Public Quarterly Report

Date of Report: 4th Quarterly Report – September 30, 2023

Contract Number: 693JK32210006POTA

Prepared for: The U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (DOT-PHMSA)

Project Title: Accelerating Pipeline Leak Detection Quantification Solutions Through Transparent and Rigorous Scientific Validation

Prepared by: Colorado State University / Southern Methodist University

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For quarterly period ending: September 30, 2023

1: Items Completed During this Quarterly Period:

Item #	*Task #*	*Activity/Deliverable*	*Title*	*Federal Cost*	*Cost Share*
6	4	Comprehensive experimental data sets from METEC test site.	Data collected at METEC	59,186	
7	xx	3rd Quarterly Status Report		2,000	
		3rd Payable Milestone		**61,186**	**24,828**
8	4	Comprehensive experimental data sets from leak field test sites.	Data collected in the field		
	4	**Deliverable #4**	*Comprehensive experimental data sets from METEC test site*		
9	xx	4th Quarterly Status Report			
		4th Payable Milestone			**20,737**
		Total		**$61,186**	**$45,466**

2: Items Not Completed During this Quarterly Period:

Deliverable 5 - Comprehensive experimental data sets from leak field test sites: We made great progress towards this deliverable as outlined in Activity 10, Task 4.2 below. However, we are still working on the data analysis. This item will be completed during Quarter 5 for inclusion in the 5th Quarterly Report.

3: Project Technical Status:

In this quarter, progress related to METEC and leak field sites was made (Activity 9 and 10). In addition, progress on test summary reporting and data analysis (Activities 11 and 13). During this quarter, Deliverable 4, "Comprehensive experimental data sets from METEC test site" was completed. We also met with our technical advisory group on September 18th, presenting our work and gaining input to our follow-on experiments. The slides from this meeting are attached Appendix B)

Follow on efforts during the next quarter (Quarter 5) will be focused on: (1) Analyzing the data from the USAFA and CSU Mountain Campus experiments (Activity 10 Task 4.2 – Controlled tests leak field sites) (2) preparing the initial guidance comparing the probability of detection under diverse conditions (Activity 11, Task 4.3) and performing follow on experiments at METEC based on input we have received from our technical advisory group (Activity 12, Task 4.4) (3) prepare for Task 5 via organizing field sites with interested partners for us to conduct our real-world protocol testing at.

The following section outlines the progress that was made during the quarter.

Activity 9, Task 4.1 – Controlled tests at METEC in diverse conditions

The team completed controlled field testing at METEC from May 15th – 19th, 2023 to investigate the impacts of soil type and soil moisture on probability of detection. From June 12th – 23rd 2023 a second round of controlled testing at METEC occurred investigating the impact of gas compositions on probability of detection. Based on the results, a follow-on set of experiments is scheduled for the week of October 23rd.

Deliverable 4 – Comprehensive experimental data sets from METEC test site can be found in Appendix A

Activity 10, Task 4.2 - Controlled tests leak field site in diverse conditions

Controlled tests at leak field sites were completed at the Colorado State University (CSU) Mountain Campus from July 17th to July 21st and October 18th to the 22nd, 2023, looking at the impacts of mountainous terrain on probability of detection. From September 25th to the 29th, 2023 the team completed controlled testing at the United States Air Force Academy (USAFA), 2023 looking at the impacts of complex urban conditions on POD. Data is currently being analyzed.

Activity 11, Task 4.3 Initial guidance draft comparing PD under diverse conditions

Based on the results from Activity 9 and 10, we are analyzing the probability of detection under diverse conditions. This task is on-going.

Activity 12, Task 4.4 Follow-up experiments in additional conditions as coordinated with TAP

We have experiments planned for the week of October 23rd at the METEC site. These experiments will test the impact of soil type, texture, moisture, surface conditions and composition on the probability of detection in response to inputs from our advisory group members/ meeting on September 18, 2023.

Activity 13, Task 4.5 Extend results via PD analysis

We are currently analyzing the data for the probably of detection. Initial results can be found in Appendix A. This task is on-going, and results will be presented in future updates.

Activity 16, Task 5.1 Field Trial Planning

We are currently in communication with a partner about real-world testing along some of their pipeline assets. Additionally, a separate METEC field project in the Denver-Julesburg basin scheduled to occur Spring 2024 will provide additional opportunities for testing with interested instrument partners.

Presentations and Conferences

1. Smits, K.M., GHG Reduction Opportunities through Detection and Quantification of Belowground Natural Gas Pipeline Leaks, EPA Region 6 Science Council Seminar, Dallas TX, Sept 12, 2023, Invited presentation.
2. Smits, K.M., GHG Reduction Opportunities through Detection and Quantification of Belowground Natural Gas Pipeline Leaks, TX ASCE Science Seminar Series, July 11, 2023, Dallas TX, Invited presentation.
3. Tian, S., S. N. Riddick, M. Mbua, Y. Cho, A. Hodshire, Y Zhang, D. Zimmerle, K. M Smits. (2023). Improving the Efficiency of Mobile Leak Survey Methods Using 3D Plume Modeling and Measurements. CH_4 Connections-The Methane Emissions Conference, to be held on 4-5 October 2023, Fort Collins-Colorado.
4. Lo, J., K.M. Smits, Y. Cho, J. Duggan. (2023). Quantifying Non-steady State Natural Gas Leakage from the Pipelines using an Innovative Sensor Network and Model for Subsurface Emissions. CH_4 Connections-The Methane Emissions Conference, to be held on 4-5 October 2023, Fort Collins-Colorado.
5. Kolodziej, R., S. Tian, V. Rao, K. M Smits, A. Hodshire, D. Zimmerle. (2023). Assessing the Impact of Environmental and Pipeline Conditions on Subsurface Natural Gas Pipeline Leak Detection. CH_4 Connections-The Methane Emissions Conference, to be held on 4-5 October 2023, Fort Collins-Colorado.

4. Project Schedule

The project is progressing as scheduled with a few amendments to the deliverable schedule. This is due to a reorganization of the personnel on the team as well as variations in the workload that were discussed in the project technical status sections above. The amended team project activities that are in line with the actual project are below. (*Redacted for public report.*)

Appendix A

Deliverable 4 – Comprehensive Experimental Data Sets From METEC Test Site.

(*Redacted for public report.*)

Appendix B

Slides from the project's Technical Advisory Panel meeting, held September 18, 2023.

APPENDIX A - *redacted for public report*

APPENDIX B

APPLIED: Accelerating PiPeline Leak Identification & Emission Detection

Technical Advisory Meeting

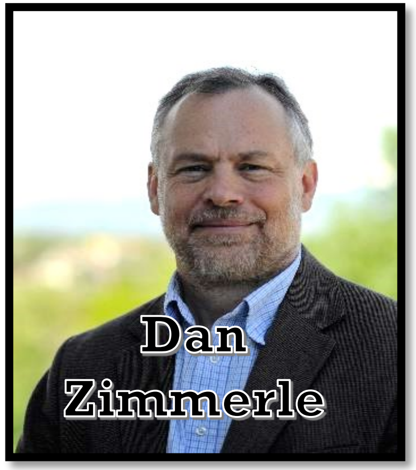
Sept 18, 2023

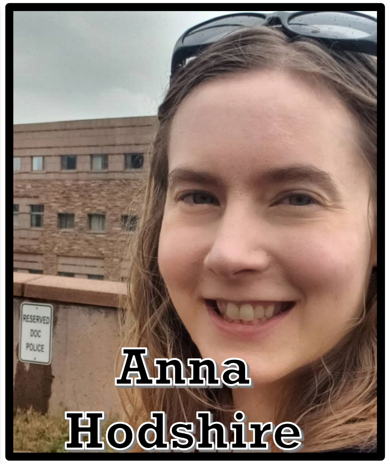
Anna Hodshire, PhD
Project Manager
Colorado State University

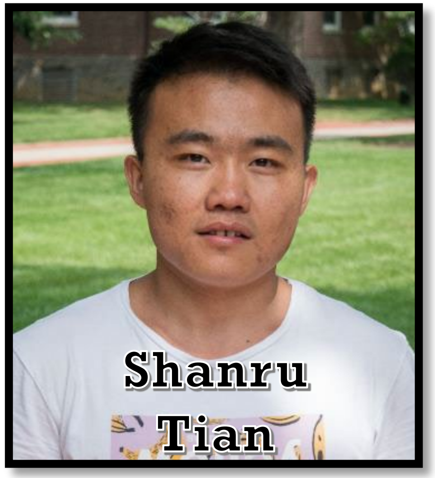
Dan Zimmerle
Director, Methane Emissions Program, Energy Institute
Director of METEC
Colorado State University

Kate Smits, PhD, P.E.
Solomon Professor for Global Development
Chair, Civil & Environmental Engineering
Southern Methodist University

Study Team: Joint team from CSU & SMU







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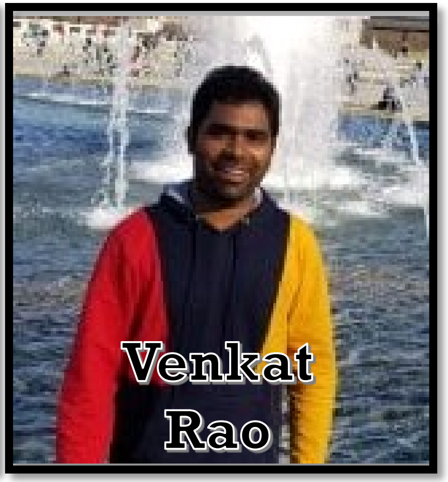

Not shown:
Ryan Cleaves (CSU)
Conner Mikesell (CSU)

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PHMSA Pipeline and Hazardous Materials Safety Administration

Agenda

1. Review of project objectives and tasks
2. Current and emerging LDAQ methods
3. Preliminary results of solution testing performed at METEC
4. Emission mat design and preliminary results
5. Upcoming USAFA and CSU mountain campus testing –*inputs needed from advisory members*

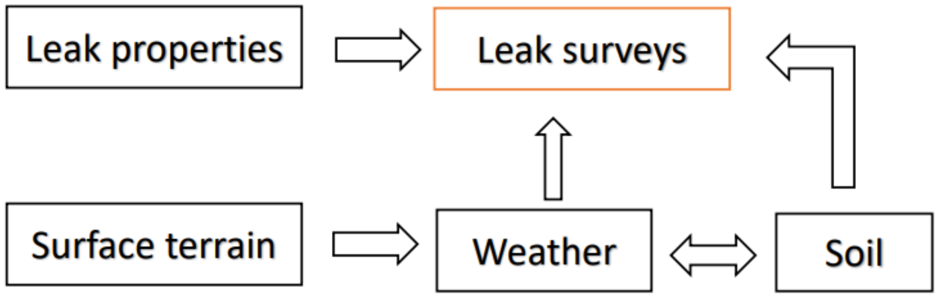
1. Review of project objectives and tasks

APpLIED Project

- **Funded by**
  - *PHMSA, 9/22 – 8/24*
- **Objectives:**
  - Develop a method-centric, rather than tech-centric understanding of leak detection and quantification for pipelines in production, midstream, and distribution
  - Conduct comprehensive, multi-solution controlled and field testing for a variety of diverse operating conditions
  - Deliver empirical analysis of enhancements to LDAQ protocols that can be realistically incorporated into operator and service provider practice

Definitions of Diverse Operating Conditions

- Categories
  - Leak Characteristics
  - Environment
- Leak Characteristics
  - Gas composition (C3+ and C1-C2)
  - Leak rate (0.2 scfh to 20+ scfh)



- Environment
  - Weather
    - Atmospheric turbulence (stability)
    - Humidity (dry to wet conditions including rain, and snow)
    - Wind (driven by the difference of barometric pressure mainly)
    - Temperature
  - Terrain/Surface
    - Flat (open field condition)
    - Dense vegetation (trees), blocked ROWs
    - Hills
    - Urban complexity (pavement, buildings)
  - Soil Conditions (type)
    - Sands and Clays

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Schedule (APpLIED)

9/2022 9/2023

	Year 1				Year 2			
Task 1: Develop / convene project guidance committee	■							
1.1 Team Formation	■							
1.2 Establish TAP	■							
Task 2: Investigate and document RPs	■	■						
Task 3: Develop enhancements to LDAQ approaches		■	■					
3.1 Initial protocol development		■						
3.2 Final protocol development			■					
Task 4: Controlled testing at METEC and leak field sites		■	■	■	■			
4.1 METEC tests		■	■					
4.2 Leak field tests			■					
4.3 Follow-up experiments				■				
4.4 Test summary/ reporting					■			
Task 5: Real world field observations			■	■	■	■	■	
5.1 Field trial planning (test sites, solutions etc.)			■	■				
5.2 Field trials					■			
5.3 Initial analysis of field trial						■		
5.4 Follow on testing							■	
5.5 Test summary/reporting							■	
Task 6: Recommended Practices						■	■	
6.1 Initial guidance draft						■		
6.2 Final guidance doc							■	
Task 7: Final reporting								■

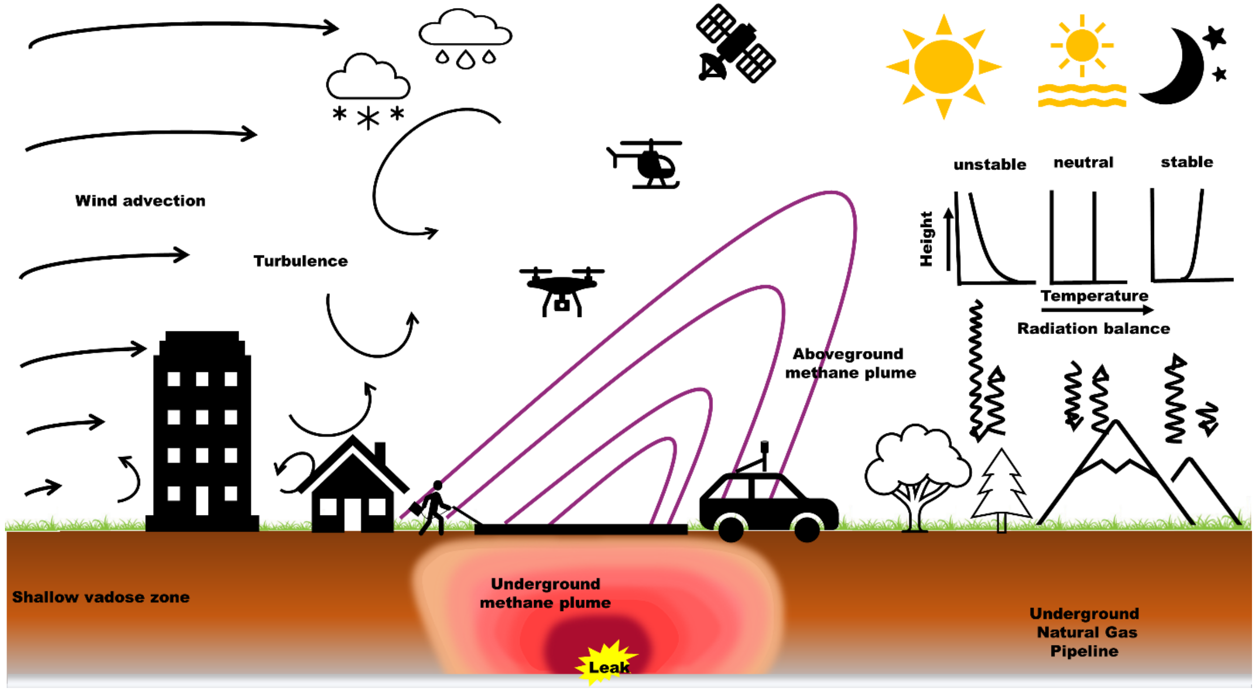
Upcoming:

- 3-4 final experiments for Task 4 (CSU Mountain Campus, USAFA, METEC x1, Taos (possible))
- Analysis of Task 4 experiments
- Field trail planning

2. Current and emerging LDAQ method applicability to diverse operating conditions (Task 2 results)

Objectives

- Investigate and document current and emerging LDAQ effort applicability to diverse operating conditions
- Develop enhancements to LDAQ to overcome the limitations of existing approaches



Investigate and document current and emerging LDAQ efforts

Literature Review

- 50+ PHMSA-sponsored projects
- Internal operation documents
- Peer reviewed papers and reports

Conversations with the Technical Advisers

- R&D program managers and engineers
- Operator area managers
- Technicians

Field Observations

- Walking, mobile, and aerial survey operators
- Up/mid/downstream

Key findings: the current and emerging LDAQ efforts

- Most of the LDAQ methods have not been validated in diverse operating conditions and the efficiency remains unknown
- LDAQ methods mostly focus on the technologies, and less attention is paid to integrating the understanding of the evolution of plume behaviors in diverse conditions
- Methods developed & deployed for above ground leaks – only a few specific to belowground leak scenarios, esp. for up- and mid- stream
- Performance modeling to assess various LDAQ methods for NG pipeline leaks in diverse conditions is missing
- Interest increasing due to federal and state – level carbon accounting proposed legislation

Smits, Tian, Kolodziej, Zimmerle et al., Applicability of LDAQ methods to underground natural gas pipelines in diverse conditions: analysis of existing and emerging effort, PHMSA Report, 2023

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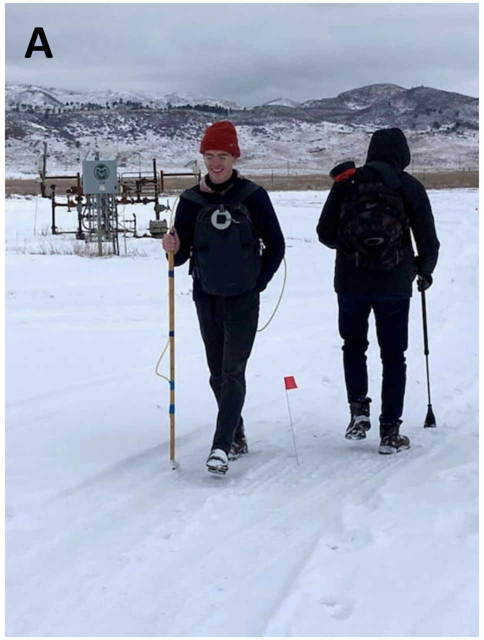
3. Controlled solution testing performed at METEC (Task 4)

Experimental Objectives

- Test the developed survey protocol methods at METEC
- Investigate the detection probability of survey methods under diverse conditions, focusing specifically on:
  - A- Snow pack
  - B - Soil type/surface cover (grass vs asphalt)
  - C - Gas composition



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Protocol & Solution tasting at METEC – Summary of Experimental Methods

- Three sets of experiments, five days each set
  - Snow weather experiment (Jan 23rd - 28th, 2023)
  - Soil type experiment (May 15th – 19th, 2023)
  - Gas composition experiment (June 12th – 23rd, 2023)
- Release rates ranging from 0.2 scfh to 20+ scfh
- Multiple survey methods (walking, mobile, and Simulated UAV)
- Survey times including morning, noon, & afternoon survey (approx. 1 hr each survey)
- Multiple passes/ pipeline ROWs

Survey method	Walking	Mobile	Simulated UAV
Gas analyzer	DP-IR+	Aeris/G4302	MGGA
Survey platform	Pedestrian	Vehicle	Vehicle & Mast
GPS	RTK	RTK	RTK
Survey height (m)	0	0.5m, 2m	7m
Morning survey	7:00 AM - 8:00 AM	7:00 AM - 8:00 AM	7:00 AM - 8:00 AM
noon survey	11:00 AM- 12:00 PM	11:00 AM- 12:00 PM	11:00 AM- 12:00 PM
afternoon survey	3:00 PM - 4:00 PM	3:00 PM - 4:00 PM	3:00 PM - 4:00 PM

Walking survey

Mobile Survey

Simulated UAV

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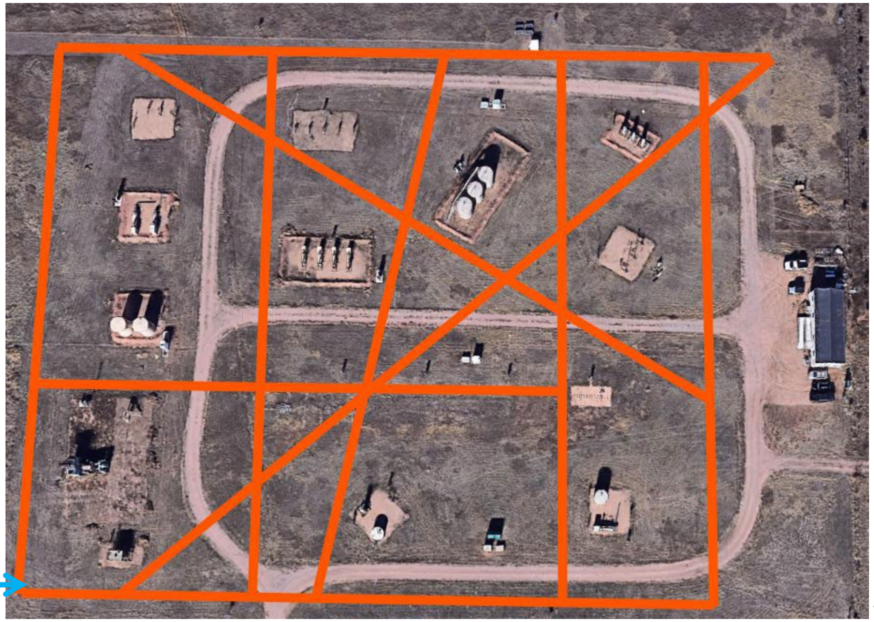
Methods (cont'd)

- Pipeline right-of-ways (ROWs) at METEC facility (red lines)
  - Emission points are located along the ROWs
    - Typically, at 3 ft depth
  - Route (a section of ROWs)
- Continuously measure:
  - Methane concentration, GPS coordinates
  - Weather conditions (local and site level) (wind speed, direction, relative humidity, air temperature, and atmospheric pressure)
  - Soil moisture, pressure, temperature

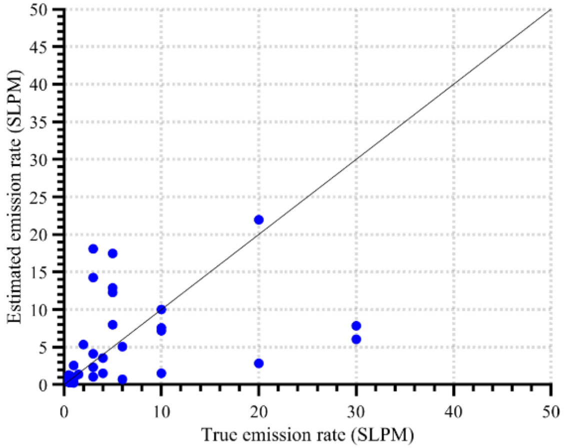
ROWs



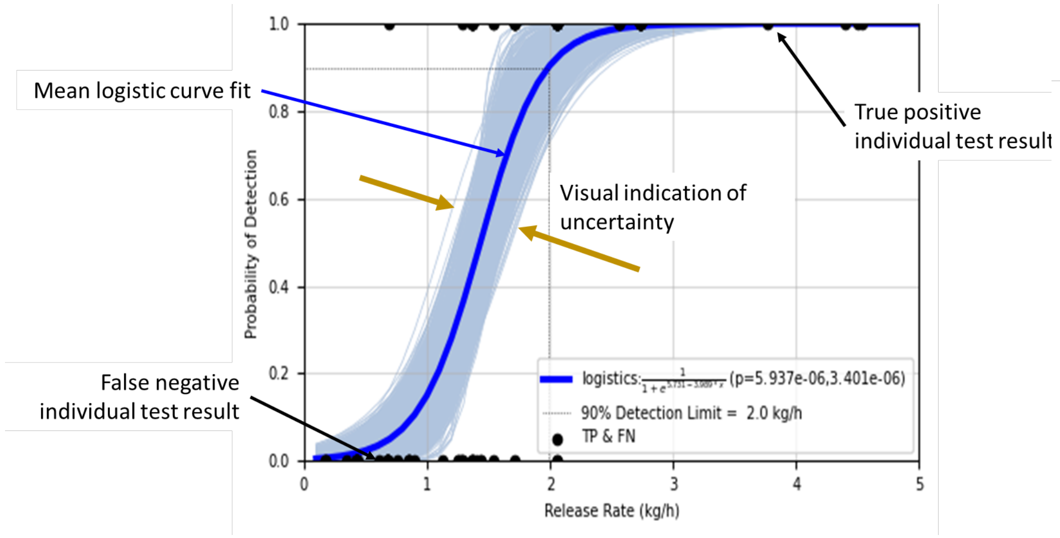
Methods: Performance Metrics

- Probability of Detection (PD)
- False positive fraction
- Localization Accuracy
- Quantification Accuracy (when applicable)

Quantification

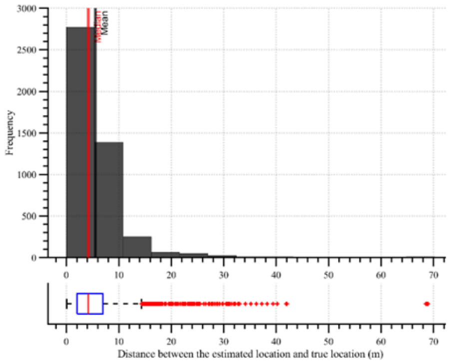


Probability of Detection

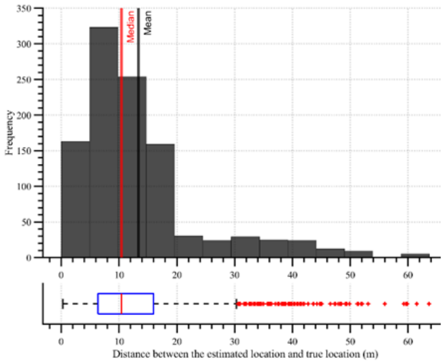


Localization

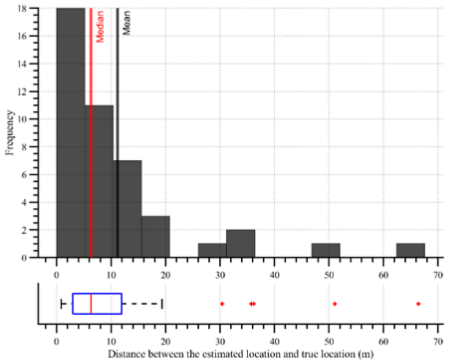
Walking A



Mobile B



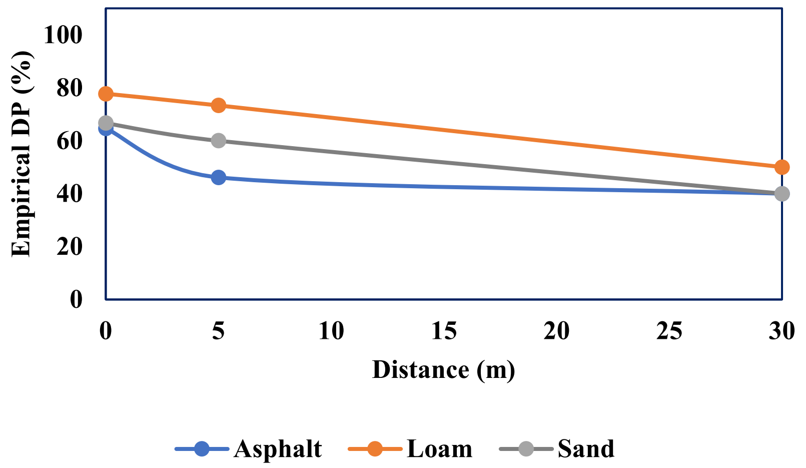
Mobile C



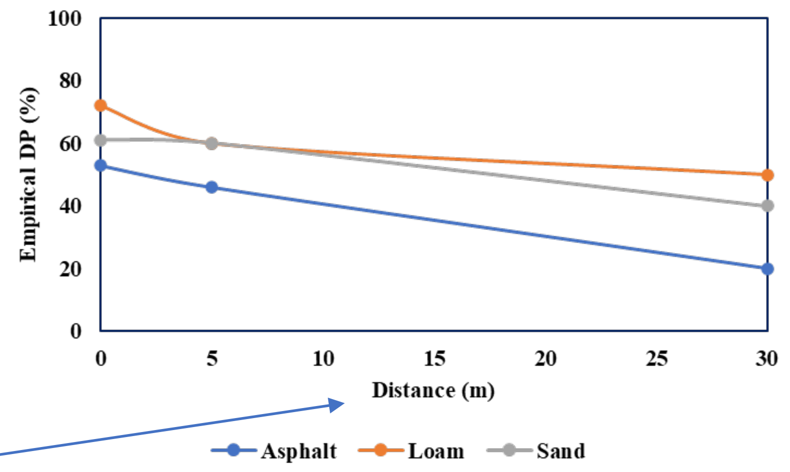
Preliminary results: impact of soil type and surface condition on survey performance

- For both driving and UAV surveys, loam soil had the highest probability of detection, while asphalt has the lowest probability of detection.
- For all soil and surface conditions tested, driving survey has a higher probability of detection than UAV survey.

a) Driving survey



b) Simulated UAV survey



Distances are from the pipeline centerline where 0m is the pipeline extent

Leak rate: 21 scfh

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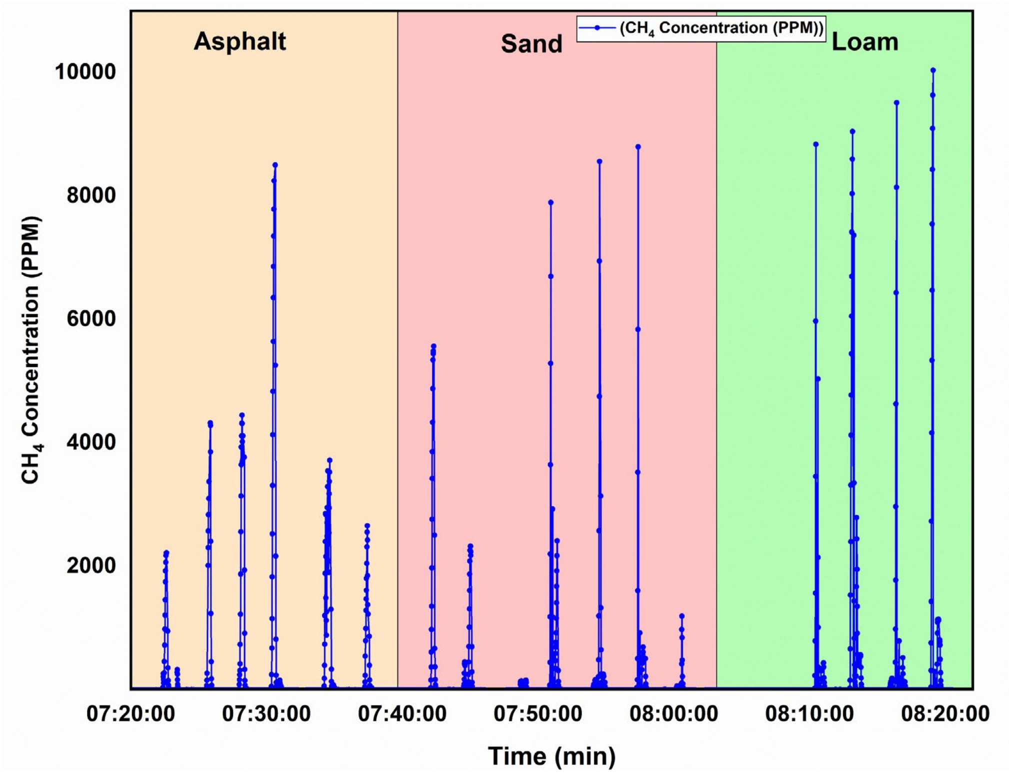
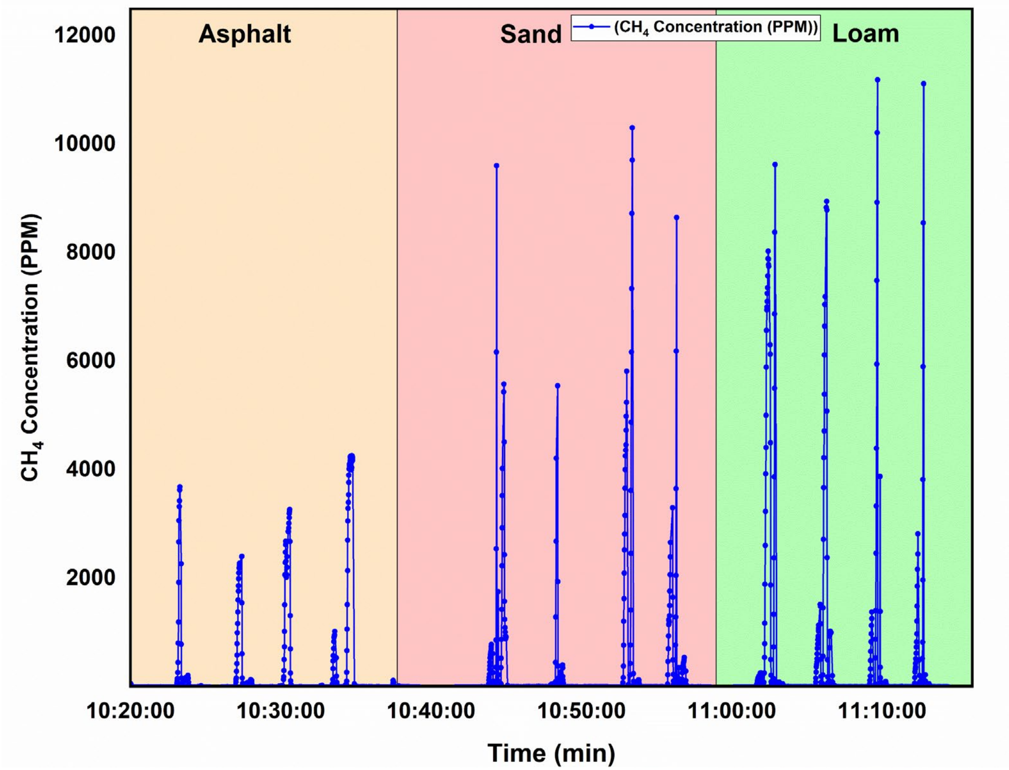
DIPR walking survey

- Surface CH_4 concentrations for three soil/surface types
  - Highest in Loam
  - Medium in Sand
  - Lowest in Asphalt

a) Walking survey early morning



b) Walking survey mid-day

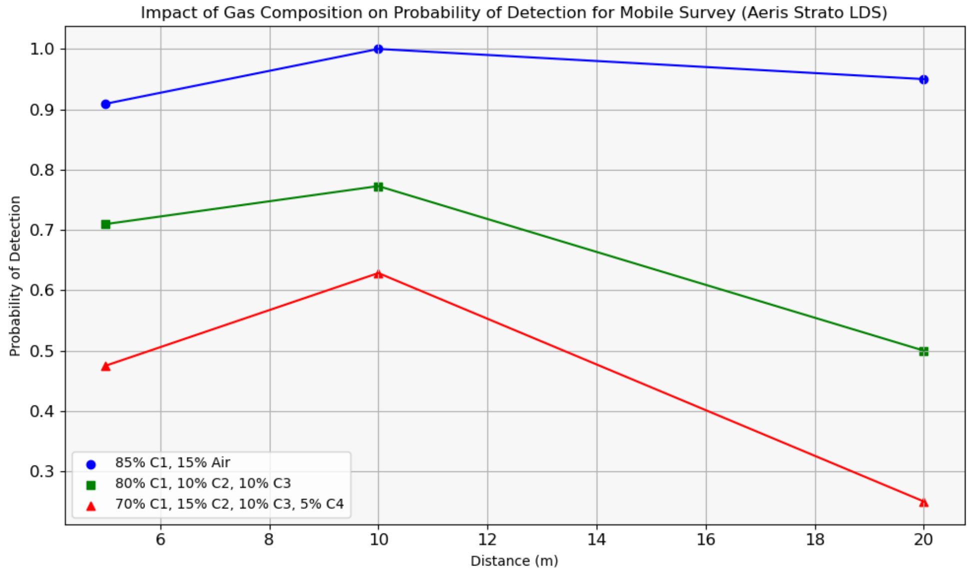


Leak rate: 21 scfh

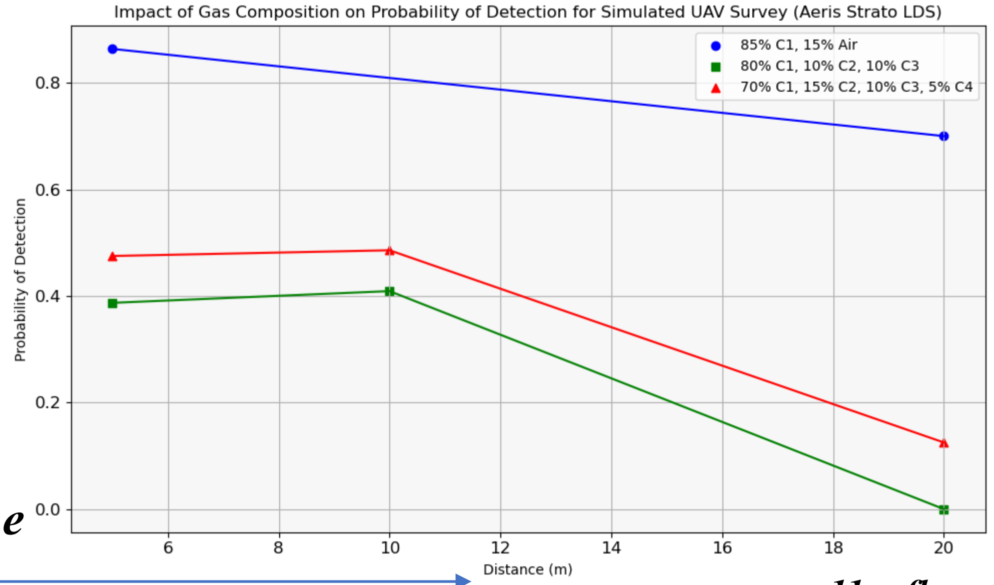
Preliminary results: impact of gas composition on survey performance

- Both driving and UAV surveys show lower PD with a higher percentage of heavy carbon components

a) Driving survey



b) Simulated UAV survey



Distances are from the pipeline centerline where 0m is the pipeline extent

q: 11 scfh

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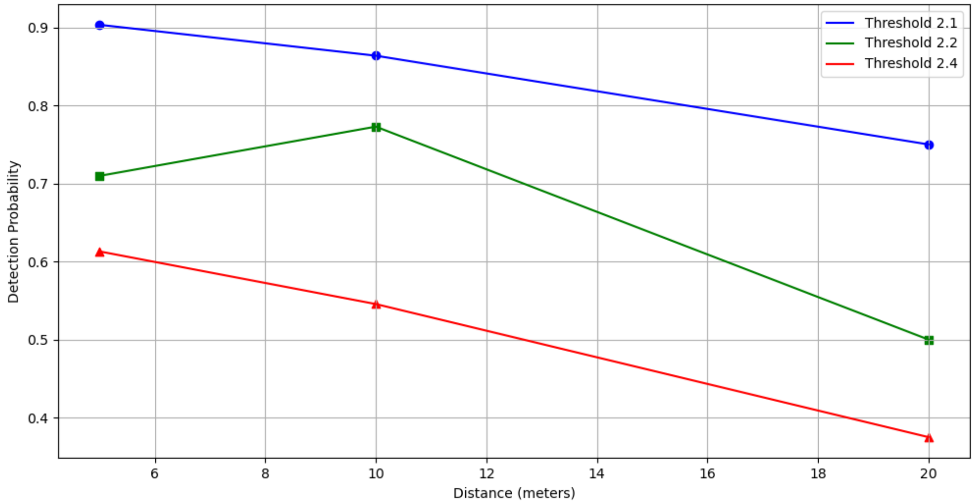
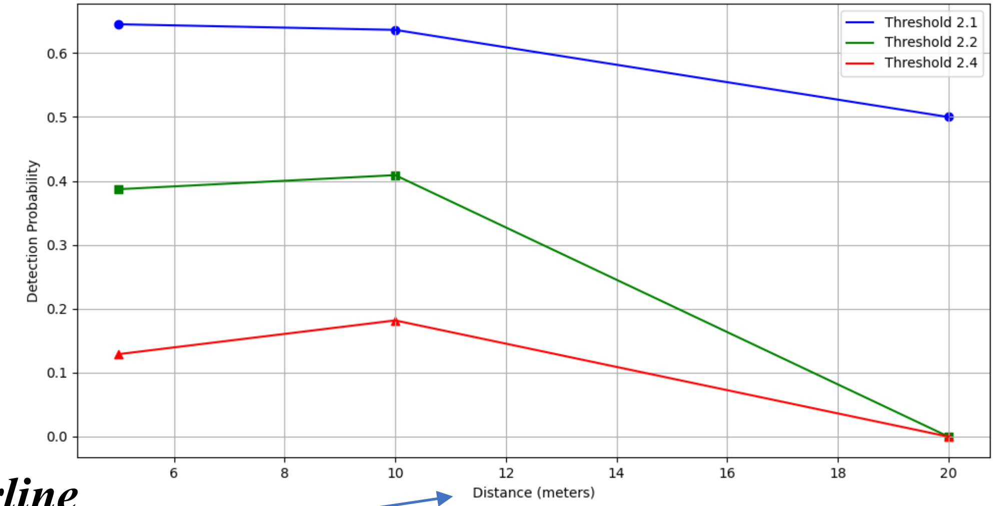
Preliminary results: impact of detection threshold on the survey performance

- Both driving and UAV surveys show the detected probability decreases with an increase of the detection threshold

a) Driving Survey



b) Simulated UAV survey



Distances are from the pipeline centerline where 0m is the pipeline extent

q: 11 scfh (70% C1, 15% C2, 10% C3, 5% C4)

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4 Emission mat design and preliminary results

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Objectives

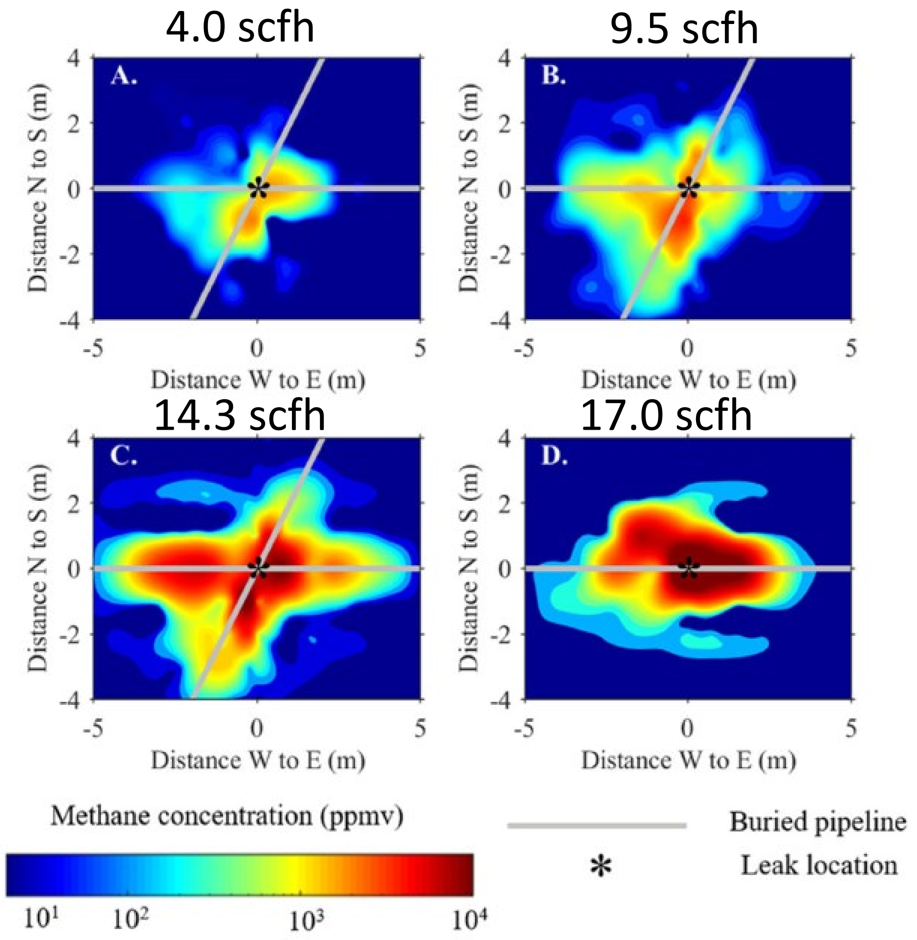
- Develop, test and validate a mobile, area emission source mat that can simulate the surface expression of belowground NG leaks
- Deploy the mobile emission mat for solution testing experiments

CH_4 surface expression of a belowground plume

Design criteria:

- Mimic the size, shape and concentrations
- Correlate the apparatus leak rates to actual leak rates
- Consider the boundary layer development downwind of the plume that mimics the belowground area expression

Steady State CH_4 surface plots (CH4 expressions)

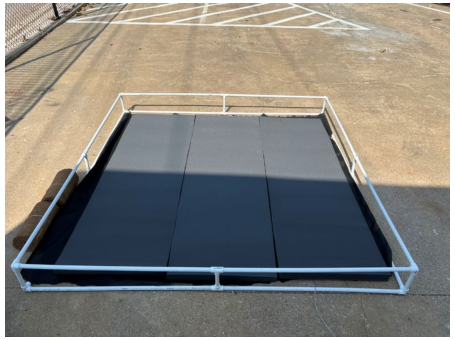


Cho et al., Env Pol, 2020

Mat prototype & materials

- Porous media separated into distinct layers, varying the layers based on the permeability of the media
- Media layers are organized in a 2m x 2m box frame

Prototype 1 – Foam Layer Only



Foam Layer

Prototype 2 – Foam combined with a Base soil Layer

Foam Layer
Soil

Prototype 3 – Foam with a top and base soil layer (Final version)

Soil
Foam Layer
Soil

Prototype 4 – Soil Only (Final version)

Soil

Complexity

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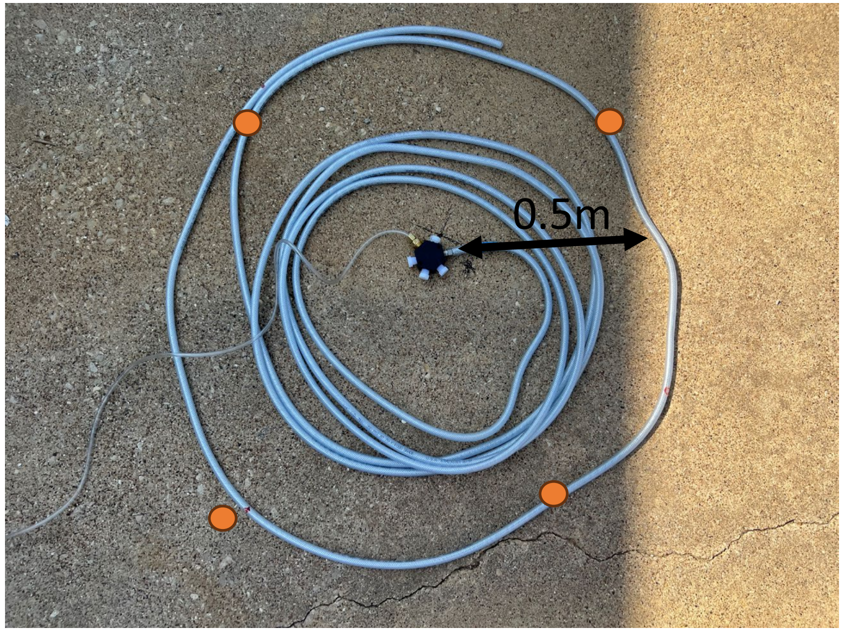
Prototypes – Gas Distribution System

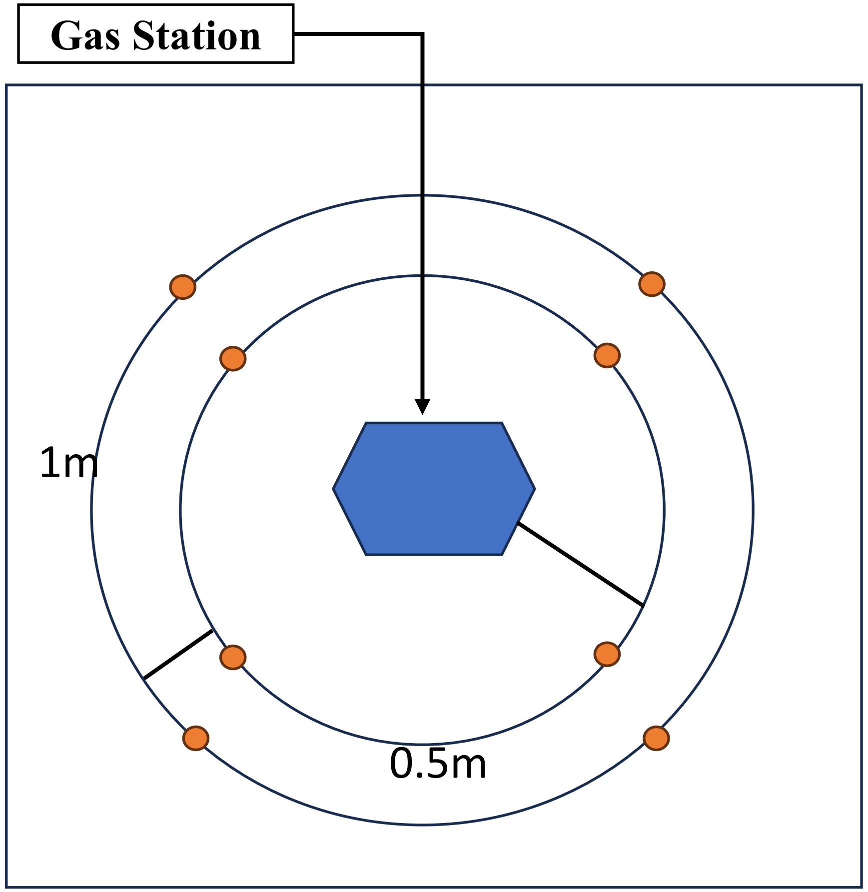
Prototype 1 – Simple configuration to understand media performance

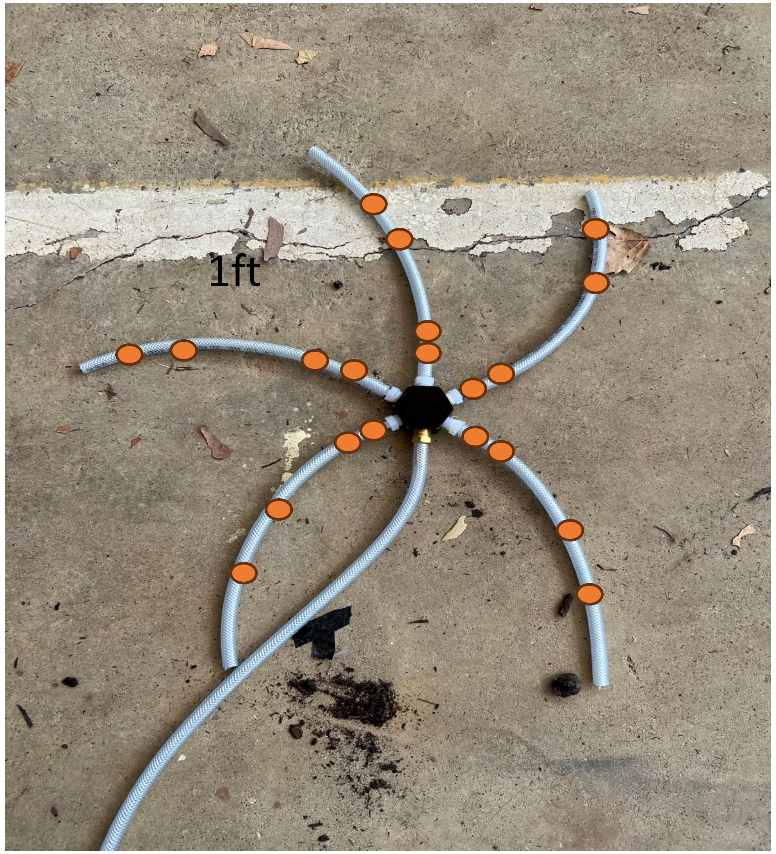
Prototype 2 – Configuration of two concentric circles with multiple release points

Prototype 3 and 4 – Simplified design of multiple emission points in a spider-based design (final version)

Emission points







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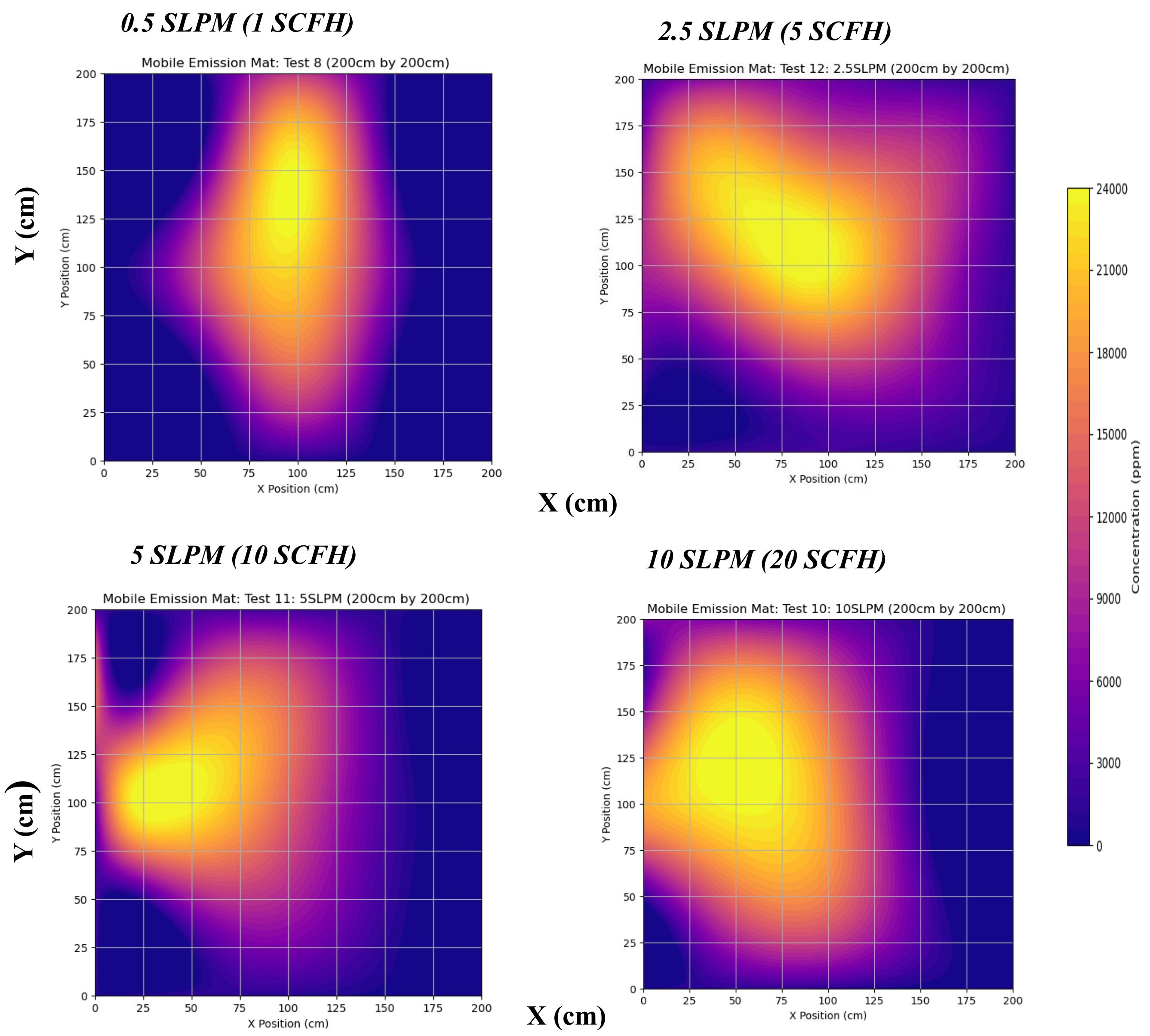
Results

- The mobile emission mat is capable of simulating below NG pipeline leaks
  - Surface expression shape
  - Surface expression size
- Correlation between apparatus leak rate and real-world leak rate underway



5 Upcoming USAFA and CSU mountain campus testing –*inputs needed from advisory members*

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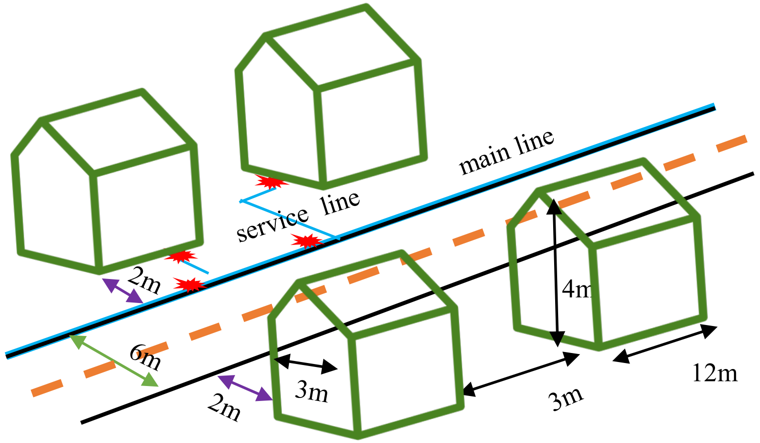
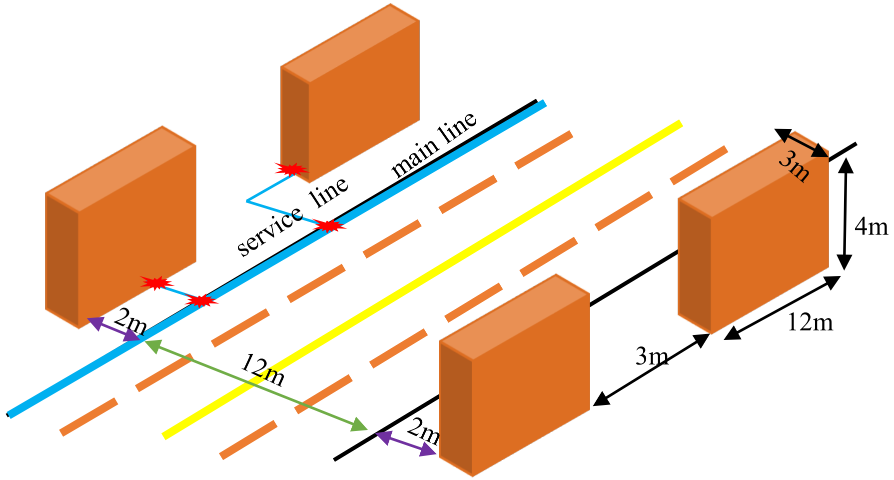
APpLIED – USPIDE in complex conditions

- Urban canyon – USAFA
- Topography – CSU Mountain Campus/ SMU Taos campus



Residential community



Business community

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USAF Academy: urban canyon experiment

- USAFA site
  - One-way road with one center lane
  - 2 leak point locations: 1 main line leak, 2 service line leak
  - Two canyon street types: 1 closed building block; 1 half-closed building block (backup)

MX&MET

USAF Academy’s Field Engineering and Readiness Laboratory

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USAFA urban canyon experimental plan

- Four experiments
  - Sep 26 to 29, 2023
  - Two leak rates (small, and large size)
  - Two leak types (main, and service line)

Exp ref	Date	Leak rate (SLPM)	leak location	Canyon street type
1	Sep 26, 2023	0.5	Main line	Closed building block
2	Sep 27, 2023	10	Main line	Closed building block
3	Sep 28 , 2023	0.5	Service line	Closed building block
4	Sep 29 , 2023	10	Service line	Closed building block

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USAFA urban canyon experiment: survey measurement schemes

- Four survey methods in parallel)
  - Stationary survey (MX)
  - Walking
  - Driving
  - Simulated UAV
- For each day, test survey solutions up to three times each (6 hr each survey) including morning, noon and afternoon surveys
- Gas release time at 6:55 AM, 10:55 AM, and 2:55 PM each day, respectively

Survey method	Stationary	Walking	Driving	Simulated UAV
Gas analyzer	UGGA	DP-IR+	G4302	AERIS
Survey platform	Mast	Pedestrian	Vehicle & MAST	Vehicle & Mast
GPS	No	RTK1	RTK2	RTK 2
Survey height (m)	0.5, 2, 5, 7	0	2	7
Morning survey	7:00 AM - 9:00 AM	7:00 AM - 9:00 AM	7:00 AM - 9:00 AM	7:00 AM - 9:00 AM
noon survey	11:00 AM- 1:00 PM	11:00 AM- 1:00 PM	12:00 PM- 1:00 PM	12:00 PM -1:00 PM
afternoon survey	3:00 PM - 5:00 PM	3:00 PM - 5:00 PM	3:00 PM - 5:00 PM	3:00 PM - 5:00 PM

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Understanding detection probabilities in comples terrain: controlled testing at the CSU mountain campus

- July and September tests using CSU/SMU prototyped controlled-release mat
- Access to two ROWs:
  - Leak is on slope, ROW is beneath on flat ground
  - Leak and ROW are on the same slope

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Year two real-world testing: collaboration opportunities

- We will be applying all methods and protocols developed in year one to pipelines
- Timing: ~spring 2024
- Desired: variable terrain, variable ROWs
- We are open to working with solution providers to independently test their technologies

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Thank you

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