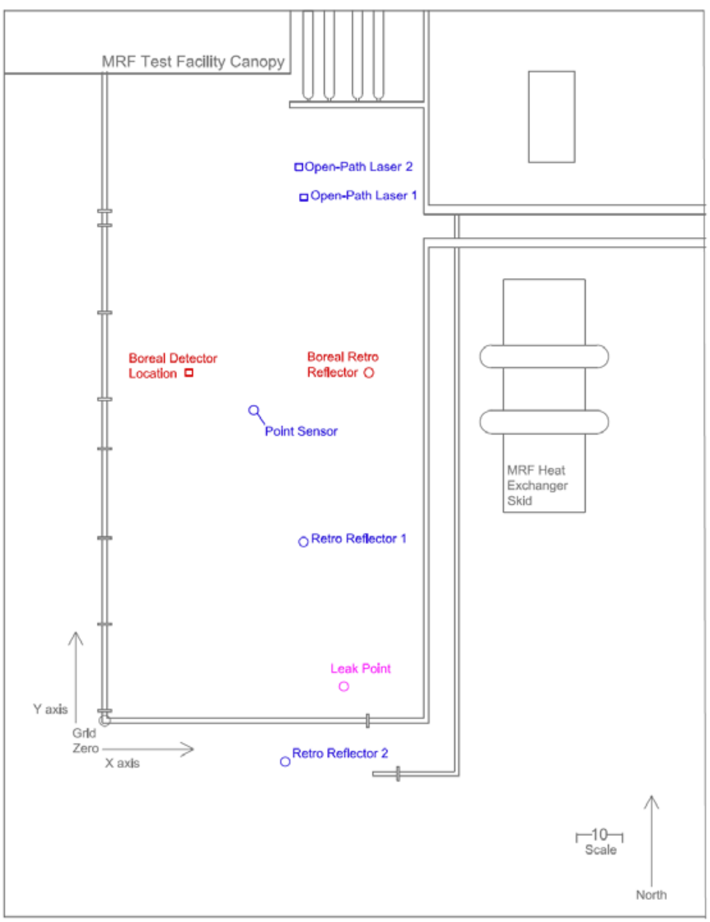

Figure 2.10. Location of Leak for the Data Analyzed in this Section
The data analyzed include several methane releases from a single leak point.

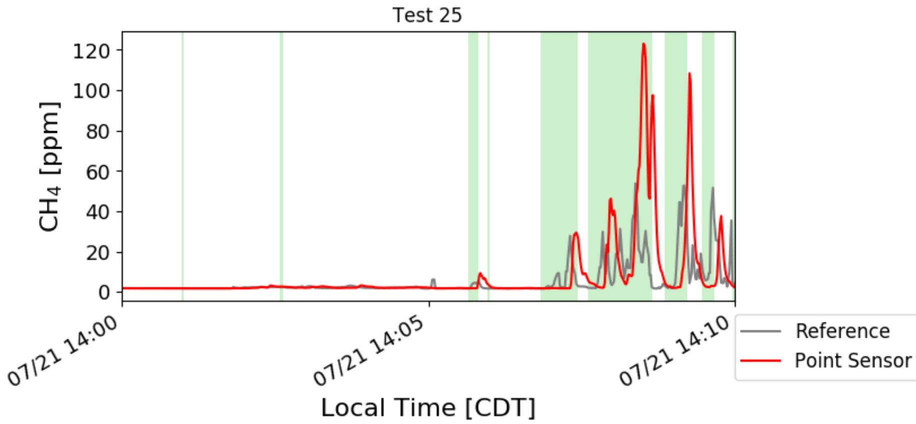

Figure 2.11. Example Test Data from 300-scfh Release for the Point Sensor
The green bars represent periods in which the wind generally was directing the released gas towards the technology. The measurements from this technology aligned well with the reference measurements.

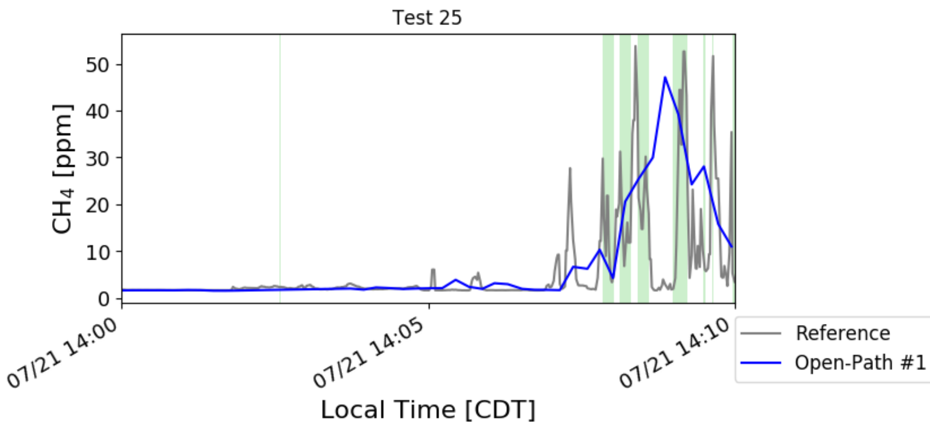

Figure 2.12. Example Test Data from 300-scfh Release for Open-Path #1
The green bars represent periods in which the wind generally was directing the released gas towards the technology. The measurements from this technology aligned well with the reference measurements, but did not respond as quickly to sudden changes.

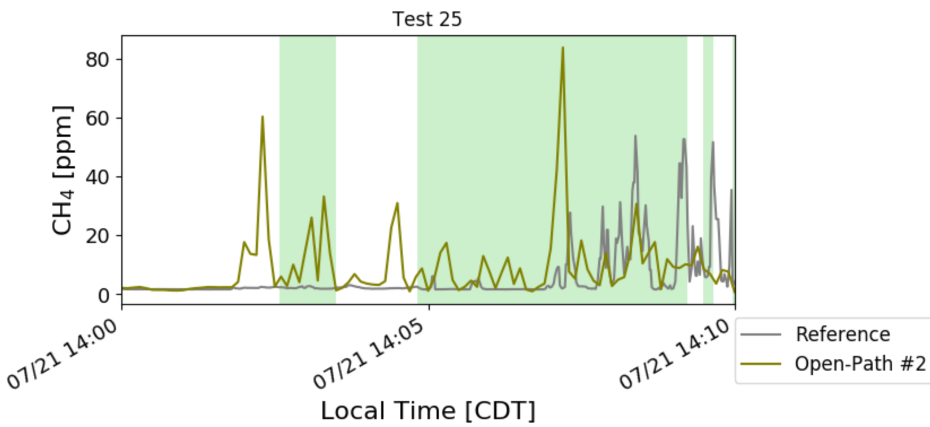

Figure 2.13. Example Test Data from 300-scfh Release for Open-Path #2
The green bars represent periods in which the wind generally was directing the released gas towards the technology.

2.5.2 *Measured Concentration*

This report presents various plots that capture the measured methane in parts-per-million. It is critical to note that the reference instrument for this testing was an open-path TDLAS system that provided an integrated measurement in ppm-m over its full path length. As pointed out in Figure 2.2, two different orientations of the reference instrument were also utilized. Thus, some caution should be exercised when comparing quantitative values from the different instruments.

Figure 2.14 provides an example of an hours-long period of testing with measurements from the reference instrument and a point sensor. This figure shows a correlative behavior between the two instruments. Figure 2.15 shows the exact same dataset, but allows for each of the two instruments to be independently scaled. This plot shows a large difference in measured value. One possible explanation is that there is a measurement error in one of the instruments. Another, and more plausible reason, is the danger in direct quantitative comparison between two values that are determined in different ways. It is quite possible that the higher concentration measured by the point sensor is correct, but that a relatively small plume integrated over a longer distance from the reference sensor would result in the latter having a small concentration reading. In summary, it is more useful to characterize relative changes in concentration and not absolute measurements when reviewing the data in this report.

These data also highlight the relative strengths and weaknesses of both point and open-path sensors. Open-path sensors can provide coverage over a larger area, but will inherently dilute the concentration reading since the signal is integrated over its entire length. A point sensor will have greater sensitivity, but requires direct contact with the leaked gas.

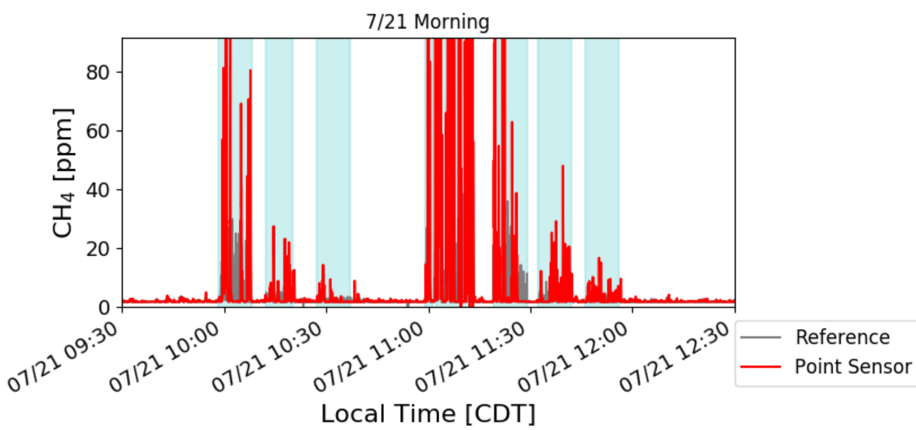

Figure 2.14. Measurements from a Point Sensor
This plot has the same scale for both the reference TDLAS system and the point sensor.

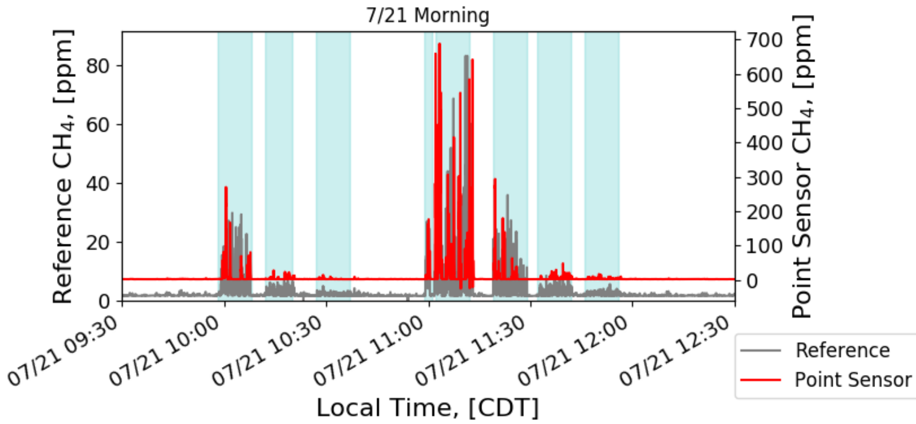

Figure 2.15. Same Figure as Previous Plot with a Secondary Scale
This plot shows a significant difference in readings between the two instruments. However, the fact that one is a point sensor and the other an open-path device may explain this discrepancy.

2.5.3 Impact of Monitoring Ethane

The point sensor had the ability to independently measure methane and ethane. One potential advantage of utilizing such a feature is the ability to differentiate thermogenic and biogenic sources of methane. This differentiation can be important when oil and gas facilities are operating in the near proximity to biogenic sources of methane, such as landfills or various agriculture facilities. Figure 2.16 shows data from a leak of 5 scfh having significant correlation between the methane and ethane peaks. This leak was of transmission-grade natural gas that included nominally 4% ethane, while the intended releases had no ethane.

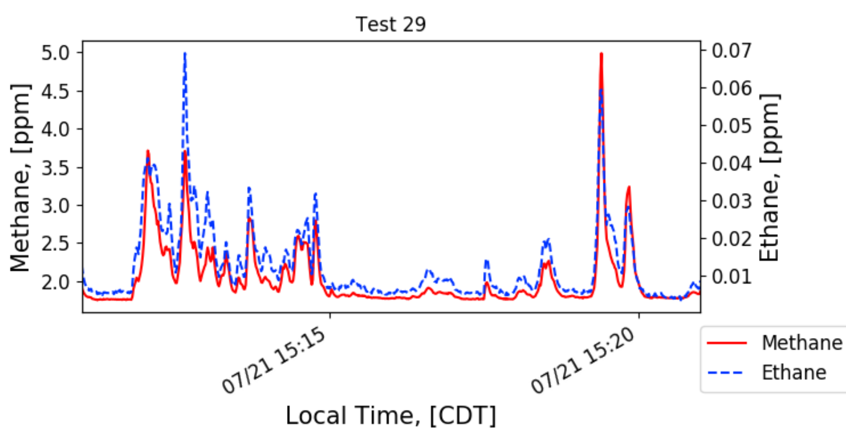

Figure 2.16. Test of Point Sensor during a 5-scfh Release
The fact that each peak of methane correlates with a peak of ethane suggests that this detection is of a known leak in the facility that contains transmission-grade gas.

A Pearson (or bivariate) correlation was developed to evaluate how closely the two measurements followed each other. The results of this analysis are shown in Figure 2.17. A value of 1.0 implies perfect correlation. For this specific exercise, this 1.0 value equates to the measured methane coming from the background, whether that is the general background value or from a fugitive leak in the facility. A value of 0 would mean no correlation. In this example, the value of 0 would equate to the methane originating from the intentional release of 100% methane. This correlation was calculated in windows utilizing the previous 30 seconds of data, so the calculated correlative coefficient leads the measured data. As an example, the only value approaching 0 was from the first methane peak. Figure 2.18 shows the same calculation for a leak of 100 scfh. This analysis shows that several methane peaks existed with a correlation approaching 0, implying that these measurements were of the intentional release and not from the background.

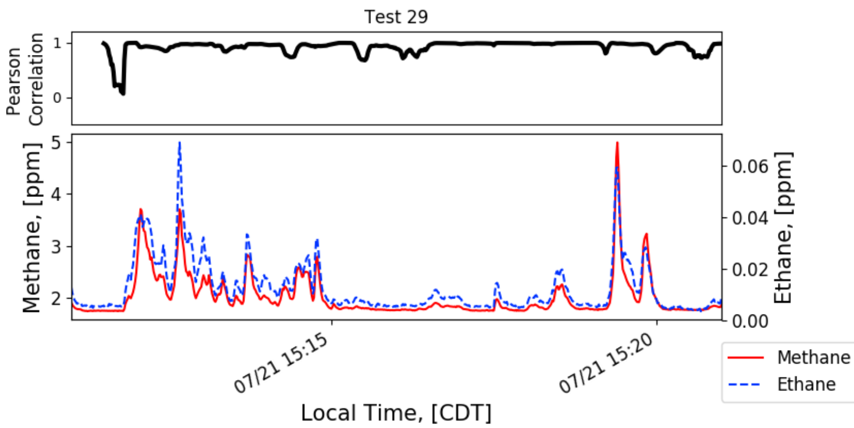

Figure 2.17. Pearson Correlation of a 5-scfh Leak

Values near 1.0 demonstrate strong correlation between the background and the measured values of methane. Thus, with one possible exception during the first methane peak, most of the measured methane was from changes in the background, such as the unintended leak from the facility.

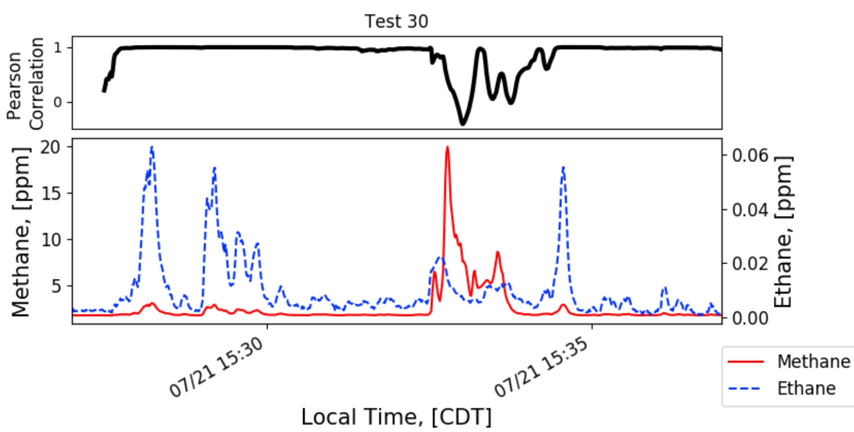

Figure 2.18. Pearson Correlation of a 100-scfh Leak

Values near 1.0 demonstrate strong correlation between the background and the measured values of methane. Thus, there are several peaks that result in 0, implying these measurements were from the intentional release and not from the background, such as the unintended leak from the facility.

2.6 General Findings

- There are two open-path stationary technologies that are largely ready for commercial deployment. These technology sensors are powered by solar panels and upload their data automatically to a cloud. Such technologies could, therefore, be installed at sites not having significant existing infrastructure.

- One of the point sensors tested is largely ready for commercial deployment. The tested unit was powered off the grid, but field versions may need to be fitted with solar power, which should not be an obstacle.
- The development of robust algorithms that can factor in a dynamic background environment are still needed in order to have unattended operation of such equipment in a real-world environment.
- Some of the technologies are not ruggedized to the point that they could be left unattended in severe weather, such as high temperature, humidity, or precipitation.

2.7 Technology Readiness Assessment

2.7.1 Spectrometers

The three technologies highlighted in this report section are all spectrometers. These systems provided stable readings at commercial or near-commercial readiness levels. Table 2.1 summarizes the status of each technology *as tested* with respect to several parameters.

Table 2.1. Technology Assessment of Spectrometers Tested

These three technologies were the best performing units during the testing. This table only reflects the specific hardware provided for this test and does not infer that other units of the same technology could be outfitted differently.

PARAMETER	POINT SENSOR	OPEN-PATH #1	OPEN-PATH #2
Potential for Detecting Small Leaks	Yes	Yes	Possible
Biogenic/Thermogenic Differentiation	Yes	No	No
Solar Powered	No	Yes	Yes
Data Communication	Local	Cloud	Cloud
Robust Detection Algorithm	No	Rudimentary	Rudimentary

2.7.2 Electro-Chemical Sensors

The two more developmental technologies are various forms of electro-chemical sensors. These yielded the least-reliable measurements and are not considered commercially viable for methane leak detection at this time. Generally speaking, laser-based spectroscopy still represents the state-of-the-art in methane leak detection systems with measurements that are accurate, reliable, and well understood. However, it is worth emphasizing that electro-chemical sensors present potential due to their low fabrication cost, which is orders of magnitude lower than laser-based technologies.

Additionally, one of the technologies is a plug-and-play unit that allows for multiple units to come online without the end user doing anything other than supplying power. This ability to have a large network of sensors may be a valuable approach to methane detection when monitoring large areas.

3. HANDHELD TESTING

A separate set of tests was performed on handheld technologies than those releases utilized to test the stationary technologies. The handheld technologies were evaluated for two different purposes:

- Use as a screening tool to narrow down the location of a source when personnel are sent to a site with a known leak, but without the user having to individually check every potential leak source.
- Use as an alternative to optical gas imaging as a means of detecting small, fugitive leaks from equipment as part of a compliance program (such as 40 CFR Part 60, Subpart OOOOa).

Schlumberger also utilized this testing as an exercise for the selection of potential technologies to deploy, but that commercial aspect is being left out of this report.

3.1 Technology Overview

There were nine devices tested for this work. One of these, a stationary device described in the previous section, was briefly used in a mobile mode as a handheld technology. The technologies fell into the following categories:

- Two devices were commercially available "sniffer" probes. These devices were small, portable units that could be operated with one hand.
- Four devices were developmental units that could be carried by a backpack or shoulder strap with a separate sniffing tube. These technologies ranged from early stage development to close-to-commercial units.
- Three technologies were commercially available open-path lasers.

3.2 Training

The handheld technologies were operated by the staff members of Schlumberger. These staff members were trained on the use of the technologies by representatives of the technology developers over a period of about one hour per technology. In addition to providing training on the mechanics of use, this time was also used as an opportunity for the technology developers to communicate the methodology for locating a leak using their respective technology, including factoring in the use of wind direction and gas concentration.

3.3 Test Setup

The initial plan for the testing was to conduct "scavenger hunts" in which the operator of the technology was asked to determine the source(s) of leaks when given a general indication of the area of the facility in which the leak(s) originated. Testing was performed in a variety of weather conditions, including elevated temperatures (above 95ºF), elevated humidity, light rain, pre-dawn light, and mid-afternoon sunny conditions.

This testing was divided into two exercises. In the first set of tests, leaks were created at one or more flanged locations on a 135-ft straight section of piping. In the second set of tests, leaks were created at hidden locations within a small section of the MRF.

3.3.1 Handheld Testing Set #1 – Flange Leaks

Figure 3.1 shows a picture of the facility where the first set of tests was completed. The operators were informed that leaks may or may not be emanating from each of the eight flange pairs along the 135-ft length of pipe. Each flange was outfitted with a hose connected to the release rig, as described in Section 2.2.3. The hoses carrying the methane gas were terminated at either 3:00, 6:00, 9:00, or 12:00 positions on each flange. During testing, up to two leaks were initiated and maintained at a combined rate of approximately 20-100 scfh. Figure 3.2 shows the test site layout for the handheld testing. Upon starting each test run, the device operators began searching for leaks simultaneously. Once all operators completed their leak detection search and gave the "all clear," the leak(s) was turned off.

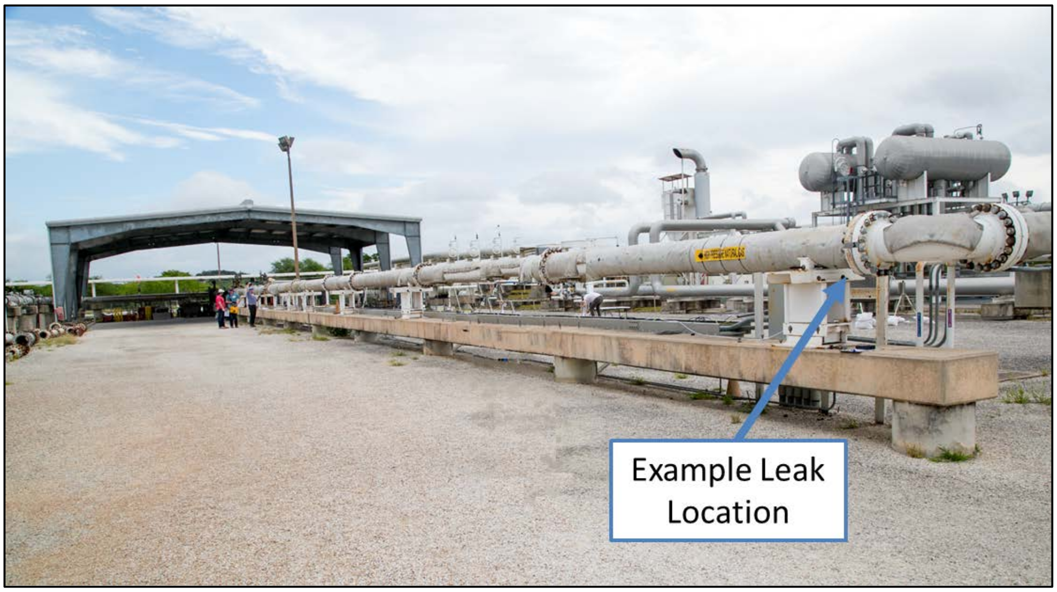

Figure 3.1. Handheld Testing Set #1

Eight leaks were initiated at the flange pairs on a 135-ft section of straight piping.

The initial plan was for the operators to record such information as the time to find each leak and the total time to issue the "all clear." The intent behind this arrangement was to determine if technologies such as the laser systems would provide a quicker means of scanning the area to triangulate the location of the source. However, it was discovered early on in the testing that evaluating each joint was required. The testing then shifted to having most of the operators travel in a group to test each flange joint while feedback was exchanged between operators.

3.3.2 Handheld Testing Set #2 – Hidden Leaks

The second set of tests for the handheld devices investigated the detectors' abilities to find leaks at unknown locations. In theory, this test should have provided an advantage for a leak detector capable of scanning an area, as opposed to a sniffing detector. The eight leak points were hidden among flow components on the MRF heat exchanger skid where leaks could realistically occur. Figure 3.3 shows a subset of leak locations on the heat exchanger skid, which included a leak at an elevation that was unreachable by sniffer-type detectors. During the second set of testing, up to two leaks were initiated at the hidden leak points at a combined rate of approximately 20-100 scfh. As with the first set of testing, all operators started searching for leaks simultaneously. Each methane release was maintained until all operators gave the "all clear" and the test was completed. It was determined early on in the testing that the handheld devices were not well suited for use as a means of narrowing down the source of a leak in a large area, but should focus on compliance at individually-monitored assets.

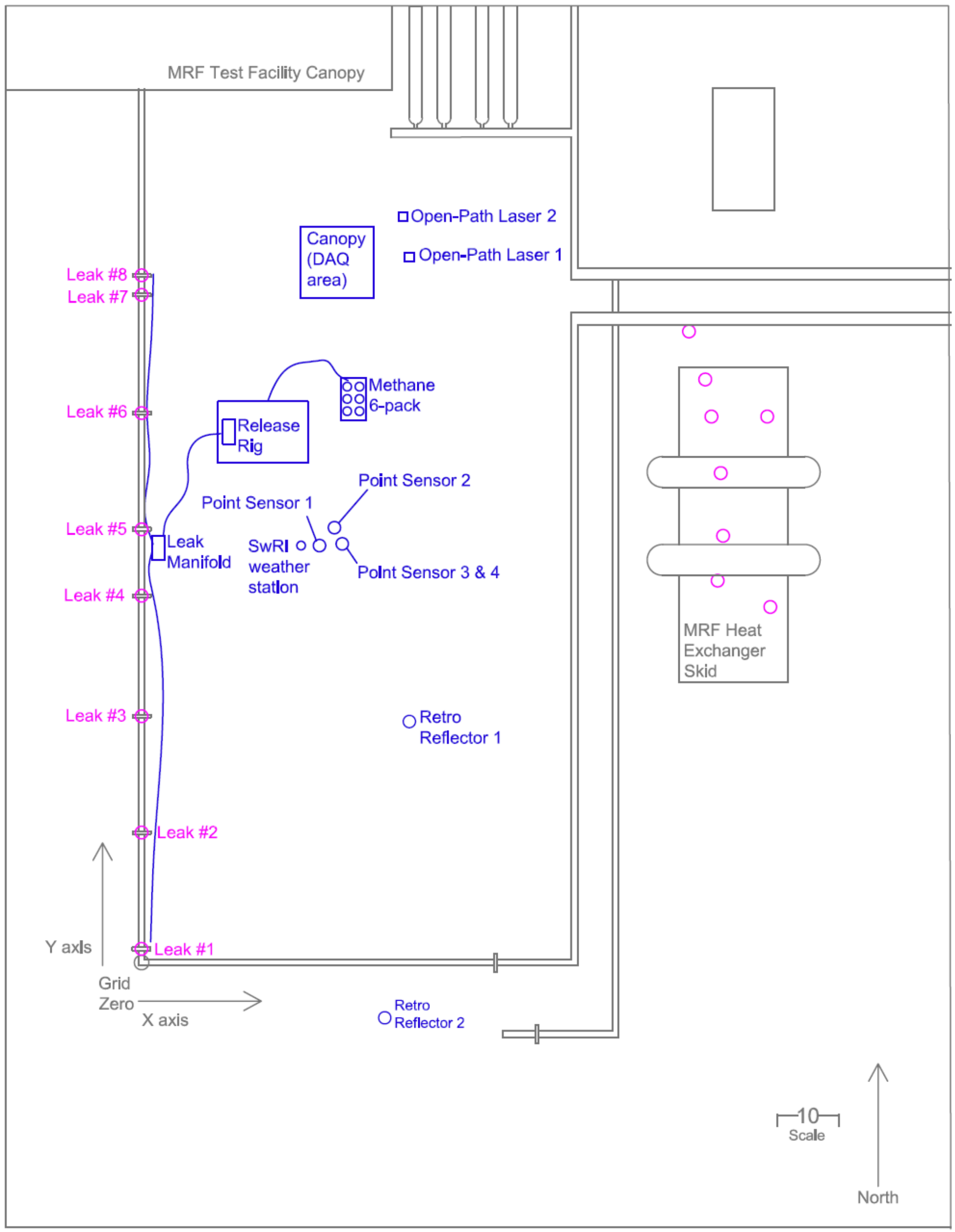

Figure 3.2. Handheld Detector Test Setup

A compressed methane source was plumbed to eight flange pairs, where intentional leaks could be initiated.

Figure 3.3. Handheld Device Testing Set #2
Various leaks were hidden amongst the valves and fittings on the MRF heat exchanger skid. Example locations of the leaks are represented as green triangles in the figure.

3.4 General Findings

The nature of this testing was more amenable to qualitative assessment than any sort of quantitative evaluation. After each test with the handheld detectors, the technology operators recorded their observations on factors such as ease of use, success at detecting leaks (including false alarm rate), ruggedness, and ergonomics. Further, the operators held panel discussions after each test to discuss each technology.

Leak Location

The operators were not able to get the technologies to reliably narrow down the location of a fugitive leak without sampling from each possible leak point. In other words, a user would not be able to go to a site where a stationary system had sent an alarm and then quickly find the source of this leak. At a site where a stationary system had alarmed, a realistic standard operating procedure would involve systematic inspection of each component at the site using the handheld device.

Compliance

Various inspection requirements such as 40 CFR Part 60, Subpart OOOOa, allow for either a Method 21-style device (e.g., sniffer) or use of an optical gas imaging (OGI). The former utilizes less-expensive equipment, while the latter can produce cost savings. The sniffer-based technologies evaluated in this project fall into the Method 21 category, while the laser-based systems provide a potentially more economical alternative to OGI. The results of the testing were:

- The commercial sniffer probes performed largely as advertised. They were able to find leaks <500 ppm and identify the specific source of the leak.

- The developmental sniffer probes demonstrated significant promise, but it is not clear that they offer features missing from existing Method 21-compliant sensors.
- The laser-based systems were particularly sensitive to the position of the plume when monitoring from an appreciable distance. For very small leaks, even slight changes in wind direction could have a significant impact on the ability of the sensors to detect the leak. For leaks in which a specific source, such as a flange, was known, the laser devices would eventually find the leak.

Opportunities for Improvement

Approximately one-half of the technologies proved to be very robust during testing, while the other half would benefit from reliability improvements. Some specific areas of consideration for improvement are:

- Several of the devices had displays that were not local to the sensor. This made it difficult to "stay on target" when looking at the local display.
- The laser systems relied on a visual laser for marking the location. It was often times difficult to see this laser when lighting conditions were not favorable, such as in situations with reflective surfaces nearby.
- Improvements could be made to the portability of some of the devices to make them more ergonomic. Additionally, thought should be given to various human factor elements, such as audible alarms. When operating a device in an environment where leaks are not expected, an audible alarm can provide an additional layer of fidelity to the process. However, in environments where one or more leaks are present, the constant alarming is not useful and can instead be distracting.

4. SUMMARY

This project was initiated to capture the performance of various low-cost technology solutions for methane detection. Both stationary and handheld technologies were evaluated. The project included testing of technologies over a wide variety of commercial readiness levels.

4.1 General Conclusions

The objectives at the outset of the testing project were:

- Assess the technology readiness level of various methane leak detection technologies.
- Determine if any of the tested devices are suited for commercial deployment and/or have minor gaps that would need to be closed prior to further use.
- Provide data from realistic tests back to the technology developers to allow for continued development of the systems.

Specific recommendations were provided to each technology developer to aid in the continual improvement of their technology. Here are the key takeaways from the testing in regards to meeting these objectives:

Stationary Technologies

- There are two open-path stationary technologies that are largely ready for small-scale commercial deployment. These technology sensors are powered by solar panels and upload their data automatically to a cloud. Such technologies could, therefore, be installed at sites not having significant existing infrastructure.
- One of the point sensors tested is largely ready for commercial deployment.
- Even for the technologies that are largely ready for commercial deployment, the development of robust algorithms that can factor in a dynamic background environment are still needed in order to have unattended operation of such equipment in a real-world environment.
- The technology readiness of the best-performing sensors is provided in Table 4.1.

Table 4.1. Technology Readiness of Best-Performing Sensors

The two open-path technologies were at the same stage of development. This table only reflects the specific hardware provided for this test and does not infer that other units of the same technology could be outfitted differently.

PARAMETER	POINT SENSOR	OPEN-PATH #1	OPEN-PATH #2
Potential for Detecting Small Leaks	Yes	Yes	Possible
Biogenic/Thermogenic Differentiation	Yes	No	No
Solar Powered	No	Yes	Yes
Data Communication	Local	Cloud	Cloud
Robust Detection Algorithm	No	Rudimentary	Rudimentary

Handheld Technologies

- There were multiple handheld devices that could be used for compliance purposes (e.g., 40 CFR Part 60), but none provided benefits over existing Method 21 devices.

- While portable, open-path sensors provide the possibility of using such devices for narrowing down the location of a leak source, the testing conducted did not demonstrate the commercial readiness of the technologies in upstream and midstream applications.
- At least one of the handheld technologies had an embedded GPS system. This feature could eventually be leveraged to overlay readings onto a map of the site for ease of reporting.
- The training on the handheld devices was straightforward for most of the technologies, indicating it would be relatively simple to have personnel trained to use these devices as a "side function" of their job, as opposed to having to be an optical gas imaging (OGI) "expert" in order to provide leak detection and repair LDAR services.

4.2 Closing Thoughts

Several of the technologies demonstrated the ability to transmit data in real-time to servers or a cloud without requiring the use of onsite infrastructure. Additionally, some progress has been made on some of the technologies to develop rudimentary algorithms, such as signaling the persistence of an elevated level of methane. However, much progress is needed in the area of analytics. Some of this development may come from the sensor developers, but there is not a need for a one-size-fits-all approach in the marketplace. Some consideration should be given to oil and gas operators essentially purchasing a robust sensor and communications package, but handling the analytics on their own or through a third party.

Two of the more developmental technologies evaluated in this project were relatively low-cost sensor nodes that could be arrayed into larger networks. This provides an opportunity for operators who have facilities over large areas to integrate sensors on multiple sites to provide a more complete picture of methane emissions.

The discussions of algorithm development in this report focus largely on the ability to have a robust binary alarm to alert a user to a leak. Further evolution of algorithms should strive towards being able to locate a leak within a zone of a large facility to allow for handheld devices to more easily pinpoint the leak source.

This report started with commentary relating to the original MDC work performed by EDF. Multiple technologies evaluated in this project were not available at the time of the MDC request for proposal. This implies that the sensor industry continues to innovate in this space. Industry, government, and the environmental advocacy community should consider how to continue to evaluate new technologies as they evolve into the marketplace.

APPENDIX A

Test Matrix for the Stationary Monitor Testing

TEST POINT	FLOW RATE (scfh)	LEAK GEOMETRY	LEAK LOCATION X (ft)	LEAK LOCATION Y (ft)	LEAK LOCATION Z (ft)	BOREAL ORIENTATION
1	10	1/4" Open Tube	53	8	2.5	West-East
2	50	1/4" Open Tube	53	8	2.5	West-East
3	100	1/4" Open Tube	53	8	2.5	West-East
4	300	1/4" Open Tube	53	8	2.5	West-East
5	10	Loose 2" Hammer Union	53	8	2.5	West-East
6	5	Loose 2" Hammer Union	53	8	2.5	West-East
7	50	Loose 2" Hammer Union	53	8	2.5	West-East
8	100	Loose 2" Hammer Union	53	8	2.5	West-East
9	300	Loose 2" Hammer Union	53	8	2.5	West-East
10	300	Loose 2" Hammer Union	62	-22	2.25	West-East
11	100	Loose 2" Hammer Union	62	-22	2.25	West-East
12	50	Loose 2" Hammer Union	62	-22	2.25	West-East
13	10	Loose 2" Hammer Union	62	-22	2.25	West-East
14	100	1/16" Orifice	62	-22	2.25	West-East
15	100	1/32" Orifice	62	-22	2.25	West-East
16	100	1/4" Open Tube	35	50	3	West-East
17	50	1/4" Open Tube	35	50	3	West-East
18	10	1/4" Open Tube	35	50	3	West-East
19	5	1/4" Open Tube	35	50	3	West-East
20	100	1/4" Open Tube	35	50	1	West-East
21	100	1/4" Open Tube	35	50	1	West-East
22	50	1/4" Open Tube	35	50	1	West-East
23	10	1/4" Open Tube	35	50	1	West-East
24	5	1/4" Open Tube	35	50	1	West-East
25	300	1/4" Open Tube	53	8	2.5	West-East
26	100	1/4" Open Tube	53	8	2.5	West-East
27	50	1/4" Open Tube	53	8	2.5	West-East
28	10	1/4" Open Tube	53	8	2.5	West-East
29	5	1/4" Open Tube	53	8	2.5	West-East
30	100	1/4" Open Tube	30	92	1	West-East
31	100	1/4" Open Tube	64	-30	2.25	North-South
32	50	1/4" Open Tube	64	-30	2.25	North-South
33	100	1/4" Open Tube	100	34	2.5	North-South
34	50	1/4" Open Tube	100	34	2.5	North-South
35	5	1/4" Open Tube	100	34	2.5	North-South
36	10	1/4" Open Tube	100	34	2.5	North-South
37	50	1/4" Open Tube	100	34	2.5	North-South
38	100	1/4" Open Tube	53	8	2.5	North-South
39	10	1/4" Open Tube	27	60	3	North-South
40	10	1/4" Open Tube	27	60	3	North-South
41	50	1/4" Open Tube	27	60	3	North-South
42	100	1/4" Open Tube	27	60	3	West-East
43	300	1/4" Open Tube	27	60	3	West-East
44	10	1/4" Open Tube	27	60	3	West-East