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Project Objective

Gas Technology Institute's (GTI) objective in this project is to

- Develop a recommended practice (RP) for external based leak detection on natural gas transmission lines that includes at a minimum:

    - Descriptions of various leak detection programs
    - Criteria for selecting leak detection methods
    - Instrument detection specifications
    - Guidelines for a technology certification organization
    - Metrics for measuring effectiveness

- Leverage the frameworks from other existing industry RPs and account for the continual emergence of new technologies to create an RP that will remain relevant in a constantly changing field of leak detection.

Table 1. Project Goals and Objectives

Goal 1 – Assess the current body of knowledge on leak detection from natural gas transmission pipelines.	Objective 1a – Compile current operating procedures from specific companies and existing RPs. Objective 1b – Identify specific leak detection use cases for individual companies. Objective 1c – Create a technology review document.
Goal 2 – Develop standardized sensor specifications, test procedures, and a certification organization framework.	Objective 2a – Use existing framework documents to finalize recommended sensor test procedures. Objective 2b – Conduct evaluation of current technologies and establish sensor performance specifications. Objective 2c – Produce recommendations for a technology certification organization.
Goal 3 – Compile knowledge in a single location.	Objective 3 – Produce an RP document that summarizes recommendations and is distributed to end users/operators.

Executive Summary

During this quarter, GTI completed Task 2 - Information Gathering and Technology Assessment and began work on Task 3 - Establish Standardized Sensor Specifications and Testing Practices.

The main activities this quarter were to:

1. Complete the in-depth literature review on the current state of knowledge/technology pertaining to external leak detection for natural gas transmission pipelines. This included reviewing and analyzing existing guidance documents, Recommended Practices (RP's), research papers, reports, and books.
2. Establish target sensor technologies that will be discussed in the RP and develop the preliminary framework for evaluating sensors based on a standardized set of performance metrics.
3. Information collected from literature and GTI industry advisors during the quarterly TAP meeting culminated in 2 interim reports where the target technologies and the preliminary technology evaluation metrics were established.

Technical Status

Activity: Task 2 – Completion of Literature Review

During this quarter, GTI completed information gathering from literature in support of Task 2. GTI identified applicable RP's, Methods, and/or Standards from API, EPA, ASTM, DOT PHMSA, GTI OTD, AGA, NGA, INGAA, PRCI, GPTC, DOE, EDF, and ITRC. Although the task is complete, this work activity is anticipated to remain ongoing as new information becomes available. The following references include literature that has been reviewed and analyzed in detail:

[1] W. Frish, "Standoff Gas Leak Detectors based on Tunable Diode Laser Absorption Spectroscopy," *Proc. SPIE Optics East*, pp. 23-26, 2005.

[2] S. Yang, R. W. Talbot, M. B. Frish, L. Golston, N. Aubut, M. Zondlo, C. Gretencord and J. McSpiritt, "Natural Gas Fugitive Leak Detection Using an Unmanned Aerial Vehicle: Measurement System Description and Mass Balance Approach," *Atmosphere*, vol. 9, no. 10, p. 383, 2018.

[3] Safety Scan USA, "Laser Portable Methane Detector," [Online]. Available: https://www.safetyscanusa.com/laser-portable-methane-detector/. [Accessed March 2019].

[4] Heath Consultants, "RMLD - Complete Solution (RMLD-CS)," [Online]. Available: https://heathus.com/products/rmld-cs/. [Accessed March 2019].

[5] D. Tannant, K. Smith, A. Cahill, I. Hawthorne, O. Ford, A. Black and R. Beckie, "Evaluation of a Drone and Laser-Based Methane Sensor for Detection of Fugitive Methane Emissions," British Columbia Oil and Gas Research and Innovation Society, British Columbia, 2018.

[6] "Pipeline Leak Detection - Boreal," 2019. [Online]. Available: http://www.boreal-laser.com/applications/pipeline-leak-detection/. [Accessed 1 April 2019].

[7] Heath Consultants, "April 2017 Technology and Services Update," April 2017. [Online]. Available: https://heathus.com/wp-content/uploads/2017_april_newsletter.pdf.

[8] C. Schutze, S. Lau, N. Reiche, P. Borsdorf and P. Dietrich, "Ground-based Remote Sensing with Open-path Fourier- transform Infrared (OP-FTIR) Spectroscopy for Large-scale Monitoring of Greenhouse Gases," *Energy Procedia,* vol. 37, pp. 4276-4282, 2013.

[9] Harig and et al., "Remote Detection of Methane by Infrared Spectrometry for Airborne Pipeline Surveillance: First Results of Ground-Based Measurements," *Remote Sensing of the Clouds and the Atmosphere VII,* 2016.

[10] Picarro, "Picarro - Cavity Ring-Down Spectroscopy," [Online]. Available: https://www.picarro.com/company/technology/crds. [Accessed 2019].

[11] Picarro, "Routine Regulatory Compliance Leak Survey," 2019. [Online]. Available: https://naturalgas.picarro.com/use-cases/regulatory-compliance.

[12] Weller, Z.D. et al., "Vehicle-Based Methane Surveys for Finding Natural Gas Leaks and Estimating Their Size: Validation and Uncertainty," *Environ. Sci. Technol.,* 2018.

[13] Licor Environmental, "LI-7700 Technology LiCor Environmental," [Online]. Available: https://www.licor.com/env/products/gas_analysis/LI-7700/technology.html. [Accessed 20 March 2019].

[14] ABB/Los Gatos Research, "Los Gatos Resarch, Inc. - Advantages," [Online]. Available: http://www.lgrinc.com/advantages/.

[15] Heath Consultants, "MobileGuard Advanced Mobile Leak Detection," November 2017. [Online]. Available: https://heathus.com/wp-content/uploads/MobileGuard.pdf.

[16] Heath Consultants, "Detecto Pak-Infrared (DP-IR)," [Online]. Available: https://heathus.com/products/detecto-pak-infrared/. [Accessed March 2019].

[17] Sensit, "Sensit Portable Methane Detector (PMD)," [Online]. Available: http://www.gasleaksensors.com/products/sensit_pmd.html. [Accessed March 2019].

[18] Heath Consultants, "RMLD - Remote Emissions Monitor (RMLD-REM) - Heath Consultants," [Online]. Available: https://heathus.com/products/rmld-remote-emissions-monitor-rmld-rem/. [Accessed 20 March 2019].

[19] United Electric Controls, "Vanguard Toxic and Combustible WirelessHART® Gas Detector," [Online]. Available: https://www.ueonline.com/products/wirelesshart-gas-detector/. [Accessed March 2019].

[20] FLIR Systems, "What is Infrared? FLIR Systems," [Online]. Available: https://www.flir.com/discover/what-is-infrared/. [Accessed 20 March 2019].

[21] C.-I. Chang, "Hyperspectral Imaging: Techniques for Spectral Detection and Classification," *Springer Science & Business Media,* 2003.

[22] P. G. Hans Grahn, "Techniques and Applications of Hyperspectral Image Analysis," *John Wiley & Sons,* 2007.

[23] N. Hagen and M. Kudenov, "Review of Snapshot Spectral Imaging Technologies," *Optical Engineering,* no. 9, p. 52, 2013.

[24] W. Eugster and G. Kling, "Performance of a low-cost methane sensor for ambient concentration measurements in preliminary studies," *Atmospheric Measurement Techniques*, vol. 5, pp. 1925-1934, 2012.

[25] M. L. Garcia and M. Masson, "Environmental and geologic application of solid-state methane sensors," *Environmental Geology*, vol. 46, no. 8, pp. 1059-1063, 2004.

[26] SGX SensorTech, "Thermal Conductivity Sensors Pellistor Application Note 5," August 2014. [Online]. Available: https://www.sgxsensortech.com/content/uploads/2014/08/AN5-%E2%80%93-Thermal-Conductivity-Sensors.pdf. [Accessed March 2019].

[27] W. Deng, "Thermal Conductivity Sensors in Automotive Applications," University of Windsor, Windsor, 2013.

[28] Bascom Turner, "Gas-Rover™," [Online]. Available: http://www.bascomturner.com/rover.php. [Accessed March 2019].

[29] RKI Instruments, "EAGLE 2 Gas Monitor," [Online]. Available: https://www.rkiinstruments.com/product/eagle-2/. [Accessed March 2019].

[30] Zimmerle, D. J., et al., "Current and Near-term Technology Options to Detect Leakage of Hydrocarbons, Water, and Gas from Flowlines," COGCC: Integrity of Oil and Gas Pipelines, 2018.

[31] LASEN , "LASEN - Technology - Airborne LIDAR Pipeline Inspection Service," 2018. [Online]. Available: https://new.abb.com/news/detail/1120/mobile-gas-leak-detection.. [Accessed 11 January 2019].

[32] Ball Aerospace , "Ball Aerospace Remote Sensing Technology Detects Methane Leaks During Mobile Monitoring Challenge," 2018. [Online]. Available: https://www.prnewswire.com/news-releases/ball-aerospace-remotesensing-sensing-technology-detects-methane-leaks-during-mobile-monitoring-challenge-300667958.html.. [Accessed 11 Jan 2019].

[33] Tandy, W.D. , "Practical Design Guidelines for Fugitive Gas Detection from Unmanned Aerial Vehicles," 2017.

[34] J. Oh and et al., "Biomimetic virus-based colourimetric sensors," *Nature Communicaations*, vol. 5, p. 3043, 2014.

[35] "Going to the Dogs," 2018. [Online]. Available: https://www.ogj.com/articles/print/volume-102/issue-45/regular-features/journally-speaking/going-to-the-dogs.html.. [Accessed 11 Jan 2019].

[36] "How Satelytics Works," 2019. [Online]. Available: https://www.satelytics.com/how-it-works/. [Accessed 11 Jan 2019].

[37] USEPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015," 2017.

Activity: Task 3 – Technical Advisory Meeting to Establish Categorization of Targeted Technologies

A quarterly TAP meeting was held on April 2, 2018. Meeting participants included: Kristine Wiley (GTI), Chris Moore (GTI), Susan Stuver (GTI), Gerry Bong (GTI), Brian Barron (GTI), Ed Newton (SoCal Gas), Karen McInnis (SoCal Gas), Bob McGuire (National Grid), Mary Holzmann

(National Grid), Andy Treadway (Atmos), Francois Rongere (PG&E), Arvind Ravikumar (HU), and Jim Rutherford (Heath Consultants).

The purpose of the meeting was to begin receiving feedback on various components of the Recommended Practice (RP) and included the following discussions:

- Discussion on variables assessed for development of the preliminary bounds for sensor technologies.
- Discussion on how to categorize instrument types into broader technology classes that also align with preferred platforms and sampling methods.

Activity: Task 3 – Development of Targeted Sensor Technologies

Using the information gathered from literature and from industry advisors, a second interim report was developed to establish the targeted technology types that will be described in the RP. Commonly used instrumentation types were categorized into technology classes and then coupled with applicable platforms and methods to target the specific types of leak detection technology that will be included in the RP (Table 2). Interim Report 2 will be delivered in parallel with this Quarterly Report.

Table 2. Target Sensor Technologies Aligned with Platforms and Methods

Method	External LDS Platforms	Technology Classes	Commonly Used Instrument Types
Continuous Monitoring	Above Ground Stationary	Laser Ranged	OPFTIR, TDLAS
		Laser In Plume	WMS, CRDS, ICOS
		Catalytic Combustion/Pellistor	Catalytic Pellistor
		Metal Oxide	MOS
		Nondispersive IR	NDIR
		IR Imaging	OGI
Ground-Based Mobile Surveys	Vehicle Mounted Sensors	Laser Ranged	TDLAS
		Laser In Plume	CRDS, ICOS, WMS
		Etalons	CIPS (ex. DPIR, OMD)
		IR Imaging	OGI
	Foot Patrol (Handheld) Sensors	Laser Ranged	TDLAS
		Laser In Plume	Miniature OPLAS
		Etalons	CIPS (ex. DPIR, OMD)
		Nondispersive IR	NDIR
		Flame Ionization (FI)	FID
		Photo Ionization	PID
		Thermal Conductivity	Thermal Conductivity
		IR Imaging	OGI
		Catalytic Combustion/Pellistor	Catalytic Pellistor
Air / Space-Based Mobile Surveys	Unmanned Rotary (Drone) Mounted Sensors	Laser Ranged	TDLAS, LiDAR
		Laser In Plume	Miniature OPLAS
	Manned Rotary (Helicopter) Mounted Sensors	Laser Ranged	TDLAS, DIAL
	Unmanned Fixed Wing (Airplane) Mounted Sensors	Laser In Plume	TDLAS, ICOS, WMS, Miniature OPLAS
	Manned Fixed Wing (Airplane) Mounted Sensors	Laser Ranged	DIAL
		Laser In Plume	CRDS, ICOS, WMS
		IR Imaging	Imaging Spectrometer (Hyperspectral)
	Satellite	IR Imaging	Imaging Spectrometer (Hyperspectral)

OPFTIR: Open Path Fourier Transform Infrared

TDLAS: Tunable Diode Absorption Laser

WMS: Wave Modulation Spectroscopy

CRDS: Cavity Ringdown Spectroscopy

ICOS: Integrated Cavity Output Spectroscopy
MOS: Metal Oxide Sensor
NDIR: Nondispersive Infrared
OGI: Optical Gas Imaging
CIPS: Correlated Interference Polarization Spectroscopy
OPLAS: Open Path Absorption Spectrometer
FID: Flame Ionization Detector
PID: Photoionization Detector
LiDAR: Light Detection and Ranging
DPIR: Detekto-Pak Infrared
OMD: Optical Methane Detector
DIAL: Differential Absorption LiDAR

Activity: Task 3 – Development of Technology Evaluation Framework

The ultimate purpose of Task 3 is to begin framing the necessary metrics needed to defensibly and quantifiably evaluate leak detection instrumentation. The evaluation of leak detection systems were based on an objective assessment of technology-neutral, quantitative metrics and directly related to stakeholder goals. Implementing and supporting an LDS requires that pipeline operators demonstrate measurable benefit. To that end, Interim Report 3 was developed to provide the foundation of the evaluation framework for the Recommended Practice (RP).

This framework begins to quantify performance parameters of each instrument within an LDS that can ultimately be used to evaluate the LDS as a whole. Since there is no single metric that will fully define the performance of a leak detection instrument, development of a range of useful metrics was developed to provide greater insight into the value each instrument contributes to the LDS and ultimately how well the entire LDS functions for the company (Table 3).

Table 3. Framework for Development of Quantifiable Instrument Performance Metrics

Framework for Instrument Performance Metrics		
Metric	**Metric Type**	**Description**
Monitored Fraction	Hardware	Fraction of pipeline monitored by the leak detection instrument. This fraction should be disaggregated for each instrument so that instrument effectiveness can be measured against other equivalent instruments and as a fraction of the entire pipeline system.
Evaluation Period	Hardware	Period of time for which the leak detection instrument monitors the pipeline fraction for signs of a leak. This metric can be used as an indicator of lag time that the instrument may take to detect a leak.
Service Factor (Instrument Hardware)	Hardware	Fraction of time that instrument hardware is fully operational. This metric can be used to gauge operational performance of the system and should be as close to 100% as possible.
Service Factor (Instrument Software)	Communication	Fraction of time that data communication software is fully operational. This metric can be used to gauge communication performance of the system and should be as close to 100% as possible.
Service Factor (Ancillary Hardware)	Hardware	Fraction of time that ancillary hardware (such as meteorological stations or photovoltaic systems) are fully functional. This metric can be used to delineate cause in the event of multiple hardware failures.
Service Factor (Ancillary Software)	Communication	Fraction of time that ancillary software (such as wireless or cellular networks) are fully functional. This metric can be used to delineate cause in the event of multiple software failures.

Leak Detection Time	Detection	Period of time after leak onset required to detect a leak of predetermined size within a predetermined confidence (ex. 95%). This metric is best evaluated with controlled releases at the site of installation and under varying wind conditions.
Leak Location Error	Detection	The distance error that the instrument can be expected to exhibit when calculating the location of a leak within a predetermined confidence (ex. 95%). Units are typically expressed as feet from the source.
False Alarm Rate	Data Quality	Rate at which alarms are generated by the instrument in the absence of an actual leak. This metric can also be used to determine the likelihood that an instrument alarm was caused by an actual leak. This metric is expressed as the number of false alarms per a predetermined timeframe (ex. 10 false alarms / year).
Calibration Error Fraction	Data Quality	The fraction of time that an operating instrument is producing unreliable data due to sensor calibration drift.
Diagnostic Failure Rate	Data Quality	Rate at which an instrument fails its self-diagnostic test and is therefore considered unreliable until it is serviced. This metric is expressed as the number of diagnostic failures per a predetermined timeframe (ex. 10 diagnostic failures / year).

Interim Report 3 will be delivered in parallel with this Quarterly Report.

Activity: Task 7 – Project Management

During this quarter, GTI conducted project scheduling, budgeting, establishment of data management strategies, preparation of reports, and organization of required meetings. The following meetings were completed during the last quarter:

- Conference call with SoCal Gas - February 2019
- Conference call with Heath Consultants – March 2019
- Quarterly TAP meeting - April 2018
- Development of Interim Report 2 (Target Sensor Technologies) - April 2019
- Development of Interim Report 3 (Technology Evaluation Framework) – April 2019
- Development of Quarterly Report – April 2019

Plans for Future Activity (Project Quarter #4)

The planned activities for the 4th Quarter are:

- Schedule a quarterly TAP meeting and seek feedback on the preliminary set of technology evaluation metrics.
- Further refine the evaluation metrics based on industry feedback.
- Begin Task 4 (Develop Certification Organization Framework) and examine existing technology review organizations and existing standards for certification organizations
    - Ex. American Association for Laboratory Accreditation (A2LA)

    - Ex. American Society of Mechanical Engineers
    - Ex. American National Standards Institute
    - Ex. ICC Evaluation Service.
    - Ex. METEC outdoor technology testing lab at CSU

- Evaluate ISO17025 process for accreditation such as record keeping, equipment maintenance criteria, test work instructions, quality control data, aptness of equipment to use, and ability to perform as stated.
- Define a process to evaluate technology according to multiple criteria and to grade results based on performance standards. (Task 3 – Establish standardized sensor specs and testing practices)
- Submit monthly reports, interim report, and the quarterly report