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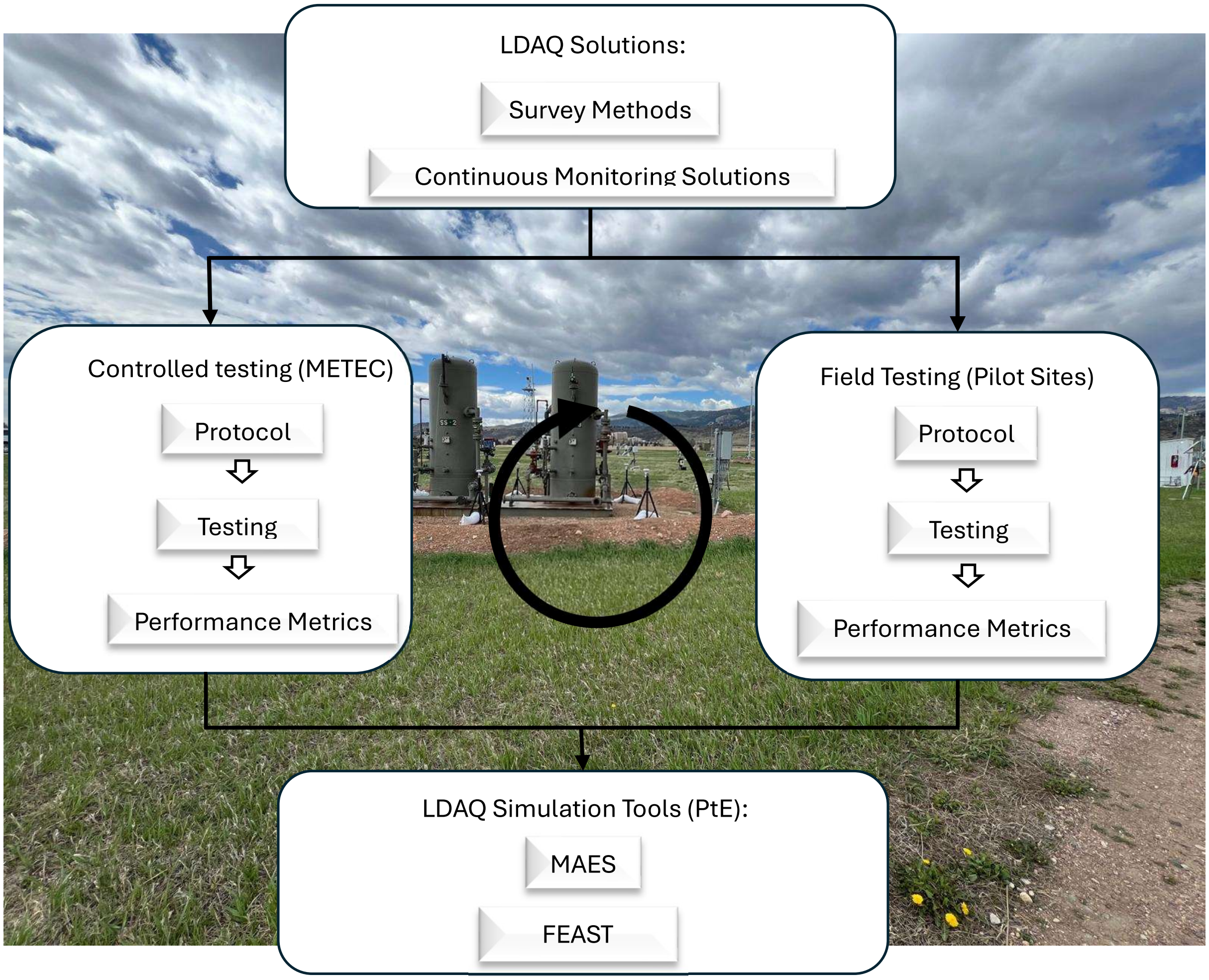
Project: Advancing Development of Emission Detection 2.0 (ADED 2.0)



1. Project Overview

Natural Gas (NG) contains between 70 to 90% of methane (CH_4); CH_4 is one of the major greenhouse gases (GHG) alongside CO_2. Although it has a shorter lifespan (approximately 12 years) in the atmosphere than CO_2 (hundreds of years), it has a greater global warming potential (GWP: between 28 to 30 over 100 years) than CO_2 [1], [2]. Methane emissions from US oil and gas (O & G) operations are more than 6 million tons annually [3]. Federal and state regulations require O & G operators to conduct regular Leak Detection and Repair (LDAR) to mitigate emissions from the industry. Methods in the LDAR program can be expensive to scale up over many facilities. Continuous Monitoring (CM) solutions may be an alternative and cheaper approach to traditional methods. However, to be used in place of traditional methods, it should demonstrate equivalence before approval. In collaboration with regulators, environmental agencies, and more than 70 O & G operators, the ADED project has developed controlled testing protocols to assess the performance of survey and CM solutions [4], [5]. The objectives of the ADED project include: 1. Developing, testing, and improving testing protocols at a controlled facility; 2. Implement protocols at field trials, and 3. Ensure that solution testing is rigorous, affordable, repeatable, and adaptable to conditions in the field.

2. Research Progress

My work has been focused on implementing controlled testing protocols to assess the performance metrics for CM solutions. The first protocol was developed in 2020 and has been implemented thrice since 2022 for CM solutions. The protocol tested 11, 10, and 13 CM solutions in 2022, 2023, and 2024, respectively [6], [7], [8]. My research has recently focused on the third implementation, where I assessed the performance of 10-point sensor networks (PSNs) and three scanning/imaging solutions. Out of the 13 solutions, four were retested relative to Ilonze et al., [7] and 3 retested relative to Bell et al., [6]. Retesting of solutions enables year-to-year inter-solution comparison. Continuous testing also enables intra-solution comparison.

Testing was single-blind and involved testing a CM solution comprising a CH_4 or a NG sensor, the deployment mode, and the analytics involved in interpreting emissions data. Single-blind testing means that the test center is aware (but the solution provider is not) of emission information such as the gas release rate, the release's location, and the release's duration. Testing was conducted 24 hrs a day and up to 7 days a week to capture a wide range of weather conditions. The release rates ranged from 0.08 to 6.75 kg CH_4 hr^{-1}. Some metrics assessed include the probability of detection (POD), localization accuracy and precision, quantification accuracy, detection time, and operation downtime.

Results of the four retested solutions relative to Ilonze et al., [7] are shown below with anonymized IDs used to identify each of the solutions. A preprint of the third implementation can be found in Cheptonui et al., [8]. For the POD curves, since the results of a multivariate logistic regression model showed that the emission rate has a statistically significant impact on the probability of 12 solutions detecting emissions, I present the POD as a function of the emission rate. Results of the effects of other tested variables can be found in the SI of the paper [8].

2.1. *Results*

2.1.1. Probability of Detection, False Positive, and False Negative rates

Generally, results show that 6 out of the 13 solutions had DL90s within the range of tested release rates. The DL90 is the emission rate at which a solution detected emissions 90% of the time. All the 13 solutions had FP rates less than 50%, and FN rates ranging from 8 to 93%. All scanning/imaging solutions had the highest FN rates, greater than 80%. All six solutions balanced method sensitivity and low FP and FN rates, as in Ilonze et al., [7]. The remaining seven solutions had DL90s outside the tested release rates range and high FP and FN rates (Figure 1).

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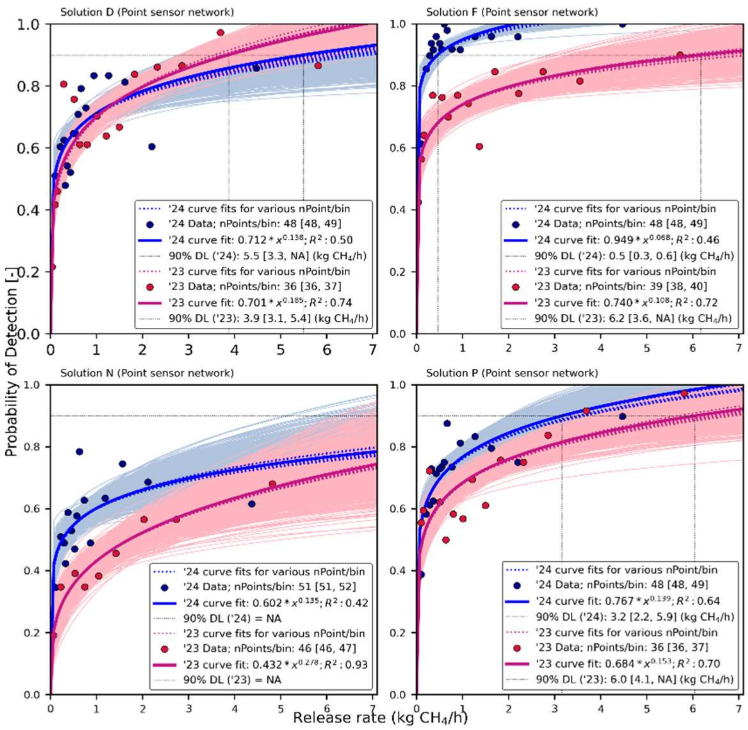

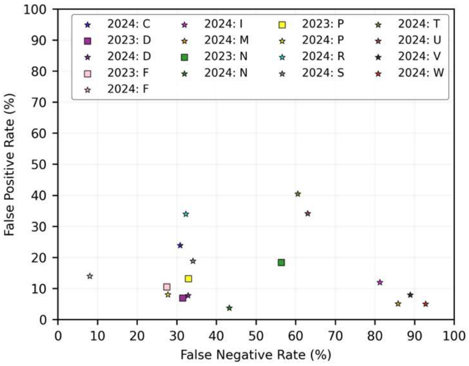

Figure 1. The left panel (with four plots) illustrates the POD curves for the four retested solutions relative to Ilonze et al. In contrast, the right panel illustrates the FP against FN rates for all the tested solutions in 2024 and the corresponding rates for retested solutions. Solutions whose DL90 could not be estimated are labeled as NA.

2.1.2. Localization precision and accuracy

The localization precision is identified for each TP detection at the equipment unit level. In contrast, the localization accuracy is calculated for the equipment unit level as the number of TP detections divided by the reported number of detections. Results show that scanning/imaging solutions have higher localization precision (> 50%: Figure 2) and accuracies (> 40%) compared to PSNs. This means scanning/imaging solutions better pinpoint the emissions source than PSNs. For the PSNs, four out of 10 solutions had ≥ 50% localization precision and > 40% localization accuracy.

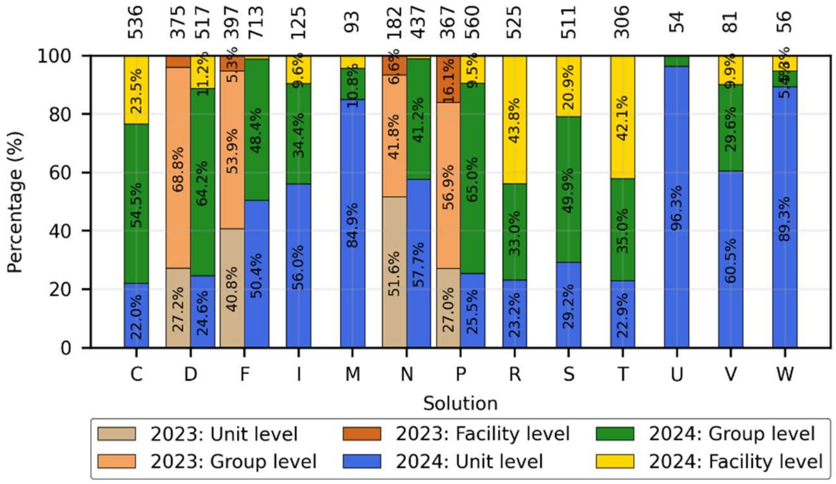

Figure 2. Localization precision to the equipment unit, group, and facility levels for the 13 tested solutions. The figure also shows the localization precision for the *four* retested solutions relative to Ilonze et al.

2.1.3. Quantification accuracy

Solutions optionally reported the source emission rate; 11 reported the emission rate in Cheptonui et al. Therefore, the quantification accuracy was assessed for these solutions. Results in Figure 3 show the percentage of single estimates within a factor of 3 for the three retested solutions (1 out of the four retested solutions did not report the emission rate in Cheptonui et al.). Generally, 31 to 92% of single estimates for 3 of the 11 solutions were within a factor of 3. Eight of the 11 solutions had over 50% of single estimates within a factor of 3 (Figure 3).

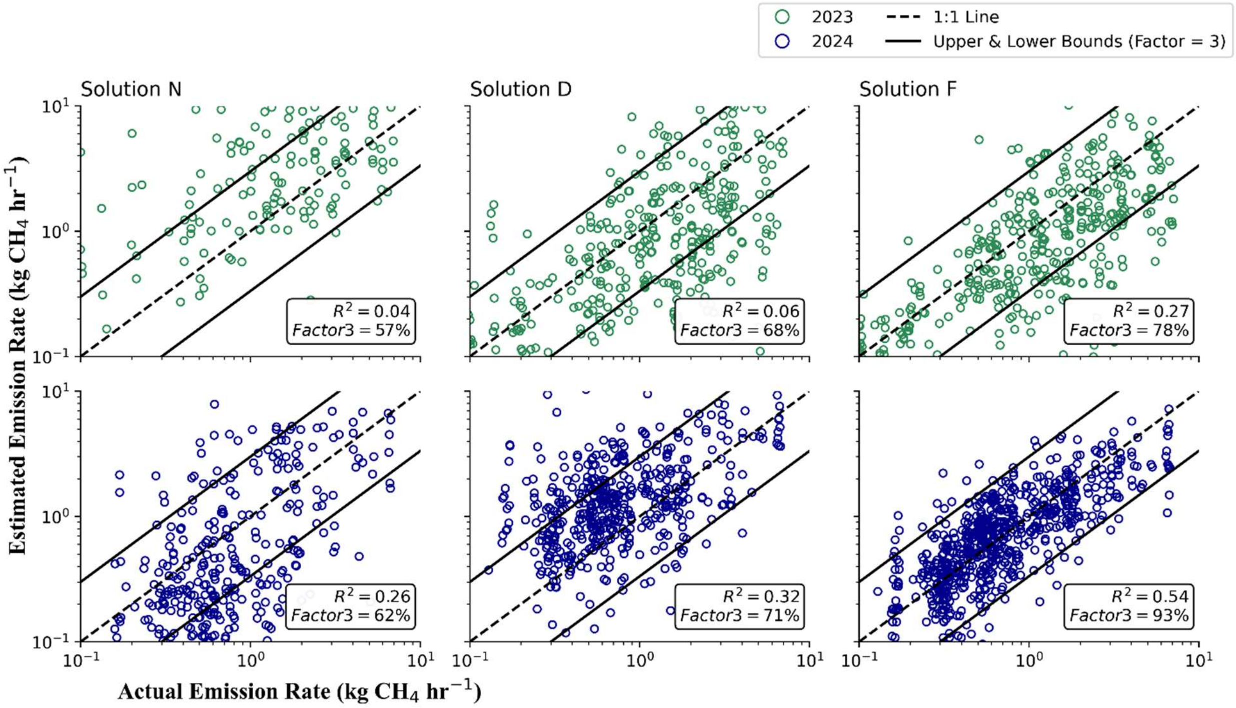

Figure 3. Reported versus the actual emission rate for the three retested solutions, the green points illustrate the data from Ilonze et al. In contrast, the blue points illustrate the data from Cheptonui et al.

2.1.4. Operation downtime and Detection time

The operation downtime for 12 of the 13 solutions was ≤ 6.4%. Although the US EPA stipulates a maximum operation downtime of <10% on a 12-month rolling average for CM solutions, results show that CM solutions can operate for more than 3 months without malfunctioning. As for the detection time, the mean detection time for all the solutions ranged from 5.1 hrs to 5 days (Figure 4). The wide variation in the mean detection time is attributed to the manual evaluation of the detection reports before submission and the failure of the automated reporting system.

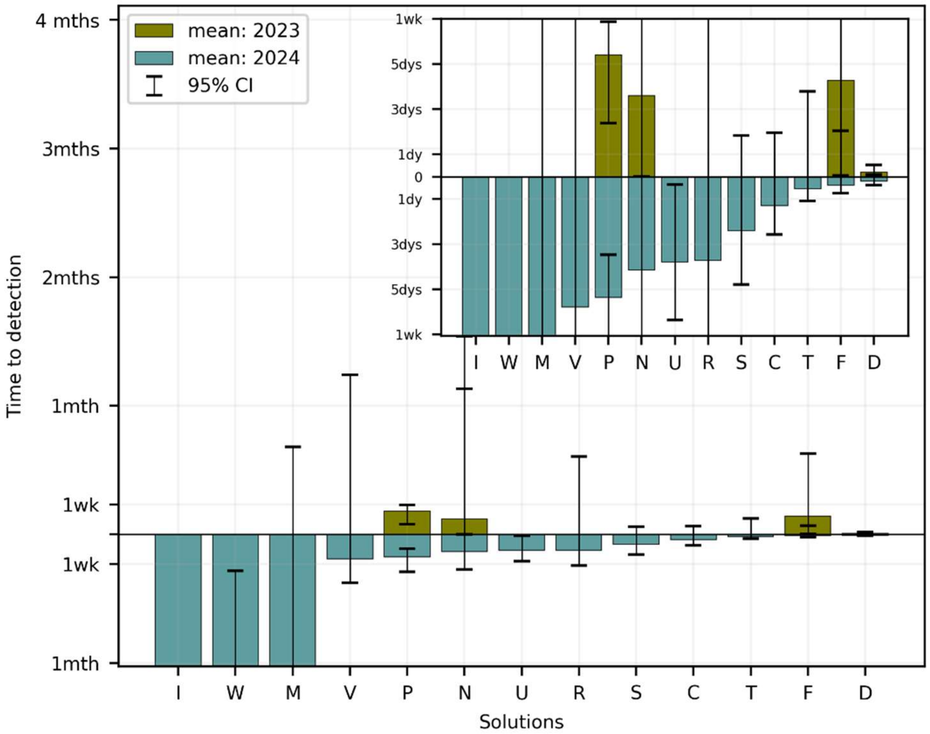

Figure 4. The mean detection time for the 13 solutions tested in Cheptonui et al. and the four retested solutions tested relative to Ilonze et al.

2.2. *Revised controlled testing protocol*

Results of the subsequent protocol implementation highlight the importance of continuously and rigorously testing the solutions to understand better how the solutions could perform in the field. Since different solutions perform well based on various metrics, they could be tailored to desired functionalities or applicability. Finally, the field testing of solutions was done in a study by Day et al., [9] show that there is a need for future testing to include baseline emissions during controlled release testing. This would better inform on EPA's detection threshold of 0.4 kg CH_4 hr^{-1} (of a facility's fugitive emission) above baseline emissions for CM solutions. Since the three implementations of the protocol did not account for baseline emissions, the controlled testing protocol was updated to include both fugitive and baseline emissions during testing (Figure 5).

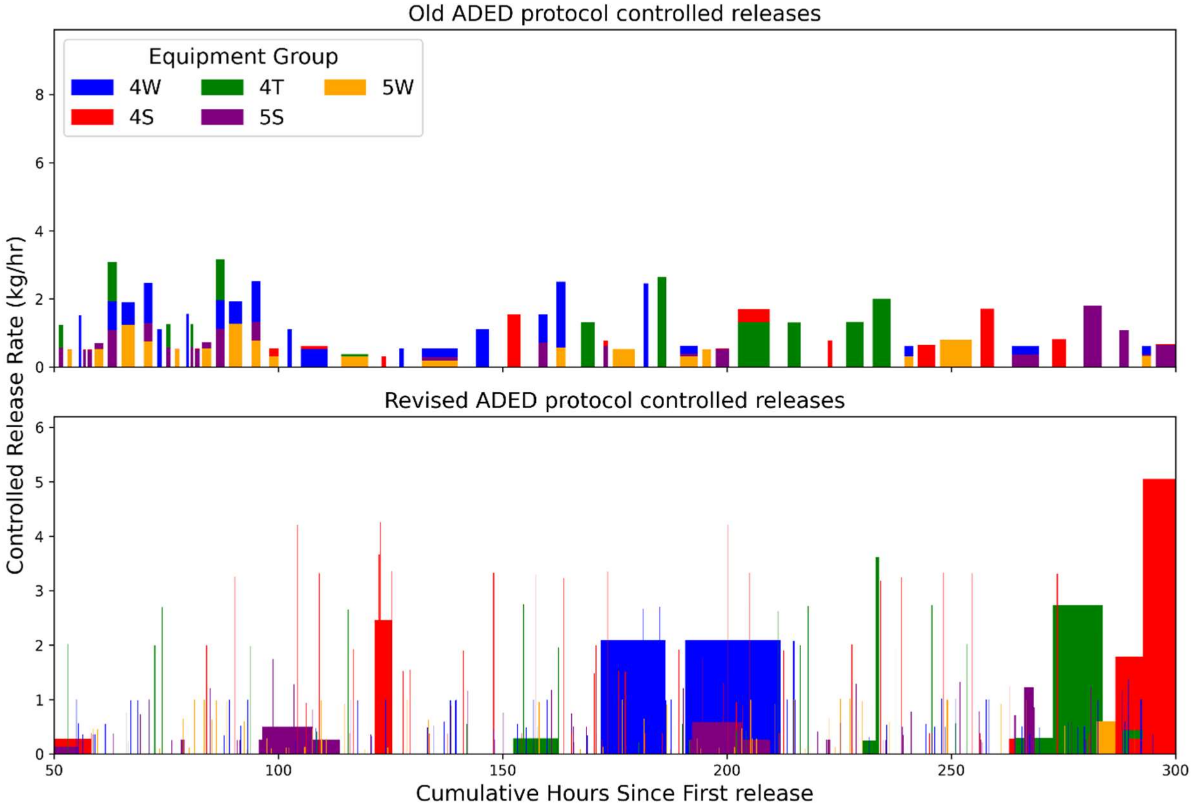

Figure 5. The top plot shows a sample of controlled releases from the old controlled testing protocol, while the bottom plot shows a sample of controlled releases from the second/revised protocol.

Additionally, the controlled testing of the revised protocol will include a wide range of emission rates. Some of the revisions to the protocol include: 1. Establishing baseline emissions before testing, 2. Overlaying fugitive emissions on top of baseline emissions (Figure 5), 3. Overlapping emission sources within the same duration, 4. There could be a break or not between controlled releases, and 5. Emissions may or may not be steady during testing. Performance metrics, including the probability of detection (Figure 1) and quantification accuracy (Figure 3), will be assessed in the revised protocol.

3. Research plans

- Compile the preliminary performance metrics results for CM solutions tested using the revised protocol.
- Design experiments for the first implementation of the revised protocol
- Design experiments for testing laser-based survey solutions as an alternative work practice

4. Publications

- **Cheptonui, Fancy.** "Using Above-Ground Downwind Methane and Meteorological Measurements to Estimate the Below-Ground Leak Rate of a Natural Gas Pipeline." Master's thesis, Colorado State University, 2023.
- **Cheptonui, Fancy,** Stuart N. Riddick, Anna L. Hodshire, Mercy Mbua, Kathleen M. Smits, and Daniel J. Zimmerle. "Estimating the Below-Ground Leak Rate of a Natural Gas Pipeline Using Above-Ground Downwind Measurements: The ESCAPE− 1 Model." *Sensors* 23, no. 20 (2023): 8417.

- **Cheptonui, Fancy,** Ethan Emerson, Chiemezie Ilonze, Rachel Day, Ezra Levin, Daniel Fleischmann, Ryan Brouwer, and Daniel Zimmerle. "Assessing the Performance of Emerging and Existing Continuous Monitoring Solutions under a Single-blind Controlled Testing Protocol." (2024).
- Riddick, Stuart N., **Fancy Cheptonui**, Kexin Yuan, Mercy Mbua, Rachel Day, Timothy L. Vaughn, Aidan Duggan, Kristine E. Bennett, and Daniel J. Zimmerle. "Estimating regional methane emission factors from energy and agricultural sector sources using a portable measurement system: Case study of the Denver–Julesburg Basin." *Sensors* 22, no. 19 (2022): 7410.
- Riddick, Stuart N., Ancona Riley, **Cheptonui Fancy,** Clay S. Bell, Aidan Duggan, Kristine E. Bennett, and Daniel J. Zimmerle. "A cautionary report of calculating methane emissions using low-cost fence-line sensors." *Elementa* 10, no. 1 (2022).
- Riddick, Stuart N., Mercy Mbua, Arthur Santos, Ethan W. Emerson, **Fancy Cheptonui,** Cade Houlihan, Anna L. Hodshire, Abhinav Anand, Wendy Hartzell, and Daniel J. Zimmerle. "Methane emissions from abandoned oil and gas wells in Colorado." *Science of The Total Environment* 922 (2024): 170990.
- Jayarathne, Navodi JRR, Kathleen M. Smits, Stuart N. Riddick, Daniel J. Zimmerle, Younki Cho, Michelle Schwartz, **Fancy Cheptonui,** Kevan Cameron, and Peter Ronney. "Understanding mid-to large underground leaks from buried pipelines as affected by soil and atmospheric conditions–Field scale experimental study." In *Proceedings from the pipeline research council international (PRCI) REX2022 Meeting. Orlando, FL. doi: https://doi. org/10.18738*, vol. 8. 2022.
- Riddick, Stuart N., John C. Riddick, Elijah Kiplimo, Bryan Rainwater, Mercy Mbua, **Fancy Cheptonui,** Kate Laughery, Ezra Levin, and Daniel J. Zimmerle. "Design, Build and Testing of a Portable Methane Measurement Platform." (2025).

5. Literature Cited

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[6] C. Bell, C. Ilonze, A. Duggan, and D. Zimmerle, “Performance of Continuous Emission Monitoring Solutions under a Single-Blind Controlled Testing Protocol,” Environ. Sci. Technol., vol. 57, no. 14, pp. 5794–5805, Apr. 2023, doi: 10.1021/acs.est.2c09235.

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[8] F. Cheptonui et al., “Assessing the Performance of Emerging and Existing Continuous Monitoring Solutions under a Single-blind Controlled Testing Protocol,” Nov. 22, 2024. doi: 10.26434/chemrxiv-2024-f1znb.

[9] R. E. Day, E. Emerson, C. Bell, and D. Zimmerle, “Point Sensor Networks Struggle to Detect and Quantify Short Controlled Releases at Oil and Gas Sites,” Sensors, vol. 24, no. 8, p. 2419, Apr. 2024, doi: 10.3390/s24082419.