# Final Outcomes Report – Non-Confidential

**Project Title**: Methane Imaging & Quantification System for Fixed Site Monitoring
**Agreement Number:** O160169



**Project Leader**: Ed Cullinan (ed.cullinan@atco.com)
**Lead Institution**: ATCO Gas and Pipelines Ltd (ATCO)
**Project Partners**: MultiSensor Scientific, Zedi, Target Emissions Services
**Project Budget:** $6,108,484
**ERA Project Advisor:** Chris Owttrim
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# 1 Executive Summary

Provincial and Federal methane emission regulations came into effect January 1, 2020 designed to reduce fugitive methane emissions throughout the oil and natural gas supply chain from production to distribution via increased leak detection and repair programs. These new regulations present a significant cost burden for Alberta's oil and gas industry. This project was initially designed to develop and commercialize a better and cheaper portable or relocatable inspection solution for the Alberta oil and gas industry to conduct optical gas imaging (OGI) inspections as required by regulations.

For ATCO, the aim was to deploy this technology at ATCO owned and operated facilities including gas processing, transmission, and storage sites across Alberta to reduce the cost impact of new emissions regulations and increase the effectiveness of fugitive emissions management programs to come. ATCO also was interested in the potential of growing it's operational services business by underpinning its emissions testing services with new, superior technology.

**Key Results**

MultiSensor Scientific (MSS) and its wholly owned Canadian subsidiary, MultiSensor Canada (MSC), designed, built and tested a Beta1 Sensor (initial prototype), a Beta2 (portable system) and a Beta3 (re-locatable system) under this project. The core technology and hypothesis were successfully demonstrated: image-based detection of methane using a scanning, low-cost, non-thermal, single pixel sensor in the short-wave infrared (SWIR) spectrum. Moreover, it was concluded that, with further hardware upgrades, the technology is well suited for installed or relocatable monitoring. The technology is less well suited for portable gas inspection.

The Beta Sensor was able to clearly show the presence of gas when it was present in many situations and at relatively low leak rates (<7g per minute) from distances of 20m or less in a controlled environment. Field testing showed the ability to see emitted gas from tank vents without the need to climb onto the tank or connect any physical equipment to the vent. Improvements made after the end of the active project period have since further lowered the detection limit, extended the range and very significantly reduced the power requirement of the camera.

The original goal of commercializing a portable camera for inspection purposes was determined to be not viable unless very significant additional resources were spent. This outcome negatively impacted ATCO's ability to deploy this technology in an operational setting at this time, in order to meet compliance targets, and ATCO's ability to underpin emissions testing services with this technology.

At the same time, a key strength of the technology platform was discovered and explored during this project: the ability to commercialize the technology at significantly lower cost than initially anticipated as an installed or relocatable camera.

At high manufacturing volumes the customer price per camera could be below CAD$10,000, which is well below the initial commercialization target of CAD$45,000 and far below any other commercially available infrared camera with automatic gas leak detection. Due to these favorable economics, MultiSensor is currently working to commercialize the technology developed under this project as a low-cost camera system for installed monitoring, automatic alarming and continuous leak rate quantification of gas leaks and tank vents.

ATCO engaged in this research and development project for the purpose of supporting the development of a superior alternative to incumbent optical gas imaging technology that could both reduce the cost of compliance and increase outcomes (likelihood of emissions decreasing) and so is ultimately interested in the success of the pivot to an installed or relocatable camera and will be open to testing its utility in its operations at that time.

**Methane Regulation Compliance at ATCO**

ATCO has implemented a plan for compliance with Federal and Provincial Methane Regulations beginning in 2020 based on incumbent technology.

# 2 Project Description

## 2.1 Introduction

Provincial and Federal methane emission regulations came into effect January 1, 2020 and are designed to detect and compel the mitigation and reduction of fugitive methane emissions from the oil and gas upstream and midstream activities. These regulations however are expected to be costly for industry and the need and opportunity for a cheaper, more effective alternative is clear. This project was meant to provide a better, cheaper solution to the optical gas imaging (OGI) inspection that is currently industry standard.

For ATCO, the aim was to deploy this technology at ATCO owned and operated facilities including gas processing, transmission, and storage sites across Alberta to reduce the cost impact of new emissions regulations and increase the effectiveness of fugitive emissions management programs to come. ATCO also was interested in the potential of growing it's operational services business by underpinning its emissions testing services with new, superior technology.

The ATCO led project team has developed and tested a prototype scan-based methane imaging and quantification system for inspecting and monitoring of major emitting facilities with the aim of contributing to the government objective of reducing fugitive methane emissions from oil and gas in Alberta by more than ½ Mt/yr (30% of 2014) emissions by the year 2030. The team consists of MultiSensor Scientific (technology developer), Zedi Solutions (now Emerson Electric Canada; data handling), Target Emissions Services (optical gas imaging inspection expertise) and ATCO (facility owner, operator and project manager).

MultiSensor Scientific has been developing a novel, non-thermal gas imaging & quantification camera since 2015. This project has seen the development of a product prototype from conception to field demonstration that was targeted at portable and relocatable gas leak detection, imaging & quantification for industries impacted by increased methane emissions regulations, including the Alberta oil and gas industry.

## 2.2 Description of Technology

The core technology that has been developed and demonstrated in this project is a non-thermal infrared camera by MultiSensor Scientific (MSS). Instead of mid- or long-wave thermal infrared detection, like current OGI technologies, the MSS camera operates in the Short-Wave Infrared (SWIR) spectrum. It uses absorption spectroscopy to detect gas, as opposed to the incumbent methodology, which measures the difference between the gas temperature and background temperature to detect gas. Two major benefits of this novel approach are that background temperatures do not affect the ability to detect gas and continuous calibration of background temperatures are not required, making the automation of gas detection much simpler. The MSS technology does however require a source in the SWIR spectrum (such as the sun or a SWIR illuminator). The need for a light source of SWIR light means that, in the absence of daylight, a bulb must be used that produces SWIR light and that light must be directed or focused to the areas being observed. Although these components are cheap to purchase, it was found that the power consumption and added size of such an illuminator limited the overall application in the current design. One other key benefit to the use of gas detection in the SWIR spectrum is that steam and water vapour do not elicit the same absorption response as methane, unlike the incumbent mid-wave IR technology where steam and water vapour appear the same as methane.

The MSS approach is to use primarily off-the-shelf components with moderate complexity, while combining them in a novel way. The sensing technology does not require cryo-cooling or custom optics, and uses proprietary circuit boards populated with commercial industrial electronics. The primary driver of cost reductions compared with other technologies is the use of a single pixel that is scanned horizontally and vertically (that produces individual images) as opposed to a two-dimensional array (that produces video rate imagery). Although this means that only one pixel is observed at any given moment, a full image can be collected in a matter of seconds by scanning the scene.

## 2.3 Project Goals

The primary goal of the project was to develop and pilot test a prototype scan-based methane imaging and quantification system for inspecting and monitoring of major emitting facilities with the aim of enabling cheaper and better methane emission detection programs. This is to limit the cost impact of and increase the probability of industry meeting climate goals of reducing fugitive methane emissions from oil and gas in Alberta by more than ½ Mt/yr (30% of 2014) emissions by the year 2030. In order to do this, the following project goals were set:

I. Develop two types of scan-imager product prototypes, one portable version, and one relocatable semi-permanent platform for inspection and monitoring of fixed site with potential methane emissions.

II. Assess performance of the prototypes compared to currently utilized methane measurement equipment and methods.

III. Test utility of the technology for short-term inspections (portable version) and for semi-permanent monitoring (relocatable platform version) of multiple sites vs. existing survey techniques and methods

IV. Conduct pilot tests of the portable version at least 10 different sites and of the semi-permanent relocatable platform at least 4 different sites, in the upstream and midstream sectors, to assess utility of the technology and drive refinement of the prototype.

V. Estimate methane emissions reduction for Alberta as a function of deployment by sector and region.

VI. Determine strategies for product deployment in Alberta, market penetration throughout Canada, and scaling up of manufacturing, consistent with CSA certification.

Over the course of the project, each goal was completed as described above. In addition, following testing of a proof of concept installed camera that combined the relocatable mast with the portable camera and illuminator (Beta2) plus optional retroreflectors, MSS decided to further develop a proof of concept installed camera. See the table below for a summary of the project goals.

**Table 2-1 - Project Goals Summary**

| Goal | Outcome |
|---|---|
| Develop two types of scan-imager product prototypes, one portable version, and one relocatable semi-permanent platform (multiple units of each) for inspection and monitoring of fixed site with potential methane emissions. | Complete. Two prototypes (Multiple units of Beta2, One Beta3 MR-illuminator and one modified Beta2 for mounting on the mast of Beta3 system) were developed. |
| Assess performance of the prototypes compared to currently utilized methane measurement | Complete. |

| | |
|---|---|
| equipment and methods. | |
| Test utility of the technology for short-term inspections (portable version) and for semi-permanent monitoring (relocatable platform version) of multiple sites vs. existing survey techniques and methods | Complete. |
| Conduct pilot tests of the portable version at least 10 different sites and of the semi-permanent relocatable platform at least 4 different sites, in the upstream and midstream sectors, to assess utility of the technology and drive refinement of the prototype. | Complete. See Table 2-2. |
| Estimate methane emissions reduction for Alberta as a function of deployment by sector and region. | Complete. See Section 5. |
| Determine strategies for product deployment in Alberta, market penetration throughout Canada, and scaling up of manufacturing, consistent with CSA certification. | Complete. |

## *2.4 Work Scope Overview*

The scope of work is shown below, plus a summary of changes from the original and any minor changes that were made as the project progressed are also indicated in each section:

T1. Development of Hand-Portable (Beta1, Beta2) Units (Camera Sensor unit and low-powered short-range illuminator)

T1(a) - Detector Sub-System

- Fabricated sensor component by supplier
- Design and fabricate analog readout circuit
- Integrate input scanning optics, detector array, filter mosaic, analog board, and test

T1(b) - Engineering Prototypes

- Design and fabricate digital data control board, procure digital processor board
- Design and fabricate optical chassis and enclosures
- Assemble detector sub-system, digital boards, optical chassis, and enclosure
- Design and fabricate short-range illuminator and battery power pack
- Modify existing software and firmware, integrate into prototypes, and test

T1(c) - Beta1 unit released

- Beta1 engineering prototype performance testing at ATCO (Alberta locations)

    - Originally, Beta1 prototype performance testing was intended to be in Quebec, but the team made use of locations in and around ATCO facilities in Alberta instead.
- Build 2 Beta1 units (sensors, illuminators, power packs, portable mounting carts), deliver one unit to MSC in Calgary for testing, retain one unit for MSS in Boston for troubleshooting and refinement
    - Originally, 4 Beta1 prototypes were scheduled for build and delivery to the team, but the Beta1 was not progressing as originally intended, so only 2 were built, for testing by MSS. Originally the 4 were intended to be upgraded to Beta2, but to avoid waste, the existing 2 were upgraded and 2 new Beta2 units were built based on the learnings.
- Provide training and ongoing support to all team members in Calgary

T1(d) - Beta2 unit released

- Continue software development and field upgrades, refine both Beta1 systems, continue testing
- Integrate Beta2 units with Zedi data cloud and enable remote viewing of Beta2 inspection imagery via internet access to an MSS web portal hosted on the Zedi cloud
- Deliver 4 Beta2 units to the project team, 3 to Calgary and retain 1 unit in Boston for MSS troubleshooting and refinements
- Provide training and ongoing support to all team members in Calgary
- Draft commercialization and technology transfer plan among team to ensure future product deployment throughout Alberta

T2. Field test and assess performance of hand-portable Beta1 and Beta2 prototypes at ATCO's natural gas facilities (transmission, distribution and storage) and selected industry pilot test sites across Alberta.

T2(a) - Hand-portable testing of Beta1 prototypes

- Testing of Beta1 prototypes in the MSC lab at SAIT
- MSC testing at multiple ATCO facilities

T2(b) - Hand-portable testing of Beta2 prototypes and performance assessments vs. state-of-the-art equipment (the original tasks T2(c) and T2(d) were combined to be T2(b) in the Amended Schedule A (March 2019), and began 9 months late due to the delay in T1(d))

- Refine testing for Beta2 prototypes in the context of on-site inspections
- Conduct pilot tests at ATCO facilities
- Conduct pilot tests at 8 (goal) upstream sites
- Conduct performance assessments at pilot test site inspections, and compare Beta2 system to FLIR GF320 thermal gas camera and industry standard "sniffers"

T3. Development of Semi-Permanent, Relocatable Trailer (Beta3) Unit (high-powered illuminator, mast-mounted sensor unit, on trailer with electrical generator).

T3(a) - Beta3 prototypes released

- Modify Beta2 camera for mast-mounting

- Design and fabricate proof-of-concept high-power illuminator for medium-range (15 meter) operation.
- Deliver 3 Beta3 camera & illuminator systems to the team, 2 to Calgary (for MSC and ATCO), and 1 to MSS in Boston for troubleshooting and refinements
    - Only 1 Beta3 system was delivered as the usability of the mid-range illuminator was not viable with the chosen design. See discussion in Section 5.

T3(b) - Beta3 system integrated with mast and generator assembly on trailer

- Integrate 2 Beta3 systems onto trailers with telescoping masts and electric generators
- Deploy 1 Beta3 system to ATCO, and 1 Beta3 systems to MSC
    - Only 1 Beta3 system was delivered, which was to MSC, as noted above.
    - In lieu of delivering all Beta3 systems, a novel approach to combine the Beta2 system on the trailer mast along with retro-reflectors was applied with successful results. This concept was first created during the field testing in the spring of 2019.

T4. Field Test and assess performance of relocatable Beta3 system at ATCO's natural gas facilities (transmission, distribution and storage) and selected industry pilot test sites across Alberta for extended time periods of emissions monitoring.

T4(a) - Semi-permanent, relocatable testing of Beta3 system

- Arrange pilot testing of Beta3 prototypes in the context of extended period monitoring of methane leaks and emissions quantification (hours or days)
- Conduct pilot tests at ATCO facilities
- Conduct pilot tests at 4 upstream sites

T4(b) - Beta3 system performance assessments vs. currently used methods and equipment

- Conduct performance assessments at pilot test sites, and compare Beta3 system to FLIR GF320 thermal gas camera and industry standard "sniffers"
- Refine hardware and software as needs arise during extended monitoring tests in the field

T5. Final Outcome Reporting

- Generate final report on prototype technology and pilot test outcomes
- Generate technology transfer and deployment plans for Alberta, and expected reduction in methane emissions over time for each deployment scenario
- Generate project financial report

The table below outlines the test sites and system configuration from the project.

**Table 2-2 List of Test Sites and Location**

| System Configuration | Company | Location |
|---|---|---|
| Beta 1 (Sensor only, no illuminator) | ATCO | Mazeppa compressor station |
| | | Whitehorn parking lot, Calgary (controlled releases) |

| | | |
|---|---|---|
| Beta 2 (Short Range Illuminator and Sensor) | ATCO | Whitehorn parking lot, Calgary (controlled releases) |
| | | Maryland pipeyard (controlled releases) |
| | | South-east Calgary industrial gate station |
| | | Mazeppa |
| | | Carbon, AB storage facility |
| | | Chestermere gate station |
| | | Calgary east B gate station |
| | | Jumping Pound gate station |
| | Gas Producer | Various sites near Grande Cache including gas risers, compressor station and gathering station |
| | Oil Producer | oil battery, near Cochrane |
| | | oil well pad, near Cochrane |
| Beta 3 (Mid Range Illuminator and Sensor) | ATCO | Calgary east B gate station |
| | Oil Producer | well pad, near Cochrane |
| Beta 2 mounted on Beta 3 mast | Oil Producer | well pad, near Cochrane |
| | ATCO | Maryland pipeyard (controlled releases) |

## *2.5 Literature review*

Historically there are have been two primary device types and purposes for methane detection in the oil and gas sector: installed sensors used for safety monitoring, and optical gas imaging (OGI) cameras used for fugitive emissions inspection. Although both types of devices are designed to measure methane in the atmosphere, they are different in every other aspect.

Installed sensors typically are low-cost point sensors, but only alarm if methane comes in direct contact. These sensors are found in gas plants and oil refineries and throughout all different assets along the value chain. These typically have only one or two levels of alarm, do not provide a quantitative measure of the concentration or any indication of the size, flux or location of the leak. A more sophisticated installed sensor is an open path detector, which essentially acts a single one-dimensional line of point sensors that can reach as far as 200m.

Portable Infrared Inspection cameras have become increasingly popular in recent years because of the introduction of regulatory leak detection and repair (LDAR) requirements such as the EPA Code of Federal Regulation 40 CFR 60 Subpart OOOOa and the Environmental Protection Agency Method 21 in the United States, and the methane emissions regulations from the Canadian federal government (Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector) SOR/2018-66) and equivalent or complimentary provincial regulations (i.e. Alberta Energy Regulator Directive 60) that came into force January 1, 2020 here in Alberta. Many jurisdictions in Canada and the United States now mandate fugitive emissions inspections of oil and gas infrastructure at least, if not more than, once per year.

The FLIR GF320 is an OGI camera that is considered to be the industry standard for methane leak detection. It is a handheld video-rate camera that can see methane gas by detecting a temperature difference between the gas and the background. It can be used by a competent operator to identify the source of a leak, however using it properly and to its full capacity requires significant training and practice. The OGI inspection is often coupled with a High-Flow sampler to provide an estimate of leak rate, however this technique is both time consuming and inaccurate (*Sensor transition failure in the high flow sampler: Implications for methane emission inventories of natural gas infrastructure. Howard T*). Significant efforts have been made to automate and quantify gas detection with the GF320, especially with the quantification module developed by Providence Photonics and available through FLIR, however this technology has not been widely adopted. Efforts to automate gas detection based on image processing have been very difficult due to the complexity of having to estimate the temperature of every background element in an image. Therefore, a human operator is required to determine the presence of a gas leak.

Apart from the need to train an operator to use the GF320, most companies that are mandated to conduct leak detection inspections of their assets do not purchase a GF320 because of its cost of more than $130,000 CAD. Instead, these companies opt to hire specialized service companies such as Target Emissions Services to perform inspections with the GF320. The cost and risk associated with inspections are not negligible, as they require an individual to travel to site and walk within a few meters of all pipe and equipment to be inspected in order to survey the entire site.

With increasingly stringent environmental regulations coming into force, a clear opportunity exists to make inspections more efficient and improve upon methane detection and quantification. Technology innovators are trying to capitalize on this by creating a product or service that can do this in many different ways. Some examples of types of technologies that are being developed are:

- Products that facilitate completing surveys more quickly, with less manpower or more accurately
- Using sensors mounted to planes or satellites to provide a service that can potentially eliminate the need to visit sites to do the inspection.
- Creating a better installed sensor or system of sensors in order to continuously monitor for leaks, reducing or possibly eliminating the need for inspections altogether.

Although point sensors have typically been low-tech, independent sensors that can be connected to a site control system for safety purposes only, there has been an effort to connect these sensors to others in order to build a more comprehensive system used for environmental monitoring as well as safety. With the rise of rapidly advancing technologies known collectively as the Industrial Internet of Things (IIOT), battery powered methane point sensors, that are wirelessly connected and relatively low-cost, are now available. These sensors, such as the Vanguard WirelessHART detector from United Electric Controls, can be combined with meteorological sensors to create a system designed to estimate leak locations and rates. One problem with a system of many point sensors is the same as the problem with one sensor; the sensor only monitors one point in three-dimensional space so if a leak exists, the plume may completely bypass the sensor above, below, or around it. Other issues are that in order to locate the leak, the total number of sensors required could be prohibitive, either by cost or limited installation possibilities, and that a complex dispersion model must be developed that is unique to each site.

The SeekOps SeekIR system combines a highly sensitive methane sensor with a drone and several other sensors (wind and GPS). This allows point sensor data to be collected from many points using one piece of equipment. The algorithms that have been developed combine all sensor data to help detect, quantify and locate possible methane leaks. Several disadvantages of this system are that the drone can only be in one location at a time so if the wind changes, a leak could be missed, drone based systems only have a limited flight time, and range, currently the drone must have a human operator nearby (although full drone autonomy and beyond line of sight flights might be permitted in the future), the drone can only be flown in certain weather conditions and specific flight patterns must strictly be adhered to in order to collect the necessary data.

Companies that have developed sensors that mount to manned aircraft include Kairos, Bridger Photonics, GHGSat. The idea here is that one plane can cover many times more ground than a human, even if it can only detect very large leaks. GHGSat also employs several satellites that can detect methane from Earth's orbit. Compared to OGI cameras leaks have to be on the order of 100x larger to be detected by airplanes and on the order of 1000x larger to be detected by satellites.

Rebellion Photonics is a company that packages their product as an installed camera which uses hyperspectral spectroscopy to detect and locate leaks and to speciate various gases. Similar to (but not the same as) the FLIR concept, the Rebellion technology is a hyperspectral camera that uses both the mid-wave and the longwave infrared spectrum, which means that frequent recalibration of background materials is required as these backgrounds emit different spectra of thermal radiation depending on their temperature. This makes reliability, automation and quantification difficult unless leak rates are high. A major benefit of the Rebellion solution is its high sensitivity in the range of up to 1 km. The cost of a Rebellion system is a major disadvantage at more than $USD250,000.

**Table 2-3 - Example Technologies for Methane Detection**

| Company | Product | Description | Technology | Cost ($CAD) |
|---|---|---|---|---|
| **FLIR** | GF320 | Handheld Video | MWIR | 130k |
| **United Electric Controls** | WirelessHART Gas Detector | Point Sensor | Non-Dispersive IR | 7k |
| **Honeywell** | Searchline Excel | Open Path Laser | MWIR | 10k |
| **Rebellion** | Mini-GCI Camera | Installed | MWIR Hyperspectral | >300k |
| **SeekOps** | Gas SeekIR | Drone | Laser Spectroscopy | Unknown / Service |
| **Bridger Photonics** | Gas Mapping LiDAR | Plane/Drone | LiDAR+Spectroscopy | Service |
| **GHGSat** | C1/C2 | Satellite/Plane | NIR Spectroscopy | Service |

# 3 Development and Results

ATCO supported MSS as it developed two types of product prototypes, a portable camera and a relocatable camera. Both consist of five main components:

- Camera sensor unit
- SWIR illuminator
- Power supply
- Mounting structure
- Tablet user interface

The camera sensor unit or Beta1 is the same for both products and can be used as a standalone product. The illuminator was developed in two versions (portable: 1m to 5m range, and relocatable: 2m to 20m range). Power supply and mounting was designed to meet specific needs of the product (portable versus relocatable trailer mounted). The low-power, hand-portable Beta1 model was used for initial testing in Alberta in the presence of sunlight. Beta1 testing was used to inform software and hardware upgrades for improvements to the Beta2 model (the portable product for short-term inspections) and for the construction of the Beta3 product, a semi-permanent, relocatable (mast-mounted on a trailer with generator) product for longer monitoring periods. Zedi developed software and communications to interface the Beta2 and Beta3 models to their data cloud, with remote data viewing enabled via an internet web portal.

MultiSensor Canada (MSC), ATCO, and Target Emissions Services (TES) carried out field-testing of all Beta products and delivered results to MSS to inform product development. The team compared the pilot tests to existing state-of-the-art OGI inspection and monitoring equipment and methods.

The main project outcome was to enable several cycles of technology development and field demonstration that eventually resulted in a product concept that has a clear path to market. This product concept, a low-cost installed camera with automatic gas detection, is based on many different technical elements developed and tested as part of this grant project. With a much-improved understanding of the challenges and possibilities of scanning type SWIR imaging technology, the product development evolved to a low-cost installed camera concept with automatic alarming when gas leaks are detected and continuous quantification of leaks or vents.

ATCO engaged in this research and development project for the purpose of supporting the development of a superior alternative to incumbent optical gas imaging technology that could both reduce the cost of compliance and increase outcomes (likelihood of emissions decreasing) and so is ultimately interested in the success of the pivot to an installed camera concept and will be open to testing its utility in its operations at that time.

## *3.1 Technology development*

At the commencement of this project in September of 2017, MultiSensor Scientific had recently completed the build and testing of a proof of concept video rate SWIR based system that was able to detect gas releases outside in sunlight. Some of the same principles from this system were used as a design basis for the Beta prototype that was at the core of this project. The primary difference being the Beta system was not video rate and therefore has a much more affordable detector package. A key element was the scan mechanism developed for the Beta system. Moreover, an active illumination system was developed for the first time.

The project included two distinct combinations of components that result in a portable system (Beta2) and a trailer mounted relocatable system with a longer detection range (Beta3). Both systems use the same camera sensor and were combined with different illuminators, power sources, modes of mobilization and software. The project enabled the progression of the technology to advance from TRL 3 at the beginning of the project to TRL 7 by the end of the project.

### 3.1.1 Camera Sensor (Beta1)

Beta1 was the first module that was completed and allowed for the development of the software and algorithm development to progress much more rapidly following results from data gathered in lab tests. Because all of the systems (Beta2 and Beta3) use the Beta1 as the core data collection technology, when discussing the capability of the sensor, it is referred to as the Beta system.

Milestones related to the sensor and software completed by the end of June 2018 were:

- First version of the electrical, optical and mechanical components installed in a chassis and housing. See Figure 1 for a photograph of the Beta1.


**Figure 1 – Beta1 Camera Sensor Prototype**

Bench top testing in Boston proved that the sensor was able to distinguish methane from ethane from $CO_2$.

- First outdoor images of methane were captured (See Figure 2)

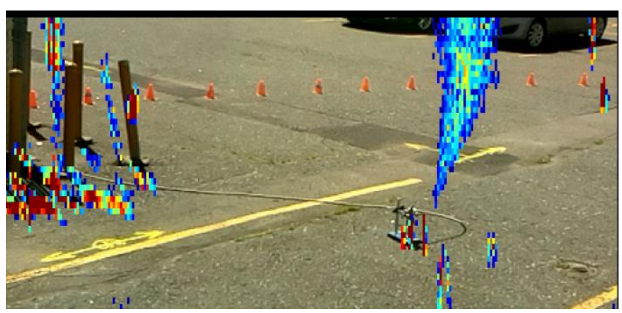


**Figure 2 - Image of Outdoor Release of Methane Jet, ATCO Parking Lot near Calgary, AB**

- An initial Graphical User Interface software version was built. This version of the GUI allowed for the following:
    a. live video feed from the RGB camera for visible scene
    b. connection of camera to tablet via USB or wired Ethernet
    c. initiation of data collection
    d. initiation of image processing in external python scripts
    e. display of gas detection overlays and jet/blob detection overlays
    f. display of raw detector signal

- With respect to the image processing, noise cleaning and enhancement of images had been implemented. Segmentation and detection of gas shapes (blobs and jets) was successfully implemented on a post-processing, image-by-image basis.

### 3.1.2 Portable Beta2 System

The first version of the Beta2 system was completed by the end of June 2018, however each of the components of the system (Cart, Power Pack, Sensor, and Illuminator), still required significant refinement prior to being field-ready. See Figure 3 and Figure 4 for examples of the first iterations of the cart and power pack.

**Figure 3 - Generation 1 of Portable Cart**


**Figure 4 - Generation 1 of Power Pack (Battery, Inverter, Mobile Modem)**

By the end of March 2019, significant improvements had been made to the first version of camera sensor, cart, illuminator and power pack, the prototype design was completed and four units were built.


**Figure 5 - Beta2 complete system**

- Software development
  - Significant upgrades were implemented including improved graphical user interface, noise cleaning, gas detection and leak rate quantification. Figure 6 below shows the user interface while viewing a gas jet

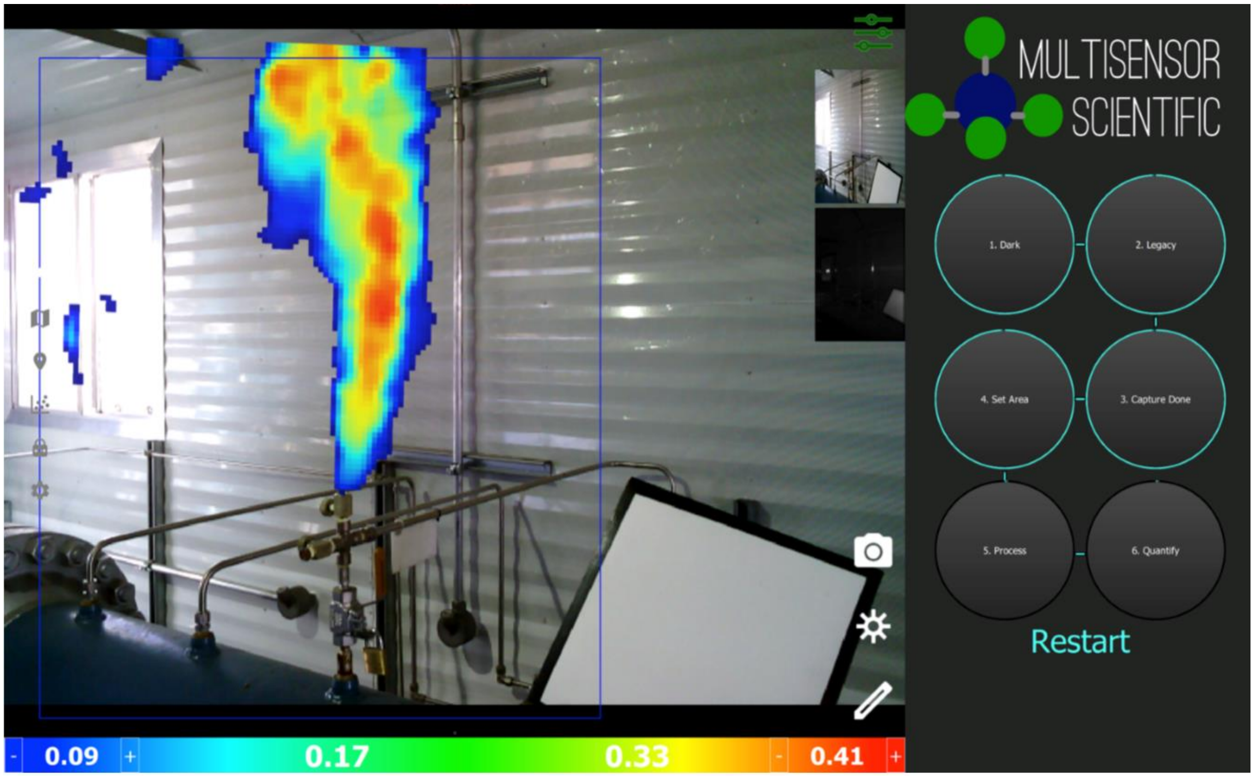



**Figure 6 – Fabricated High Pressure Jet indoors at ATCO Facility in Calgary, AB (Tablet View)**

Moreover, the ability to detect methane at a release of 2g per minute (6 SCFH) and to detect Ethane at 3g per minute in the lab from a high-pressure jet from a range of 1.5m was demonstrated(see Figure 7).

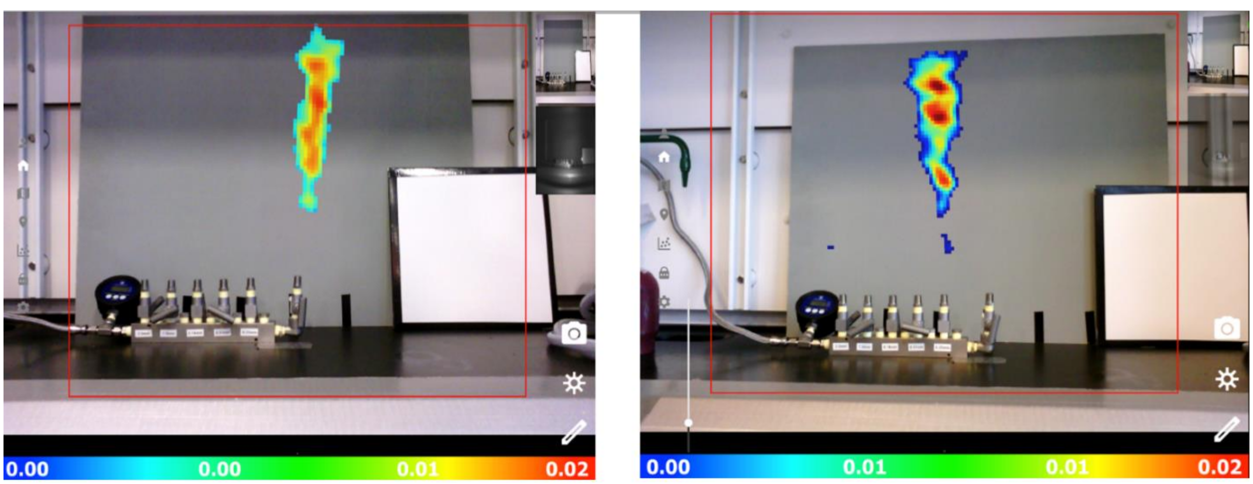
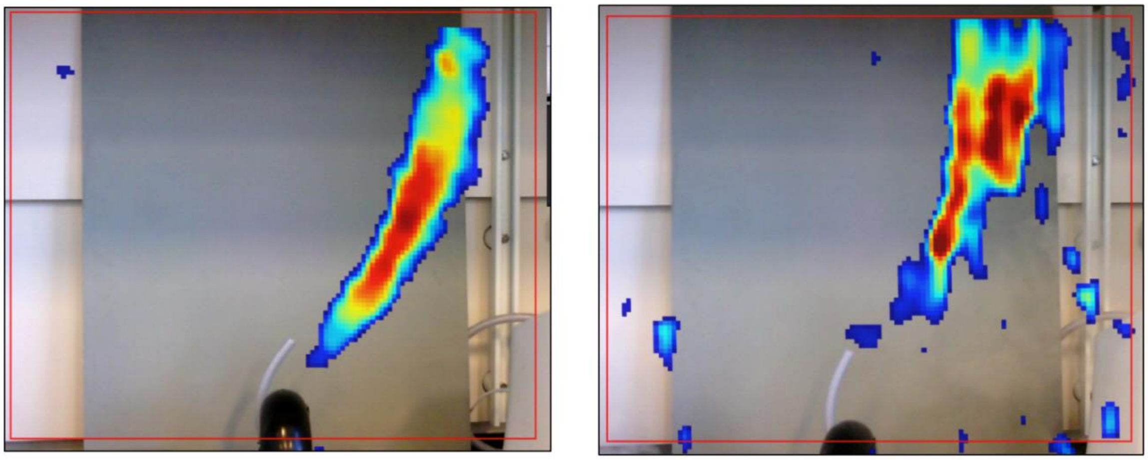



**Figure 7 - Methane and Ethane High-Pressure Releases in Lab at SAIT**

The detection of methane in the presence of steam was demonstrated as well (see Figure 8)

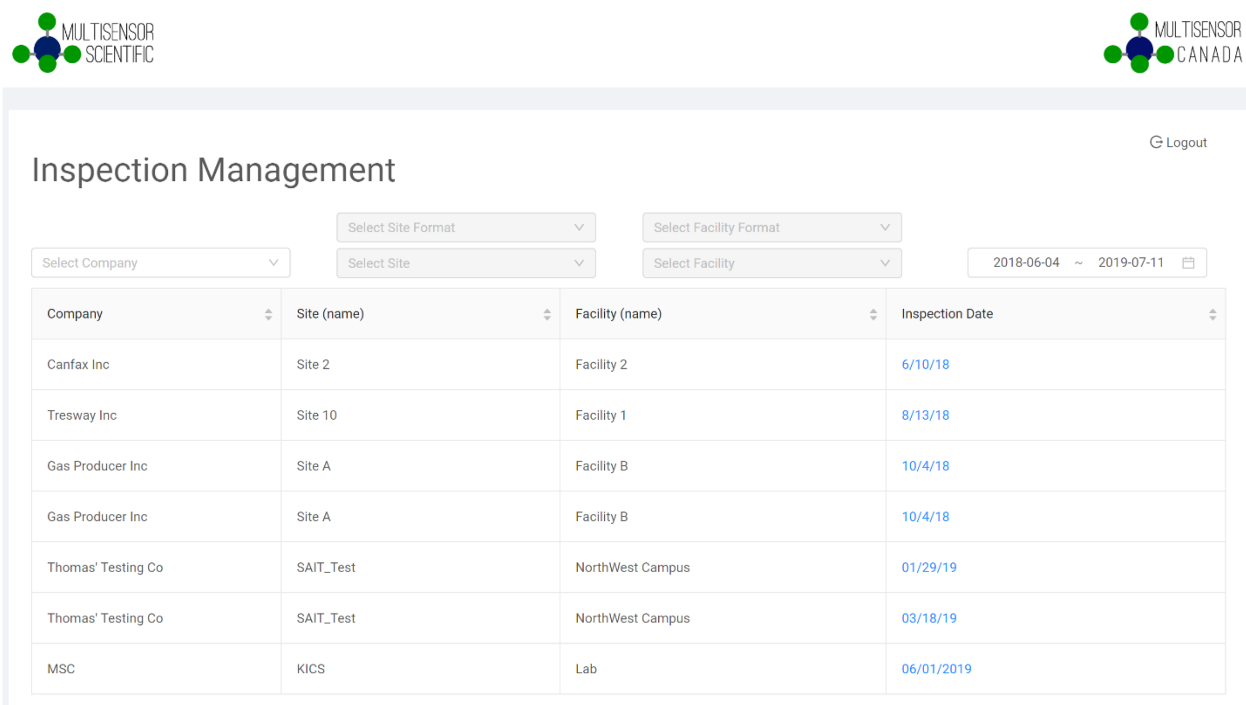


Natural Gas Plume in Clear Air
(color scale codes column density)

Natural Gas Plume in Fog & Steam
(steam & fog alter plume shape)

**Figure 8 - Natural Gas Low Pressure Releases in Fumehood with and without Steam Addition at SAIT**

A Remote Data Services web portal was constructed and activated by Zedi. Field data that is collected can automatically be sent to the cloud service and viewed remotely by an authorized user. See Figure 9 and Figure 10 for screenshots of data collected by the Beta2 system and as viewed from the Zedi Cloud.




| Company | Site (name) | Facility (name) | Inspection Date |
|---|---|---|---|
| Canfax Inc | Site 2 | Facility 2 | 6/10/18 |
| Tresway Inc | Site 10 | Facility 1 | 8/13/18 |
| Gas Producer Inc | Site A | Facility B | 10/4/18 |
| Gas Producer Inc | Site A | Facility B | 10/4/18 |
| Thomas' Testing Co | SAIT_Test | NorthWest Campus | 01/29/19 |
| Thomas' Testing Co | SAIT_Test | NorthWest Campus | 03/18/19 |
| MSC | KICS | Lab | 06/01/2019 |

**Figure 9 - Zedi Web Portal Inspection View**

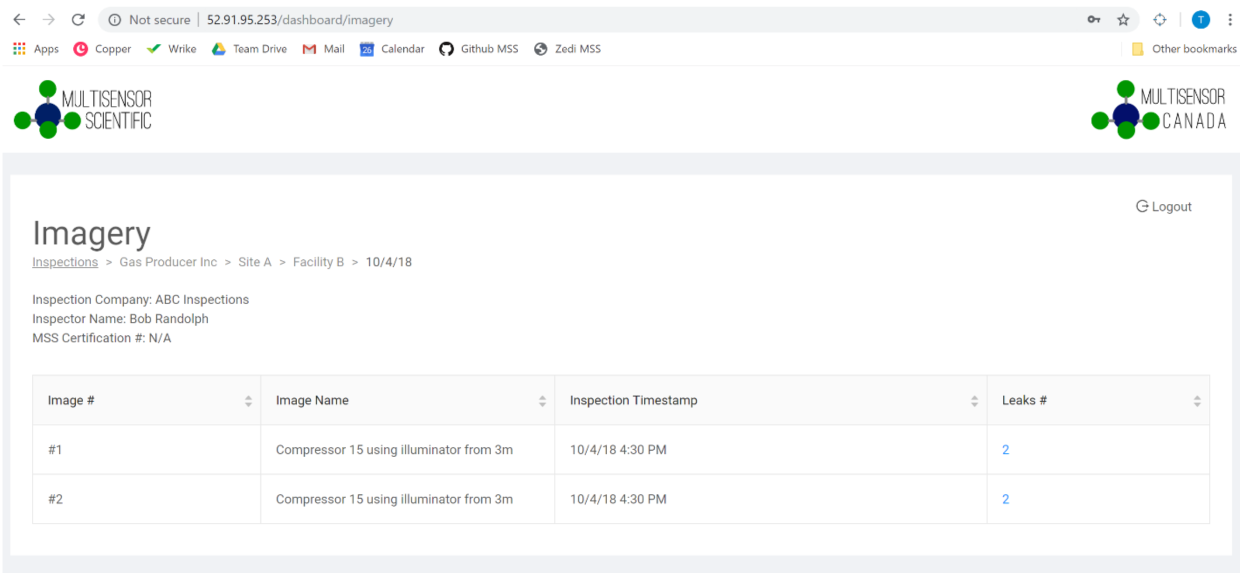



**Figure 10 - Zedi Web Portal Imagery List View**

### 3.1.3 Relocatable Beta3 System

The Relocatable Beta3 System is designed for a longer range and monitoring and consists of a sensor with a larger illuminator and a modified trailer with telescoping mast. Development and construction of the Beta3 system was completed by mid July 2019.

### 3.1.4 Installed Proof of Concept Camera

Performance assessments of the portable and relocatable units were difficult to conduct both, physically and functionally. Following testing of a proof of concept installed camera that combined the relocatable mast with the portable camera and illuminator (Beta2) plus optional retroreflectors, MSS decided to work towards a new goal to further develop a proof of concept installed camera.

By installing the camera on top of a mast, this allowed for an improved vantage point and greater range. It also allowed to safely monitor vents located on top of tanks for instance. As discussed in Section 3.2 below, emissions from tanks have recently been discovered to be a much larger portion of overall methane emissions than previously thought. See Figure 11 for results from a field test of the installed camera concept. It shows the detection and imaging of a tank venting hydrocarbon gases using only sunlight (the illuminator component is not used).

**Figure 11 – Installed proof of concept camera(L) and gas detection image (R) from camera at well site near Cochrane, AB**

## 3.2 Important lessons learned

A key lesson learned is that multiple cycles of design, modelling, prototyping, field test and customer interaction are needed to develop and refine an entirely new imaging technology. The faster these cycles can be implemented, the faster the technology progresses. The Mid-Range illuminator turned out to be too large for safe, practical use.Over the course of the project several studies related to methane emissions in Alberta were conducted, which shed light on the breakdown of the sources of methane emissions in the oil and gas sector.  It has since become apparent that venting (from pneumatic devices and tanks venting to atmosphere) is the largest source of methane emissions from upstream sites (FEMP-EA study, A. Ravikumar presented at PTAC MERN conference in Banff, November 2019). Emissions from vents in Alberta are a much larger portion of overall methane emissions than previously thought and for Alberta to reach the required 45% reduction in emissions, addressing venting from tanks will be required to a significant degree.

Throughout the development of the core technology and the project, numerous practical and technical obstacles were encountered. Lessons were learned pertaining to the prototype hardware and software, the application and collection of data in the field, and the use of the camera in various configurations. These lessons ultimately led to a better product that is more suitable and desirable to industry in Alberta and around the world.

## 3.3 Results

The Beta Camera Sensor was able to clearly show the presence of gas when it was present in many situations and at relatively low leak rates (<7g per minute from 20m distance, <3g per minute from 10m distance and 2g per minute from 2m) despite significant technical limitations of the Beta implementation.

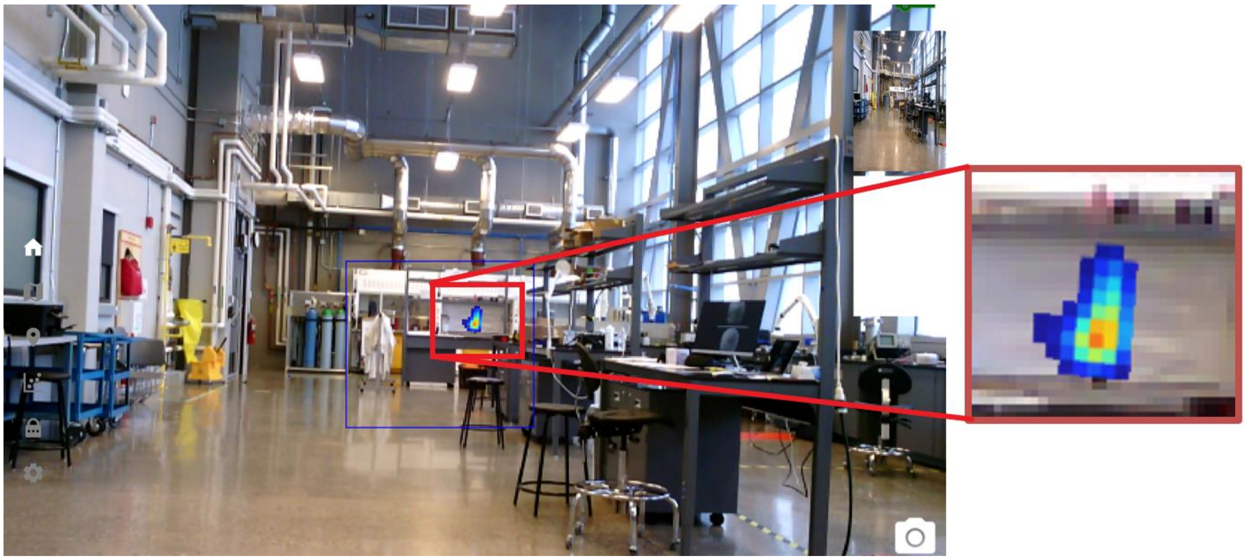


**Figure 12 - Gas release in lab: 7g/m from 20m distance**

The Beta2 system (Figure 5), designed for portable inspection, was determined in field trials to be insufficiently portable for inspection purposes. If the hardware allowed for the system to be contained in a handheld device, the conclusion may be different for this type of SWIR imaging system. While major improvements were made after the end of the active project period (reduction of illumination power requirement by the factor 25 with simultaneously improved detection performance), very significant additional resources would have to be spent to commercialize a portable unit. Feedback from industry indicated that a low-cost relocatable or installed solution was a more promising market with a smaller commercialization risk.

The Beta3 system was designed to be a semi-portable, relocatable monitoring solution. The Beta3 system is a mobile, self-contained product that can raise the camera to heights of 9m in order to monitor multiple tank vents and thief hatches. The prototype succeeded in demonstrating the imaging of tank vents from a distance. Problems encountered with the Beta3 prototype were primarily related to the design and size of the Beta3 illuminator.

Installing the camera on top of a mast allowed for an improved vantage point and greater range. It also allowed to safely monitor vents located on top of tanks. Figure 11 above shows results from a field test.

Performance assessments of the portable and relocatable units were conducted in spring 2019 and uncovered significant additional development needs for the prototypes to be commercialized. Following the testing of Beta2 and Beta3 units as well as discussions with prospective customers MSS decided in summer 2019 to focus subsequent work on commercializing a low-cost installed / relocatable camera with automatic leak detection. This outcome negatively impacted ATCO's ability to deploy this technology in an operational setting at this time, in order to meet regulatory compliance targets, and ATCO's ability to underpin emissions testing services with this technology.

Understanding the very complex interplay of the many design aspects of the underlying camera and imaging technology during this project has resulted in major progress in the development of the technology platform. The project provided the base technology foundation for a very successful costing effort and the development of the installed camera system (currently ongoing).

The installed camera system is based on a combination of the following technologies:

- A scan system evolved from the fundamentals demonstrated in the Beta1 system

- A new version of the illuminator developed with the Beta2 system with significantly smaller size and a power consumption of only 4% of the original at simultaneously improved performance
- An improved version of the mast explored with the Beta3 system
- A 2nd generation detector system
- Optional retroreflector panels for range extension
- A cloud solution that is based in part on lessons learned by integrating the Zedi Solutions cloud with the prototype

Since the finalization of the active work phase of this project in August 2019, MultiSensor has built a proof of concept of the installed camera system and successfully tested it at a well pad in Alberta.

ATCO remains encouraged by the progress and promise of the improved efforts to lower the ultimate cost of fugitive emissions surveys in Alberta.

### *3.4 Economic Benefits to Alberta*

During this ERA project, there has been substantial investment from MSS in developing a presence in Alberta including creating a subsidiary of MultiSensor Scientific in Calgary, AB called MultiSensor Canada Inc. (MSC). MSC will continue to grow in Calgary and currently leases an office and lab space at Southern Alberta Institute of Technology (SAIT). MSC now employs two full time technical employees, contracts one business development consultant part-time in Calgary, and has provided two students from SAIT the opportunity to work with MSC and learn about the clean tech start-up ecosystem. Considering the success of the SAIT student interns, MSC hopes to continue to hire SAIT students for projects as needed. As the technology progresses to commercialization, MSC is expected to hire at least three more technical personnel as needed for the deployment of the technology; field engineers for sensor deployment and software engineers for cloud integration into existing client IT systems.

Much of the work performed directly for the project went to other Alberta based companies like ACAMP, Tangent Engineering and Design, EcoConsulting, PTXi Solutions, and of course included the support of Alberta based ATCO Gas and Pipelines Ltd., Zedi Canada Inc. (now part of Emerson Electric Canada Ltd.) and Target Emissions Services.

A Calgary based engineering contractor had been contracted to perform the field engineering duties of the project. As the project progressed, it became mutually beneficial between MSC and the contractor to directly hire the contractor as a full-time employee of MSC, which occurred in February 2019. The engineer continues to be employed full-time at MSC and in addition to engineering duties, manages the Calgary office.

A Calgary based business development contractor has provided a significant contribution to the development of MSS/MSC in business development, market research and customer/client relationship building. The contractor began working with MSS in 2018Q1 through an Innovate Calgary program that evolved into a direct relationship in November 2018 with long term part-time contractual work involving additional market research, outreach, customer relationship management and feedback; strategy input; pilot project relationship management; grant strategy; regulatory strategy; investor connections; pre-sales work. The scope of work has extended beyond Alberta and now also cover parts of the US. The relationship with the contractor is expected to continue long-term.

MSS has hired a Calgary based engineering design contractor to design one of the custom electronic circuit boards for the next generation sensor system. The contractor is a leader in extreme environment electrical design for the oil and gas industry as well as industrial internet of things (IIOT) architecture, remote operation and deployment. MSS is expected to leverage the contractors expertise going forward.

In summary, the ERA grant led to MSS establishing a subsidiary company in Alberta, hiring a first local employee (with plans to hire additional employees in the future) and building close, long-term relationships with multiple Alberta based companies.

ATCO plans to grow its own capacity to carry out its fugitive emissions management plan with its own staff as outlined in Section 7.2, relying on the contracted service of Target Emissions Services in the initial years of compliance.

## 4 Financial Contributions

The total project budget was $6,108,484, of which $1,226,942 was contributed by the ERA. Most of the balance was contributed by MSS.

## 5 Greenhouse Gas Benefits

Although, as a detection technology, no direct GHG emissions will be mitigated by the camera, efficient and cost-effective identification and quantification of methane emissions is vital to informing and prioritizing mitigation efforts and for detecting malfunctions.

As per StatsCanada under the guidelines of the International Panel for Climate Change (IPCC), fugitive methane emissions from the Oil and Gas industry totalled 1.15Mt in 2014. According to figures published by Canadian Association of Petroleum Producers (CAPP), 46% of these methane emissions come from unintentional fugitive emissions. Also, although exact proportions vary depending on the study, it is estimated that 80% of emissions come from ~16% of leaks, known as “super-emitters” (Update of Equipment, Component and Fugitive Emissions Factors for Alberta Upstream Oil and Gas, ClearStone Engineering for AER, June 2018). From these values, it can be deduced that methane fugitive emissions from super-emitters accounted for approximately 0.42Mt in 2014. By far the largest portion of these super-emitters are tank-based emissions.

If a cost-effective continuous monitoring solution was installed at locations likely to become super-emitters, it would allow for the immediate detection and mitigation of such super-emitters. This would significantly reduce the 0.42Mt of methane released from super-emitters because it would detect and fix them much sooner when compared with incumbent annual or semi-annual inspections. The goal is to provide a solution that is cost effective and versatile that can be installed at sites at high risks of large leaks, especially tanks, providing information that is accurate enough so that customers know how severe a leak is and what must be fixed, saving lost product, all the while serving to satisfy their environmental regulatory requirements and reducing their GHG emissions.

Given the demonstrated performance and market analysis, it is expected that the installed system will be well suited for the following market segments to monitor for super emitters and fugitive emissions:

1) Any upstream or midstream site with tanks; especially larger sites with multiple tanks
2) Determination if upcoming upstream site-vent limits are being met (installed or relocatable)

3) Gas plants with potentially explosive equipment such as diesel generators located downwind from operations facilities. These will be typically congested, older facilities, with reduced spacing compared to modern standards
4) Underground natural gas storage for early detection of major leaks
5) Sour wells (well pads with associated $H_2S$). While a MultiSensor hydrocarbon gas camera would not detect $H_2S$ directly, the presence of hydrocarbons will indicate the presence of $H_2S$ at the same time.
6) SAGD well pads for leaks of methane, steam and emulsion. The objective here is to provide for an early detection of leaks prior to larger operational damage happening because of leaks.
7) Compressor stations, particularly aging ones, for early detection of large leaks that are indicating abnormal behavior
8) Tank storage farms (both upstream as well as produced liquids such as Diesel storage)
9) Larger new well pads near residences in jurisdictions with stringent methane regulations (especially Colorado)
10) CHOPS wells with intermittent but high emissions
11) Remote wells that are only seasonally accessible
12) Hydrocarbon processing facilities with hard-to-reach vents.

**Table 5-1 - Potential markets and their size**

| Sector | Site Type / Application | # Sites (AB) |
|---|---|---|
| Upstream | Active O&G Wells | ~120,000 |
| | Inactive O&G Wells | ~151,000 |
| | Gas Plants | >650 |
| Midstream | Compressors | >100 |

## 6 Overall Conclusions and Next Steps

The Beta1 Sensor and Beta2 and Beta3 systems were designed, built and tested as a direct result of this ERA funded project. The core technology and hypothesis were proven: it is possible to perform non-thermal detection of methane using a low cost single pixel sensor in the SWIR spectrum. However, the system behaviours that were discovered during the testing showed better prospects when applied as an installed camera. As described, this precluded ATCO from adopting the technology during the course of regular operation, but ATCO remains encouraged by the progress and promise of the improved efforts to lower the ultimate cost of fugitive emissions surveys in Alberta.

The Beta Sensor was able to clearly show the presence of gas when it was present in many situations and at relatively low leak rates (<7g per minute) from distances of 20m or less against a retro-reflective background. In general, the ability to filter out false positives created by a multitude of extraneous factors was not possible, however the root cause of this was discovered during the project and rectified following the conclusion of it. Understanding the issues that have been discovered during this project can be considered major progress in the development of the technology and has provided a strong foundation for the development of the next generation system that is ongoing and planned for demonstration and commercialization in 2020.

The Beta2 system, designed for portable inspection, was determined to be not portable enough for inspection purposes. If the hardware allowed for the system to be contained in a handheld device, the conclusion may be different for this type of SWIR imaging system, however the need for a high-powered illuminator and high capacity power supply make this unlikely.

The Beta3 system was designed to be a semi-portable, relocatable and long-term monitoring solution. The project allowed for a mobile, self-contained product that could raise the camera to heights of 9m, providing it with a highly useful vantage point that will continue to be a part of the next generation product. The main problem with the Beta3 system was the large size of the Illuminator.

Understanding the very complex interplay of the many design aspects of the underlying camera and imaging technology during this project has resulted in major progress in the development of the technology platform. It provided the foundation for a very successful costing effort and the development of the installed camera system (currently ongoing).

The installed camera system (currently under development) is based on a combination of the following technologies:

- A scan system evolved from the fundamentals demonstrated in the Beta1 system
- A new version of the illuminator developed with the Beta2 system with significantly smaller size and less power consumption
- An improved version of the mast and vantage point explored with the Beta3 system
- Retroreflector panels for range extension which have been tested as part of field testing
- A cloud solution that is based on lessons learned by integrating the Zedi Solutions cloud with the prototype

Since the finalization of the active work phase of this project in August 2019, MultiSensor has built a proof of concept of the installed camera system and successfully tested it at a well pad in Alberta.

The path forward for MSS entails designing, building and testing the next generation installed camera system with an improved detector, greater range due to an optics redesign, as well as the gas detection software. A cloud-based model to allow for remote firmware updates plus integration into existing databases and work order systems of customers will become part of the product as well.

At time of writing, ATCO is planning on meeting its requirements with the use of traditional optical gas imaging systems and looks forward to a continued relationship with MultiSensor Scientific as it commercializes its fixed site monitoring system for alternative fugitive emissions management planning scenarios. The timing of first available commercial units at the end of year one compliance should make for a timely convergence of operational understanding and innovation that could reduce the cost impact to ATCO’s business and Alberta’s ratepayers.

With the success of the installed camera test, MSS has focused on developing a complete installed monitoring system including a redesign of the camera (sensor optics, illuminator, electronic components, mechanical structure and housing, and detector), mounting systems and power supply for long term, longer range applications. An initial prototype was completed in March 2020. Field testing began in May 2020 and electrical certification is expected to be completed in 2020.

Algorithm development has shown significant improvement through 2019Q4 in various methane detection methods and image processing that have reduced false positives and improved automatic detection. These will continue to be adjusted based on new hardware performance and quantification development will follow soon after.

An improved cloud solution has been developed that not acts as a database for methane detection, pinpointing and quantification. An integration into existing systems of producers and operators is planned.

The ERA project began with a technology at TRL level 3 and with the help of the project partners and funding provided by the ERA, the product progressed to a TRL level 7. The initial vision of a portable inspection device also evolved with the experiences encountered throughout the project to become an installed continuous monitoring solution with the potential for application across thousands of upstream and midstream sites in Alberta and many more around the world. Multisensor is looking forward to assisting Alberta oil & gas industry to achieve methane emissions reductions in line with its stated objectives in a cost-effective manner and to keep Alberta on track as a world leader in environmentally responsible production of oil and gas.

ATCO continues to support advancements and innovation in Natural Gas Technology including methane emissions reduction and looks forward to keenly watching the progress of MSS as it works to commercialize its installed camera concept. ATCO will continue to engage with the provincial, national and global innovation ecosystems to deliver the best outcomes for our customers.