Public Quarterly Report

Date of Report: 3rd Quarterly Report – June 30, 2025

Contract Number: 693JK32410005POTA

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Project Title: P4: Partnership to Advance Pipeline Leak Detection Methods

Prepared by: Colorado State University

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For quarterly period ending: June 30, 2025

1: Items Completed During this Quarterly Period:

Item	Task	Activity/Deliverable	Title	Federal	Cost
#	#			Cost	Share
3	2	Literature Review		\$ 34,447	
5	7	3 rd Quarterly Status Report		\$ 4,837	\$ 0
		Third Payable Milestone		\$ 39,284	\$ O

2: Items Not Completed During this Quarterly Period:

Item #	Task #	Activity/Deliverable	Title	Federal Cost	Cost Share
4	3.1	Test Program – Year 1		\$ 53,503	\$ 0
6	3.1	Test Program – Year 1		\$ 53,503	\$ 0

Due to approval and contractor scheduling delays in the underground testbed build at the CSU METEC facility, the start of Year 1 testing has been delayed, with estimated start date of July 7, 2025.



3: Project Financial Tracking During this Quarterly Period:

4: Project Technical Status -

METEC Underground Testbed – Preliminary Pipeline Progress

While reporting on developments on the buildout of the METEC underground pipeline testbed for which testing will be performed are not task driven and are not billable to this project, they are relevant and will motivate all future project progress. Furthermore, preliminary research of survey methods, fixed sensor designs, and pipeline standards necessary for the buildout are most immediately relevant to the literature review (Task 2) and to the creation of a flexible and effective test program (Task 3).

After delays in receiving construction approvals, the build-out of the underground testbed started on May 1



Figure 1 METEC of underground testbed Phase 1 construction complete.

and major digging and backfilling was completed by June 1 (see Fig. 1). Provided there are no unforeseen delays, the team expects the testbed to be operational by July 7.

Item 3. Task 2. Literature Review

This literature review integrates insights from peer-reviewed literature, project reports, grey sources (e.g., blogs, videos), company websites and brochures, and interviews with industry stakeholders. It focuses on current sensing technologies used for detecting belowground natural gas (NG) pipeline leaks, outlining their technical capabilities and operational constraints across different survey platforms. A summary table (*Table 1*) highlights the specifications and deployment parameters for each method.

	Gas Sensing Technology and Technical Specifications				Operational Parameters				
Platform	Sensing Technology	Sampling Rate Hz	Sensitivity – Based on instrument	Accuracy	Survey Speed mph	Number of passes	Height (AGL) m	Distance from ROW m	Detection Threshold ppm
Stationary / Continuous	MO Sensor, In Plume Laser, Tracer-correlation method, IR Imaging	0.2-2	1.8 - 338 scfh @ 90% PoD	-44% to +93% error	Stationary	N/A	Up: 0–7 Down: 0–0.05	Up: 0–150 Down: 0–4	2.1-2.2
Walking	Ranged Laser,IR Imaging, In Plume Laser, Etalons, Catalytic Combustion	1-10	5.6–19.5 scfh at 90% POD		All: 1-3	All: 1-4	Up: 0.05–2 Mid: 0.05–2 Down: 0.05	Up/Mid: along pipeline Mid: 0.05–2 Down: 0–15 m	Up/Mid: 2.2–10 Down: 2.2–500
Driving	Ranged Laser; IR Imaging, In Plume Point Sensor, In Plume Laser	Up/Mid: 1–4 Hz Down: 1–2 Hz	0.01 scfh @ 90% POD	Median loc. Error = 0.4 - 31 m	Up/Mid: 2–10 Down: 11–34	Up/Mid: 1–4 Down: 1–6	Up/Mid: 0.5–3 Down: 0.1–3	On-road ROW: < 15 m; downwind	Up/Mid: 2.2–10 Down: 2.2–500
UAV	Range lasers, In plume lasers	1-10 preprogrammed transects (rasters, funnels, vertical scans)	$> 0.02 \ \mathrm{scfh}$	±50%	All: 4–67	N/A	All: 2-30	All: 0-60 m	All: 2.1-3 or ~0− 100 ppm·m
Aircraft	Ranged Laser, IR Imaging, In Plume Laser	65–175 s/pass;	Based on instrument: 25 scfh with 90% PoD	8.1 % - 68 %	Up/Mid: 70- 115	Up/Mid: 100– 800 m swaths	100-12,960	Up/Mid: Swath widths: 100– 1800 m;	200-300 ppm background concentration
Satellite	IR Imaging, GHGSat WAF-P	Up: revisit 1–14 d Down: 1–2 d	Up: 0.1–4.2 t/h Down: down to 42 kg/h	Up: ± 0.3–8.8 t/h / Down: ± 50–66 %	$\begin{array}{c} 50 \ \mathrm{m} \times 50 \ \mathrm{m} \ \mathrm{to} \\ 7 \ \mathrm{km} \times 5 \ \mathrm{km} \\ \mathrm{pixels} \end{array}$	N/A	Up: 700–800 km Down: 500–550 km	N/A;	$\begin{array}{c} Down: \geq 100 \ kg \\ h^{-1} \end{array}$

Table 1 . Literature review summary table (see Attachment 1 for larger print version).

Leak detection success is closely tied to both environmental and operational factors. Key environmental variables include wind speed and direction, atmospheric stability, background methane (CH₄) concentrations, and soil or surface characteristics. Operational considerations such as sensor placement, sampling geometry, and survey speed also critically impact detection performance.

Each survey method presents unique advantages and limitations. Fixed sensors deliver real-time continuous data at a fixed location but are limited by wind conditions and require regular calibration. Walking surveys achieve high spatial resolution but are labor-intensive and lack the ability to track continuous flux. Driving surveys enable rapid coverage of larger areas but are susceptible to false positives, may overlook small or off-road leaks, and show uncertainties ranging from $\pm 20\%$ to 100%. Unmanned Aerial Vehicle (UAV) surveys provide low-altitude plume mapping with high flexibility, but short battery life (10–20 minutes), rotor-induced turbulence, and payload constraints result in detection uncertainties of $\pm 15\%$ to 100%. Aircraft surveys cover broad swaths (150 to 3,000 m) and produce detection curves but are constrained by high detection thresholds and dependence on controlled-release validation. Satellite platforms offer near-daily global coverage with pixel sizes between 25 m and 7 km, but their ability to detect emissions is limited to large sources due to coarse resolution, clear-sky requirements, and reliance on transport models.

Industry interviews revealed that real-world belowground leak detection faces additional hurdles. These include harsh environmental and terrain conditions (e.g., wet weather, permafrost, dense canopy, rugged landscapes), complex pipeline and gathering systems that hinder leak pathway identification, and subsurface gas migration patterns that deviate from standard atmospheric models. Operators also face difficulties in developing validated protocols for extreme conditions (e.g., snow, high heat, altitude, hydrogen blends), ensuring sufficient sensor resolution and positioning, and conducting surveys in remote or restricted-access areas.

Collectively, these challenges point to a pressing need for more resilient, field-tested approaches, improved sensor technologies, and versatile detection strategies capable of adapting to the complexities of real-world underground gas leak scenarios.

These findings were presented at the June 24, 2025, TAP meeting, which slides are included here as Attachment 2.

Task 3. Test Program

Planning for the first testing round has begun with July 7 as the targeted start date. We have one partner company scheduled to begin testing at the end of July, with two more companies working to confirm time in August and September. The team continues to refine the experimental testing plan and data collection.

Task 4. Showcase Event

Planning for the first Solution Developers Showcase scheduled on October 7 continues with 11 operators registered to attend and 7 solution developers registered to provide demonstrations. The team is working to confirm research presentations for the workshop on Tuesday morning at the CSU Energy Institute's Powerhouse Campus. Additional details will be shared with the TAP as they are confirmed.

5: Project Schedule -

Minor programmatic issues include delays in issuance of billing accounts for which time can be spent on the project. Future reports will evaluate the effect on project timeline. We expect cost share reporting to catch up as well in accordance with the corresponding testing being scheduled. We will continue to monitor the need to push out deliverable deadlines due to these delays.

Our intentions for Q4 will be to continue Task 3. Testing Program, Round 1, and continue preparations for the 1st Showcase.

6. Attachments

- 1. Literature Review Summary Table
- 2. June 24, 2025, Technical Advisory Panel Meeting slides.

	Gas Sensing Technology and Technical Specifications			Operational Parameters					
Platform	Sensing Technology	Sampling Rate Hz	Sensitivity – Based on instrument	Accuracy	Survey Speed mph	Number of passes	Height (AGL) m	Distance from ROW m	Detection Threshold ppm
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Walking	Ranged Laser,IR Imaging, In Plume Laser, Etalons, Catalytic Combustion	1-10	5.6–19.5 scfh at 90% POD	Median loc. error $\approx 1 \text{ m} (\approx 10 \text{ \%})$	All: 1-3	All: 1-4	Up: 0.05–2 Mid: 0.05–2 Down: 0.05	Up/Mid: along pipeline Mid: 0.05–2 Down: 0–15 m	Up/Mid: 2.2–10 Down: 2.2–500
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PHMSA – METEC Pipeline Projects

Practical Protocols for Pipeline Leak Detection (P3LD) Partnership to Advance Pipeline Leak Detection Methods (P4)

Technical Advisory Panel Meeting

CSU PI: Daniel Zimmerle Co-PI: Bryan Rainwater

June 24, 2025

SMU Co-PI: Kate Smits Post Doc: Venkata Rao

Non-conflict Statement

• As a reminder to our members, please refrain from sharing any competitively sensitive information with other members or with the researchers.





Antitrust Guidelines

- No discussion or sharing of any company's confidential or proprietary information;
- No discussion or agreements, either explicit or implicit, regarding prices of particular products or services provided by or received by a company;
- No forecasting of prices for goods or services;
- No discussion of any company's purchasing plans for particular products or services;
- No discussion of any company's specific merger/divestment plans, market allocation, production information, refinery runs, inventories and costs (only publicly available information should be discussed or shared);
- No agreement or discussion regarding the purchase or sale of a product or service—purchasing and selling decisions are independent company decisions;
- No sharing or discussion of specific company compliance costs, unless information is publicly available;
- No discussion of how individual companies intend to respond to potential economic scenarios or government action;
- No disparaging remarks regarding vendors, products, services.





Agenda

1) Pipeline buildout and project updates

2) Literature review/interviews with stakeholders
3) TAP feedback/discussion on P3LD 3-5 advance methods and conditions of interest

4) P4 Testing Round 1 and October Showcase Updates



Source: Department of Transportation's Pipeline and Hazardous Materials Safety Administration.





P3LD/P4 Future TAP Split

PHMSA mission: to protect people and the environment from the risks of hazardous materials transportation

P3LD: Practical Protocols for Pipeline Leak Detection



P4: Partnership for Practical Pipeline Protocols



COLORADO STATE UNIVERSITY



Study Team: Joint team from CSU & SMU

CSU Team:





Bryan

Co-PI

Dan Zimmerle **PI-**METEC Director



Ryan **Brouwer** Rainwater **METEC Site** Manager Research Scientist



Robert Beauchamp **METEC** Program Coord.



Wendy

Hartzell

Project

Manager



Zenner Graduate Student



Kate Smits Co-PI-Professor



Rao

Venkata Post Doc



Navodi Jayarathne Post Doc



Isuru **Bandara** Graduate Student



Joelle Uribe Graduate Student



Sergio Escudero Graduate Student



SMU Team:

NERGY NSTITUTE

1) Testbed build out, timelines





Methane Emissions Technology Evaluation Center (METEC) Pipeline Testbed Off-Site Move & Rebuild

Existing Testbed

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None-

New Underground Testbed

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P3LD/P4 on the METEC Testbed

- Controlled leak testbeds
 - Long-term testing independent of above ground METEC operation
 - Primarily cross-wind
 - ~100m, ~20 independently controllable leaks
- Expansions Planned (over next 2 years):
 - $_{\odot}$ Triple the Pipeline sections
 - Add variation (movable obstructions, pipe/soil properties, sensor systems, testing automation)







Fine Sieved Backfill

1/2 Coarse 1/2 Fine Backfill

Utility Cross / Fine Backfill

Pending Sand Testbed 25' x 15'



Constant (Reference) Leaks (Both Projects) Jul 7, '25 → Mar 1, '26

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2) Review Current & Emerging Pipeline LDAQ Methods





P³LD Objectives

Extend and formalize advanced leak detection methods for natural gas (NG) and H₂ blends by:

- Assessing current methods and formulating approaches to select the right method(s) *for the operating and environmental conditions*
- 2. Develop practical, field-deployable protocols for 3-5 advanced methods





Task 1: Review Current & Emerging Pipeline LDAQ Methods

Objective:

Review and document current and emerging LDAQ effort applicability to diverse pipeline conditions in distribution, gathering and transmission

Purpose:

Results used to assist with research and development efforts for $P^3LD \& P4$ projects



Tian et al., 2024



Approach

Literature Review

- PHMSA-sponsored projects reports (9)
- Peer reviewed papers and reports (60)
- Internal operation documents (12)
- Related videos
- Company websites and brochures
- Published specifications
- Blogs



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



Focus on next-generation methods which are in, or are likely to be in, active deployment by pipeline operators in distribution, gathering, and transmission

Operational Parameters Used in Pipeline LDAQ

Survey Type	Walking	Driving	Unmanned Aerial Vehicle (UAV)	Aircraft
Platform	Pedestrian	Truck	UAV	Helicopter/Fixed wing aircraft
Detection threshold (ppm)	5 - 10	5 - 10	0.05 enhancement	Not reported
Survey Speed (mph)	2 - 5	2 - 50	5 - 40	2 - 123
Passes Performed (#)	1 - 2	2 - 6	1 - 2	Not reported
Height of Measurement (ft)	0	1.64 - 10	3 - 147	15 - 3000
Distance downwind from centerline (ft)	0 - 65	0 - 32	0 - 150	Not reported
Wind Speed Limit (mph)	14 - 30	14	4 - 29	12 - 18
Number of Passes	1 – 4	Up/Mid: 1 – 4 Down: 1 – 6	NA	Not reported



Technical Specifications & Operational Parameters



	Gas Sensing Technology and Technical Specifications				Operational Parameters				
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Satellite	IR Imaging, GHGSat WAF-P	Up: revisit 1–14 d Down: 1–2 d	Up: 0.1–4.2 t/h Down: down to 42 kg/h	Up: ± 0.3–8.8 t/h / Down: ± 50–66 %	50 m × 50 m to 7 km × 5 km pixels	N/A	Up: 700–800 km Down: 500–550 km	N/A;	$\begin{array}{c} Down: \geq 100 \ kg \\ h^{-1} \end{array}$

Up: Upstream, Mid: Midstream, Down: Downstream

Environmental/Operational Considerations, Limitations by Method

Platform	Environmental considerations	Operational considerations	Limitations
Stationary / Continuous	 Wind speed/direction & stability Ambient T, RH (>5% and <95%) & pressure Solar/precipitation extremes Surface/soil properties 	 Sensor height/placement & inlet depth Gas density/composition & release rate Background CH₄ stability T/RH calibration 	Single-site/test-bed only, real-world variabilityRequires ideal wind & periodic recalibration
Walking	 Wind speed/direction & stability Surface/soil properties Terrain/vegetation type Seasonal biogenic CH₄ variability 	 ΔCH₄ threshold & spatial window (0–30 m) Sampling rate (≈1 Hz) & pace (2–3 mph) GPS precision (± 3 m) 	 Labor-intensive, snapshot surveys Few samples; terrain-specific No continuous flux quantification; limited atmospheric transport modeling
Driving	 Wind speed/direction & turbulence Road surface, traffic stops & urban noise Solar angle/temperature (optical sensors) 	 Vehicle speed & # of passes (2–8) Threshold choice Inlet height 	 Often limited to controlled-release conditions False-positives 0–70 %; Small/off-road leaks under-detected Quant. ± 20–100 %; traffic constraints
UAV	 Wind speed/direction (1–5 m/s) & turbulence Atmospheric stability class (3F–5D) Solar/precip; no rain/clouds Rotor wash & surface reflectivity 	 Flight pattern & altitude (2–25 m) GPS error & sensor pre-heat Optical path length (mini-RMLD vs. open-path) Background CH₄ concentration 	 Short endurance (10–20 min); payload limits Underestimates small leaks High quant. uncertainty (± 15–100 %)
Aircraft	 Wind speed/direction & boundary-layer dynamics Atmospheric stability & turbulence Temperature, humidity, cloud/solar angle Platform motion & noise 	 Altitude & swath geometry (150–3 000 m) Wind-dependent sensitivity breakpoint (~3 m/s) Scan speed/pattern 	 High MDLs; misses small leaks Quant. uncertainty 30–68 % Limited to test-bed releases; temporal mismatches with real plumes
Satellite	 Cloud cover, surface albedo & aerosols Solar angle & viewing geometry Wind-field & plume transport modeling 	 Pixel size & overpass geometry (25 m–7 km) Revisit frequency (daily–multi-day) Background algorithm thresholds 	 Snapshot only, no intra-day data Very high MDLs; coarse resolution Strong dependence on clear-sky & transport- model accuracy

SMU

INSTITUTE Colorado State University

Key Challenges and Interests



- 1. Impact of diverse operating conditions on leak detection success
- 2. Subsurface migration
- 3. Leak quantification with minimal data
- 4. State of the art (new and existing technology)





Validate and refine technologies for leak detection

and quantification for belowground leak scenarios



Key TAP interests that expand off of previous APPLIED project

Diverse Conditions

- Snow, permafrost, rain, vegetation, urban canyon effects, terrain
- Pavement
- Gas blends (Hydrogen), gas composition
- Diurnal patterns and how to incorporate into (1) detection success and (2) quantification
- Quantification for belowground leaks using existing tools (minimal 'extra' data collection)
- Impact of **multiple passes**
- **Defining sensitivity** e.g. "90% detection success of a 5-10 kg/hr leak" (~260- 530 scfhr)



Literature availability based on survey method: *almost none for belowground pipelines*



Aircraft

Colorado State Universi

literature sources available on pipelines for upstream, 8 midstream and 28 downstream.

Next Steps for Review (P3/P4)

- 1. Finalize Leak Detection report (will be made available to the TAP)
- 2. Focus on <u>quantification</u> methods for <u>belowground natural gas pipeline leaks</u>
- 3. <u>Pipeline Condition</u> review to summarize the current pipeline portfolio, ROW conditions, and deployment challenges
- 4. Use findings to inform experimental design for P3 Protocols Project (next slide)





Experimental Design For Controlled Experiments

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Approach



Photo: Protocol Implementation in the Permian Basin during APPLIED project (V. Rao)

Plan view of

survey routes

- Controlled experiments at METEC pipeline testbed facility
- 2, 9- month cycles over project with experimental 'windows' within each cycle
- Select one constant leak rate for extended period (0.5 slpm), leaks at 1-3 locations
- Execute LDAQ experimental testing protocol
 - Walking, driving, UAV or UAV_{sim}
 - For each cycle and experimental 'window'
 - Morning, noon, night





Controlled Experiments Data Collection





- Methane Concentration Data -Walking, Driving, UAV surveys
- Meteorological Data on site weather station
- Geolocation Data High-precision RTK-GPS for each method
- Subsurface Methane Concentration
 Data (limited locations) using bar
 holes & DPIR
- Surface Methane Concentration
 Data gridded pattern using DPIR
- Soil Moisture and Soil Temperature
 Data temporarily installed environmental sensors

P3LD Experimental Plan

Objectives: Assessing the Influence of Diverse Operating Conditions on Leak Detection Effectiveness

Soil Moisture and Type Experiments (Dry Conditions)

Day	No. of Testbeds	Leak Rate (SLPM)
Day 1	3 Testbeds	0.5
Day 2	3 Testbeds	0.5
Day 3	3 Testbeds	0.5
Day 4	3 Testbeds	0.5
Day 5	3 Testbeds	0.5

Soil Moisture and Type Experiments (Wet Conditions)

Day	No. of Testbeds	Leak Rate (SLPM)
Day 1	3 Testbeds	0.5
Day 2	3 Testbeds	0.5
Day 3	3 Testbeds	0.5
Day 4	3 Testbeds	0.5
Day 5	3 Testbeds	0.5

Surface Condition Experiments				
Day	Leak Rate (SLPM)	Surface Conditions		
Day 1	0.5	Snow		
Day 2	0.5	Snow		
Day 3	0.5	Snow		
Day 4	0.5	Pavement		
Day 5	0.5	Pavement		

These experiments are designed to evaluate how the following factors influence leak detection success:

- Snow cover, vegetation, and paved surfaces
- Soil Moisture levels
- Soil Type (METEC features four testbeds)
- Diurnal (day-night) fluctuations
- Multiple passes

Note: The study team will conduct one week of experiments at the same leak rate across multiple testbeds to collect data under diverse operational conditions. Diurnal measurements will be conducted depending on weather conditions.

Parallel Leak Quantification Data Collection to Test and Refine Methods

Data Collection:

- Concentration data will be collected at surface and downwind wind locations
- Meteorological data

Methods: Multiple approaches will be used to quantify the leaks, for example:

- Dimensionless Number Approach (DINA), Cho et al (2020)
- EPA Other Test Method 33A (OTM 33A)
- Hole-in-pipe Methods:
 - Ebrahimi-Moghadam et al, 2018
 - Liu et al, 2021



Example schematic representation of surface measurements

Phase II: Comparing leak estimates on upstream pipeline leaks

Initial Results from Texas Field Work

Estimation Method	CH₄ Leak Rate (SCFH)	Total Gas Leak Rate (SCFH)
Hole in pipe (full break) ^a Liu et al, 2021	12,300	15,900
Hole in pipe (5 mm) ^b Liu et al, 2021	960	1,247
Hole in pipe (5 mm) ^b Ebrahimi-Moghadam et al, 2018	570	740
DINA (dry) ^c Cho et al (2020)	6	7.8
DINA (wet) ^c Cho et al (2020)	1.5	1.95
OTM-33a	2,400	3,117

a) Full break determines upper (i.e., maximum) limit for leak size

b) Assumed a 5mm orifice size for hole in the pipe based on provided photos from pipe repair

c) Varied soil moisture from dry (25%) to wet (54%)

Uribe, et al., 2025 (in preparation)



3) P4 Testing Round 1 and Showcase update





Anticipated schedule

- Need a commitment on participation in ~3 weeks (July 1)
- Site operational (July 7)
 - Long-term emissions and data collection begins
- METEC staff and project team works with Solution Developers in '1st deployment window'
 - Onsite safety briefing required
 - Pre-testing intake on deployment protocols
 - Testing conducted
 - Post-testing review on site use and deployment protocols
- Repeat every 3 months with next cohort of solution developers



1st Solution Showcase Preliminary Design & Timing

- When: Tuesday, October 7, 2025
- Hours: 8:00 am 4:30 pm
- Where: Energy Institute & METEC, Colorado State University, Fort Collins CO
 - The Showcase is a CH4 Connection Conference Pre-Conference Event

Summary Agenda:

Morning – Panel Discussions and Presentations; opportunities to network

- Panel Discussion: Advance leak detection survey methods
- Presentation: Latest research on environmental conditions
- Panel Discussion: Pipeline Leak Quantification Successes, Challenges, Opportunities
- Afternoon Demonstrations of solutions at METEC on underground pipelines
 - Solution developers display, describe, and demo solutions. Active leaks on pipelines are will be available for real-time demonstrations





Thank You



COLORADO STATE UNIVERSITY

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Contact

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