

Public Quarterly Report

Date of Report: 4th Quarterly Report – September 30, 2025

Contract Number: 693JK32410007POTA

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Project Title: P3LD: Practical Protocols for Pipeline Leak Detection

Prepared by: Colorado State University

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For quarterly period ending: September 30, 2025

1: Items Completed During this Quarterly Period:

<i>Item #</i>	<i>Task #</i>	<i>Activity/Deliverable</i>	<i>Title</i>	<i>Federal Cost</i>	<i>Cost Share</i>
10	5.1	R1 METEC Testing		\$113,952	\$ 0
13	7.1	4th Quarterly Status Report		\$ 1,733	\$ 0
		<i>Fourth Payable Milestone</i>		<i>\$115,685</i>	<i>\$ 0</i>

2: Items Not-Completed During this Quarterly Period:

<i>Item #</i>	<i>Task #</i>	<i>Activity/Deliverable</i>	<i>Title</i>	<i>Federal Cost</i>	<i>Cost Share</i>
9	3	Pipeline Condition Report		<i>\$ 36,150</i>	<i>\$ 0</i>
12	5.1	R1 METEC Testing		<i>113,952</i>	<i>\$ 0</i>

We started R1 testing in July and are including for payment Item #10 for that reason. The Pipeline Condition Report is expected to be completed in December and will be invoiced at that time.

3: Project Financial Tracking During this Quarterly Period:



4: Project Technical Status –

Task 1: Perform general literature and stakeholder review

SMU is performing the ongoing literature review using peer reviewed publications, grey literature and stake holder interviews to identify the current knowledge and performance gaps persistent in the existing underground natural gas (NG) pipeline leak detection practice. This review evaluates the current efforts of researchers and industrial practices to validate the performance of above ground leak detection methods (walking, driving, UAV, aircraft, and satellite platforms) to underground NG pipeline leaks. Literature review is still progressing, and attached are prepared taxonomy tables on leak detection technologies, identified survey parameters and challenges specified by researchers and industrial partners in Appendix A.

In addition to the literature review, the following efforts were made by the project team:

Presentations

1. Smits, K.M, Cracking the Code on Underground Methane: What 30 Controlled Natural Gas Leak Tests Reveal About Detection in Diverse Operating Conditions, Statistics, Analytics, and GIS for Energy Conference, GTI, Des Plains, IL, August 14, 2025 (Invited Presentation)
2. Smits, K.M., Understanding leak detection success for belowground natural gas pipeline across diverse operating conditions, Texas Railroad Commission Regulatory Conference, Round Rock, TX, July 15, 2025, (Invited Presentation).
3. Venkata Rao, G., Lo J H., Zimmerle, D., & Smits, K. M. “Advanced Leak Detection Methods for Belowground Natural Gas Pipeline Leaks: Evaluation under Diverse Environmental and Operational Conditions”. Abstract submitted to American Geophysical Union (AGU) 2025 conference to be held on 19 – 19, December 2025 at New Orleans, LA. Abstract ID 1867977.
4. Venkata Rao, G., Lo J H., Zimmerle, D., & Smits, K. M. “Advanced Leak Detection Methods for Belowground Natural Gas Pipeline Leaks: Evaluation under Diverse Environmental and Operational Conditions”. Abstract submitted to CH₄ Connections 2025, conference to be held on 8 - 9 October 2025 at Fort Collins, CO.
5. Zimmerle, et al. Invited presentation to the Western Regional Gas Conference, Pheonix, AZ, 20 August 2025.
6. The pipeline testbed and testing programs has been a topic for multiple visiting research, industry, and environmental group tours over the summer.

The SMU team is currently working on following journal publications in preparation and review:

01. Kolodziej, R.S., Venkata Rao, G., Jayarathne, J.R.R.N., Tian, S., Zimmerle, D.J., Smits, K.M., 2025. Impacts of Mixed Hydrocarbon Compositions on the Probability of Detection of Belowground Pipeline Leaks using Mobile Survey Methods. Elem. Sci. Anthr. In Review.
02. Venkata Rao, G., Josh R. Aldred, Zimmerle, D.J., Smits, K.M., 2025. Understanding Detection Success of Belowground Natural Gas Leaks in Urban Environments through Controlled Release Experiments. J. Pipeline Sci. Eng. In Review.

03. Venkata Rao, G., Lo, J.-H., Zimmerle, D.J., Smits, K.M., 2025. Advanced Leak Detection Methods for Belowground Natural Gas Pipeline Leaks: Evaluation under Diverse Environmental and Operational Conditions. Environ. Sci. Technol. In Review.
04. A. R M Isuru Bandara, G Venkata Rao, Daniel J. Zimmerle, Kathleen M Smits. " Trends and challenges in current leak detection methods for underground natural gas pipelines: State-of-the-Art." (In Preparation for Journal Submission)
05. Uribe, J. R., Venkata Rao, G., Lo, J.-H., Smits, K.M. "Comparison of estimation approaches for methane emissions\from underground natural gas pipelines using surface concentration measurements." (In Review, 2025)
06. Venkata Rao G, Zimmerle, D.J., Smits, K.M., 2025"Reliability of Aboveground Methane Measurements for Estimating Subsurface Natural Gas Pipeline Emissions ". In Preparation for Journal Submission.

Task 2: Assemble a Technical Advisory Group

The SMU team collaborated with the CSU team to assemble a technical advisory group comprising five upstream, midstream, and distribution companies, along with five regulatory agencies.

Task 3: Review and summarize the current pipeline portfolio

The literature review has been started by the SMU team and is in progress. This deliverable is delayed until the next quarterly report.

Task 4: Identify 3 - 5 next-generation methods

A combined literature review and interviews with utilities, solution providers, and program managers highlights three leak detection methods to detect underground NG pipeline leaks. These strategies showcase the latest advances in field-ready technologies designed to improve detection sensitivity, spatial coverage, and operational efficiency.

1. Walking surveys, where field technicians use handheld sensors to scan pipelines with high spatial precision.
2. Advanced mobile leak detection (AMLD) methods, including both
 - a. vehicle-based driving surveys
 - b. unmanned aerial vehicle (UAV) based surveys.

These methods integrate sensors onto mobile platforms for broader and faster survey speeds than walking methods. These approaches will be carried forward through the program as the core methods under development and will be tested for performance at METEC using available, existing, equipment. The identified methods were discussed at the TAP meeting on June 24, 2025.

These methods represent the key methods of interest for operators. However, it is important to note that there are multiple variants of each methods that will not be tested in this project. For example, AMLD methods may use cavity ring-down spectrometers (CRDS) or open-path spectrometers. The research team has access to CRDS instruments, but does not possess an open-path instrument at this time. We will continue discussions with various instrument suppliers, to see if other instrument variants may be accessible during the project.

Additional methods may be tested on occasion in cooperation with solution developers, as interest and time permits. Specifically, the team is talking with another university team to analyze the data collected at METEC using an advanced, open-source, machine learning approach that may be superior to the simple thresholding utilized in prior projects. We will provide additional updates if this cooperation develops.

Task 5. Experimental work at METEC

Since the pipeline testbed was completed and commissioned during July 2025, the team has been running continuous experiments at the facility, interrupted only when solution developers are testing under the sister PHMSA-sponsored project, *P4*. As proposed for the project, this has allowed steady-state leaks to be observed continuously as environmental conditions change, providing direct measurement of the impact of environmental conditions.

Daily surveys and surface expression collection are being performed on each active or recently terminated leak by the CSU project team. To date, 72 surface expressions, 40 walking, 35 driving and 18 simulated UAV surveys have been performed. Dataset cleaning and analysis have been developed to batch process the surveys. See figures in Appendix B (*redacted in public report*) for initial analysis efforts. Currently analysis work is focused on characterizing new leak points, assessing how leak expression changes with environmental conditions, and characterizing the testbed as a whole. Software developed during this process will provide batch analysis of survey pass readings with common independent variables such as, environmental conditions (temperature, wind speed and direction, precipitation, atmospheric stability), survey variants (time of day, instrument variants, sampling speeds), and leak conditions (leak rate, number of leaks, testbed type and point, etc.).

The combined CSU/SMU team will conduct an intensive set pipeline leak detection experiments at METEC from September 21 to October 4, 2025, ongoing at the time of this report. The primary objectives of these experiments are to:

- to systematically evaluate the impact of soil moisture on the probability of detection (POD),
- to advance quantification approaches for subsurface methane leaks.

These experiments will focus on the influence of soil moisture and backfill configuration. Soil moisture profiles will be measured from the surface down to approximately 2.5 feet, or the depth of the leak point, to assess how varying moisture conditions alter detection efficiency. METEC's three operational testbeds include two distinct backfill configurations, providing a unique platform to examine how these subsurface characteristics affect plume migration and aboveground detectability. These initial experiments will also serve as baseline studies to guide and refine subsequent investigations. The proposed experimental plan is attached in Appendix C.

Upcoming Events

Dr. Kate Smits and Dan Zimmerle are leading the development of an upcoming session at the **AGU Annual Meeting (AGU25)**, scheduled for December 15–19 in New Orleans, Louisiana.

The session, titled “*New Technologies and Frameworks to Detect and Analyze Methane Emissions from the Oil and Gas Supply Chain: Methods, Data, and Insights*,” will feature 10 invited speakers as well as a poster session with approximately 30 presentations.

The following is the submitted abstract:

Reducing methane emissions from the oil and gas supply chain is a key component of a comprehensive climate strategy. Emissions originate from upstream production, midstream processing and storage or transfer to downstream refining and distribution. Advances in measurement technologies continue to increase the quality of methane emissions data, and new frameworks for reconciling data.

This session highlights innovative technologies for measuring methane across the oil and gas supply chain and frameworks for analyzing these data. We are broadly interested in measurements from stationery to mobile platforms at all spatial and temporal scales. Relevant studies may include methods for improving emissions inventories, evaluation of sensor field performance, assessments of leak detection and repair programs, insights into spatiotemporal emission characteristics, or reconciliation of methane inventories. We are also interested in studies that compare performance across measurement platforms and studies that demonstrate the practical application of methods to mitigate risk and climate impact.

Both PHMSA-sponsored pipeline projects will also be presented at the Energy Emissions Modeling and Data Lab (EEMDL) Annual Meeting, October 21-23, 2025, Austin, TX.

5: Project Schedule –

Project is on track, with minor delays in deliverables given length of time needed to set up subaward and cost share accounts. We will continue to monitor the need to push out deliverable deadlines and keep PHMSA informed.

Our intentions for Q5 will be to complete the Pipelines Condition Report, continue updating the Literature Review and operate Testing Round 1, experiment tracking and data collection. The teams will evaluate the need for a Fall TAP meeting.

6. Attachments

Appendix A: Prepared taxonomy tables on leak detection technologies, identified survey parameters and challengers specified by researchers and industrial partners.

Appendix B: Initial Data Analysis (*redacted in public report*)

Appendix C: Presentation on upcoming controlled experimental plan.

Appendix A						
Survey platform	Detection Principle	Sampling Rate/ Hz	Precision/Accuracy	Sensitivity (Detection Limit)/ppm	Min detectable leak rate/ g/h	Sensor Technologies
Walking survey	Cavity ring-down spectrometer (CRDS) - Laser absorption in cavity	1–10	0.1–30 ppb	1 ppb (0.01 -10,000)	17-452	Picarro GasScouter; ABB MicroGuard
	NDIR -Infrared absorption	1 Hz – continuous	±5–10% of readings	1 (1- 10,000)	21.5-320	Heath DP-IR+, SENSIT PMD, INFICON IRwin, Teledyne GMI, Gas-Rover
	Tunable diode laser absorption (TDLAS)	3–10	N/A	5 ppm·m (1–50,000 ppm·m)	—	Heath RMLD-CS; Crowcon LMm
	CGI / dual - Catalytic combustion (LEL) + thermal conductivity	1–5	±10% of readings	1 (1-10,000)	4	Bascom-Turner Gas Rover
	FID / FIU - Hydrogen flame ionization	1 - 0.5	±5–10% of readings	1	—	Southern Cross FID; Dafarol A500 FIU
	Optical Gas Imaging - Infrared video visualization	30 (video)	±5–10%	-	0.8 (lab conditions)	FLIR GFx32)
Driving survey	Cavity ring-down laser absorption of CH ₄ mole fraction	0.3–4	±0.05 ppmv	1 ppb(0–100)	19-96	Picarro G4301/G2301/G2204; Los Gatos Research (LGR)
	Cavity-enhanced IR absorption	2	1 ppb	1 ppb (0.01–10,000)	—	ABB MobileGuard
	TDLAS -Open path	1	±10% of reading	5 ppm·m (1–1000 ppm·m)	—	GTI Mobile OMD, Sensit VMD, Pergam SELMA (roof scanner + bumper cell)
	TDLAS -Closed path	0.7–1	±10% of reading	1 (0–5000)	—	Gazomat VSR Inspectra; Sensit Trak-It PMD (vehicle probe)
	Laser-based absorption (closed-cell)	10		1 ppb (0.01 – 10,000)	21.5-430	Aeris MIRA Ultra LDS
	Cavity-enhanced laser absorption	1-10		0.9 ppb (0.01–10,000)	—	ABB HoverGuard; ABB GLA133
UAV survey	Tunable-diode laser absorption (TDLAS) (open-path / remote, path-integrated)	1–40	±10% of readings	0.05–5 ppm·m(0-100,000 ppm·m)	1-252	LaserMethane mini / SA3C321-BE; DJI U10; Pergam Laser Falcon / LMC (+ OEM / mdTector)
	TDLAS (closed-path)- In-plume / pumped laser absorption	10	99%+ conc. accuracy	0.01– 1.5	> 20	SeekOps SeekIR (closed-path); Soarability Sniffer4D module
	TDLAS (closed-cell)	10		1 ppb (0– 10,000)	21.5-430	Aeris MIRA Strato LDS
	Optical Gas Imaging (IR absorption video)	15–30 Hz (video rate)	—	—	1.4	Workswell GIS-320; OPGAL EyeCGas Fly; SENSIA Caroline-Y On-Board; Sierra-Olympia Ventus OGI
	NDIR/laser modules with modeling		-	—	0.1 kg @ 90% POD	Aeromon AMOS / BH-12
	Active laser-based methods - TDLAS LiDAR / DIAL (open-path, imaging, path-integrated CH ₄ ; includes wavelength-modulation / differential absorption)	0.5–25	±1–±2% of reading (ALMA and Boreal); ±20–30% of flux for GML;	1–80 ppm·m	*Bridger, 90 % PoD at 0.78 kg/h- Pipelines, 0.005-3 kg/h	Bridger Photonics GML; Pergam ALMA Gen 5; Boreal GasFinder AB; ITT Exelis ANGEL LiDAR
Aircraft survey	Passive spectroscopy -Solar reflectance / imaging spectrometers (SWIR)	1–5	—		*5–25 kg/h 10–13.4 kg/h at 90% PoD	Kairos LeakSurveyor; GHGSat DATA.AIR (airborne); Carbon Mapper (AVIRIS-NG); MethaneAIR
	Passive spectroscopy - Thermal IR spectroscopy (LWIR)	1–3	—	—	*18 kg/h at 98% PoD	Telops/Exosens Hyper-Cam Airborne
	Passive spectroscopy - thermal IR imaging (video)	30 Hz video	—	—	*0.28 kg/h at 90% PoD	ChampionX Aerial OGI
	Cavity ring-down spectrometer (CRDS) - Airborne plume sampling	1	±1 ppb CH ₄	—	*5 kg/h	Scientific Aviation

		Speed/ mph	No of Passes	Detection Height/m	Distance from Pipeline ROW/m	Detection Threshold/ppm
Walking Survey	Upstream	3	-	-	-	-
	Midstream	-	-	0-1	0-7.6	0.5-10
	Downstream	2-10 (2-3)	1-4	0-1	0-20 (along pipeline)	2.05-10 (10% above BC -5)
Driving Survey	Upstream	5-25 (2-10)	2	0.5-2.5	as closer to pipe line	2.02 - 5 (10% above BC)
	Midstream	10-37 (10-25)	2-4	0.1-2.5	0-150 (as closer to pipeline)	-
	Downstream	3.8-56 (15-25)	2-12 (2-3)	0.1-2.5	0-150 (0-20)	2.01 - 5 (10% above BC)
UAV Survey	Upstream	6.7-35.8	1-2	2-150	0-91	5-200 ppm-m
	Midstream	55	-	0-40	0-91	-
	Downstream	3.1-55 (3.1-6)	3-9	3-100 (3-15)	0-100	5-100 ppm-m
Aircraft Survey*	Upstream	60-120	1	150-915	200-1000 (swath width)	-
	Midstream	30-115	1	80-206	7-300 (swath width)	-
	Downstream	-	-	-	-	-
Sattelite Survey*	Upstream	Daily overpass	-	700-820	-	8-20 T/h
	Midstream	-	-	-	-	-
	Downstream	1-2 day revisit	-	500-550 km	-	> 100 kg/h @ 50% POD

Challengers				
From research studies			From Interviews	
Leak characteristics	belowground parameters	Atmospheric variables	Utility companies	Solution providers
Impact of Gas Composition Detection of Small Leaks	Soil Heterogeneity Moisture Content Variability	Wind-driven dilution & directionality Atmospheric Stability	Surveying challenges during adverse weather conditions Access and community interaction issues	Difficulty detecting low-intensity or widely dispersed leaks against variable backgrounds Detecting underground pipeline leaks
Leak Depth Uncertainty	Soil Texture and Density Effects Gas Transport Mechanisms	Temperature & humidity calibration Barometric pumping	Limited expertise in below-surface leak testing Difficult terrain for midstream inspections	Highly variable environmental conditions Constraints on equipment size and power for mobile survey platforms
Leak pressure	Influence of Underground Structures	Precipitation & snow Solar Radiation and Cloud Cover Surface Cover and Topography Urban and Traffic Conditions Seasonal Effects	Unclear leak-identification thresholds Complex network layouts (branching, interconnected systems) Extensive linear networks with many potential leak points (require segmental testing) Vegetation or canopy obstructing aerial/overflight surveys	Unmapped or complex gathering systems Challenges in accurate leak-rate quantification Integration of mobile surveys and ensuring detectability

		Employed paramters/concerns			
		Walking	Driving	UAV	Aircrafts
Leak characteristics	Gas composition/ vol% CH ₄	87–95	76–97	76-95	92–97
	Leak rate/ kg/h	0.004–0.51	Small leaks: 0- 0.096 Moderate leaks 0.096–1.56 Large leaks: >1.56	0.0007 – 5	0.08 – 8,200
	leak depth/m bellowground	0.5-1.5	0.9-1.5	0.6-1	Above ground
	Leak pressure/kPa	Distribution 1.5–2000, transmission “generally >2–10 Mpa	Distribution 3.5–414, Gathering 30–7720	690-7720	-
belowground paramters	porosity and permeability and soil heterogeneity	Gravel, sand, loam, Porosity (Φ): 0.23–0.59, Permeability (k): 2.6×10^{-14} – 2×10^{-9} m ²	-	Sand, sandy loam, uniform farm soil, Porosity (Φ): 0.35- 0.45, Permeability (k): 3.05×10^{-14} – 2×10^{-9} m ²	-
	moisture content/ Water saturation %	0.08–0.65	0.08–0.65	0.08–0.65	-
	Soil texture	Coarse sands, poorly graded, Sandy loam, Fine sand–loamy fine sand	Sandy loam, urban soils/cobblestone/asphalt mixes	Sand, sandy loam, uniform farm soil,	-
	soil gas transport coefficients	Dp/Do calculated	-		
	Underground structures	Utilities, trenches, and pavement channel gas	Drains/manholes/service lines channel gas	-	-
Atmospheric vaiaables	wind speed / m/s and direction	0-10 overall (Optimal: <3), Downwind	0-10 overall (Optimal: <2-3)	0–15 m/s overall, (optimal 2–3) and operational thresholds <15 m/s	0.5–9.7 overall (Optimal <3), At <0.5 m/s: plume dispersion unreliable, some data discarded At >6–8 m/s: plume too dispersed, PoD significantly reduced
	atmospheric stability	PG A–G (suitable PG A)	PG A–G, PG-B common, stable nighttime recommended	Unstable/moderately unstable (Pasquill A–C) preffered	Unstable to neutral, Stable conditions limited
	temperature, relative humidity	15–30 °C, RH > 65%	5–36 °C	–25 °C and +45 °C. favorable thermal contrast preffered	-
	barometric pressure fluctuations/ mbar	Considered but not estimated	Considered, 1007–1027 mbar		-
	precipitation		Surveys excluded rainy/frozen conditions	flights avoided rain,	-
	solar radiation and cloud cover			shadow correction, Sunny clear-sky preffered	surface reflectance (Albedo- 0.08-0.45), Dark/low, reduced detectability. Bright/high- improved plume contrast.
	Surface cover and topography	unpaved, rural short grass, asphalt paved and hilly/forested ROWs	Paved urban streets, pastoral/railway ROW, remote forested/unpaved roads	Problems in landing, Flat farm plots/crops, asphalt, rural/vegetated, grassy site.	Desert, pavement, prairie grass, snow, production pads, dry gas basin, open ROW & valley flat Permian Basin
	urban and traffic conditions		Turbulence from trafic	regulatory constraint on flying over populated areas	-
	Seasonal effects	Seperatly for summer, spring and autumn except Rao 2025: spring & autumn	winter & spring and autumn	flights avoided snow	-

P3LD: Practical Protocols for Pipeline Leak Detection Experimental Plan (Sep 22 – Oct 3, 2025)

Final plan – 9/9/2025

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Experimental Plan

Objectives: (1) obtain baseline data set (2) assess the impact of moisture on POD (3) quantification

- **Soil Moisture & backfill configuration (Sep 23 – Oct 03, 2025)**
 - A soil moisture profile from the surface down to approx. 2.5 feet or to the depth of the leak point will be analyzed to thoroughly investigate the impact of moisture on leak detection performance
 - METEC features four testbeds that have two distinct backfill configurations. These initial experiments will serve as baseline studies for subsequent investigations.

The collected data will also be used for the following sub-objectives:

- Impact of number of passes
- Impact of diurnal conditions
- Impact of soil moisture on emission rates (Moisture Condition)
- Impact of detection threshold
- Leak quantification

Testing Plan: Safety

- Safety remains our team's top priority whether we are at our home testing site or out in the field
- General safety
 - Our team will be using the following safety measures on site:
 - Safety Glasses
 - High Viz vests
 - Steel toe
 - 4-gas monitors
 - FR clothing
 - All participants have operator required safety training and certifications (SafeLand) including PhD students in training
- Safety plans and protocols
 - We will adhere to all safety protocols as outlined by METEC staff
 - Additionally, we would like our team to be briefed of any hazards or concerns that we should be aware of BEFORE any experiments are done on the pipeline

Leak Detection Survey Methods

- Walking Survey
- Driving Survey
- Unmanned Aerial Vehicle (UAV) Survey:

Walking Survey



Driving Survey



UAV_{sim} Survey



Experimental Design

Operational conditions selected:

- **Survey Speed:**

- Walking: ~ 3 mph
- Driving and UAV: ~6 mph

- **Survey Height:**

- Walking: 0 m,
- Driving: 0.3, 1 and 3 m AGL
- UAV_{sim}: 8 m AGL or 7 m from truck bed

- **Survey Times:** Early Morning, Morning, Noon, Late Afternoon, Late Evening (if possible)

- For each survey time, driving and UAV surveys will be carried out for ~90 minutes to maximize the number of passes collected.

Detection Method	Infrared Polarization Spectroscopy	Mid-Infrared Laser Adsorption Spectroscopy	Mid-Infrared Laser Adsorption Spectroscopy
Make/Model	Heath DPIR+	Aeris Mira Strato LDS	Aeris Mira Strato LDS
Range	0-10,000 PPM	10 ppb – 10,000 PPM	10 ppb – 10,000 PPM
Sensitivity	1 PPM	<1ppb	<1ppb
Accuracy	1-2% of reading	± 10% of reading	± 10% of reading

Survey Procedure

For each experiment, surveys will be conducted up to three times daily—morning, noon, and late afternoon.

Number of Passes:

- Walking surveys: 6 passes
- Mobile surveys (driving and UAV): As many as possible

Gas Analyzers:

- One analyzer per survey method is recommended:
 - *DP-IR+* for walking surveys
 - *Aeris* for both driving and UAV surveys

Minimum Pass Length:

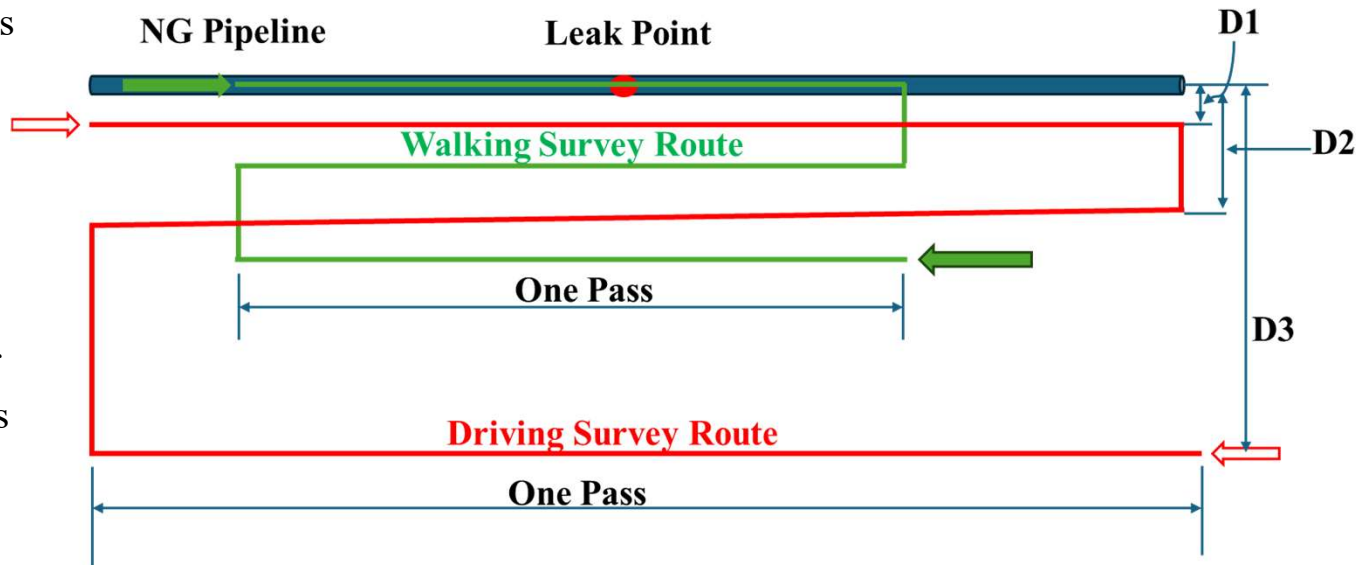
- Walking surveys: at least 50 meters
- Mobile surveys: at least 80 meters

Survey Guidelines:

- Multiple passes are required (
- Start and end times for each pass should be recorded manually
- Surveys must follow predefined, fixed routes
- Maintain a constant survey speed:
 - Walking: less than 3 mph
 - Mobile: less than 6 mph

One pass is defined as a complete measurement along the route from the survey starting point to the ending point

Plan view of
survey routes



Driving and UAV Survey Routes

- Driving and UAV surveys will be conducted at four distances from the leak source (as depicted in the figure).
- Walking surveys will be conducted at three distances from the leak source. Survey routes are not shown.



Soil Moisture Experiments

Experiments will be carried out as outlined below:

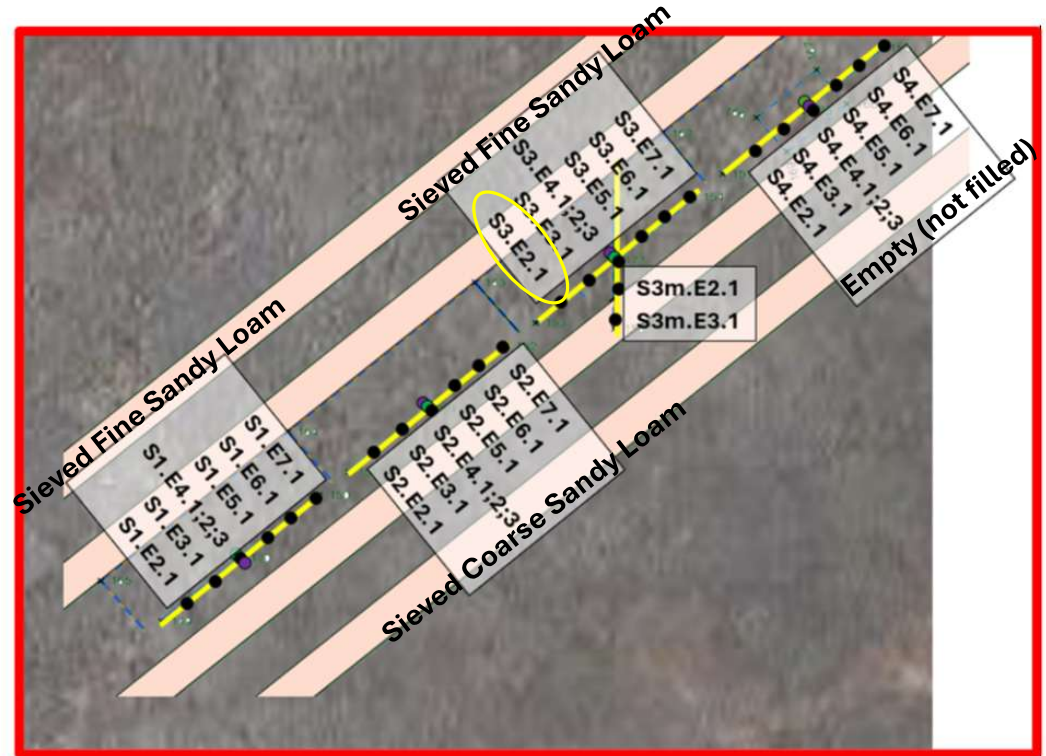
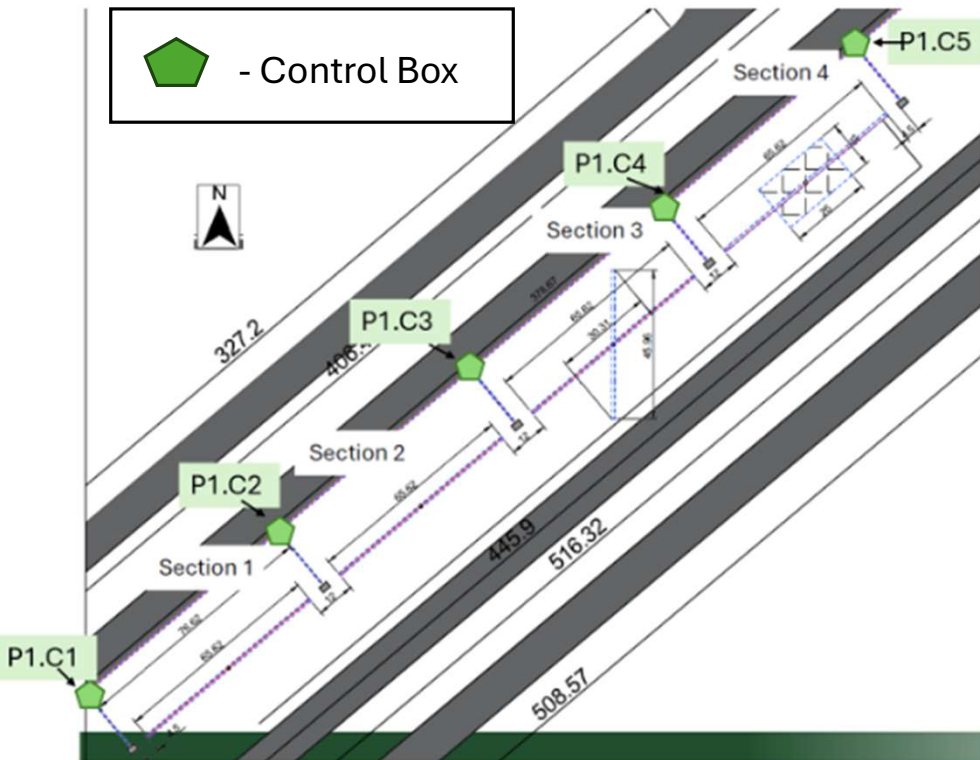
Week	Testbed	Leak Location	Leak Rate (slpm)	Gas Composition	Soil Condition
Sept 21	Section 3	S3.E2.1	5*	CNG	Wet to Dry
Sept 29	Section 3	S3.E2.1	5*	CNG	

***Note:** Gas should start to be released the Friday prior to the start of the experiment to allow it to reach a pseudo-steady state

SMU team has coordinated with Poudre Fire Authority for water support, starting on the morning of Sept 23 (Fire Authority schedule permitting)

Selected Leak Location - S3.E2.1 (soil type: sieved fine sandy loam)

Units in feet



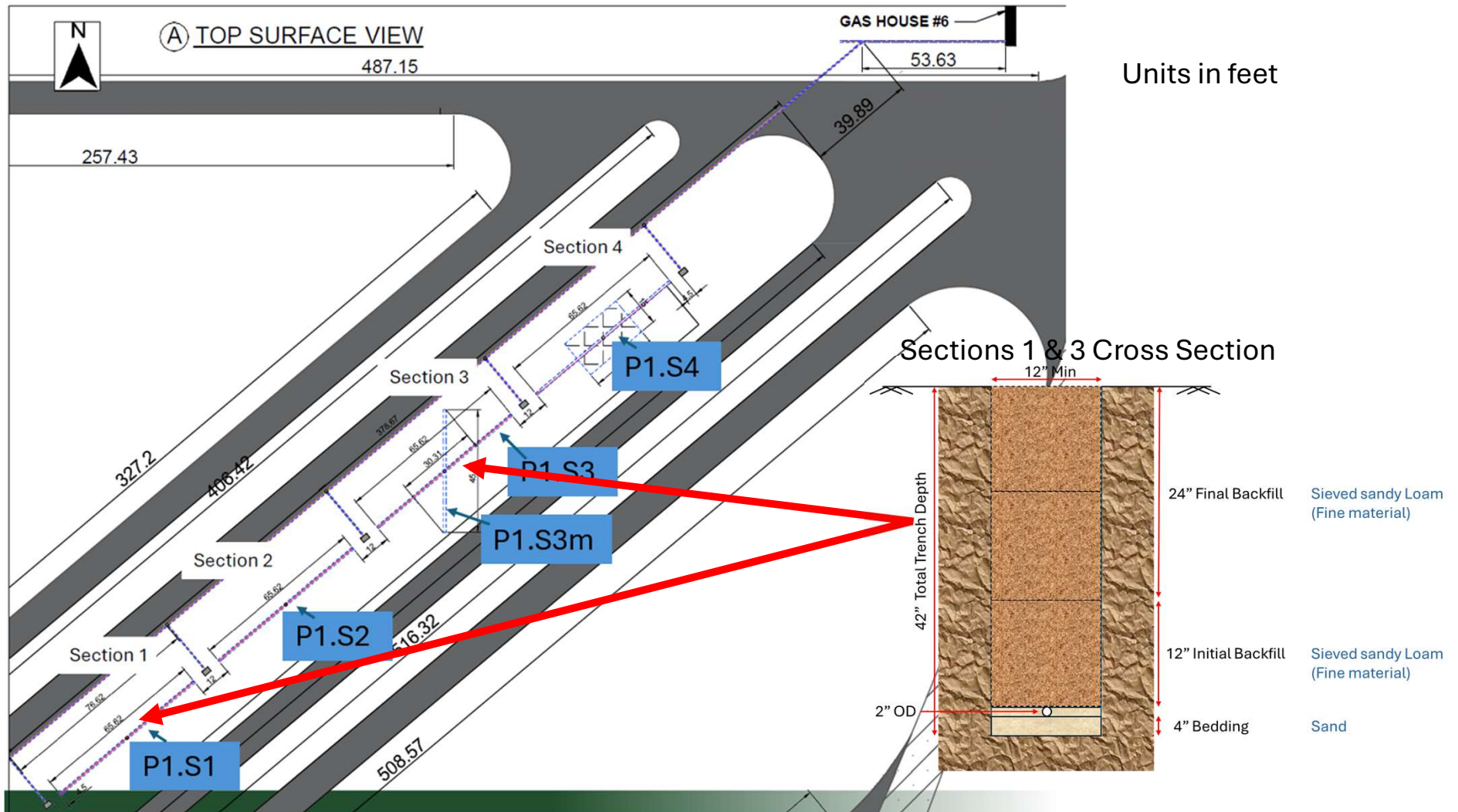
See page 3-4 and supporting photos in emission manual for more details

From CSU Pipeline Emission Manual

CSU previously tried out:

P1.S1.E4.1 — 0.5 SLPM

P1.S3.E6.1 — 2.5 SLPM



From CSU Pipeline Emission Manual

Data Collection During Experiments

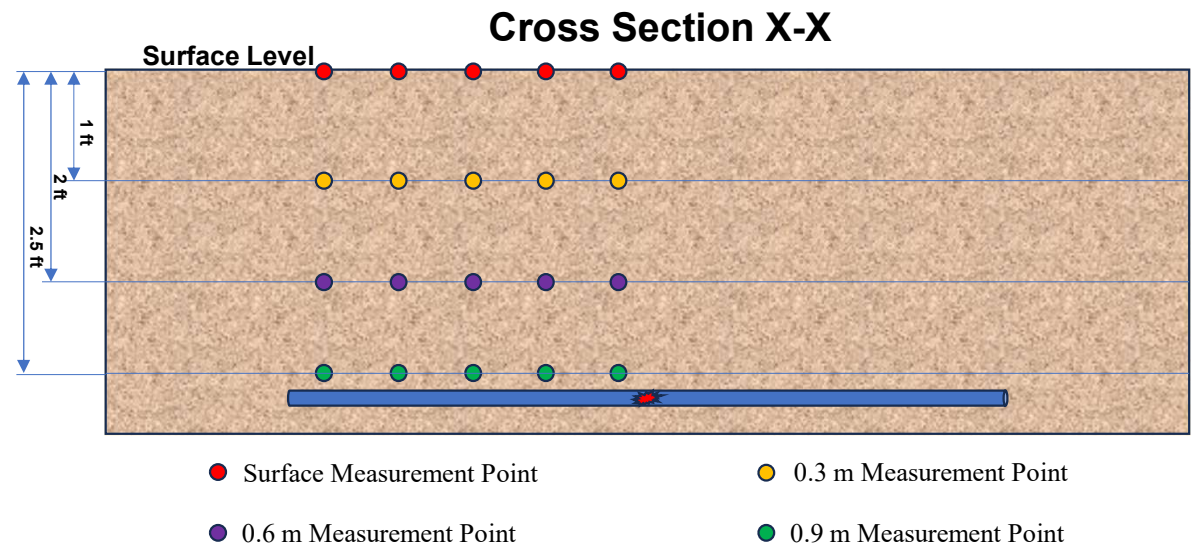
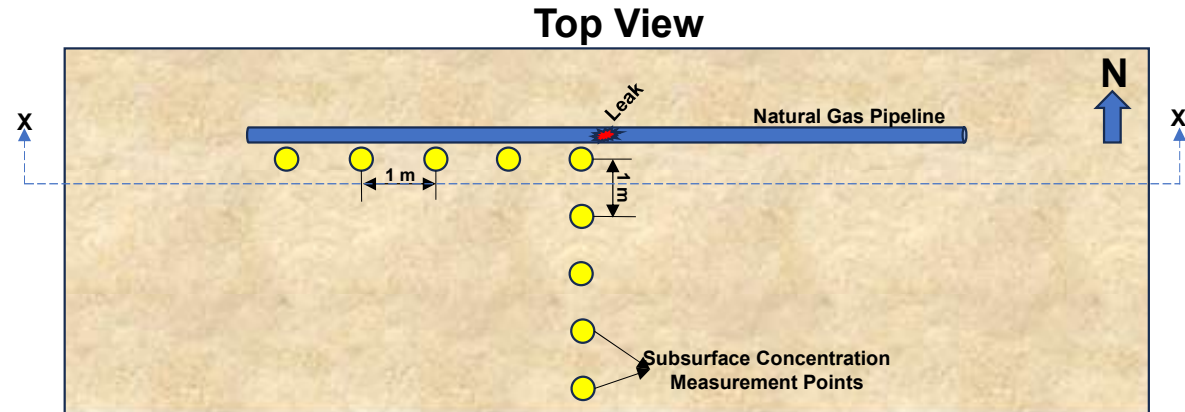
- **Methane Concentration Data**
 - **Sub-surface & surface:** Methane levels will be measured at four depths (surface and up to 2.5 ft from the surface) across approximately 12 locations – installed using the plunger bar (~ 1” diameter temporary hole)
 - **Surface:** Walking surveys & mapped surface concentration measurements (next slide) will collect methane data at the surface level
 - **Atmospheric:** CH₄ concentrations will also be recorded through driving and UAV-based surveys.
- **Meteorological Data:** Weather data will be obtained from the METEC weather station.
- **Geolocation Data:** High-precision RTK-GPS devices will be used to capture geolocation information during walking, driving, and UAV surveys.
- **Soil Moisture and Temperature Data:** 5-TM sensors will be installed at various depths (4 in, 1 ft, 2 ft, and possibly 3 ft) within the testbed



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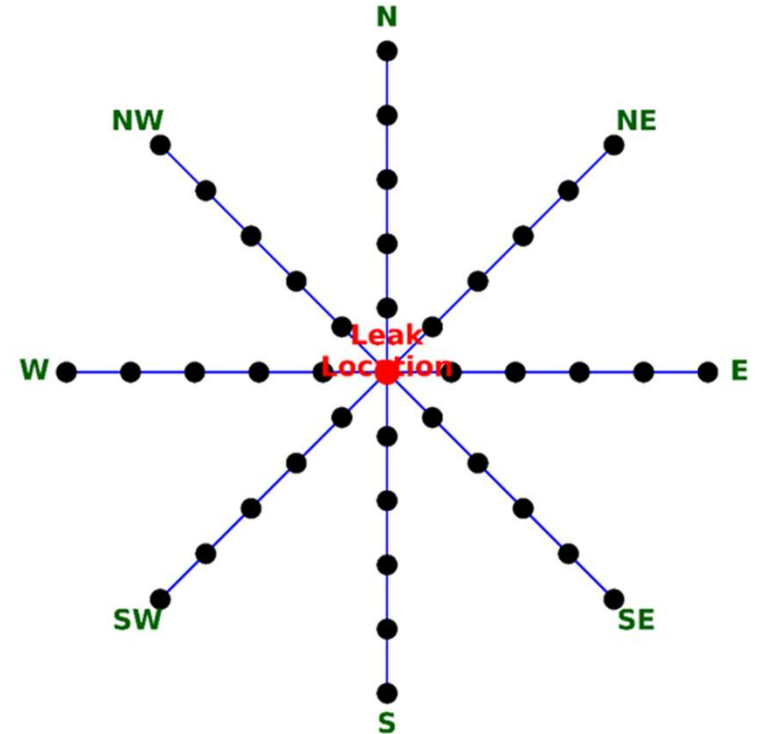
Surface and Sub-Surface Concentration Data

- Measurements will be taken (if possible) at:
 - The surface (0 ft), i.e., at ground level
 - 1 foot below ground
 - 2 feet below ground
 - ~2.8 feet below ground
- The DP-IR+ device will be used to conduct the measurements.
- Data will be collected in **two directions: along the trench and perpendicular (if possible)**.
- Measurements will be taken at **1-m intervals**, starting from the **leak location** and **extending up to 5 m (or further if needed for location of zero reading)**



Surface Concentration Measurements

- Surface concentration measurements will be taken radially from the leak point in all 8 directions
- The DP-IR+ device will be used to collect this data
- Measurements will be taken at **1-m intervals**, starting from the leak location and extending up to 5 m minimum or more if concentration readings are higher than 2ppm

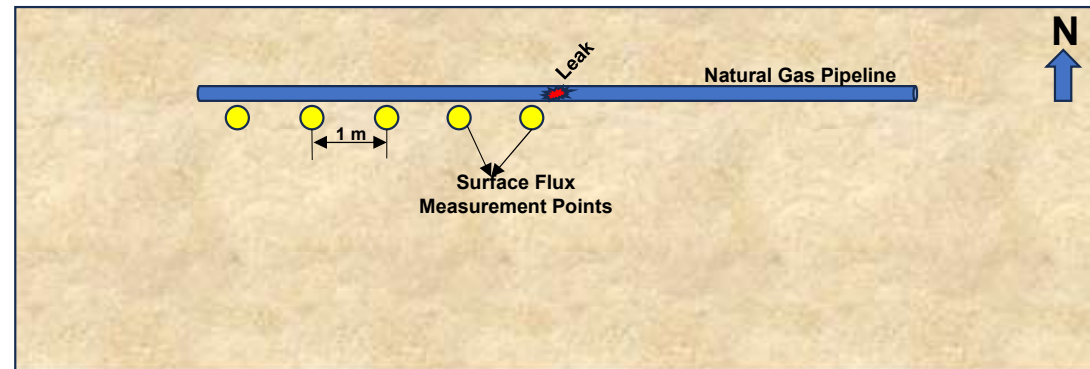


Surface Flux Measurements

- Surface flux measurements can help to:
 - Estimate the size and severity of a leak and
 - Map the spread of gas through the soil.
- Data will be collected using an Eosense flux chamber paired with an ABB–MGGa gas analyzer.
- Measurements will be taken at 1-meter intervals, starting from the leak location and extending up to 5 meters.
- At each point, data will be recorded continuously for at least 6 hours. (requires power)



Flux Chamber



Flux Chamber