From Colorado, For Colorado:

The Homegrown Tech Ready to Tackle Landfill Methane

July 31, 2025

What to Expect Today

Why Methane and Why Now

Colorado's Opportunity for Landfill Methane Leadership

Meet the Home-Grown Tech Changing the Game

- ChampionX
- LongPath Technologies
- Grand Valley Instrumentation
- TrelliSense
- Project Canary

Q&A

What Comes Next

Introductory Remarks

COLORADO SCHOOL OF MINES | The Payne Institute for Public Policy

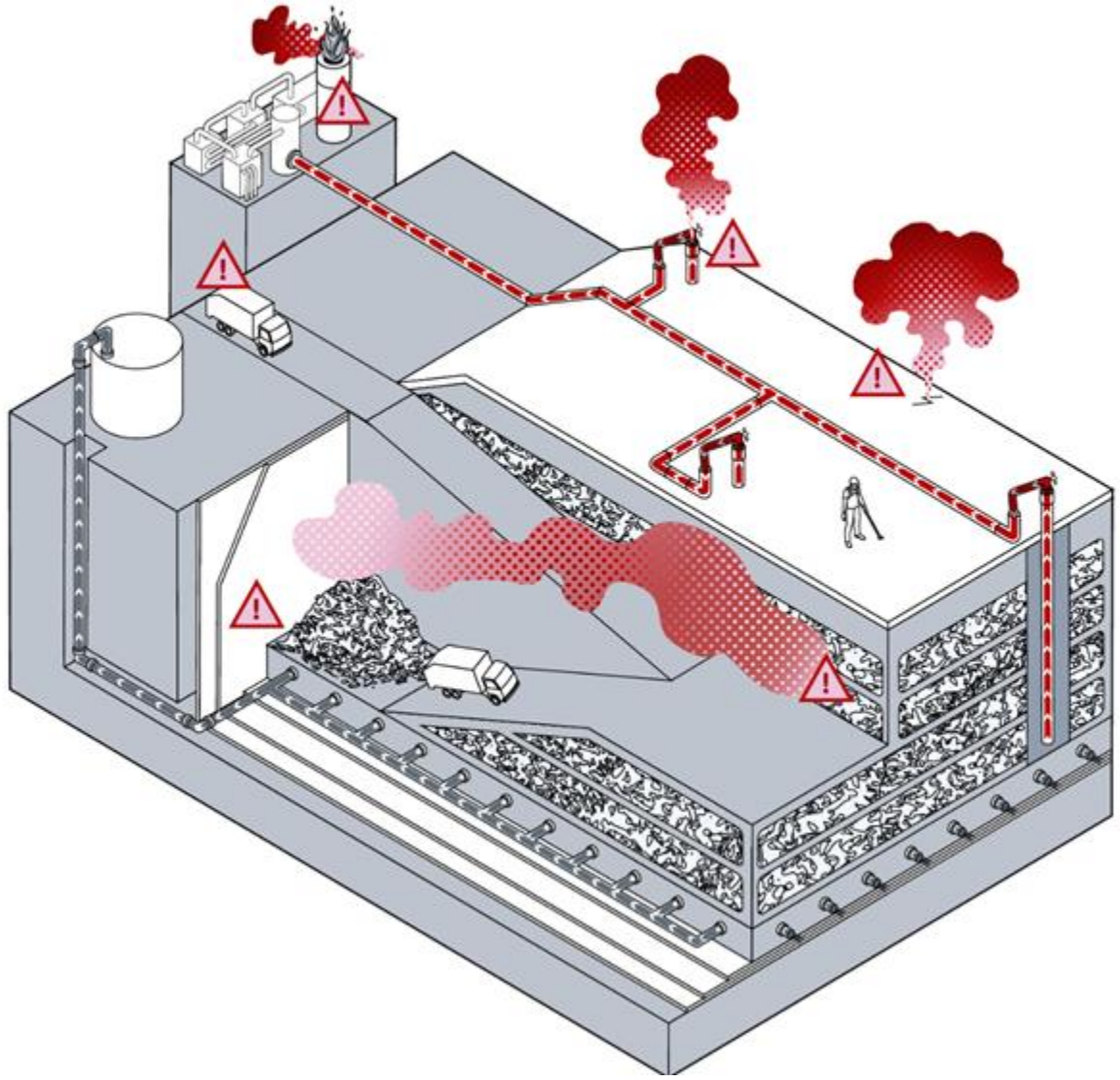
SIMON LOMAX

Director, Accelerated Methane Reduction Initiative

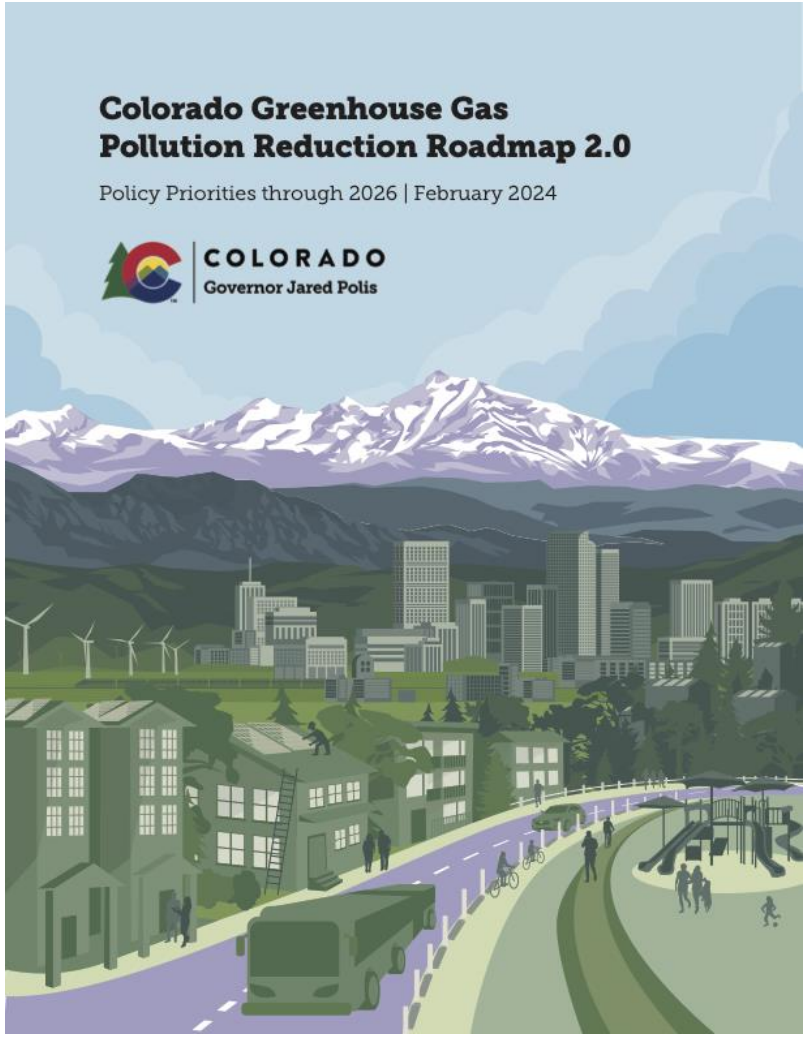
Colorado's Opportunity for Landfill Leadership

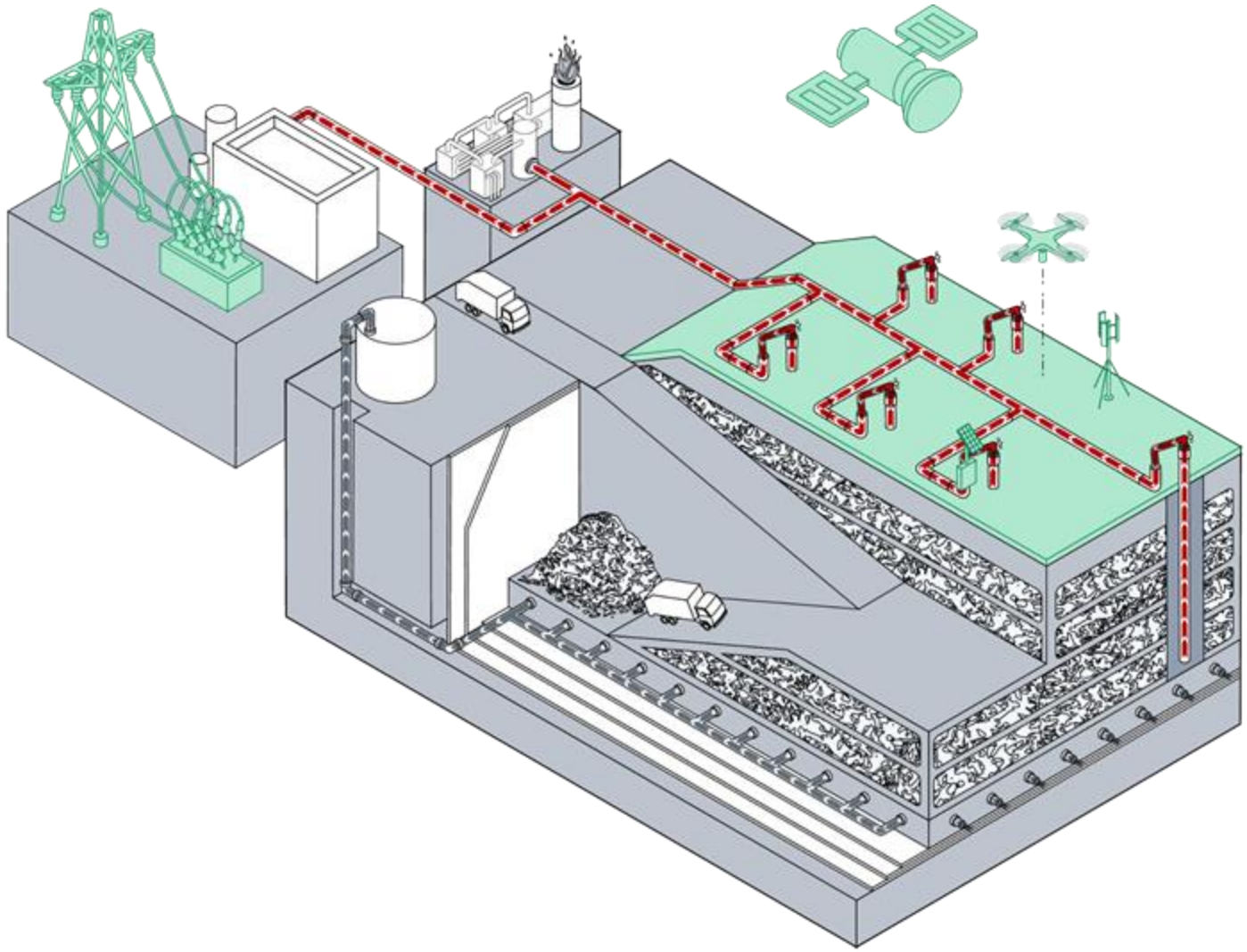
Ellie Garland, RMI

How do landfills impact the climate and communities?



Colorado has a plan to address landfill pollution





Proposed landfill standards leverage homegrown technology & innovation to deliver local benefits

Deploying advanced landfill monitoring & controls will:

- **Improve local air quality**
- **Protect public health**
- **Support local businesses**
- **Sustain 1,700+ jobs**
- **Slow near-term warming**
- **Advance Colorado's climate goals**

Projected benefits are **6X** the estimated compliance costs

Non-Endorsement. RMI is a nonpartisan nonprofit organization that is independent in its policies, vision and activities. RMI is hosting this forum to further RMI's mission of transforming the global energy system to secure a clean, prosperous, zero-carbon future for all and to raise awareness of the emerging technologies that can achieve our mission. **RMI does not directly or indirectly endorse today's speakers or the companies they represent, or any product, service or data published or provided thereby.**

Today's Panelists

MACKENZIE SMITH
Director of Airborne Operations
ChampionX

GREG RIEKER
Co-founder &
Chief Technology Officer
LongPath Technologies

RIKKI COOK
Co-Founder
Grand Valley Instrumentation

BEN SILTON
Chief Executive Officer
TrelliSense

ALI LASHGARI
Senior Scientist
Project Canary

CHAMPIONX
EMISSIONS TECHNOLOGIES

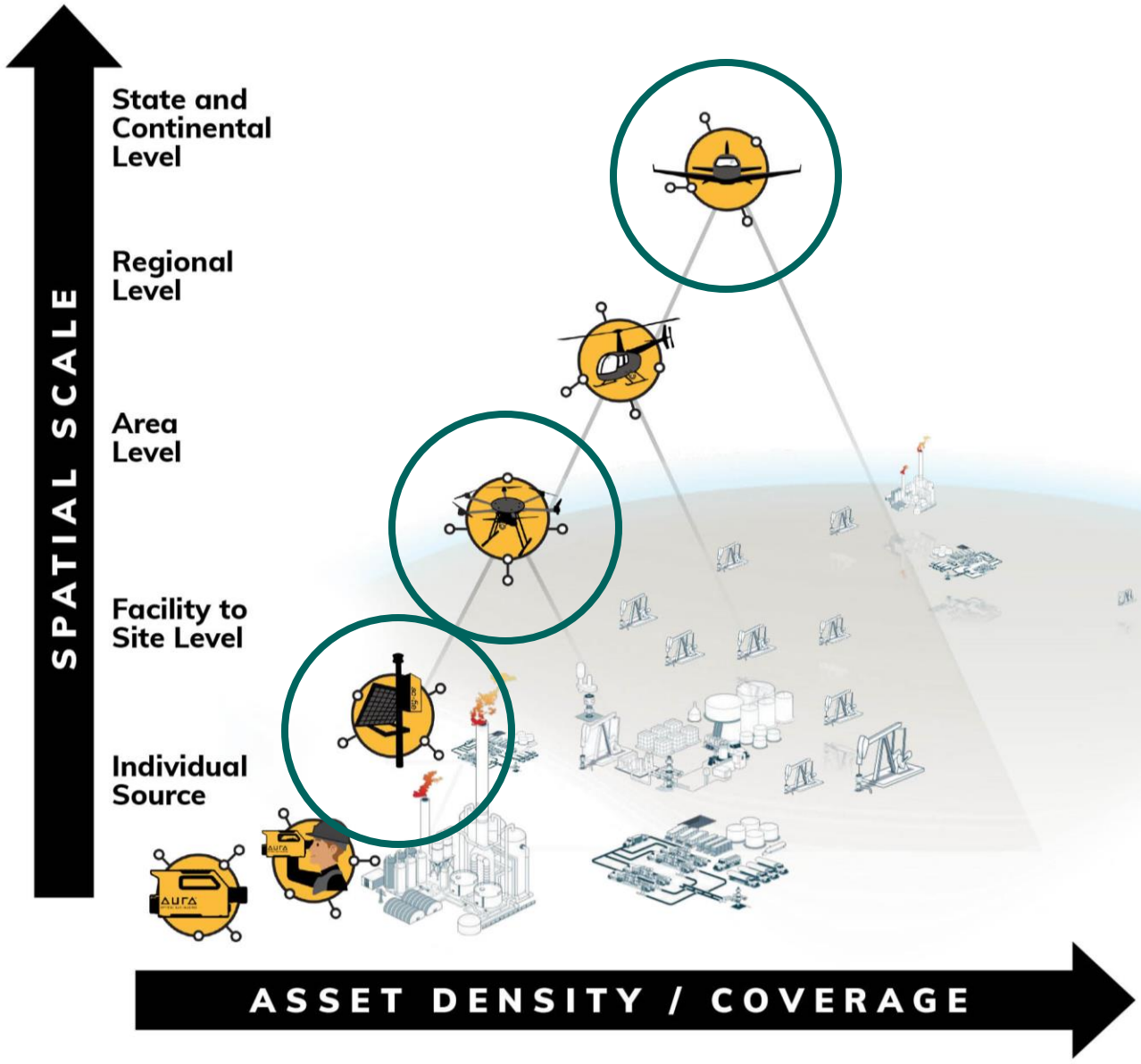
Landfill Measurements Overview

Dr. Mackenzie Smith, Director of Airborne Operations/Field Science

July 31, 2025

Emissions Solutions

CHAMPIONX
EMISSIONS TECHNOLOGIES



- Aerial Quantification Survey
- Helicopter OGI Survey
- Drone OGI and Quantification Survey
- SOOFIE® Continuous Emissions Monitoring
- Ground OGI Service/ Leak Detection and Repair (LDAR)
- AURA OGI® Camera

GOALZERO
YOU LEAD

Airborne Quantification of CH_4 Emissions

CHAMPIONX EMISSIONS TECHNOLOGIES

- Airborne quantification of methane emissions using fixed-wing aircraft and drones
- Airborne platforms fly through emissions plumes and measure CH_4 concentration
- Methane concentration combined with wind speed and direction and vertical plume mixing → Mass emission rate

Methodology established in the peer-reviewed literature:

Conley, S. A., et al. "A Low-Cost System for Measuring Horizontal Winds from Single-Engine Aircraft", J. *Atmos. Ocean. Technol.,* 2014.

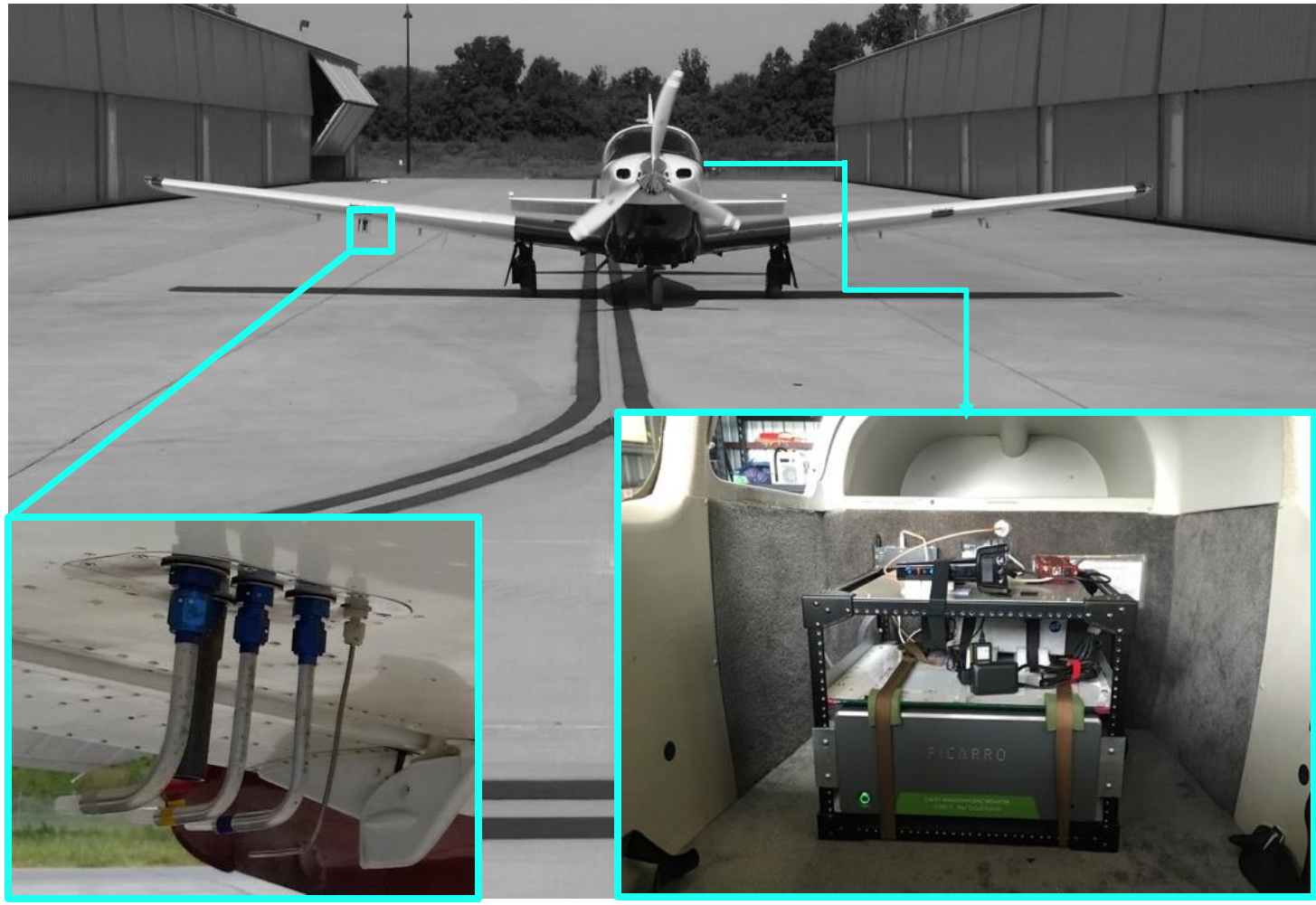
Conlet, S., et al. "Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA", *Science*, 2016.

Conley, S., et al. "Application of Gauss's theorem to quantify localized surface emissions from airborne measurements of wind and trace gases", *Atmos. Meas. Tech.,* 2017.

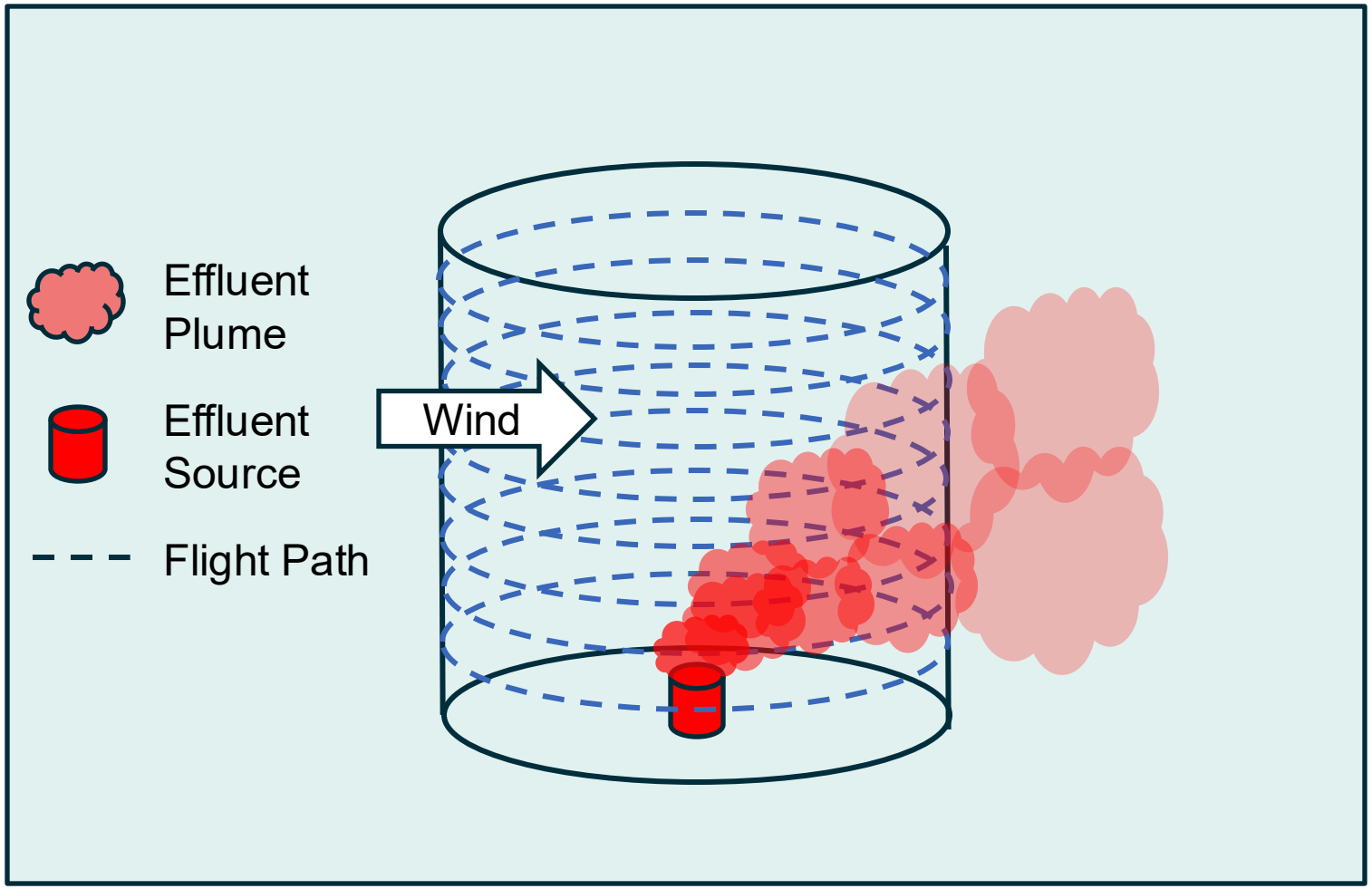
GOAL ZERO YOU LEAD

Aircraft Modified for Science Operations

- FAA approved modifications to add air sample inlet on the outboard section of the wing.
- All aircraft capable of measuring 1-second winds, along with temperature, humidity and pressure.
- Available trace-gas analyzers for CH_4, CO_2, CO, ethane, O_3, and NO_2, and whole air samples for VOC analysis
- FAA approval for low-altitude flight



Quantification Principles



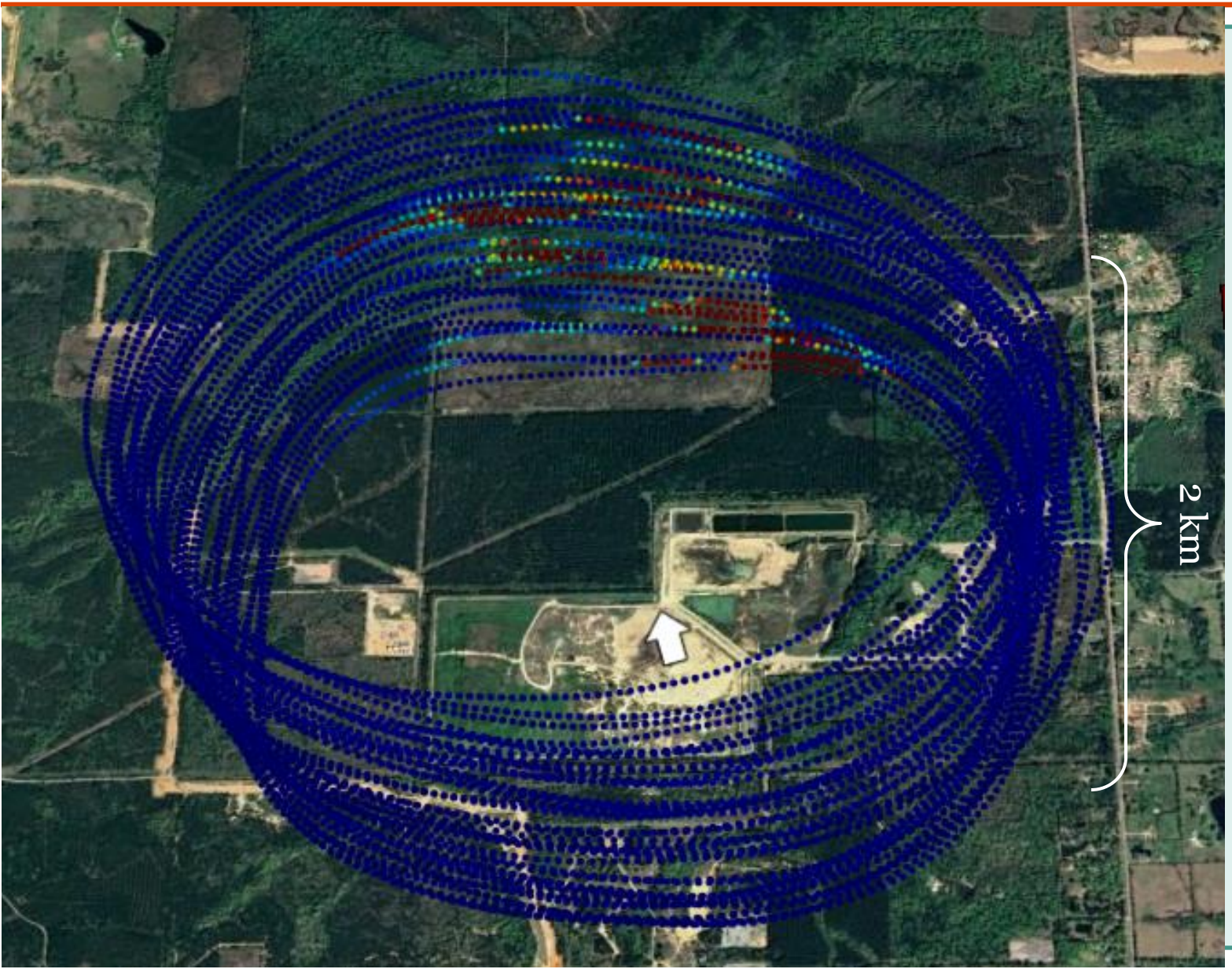
Mass Balance

Principle of mass conservation:

Emission = Out - In

Needs: Horizontal wind & species concentration

Quantification Principles

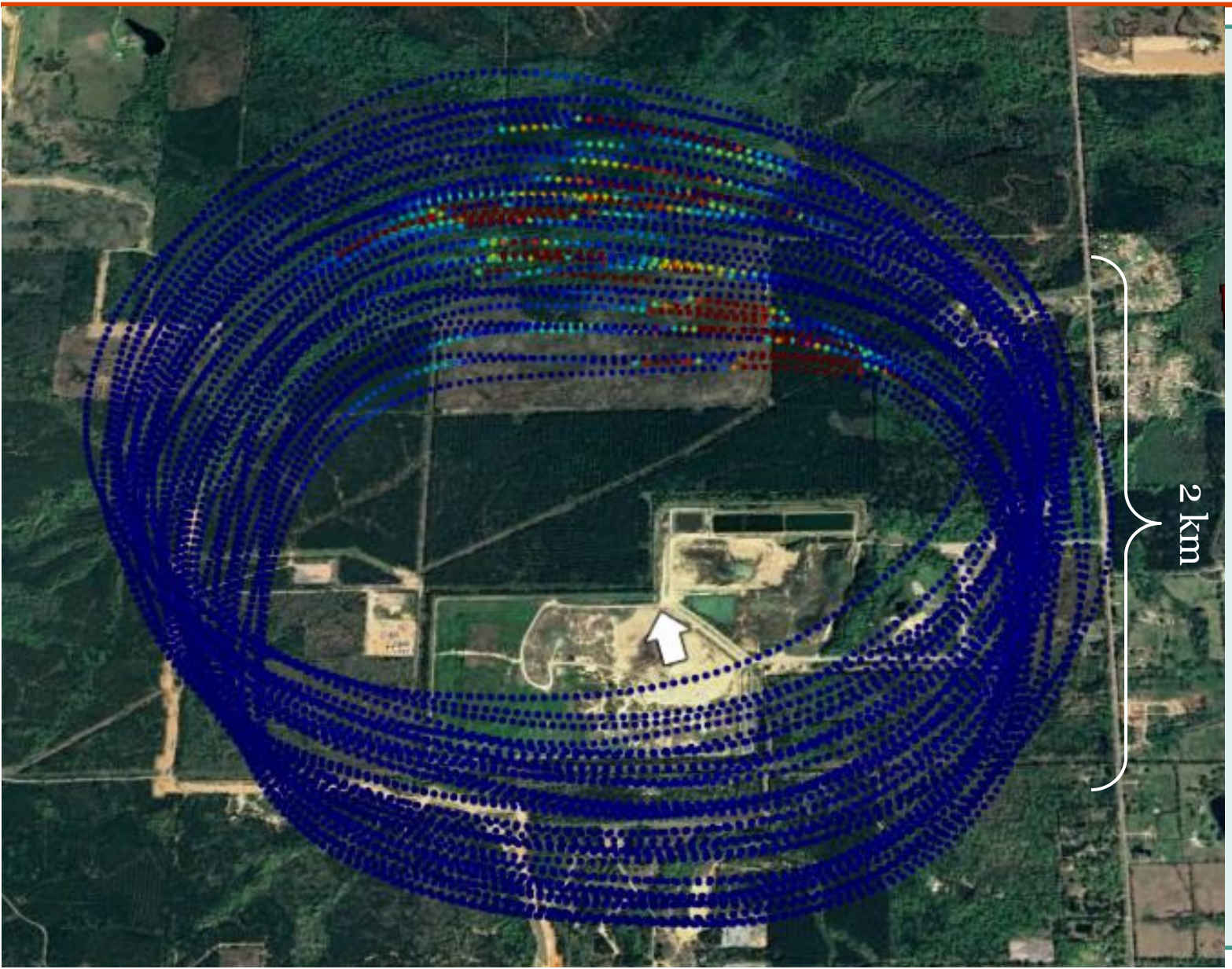


Map out the plume

- Circles as low as possible up to the top of the plume
- Enhancements are downwind
- Methodology can be scaled up to larger regions

Case Study: Emissions Reduction Validation

CHAMPIONX
EMISSIONS TECHNOLOGIES



- CH_4 emissions measured **before** and **after** a methane mitigation strategy implemented at a Louisiana landfill.
- 50% emissions reduction confirmed by aircraft measurements.
- 100s of kg/hr of methane avoided

Years of Landfill Measurement Experience

CHAMPIONX EMISSIONS TECHNOLOGIES

California Air Resources Board (CARB)

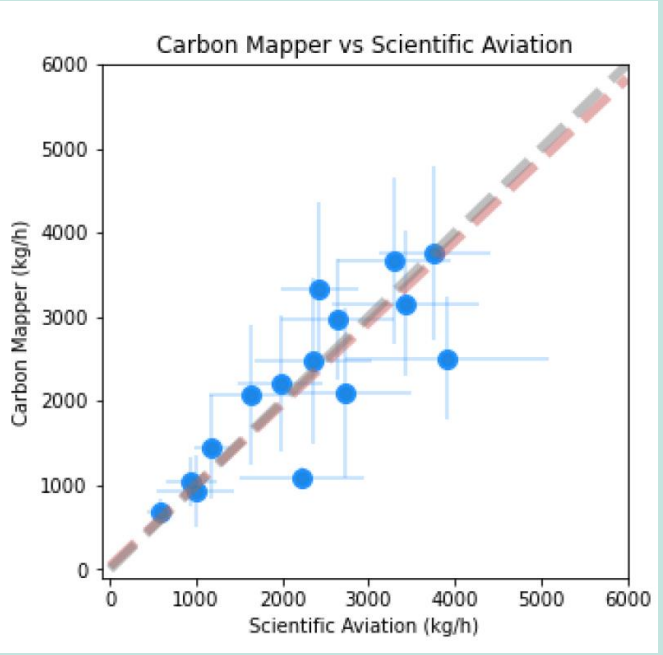
50+ landfills measured over 2 years as part of larger state-wide methane study

Colorado Dept. of Public Health and Environment (CDPHE)

Assess contribution of different source sectors to Denver Julesberg basin methane

Method Intercomparisons for US Landfills

Collaboration with Carbon Mapper and US EPA to quantify landfills across the United States



Cusworth et al., 2024, *Science.*

Three Relevant Technologies

CHAMPIONX EMISSIONS TECHNOLOGIES

Most Frequent Usage at Landfills → Least Frequent

Fixed-Wing Aircraft

- Ideal for large areas, including landfills
- Captures all emissions from within the flight path
- Useful for inaccessible areas
- No ground access required

Drones

Range of uses:

- Small areas and small emissions (10s of m; < 1 kg/h)
- Medium sites and large emissions (100s of m; > 100s of kg/h)
- Can provide some spatial localization
- Ground access usually helpful

Continuous Monitors

- Useful for identifying unexpected or large emissions
- Rough emissions localization

Research opportunities:

- Not widely used on landfills, but low cost and high time resolution are appealing
- Comparison studies using fixed-wing, drones

LONGPATH

Large Area Laser Emissions Monitoring Networks

SAFETY FIRST :

0
EMR

0
TRIR

0
Incidents

21,139
Total Q2 2025 Hours

43
Average EE Count

LONGPATH'S DNA: Rigor in Everything We Do

- Colorado Nobel Prize Winning Roots
- Rigorous Vetting at Every Stage of Growth
- Quality & Accuracy as the Basis for Trust
- 40+ team delivering Customer Success at Scale
- 900+ square mile monitoring network
- Backing from DOE, Conoco Phillips, Williams

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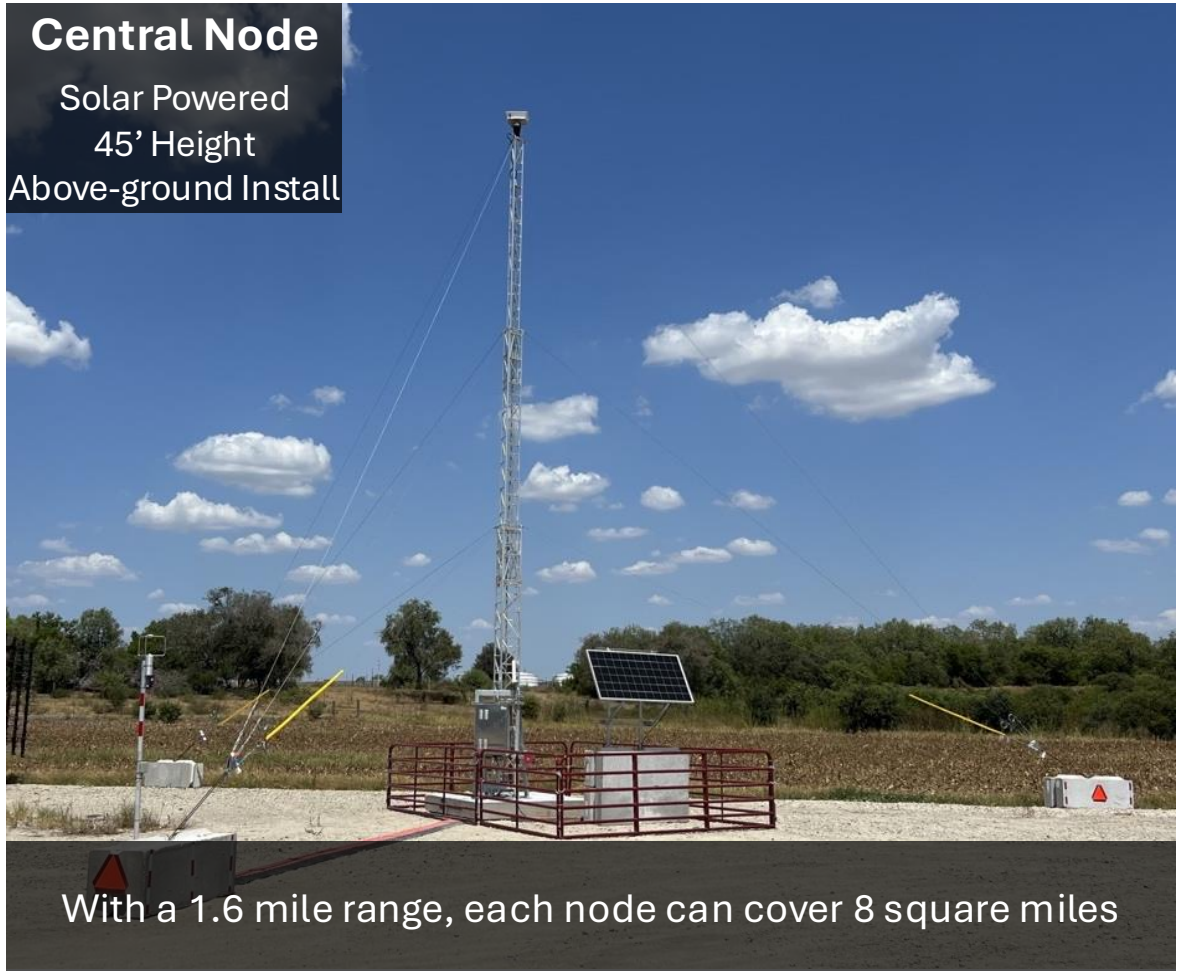
LONGPATH OIL & GAS METHANE MONITORING: Overview

Standard deployment: on-site hardware

Central Node

Solar Powered
45’ Height
Above-ground Install



With a 1.6 mile range, each node can cover 8 square miles

Passive Reflector

No power required
20’ max height
Above-ground Install

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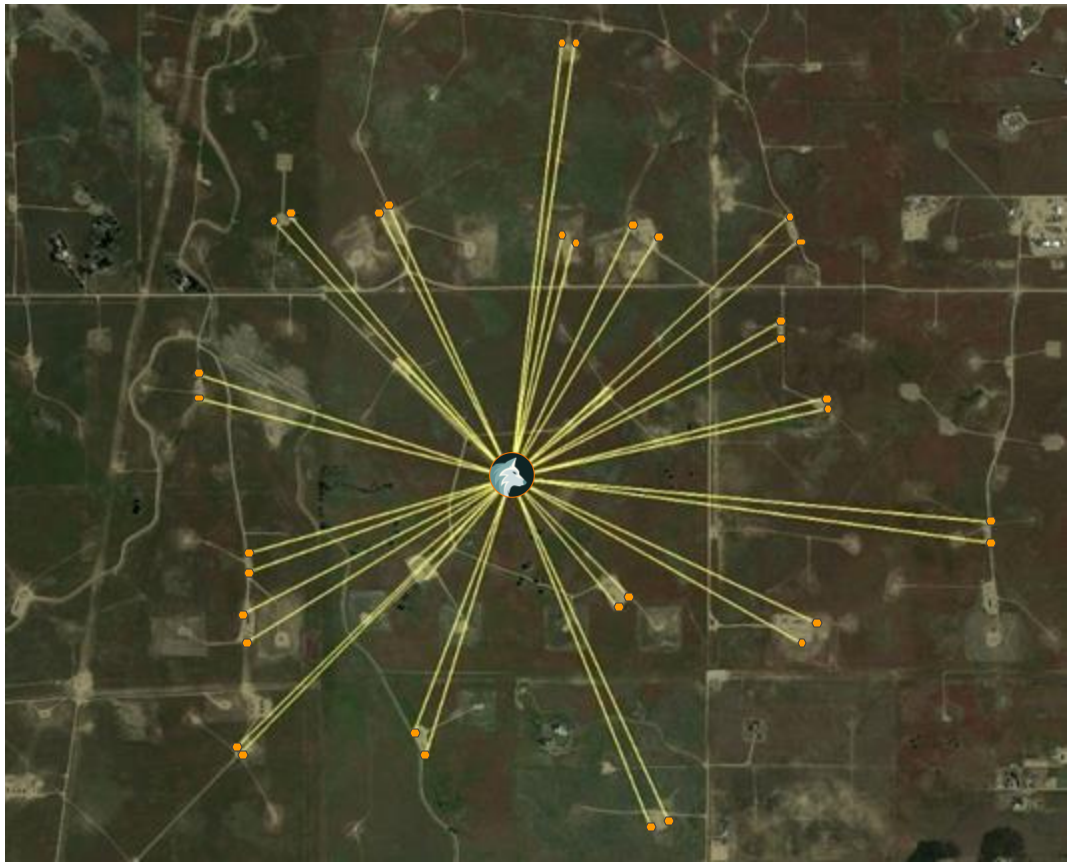
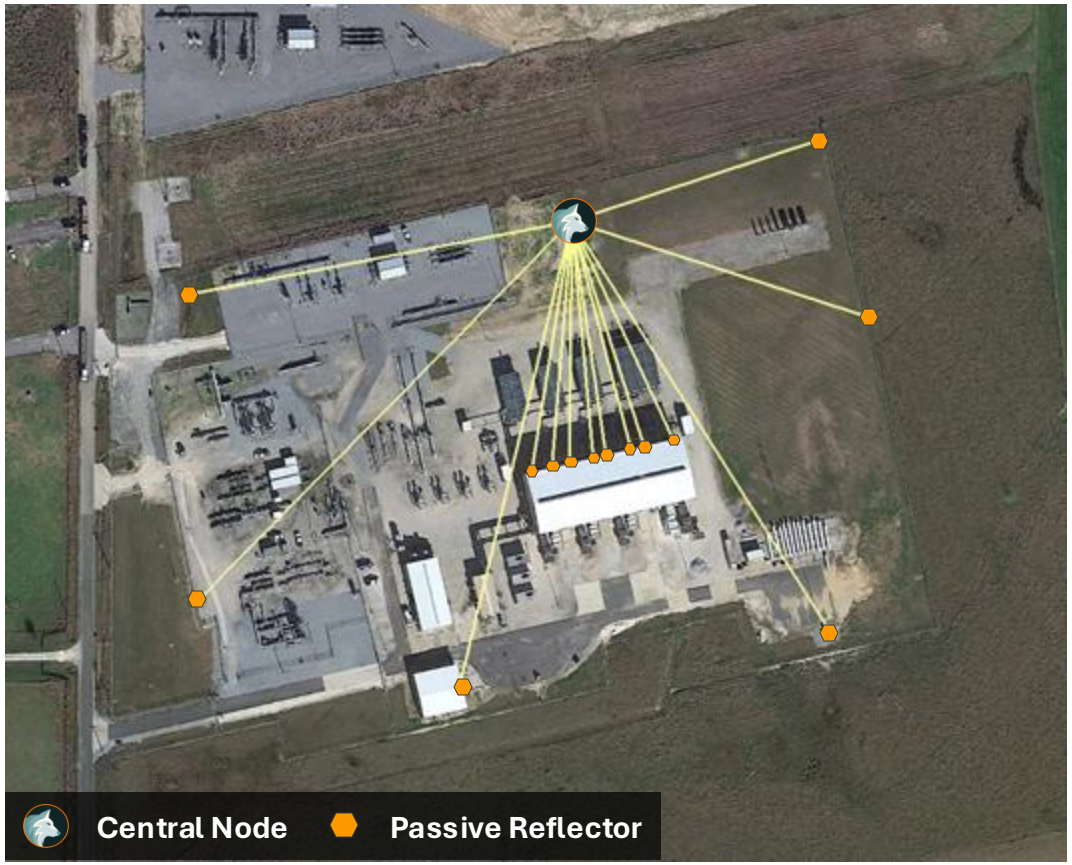
LONGPATH OIL & GAS METHANE MONITORING: Overview

Upstream



Networked monitoring from a single tower

Midstream



Accurate equipment group & full site quantification

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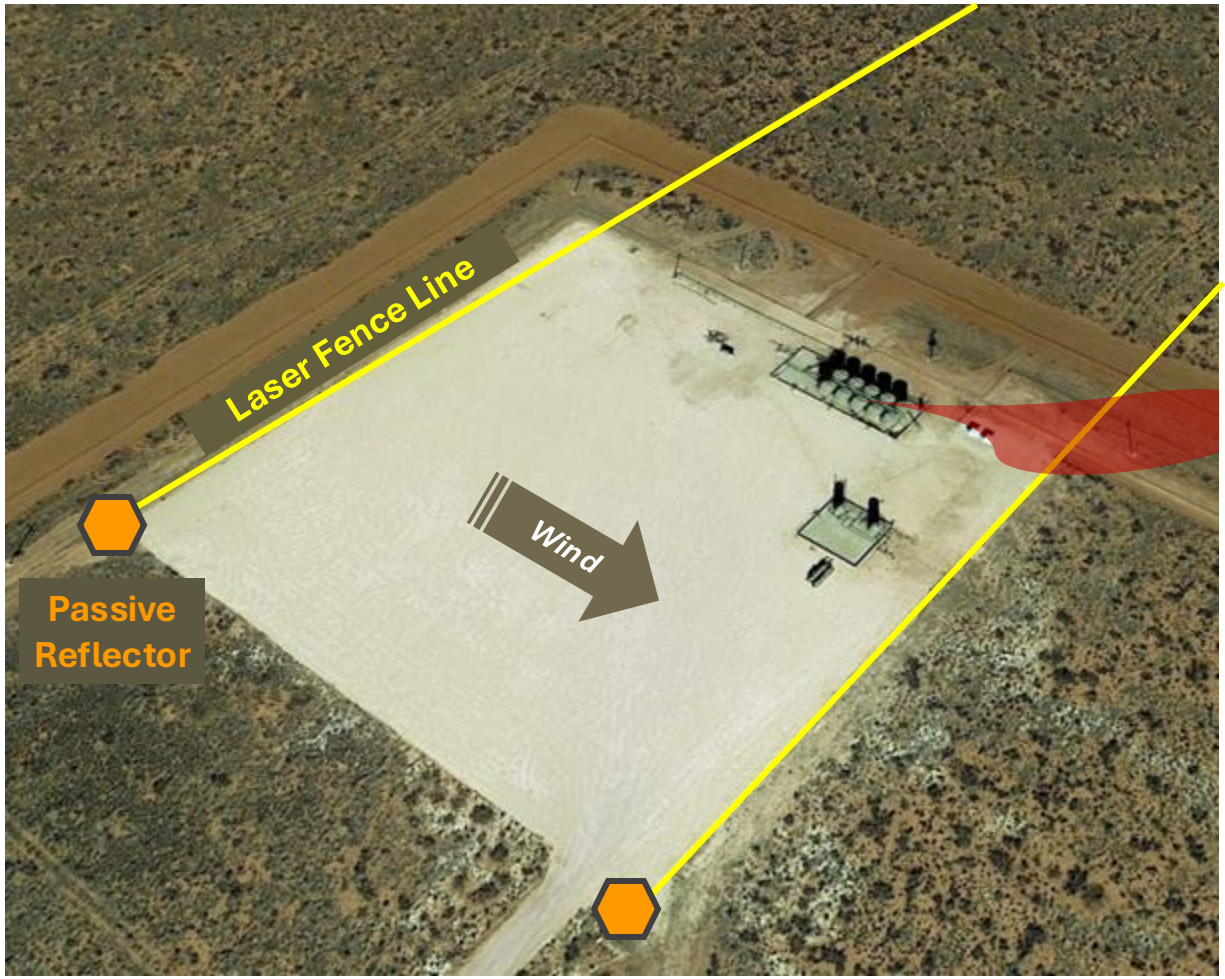
LONGPATH OIL & GAS METHANE MONITORING: Overview

Operational framework



1. Bracket facility or sector with laser beams from central node.
2. Record methane entering facility upwind and exiting facility downwind.
3. Quantify emissions rate (MCFD or kg/hr) based on methane differential.
4. Alert if persistent emission readings exceed alert threshold over a period

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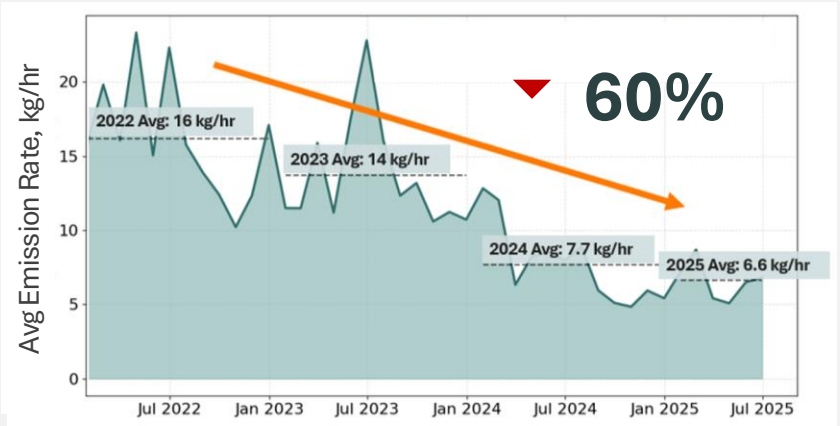
LONGPATH IS TRUSTED BY FIELD OPERATIONS

Low false positive rate → quantified emissions reductions

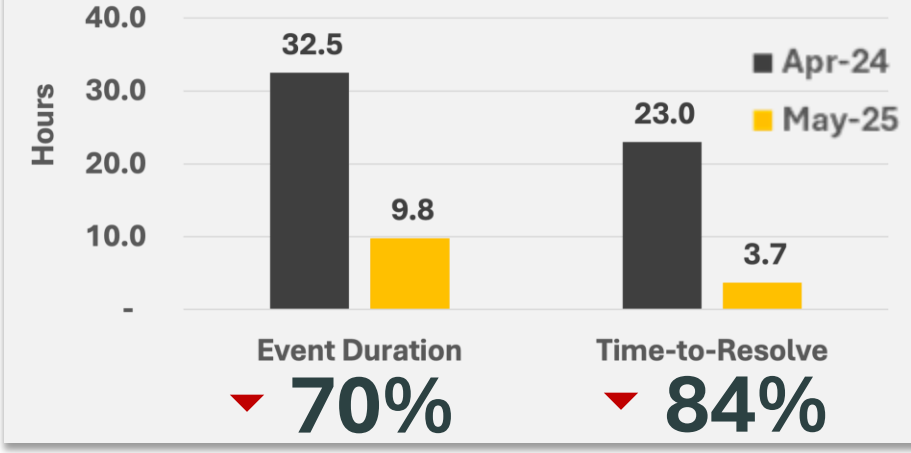
2-month In-Field Blind Testing vs Daily Inspection

TRUE POSITIVE	**100%**
TRUE NEGATIVE	94%
FALSE POSITIVE	0%
FALSE NEGATIVE	6%

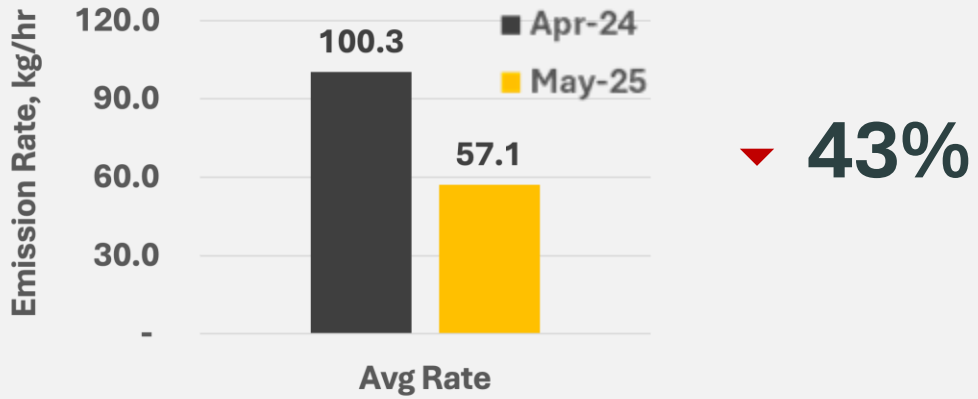
Year-on-year baseline emissions reductions



Methane Emission Event Operational Response



Methane Emission Event Severity



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TRUST AND CONFIDENCE THROUGH REGULATORY LEADERSHIP

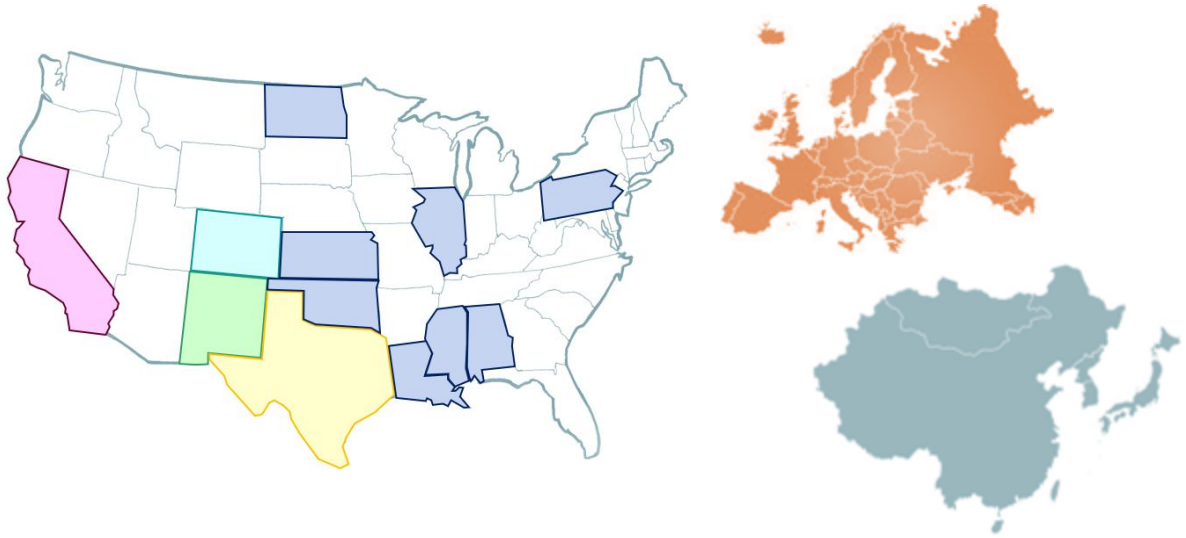
Longpath leads the industry in approvals

Current Approvals

- ✓ EPA OOOOa/b/c
- ✓ New Mexico Part 27, Part 50, and ALARM
- ✓ Colorado Alt. AIMM
- ✓ Colorado Pre-Production Monitoring
- ✓ Colorado Methane Intensity Verification
- ✓ Wyoming Ozone Non-Attainment
- ✓ BLM Waste Prevention Rule

Coming Soon

- ✓ Replacement of TCEQ AVO & OGI Inspections
- ✓ European Union MMRV Requirements
- ✓ California SB 1137 CM Requirements



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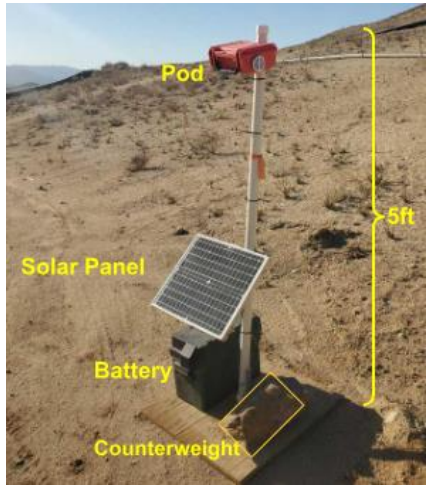
LONGPATH EXPANDS INTO LANDFILL MONITORING

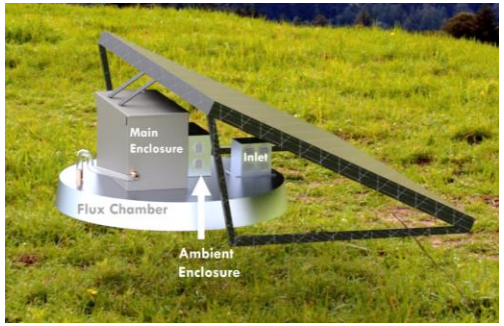
EPA STAR Program: Understand and control municipal solid waste landfill air emissions

Multi-platform assessment of methane/VOC emissions and uncertainty through evolving landfill morphology

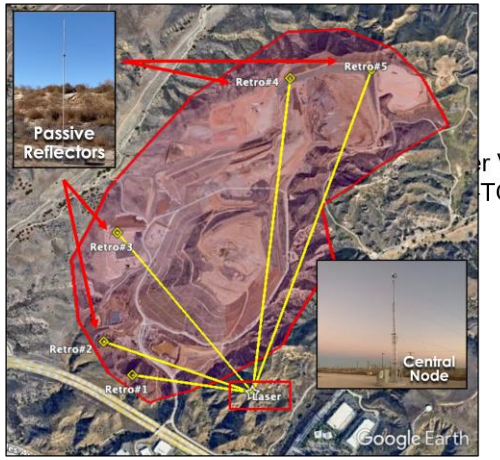
Point sensor network



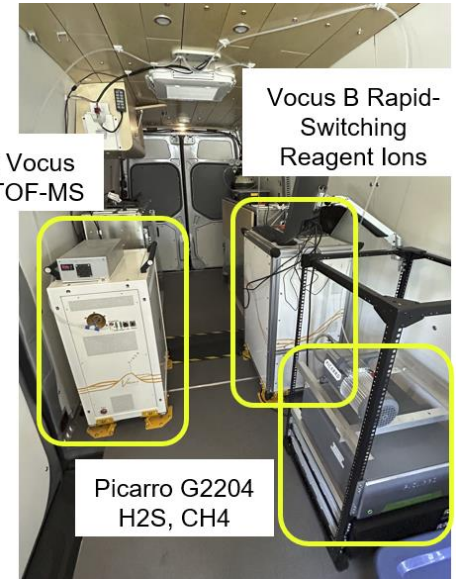
Flux chamber network



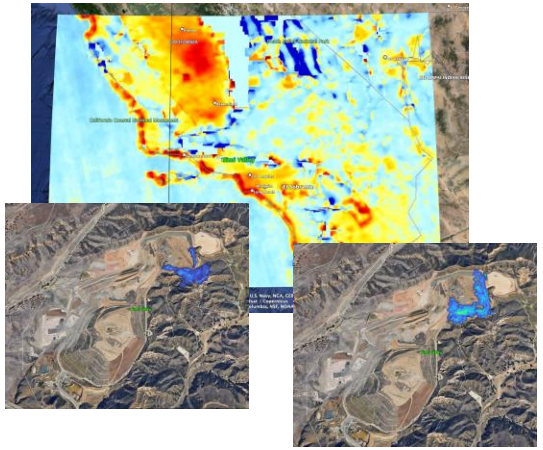
LongPath laser network



Mobile VOC measurements



Satellite/aerial data products



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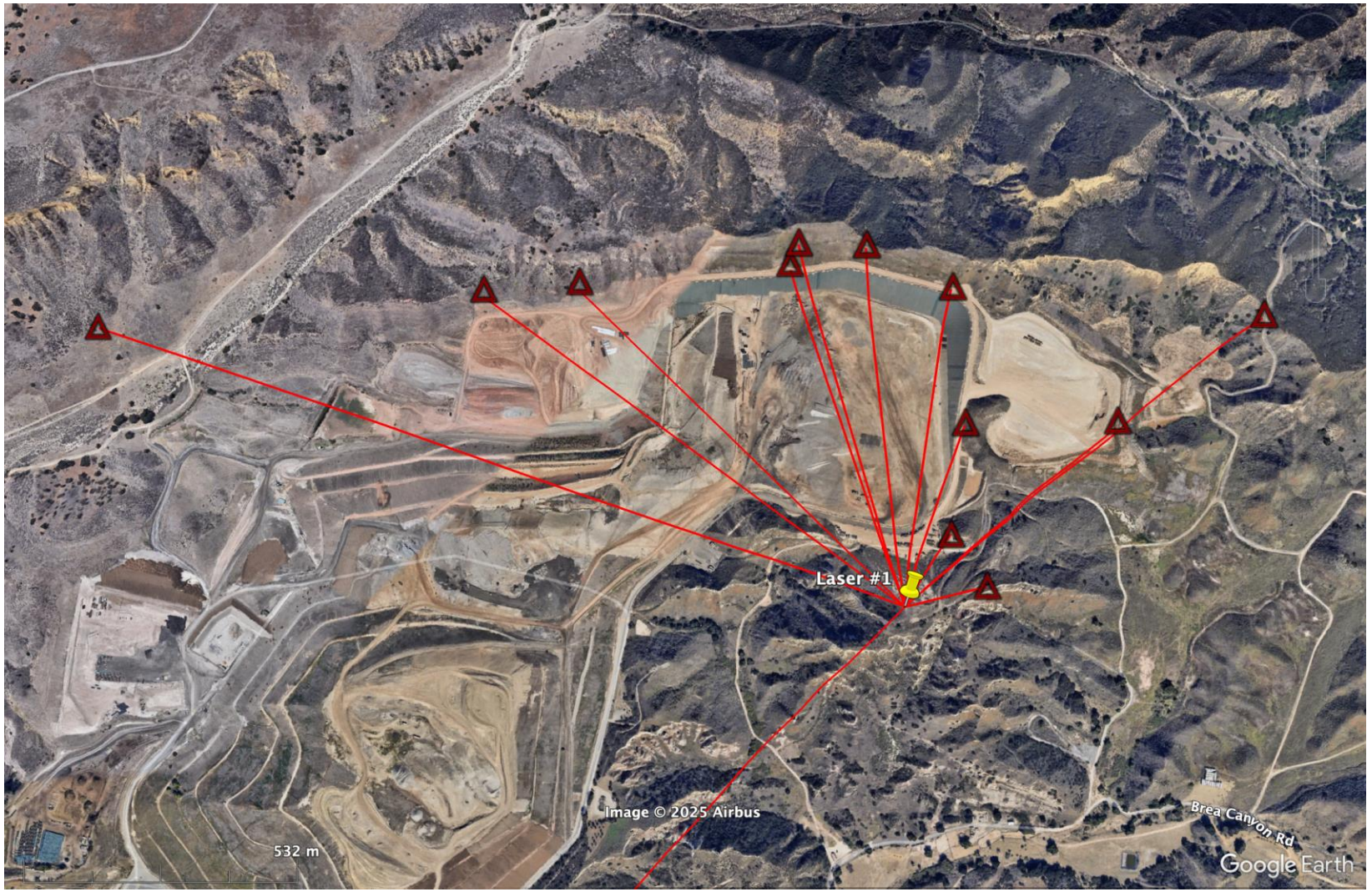
LONGPATH LANDFILL LASER SYSTEM DEPLOYMENT

Two systems deployed monitoring:

- Active face
- Maintenance area
- Gas handling infrastructure

LONGPATH

LONGPATH LANDFILL LASER SYSTEM DEPLOYMENT



North system

- Active area of the landfill
- 13 beam paths

Measurements stats

- Started March 2025
- >150k measurements

LONGPATH

LONGPATH LANDFILL LASER SYSTEM DEPLOYMENT

South system

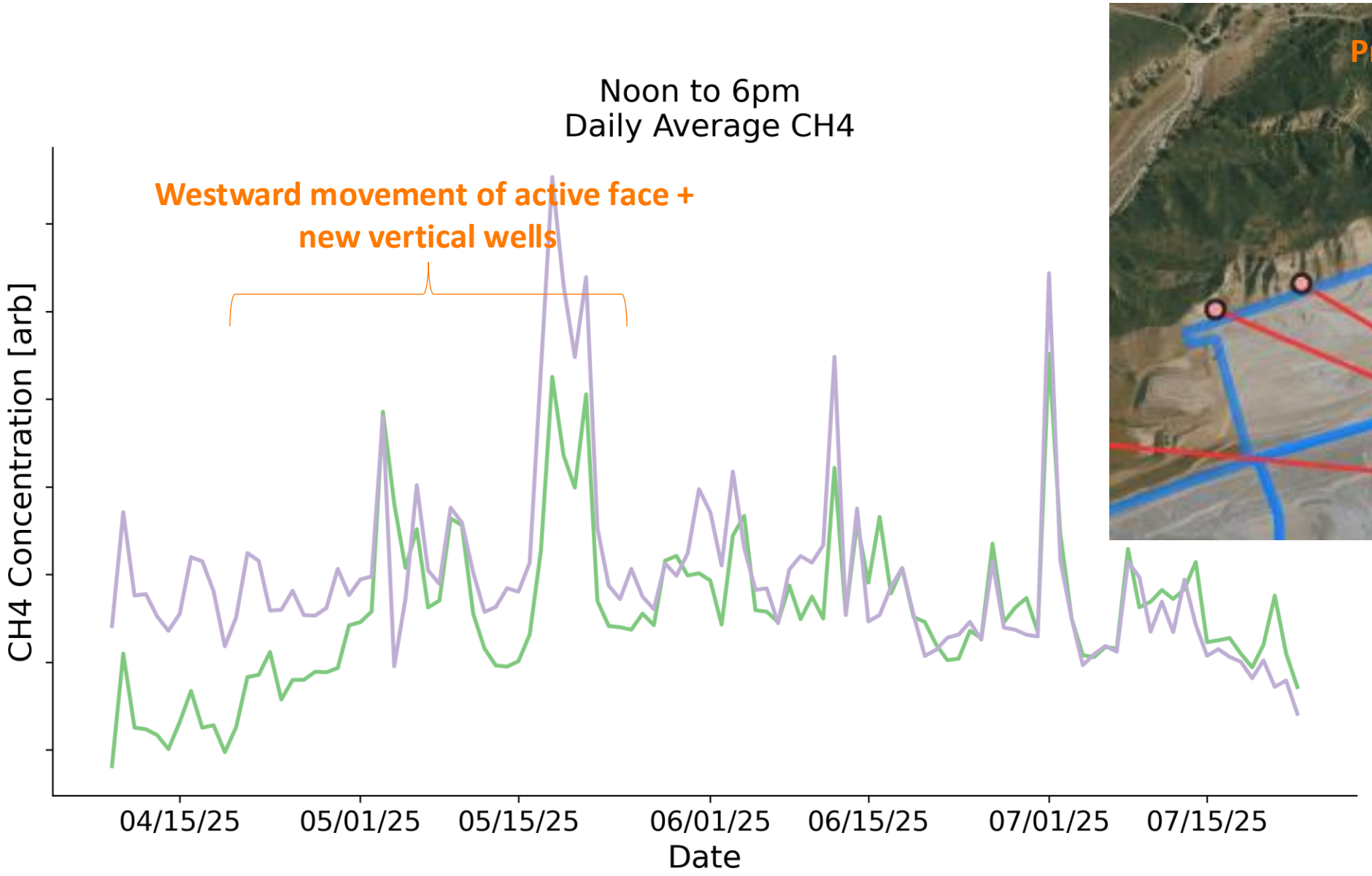
- Gas handling infrastructure
- 8 beam paths

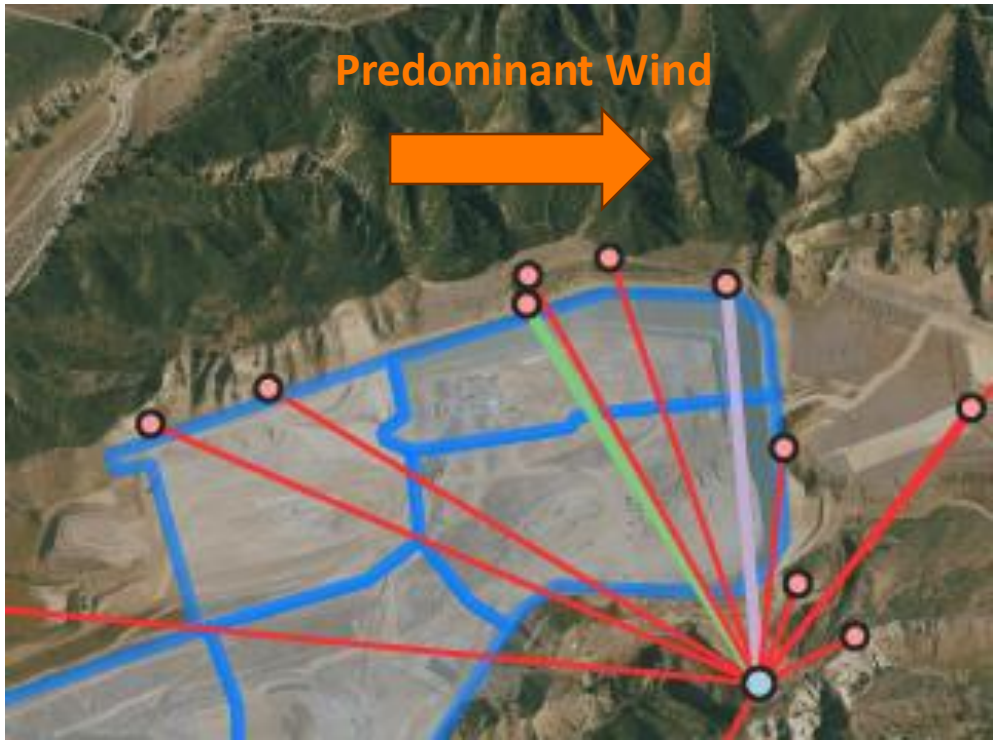
Measurements stats

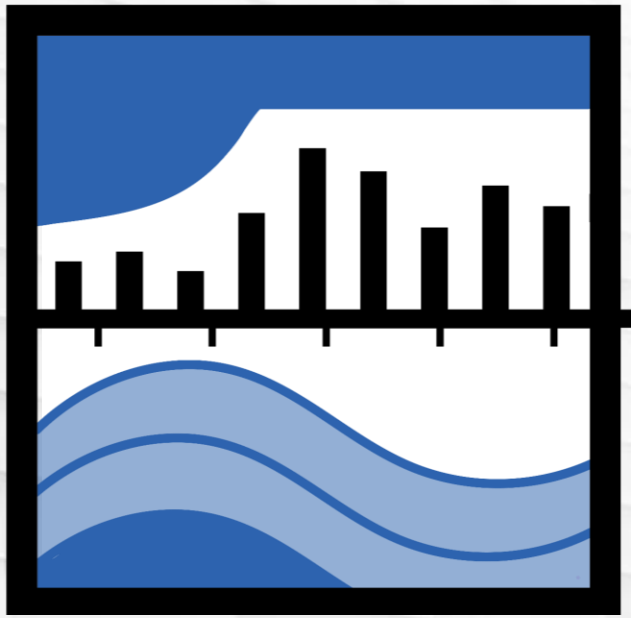
- Started March 2025
- >150k measurements

LONGPATH

EXAMPLE LONGPATH LANDFILL LASER SYSTEM PRELIM RESULTS



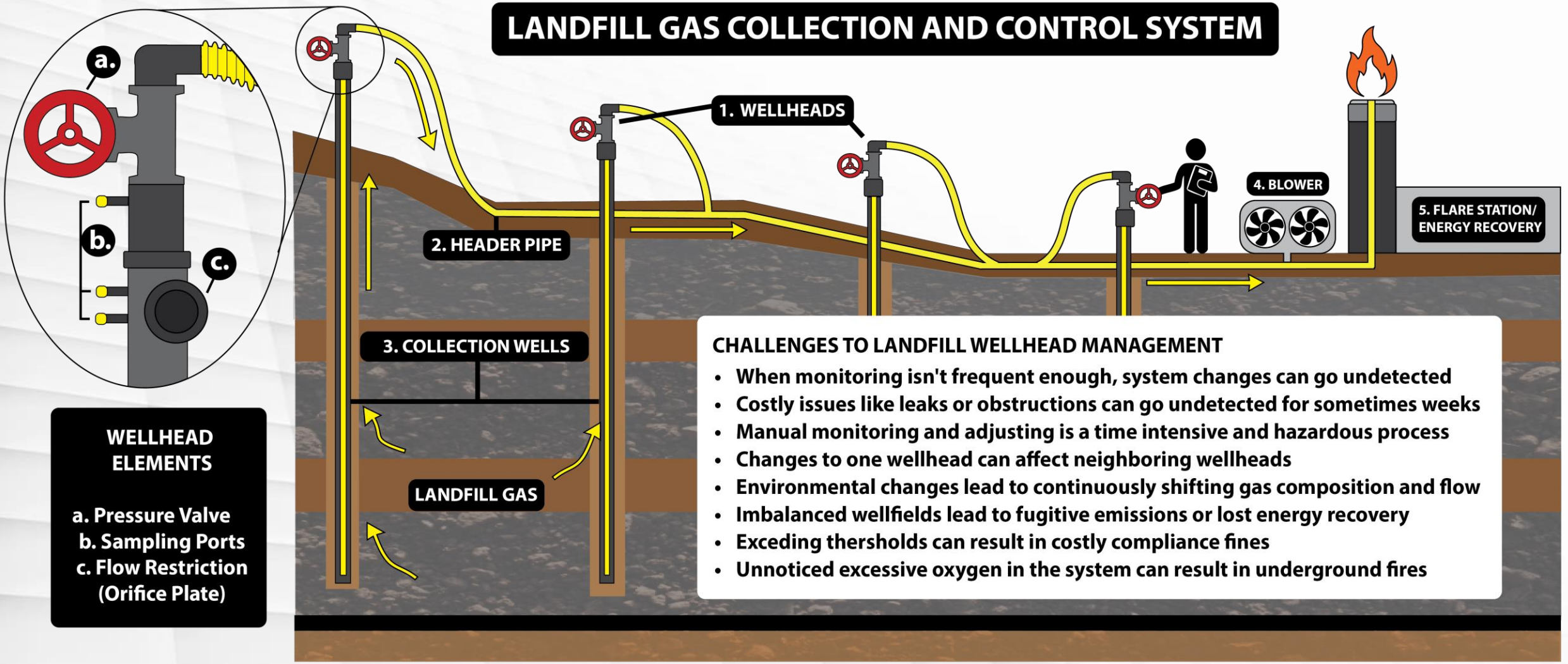




GRAND VALLEY INSTRUMENTATION

Grand Junction, Colorado

LANDFILL GAS COLLECTION AND CONTROL SYSTEM



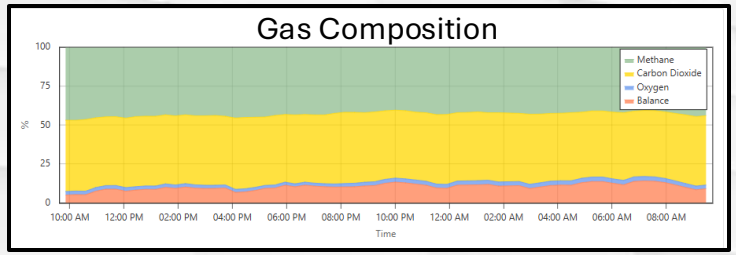
WELLHEAD ELEMENTS

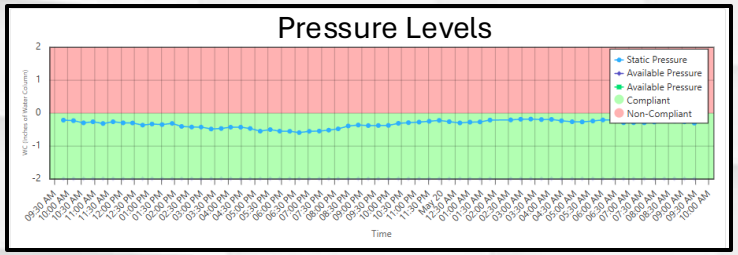
a. Pressure Valve
b. Sampling Ports
c. Flow Restriction (Orifice Plate)

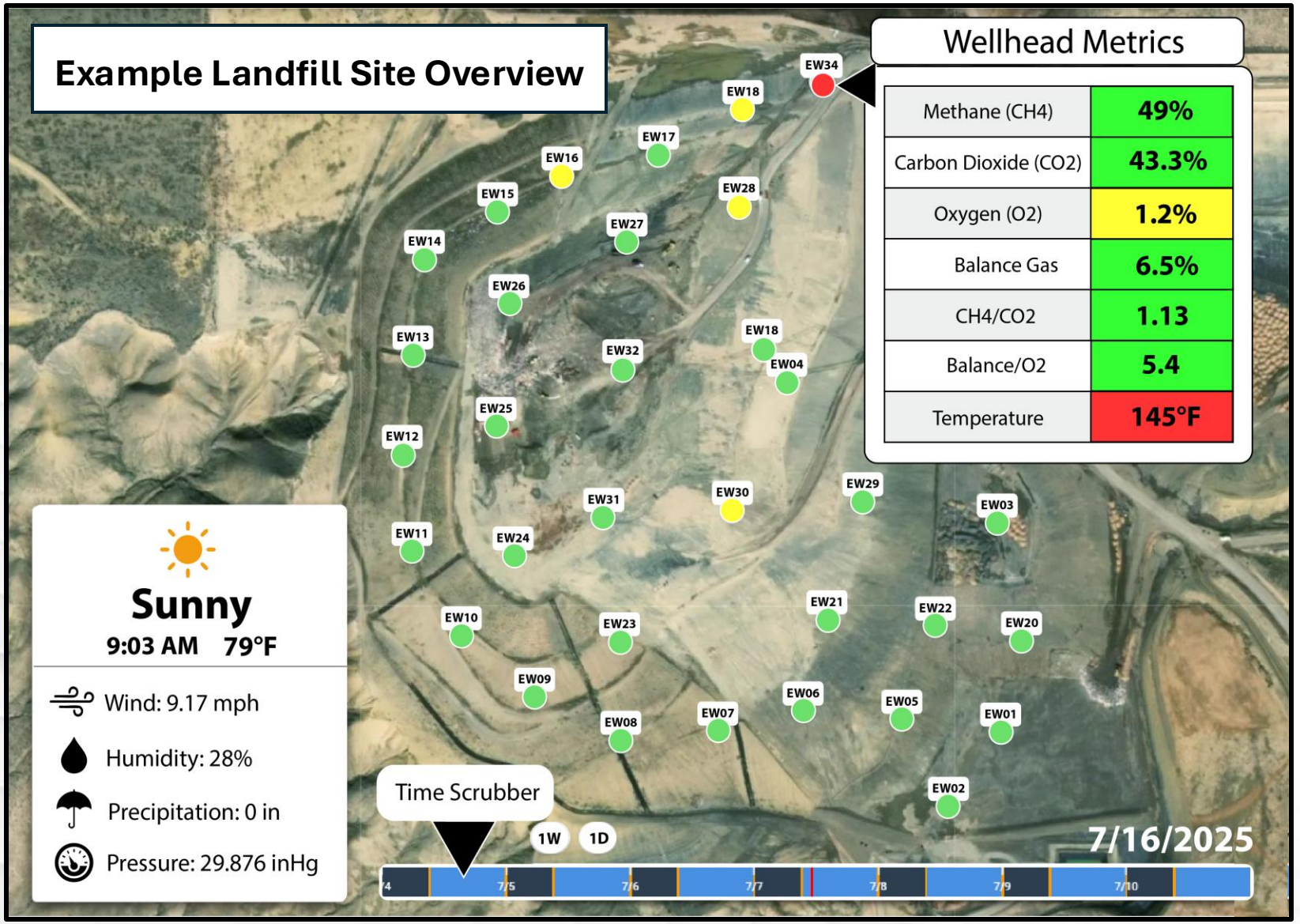
CHALLENGES TO LANDFILL WELLHEAD MANAGEMENT

- When monitoring isn't frequent enough, system changes can go undetected
- Costly issues like leaks or obstructions can go undetected for sometimes weeks
- Manual monitoring and adjusting is a time intensive and hazardous process
- Changes to one wellhead can affect neighboring wellheads
- Environmental changes lead to continuously shifting gas composition and flow
- Imbalanced wellfields lead to fugitive emissions or lost energy recovery
- Exceding thersholds can result in costly compliance fines
- Unnoticed excessive oxygen in the system can result in underground fires

MEERKAT MONITORING SYSTEM







Pilot Phase Underway

GRAND VALLEY INSTRUMENTATION

Proudly, in Partnership with:

MESA COUNTY

COLORADO MESA UNIVERSITY

Next Steps Toward Commercial Deployment

- ❑ Conduct field study for Alternative Testing Method Certification through Colorado Department of Public Health and Environment
- ❑ Submit to EPA for approval as an alternative compliance method
- ❑ Apply for Carbon Credit Certification through ACR

MEERKAT
MONITORING SYSTEM

Autonomous Landfill Wellhead Sampling and Adjusting

Increase Gas Revenue

Installation takes Minutes

Automate Compliance Reporting

Reduce Labor Costs

Receive Hazard Alerts

Reduce Fugitive Emissions

No Guesswork. Just Gas Work.

(970) 462-9192

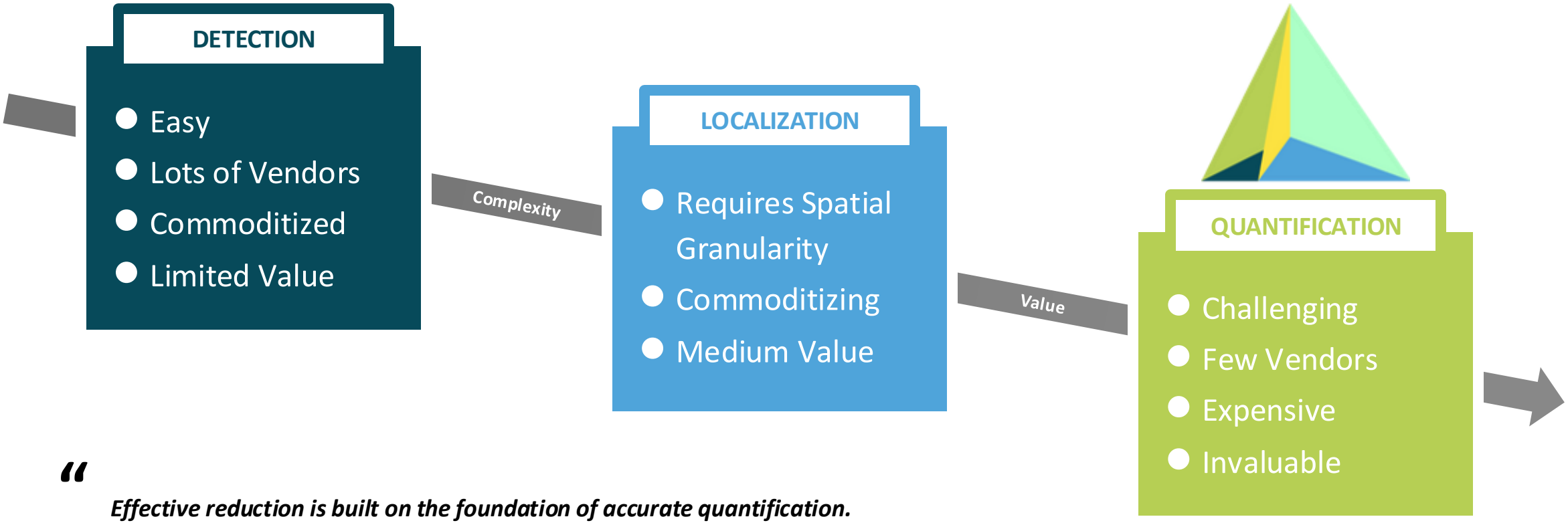
TrelliSense

Continuous Methane Measurement

A Third Derivative Company

Boulder, CO
Summer 2025

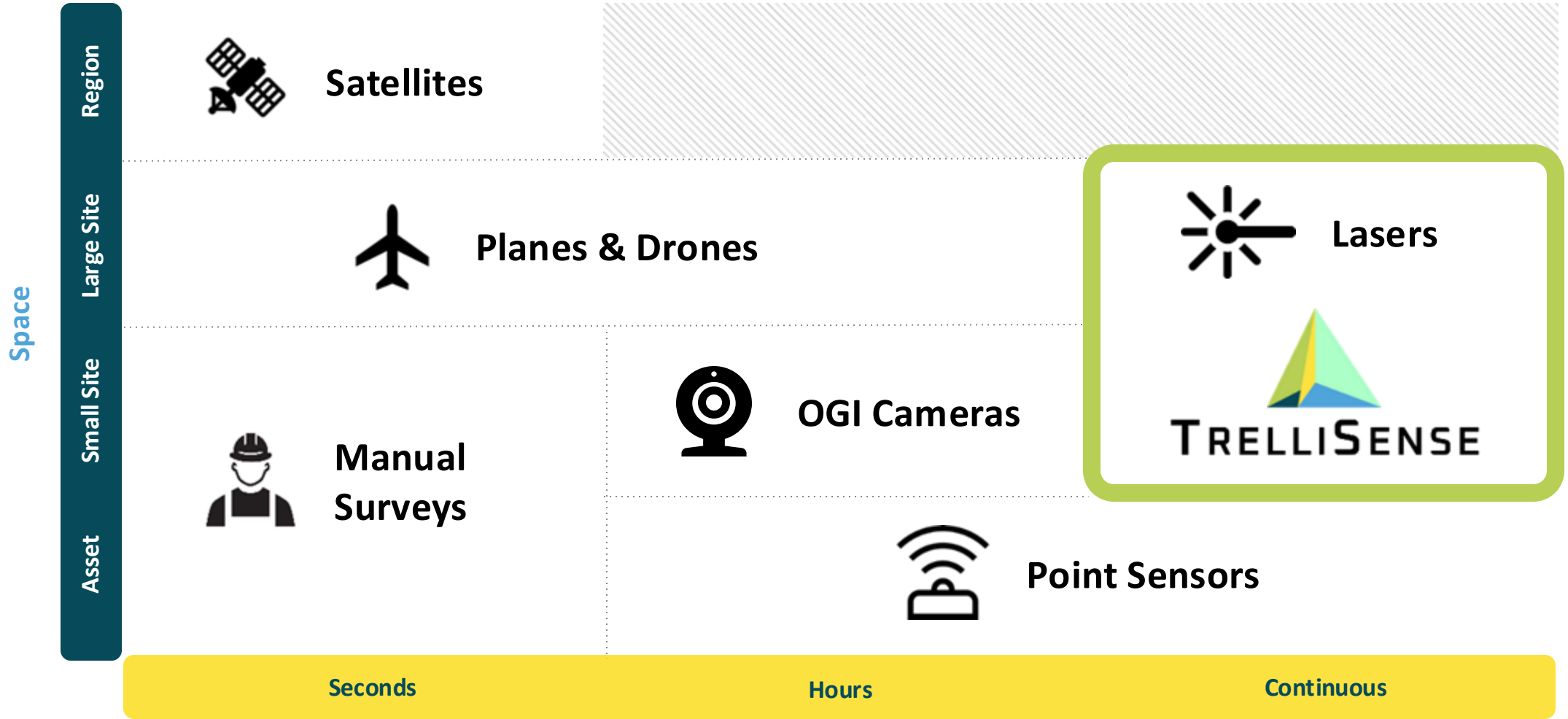
To Reduce GHGs, Quantification is Gold…



> ***Effective reduction is built on the foundation of accurate quantification.*** *Without precise data, efforts to reduce methane emissions can be misguided or ineffective… Additionally, the assumption that "I already know where my emissions are coming from" is* ***tempting but usually proven wrong.***
>
> - *Highwood Emissions Management (Source)*

TrelliSense

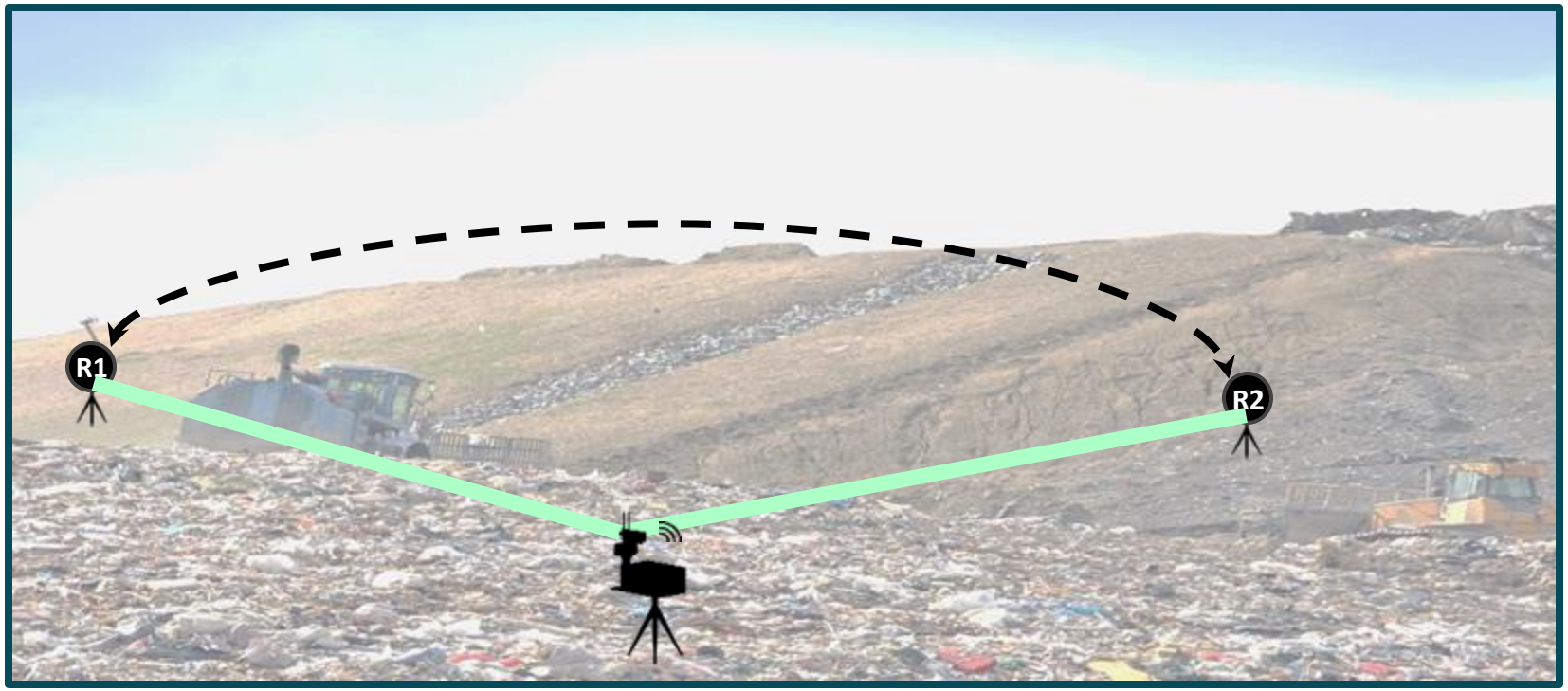
Quantification = Spatial + Temporal Coverage



TrelliSense

“TrelliBeam” || 24/7 Leak Monitoring

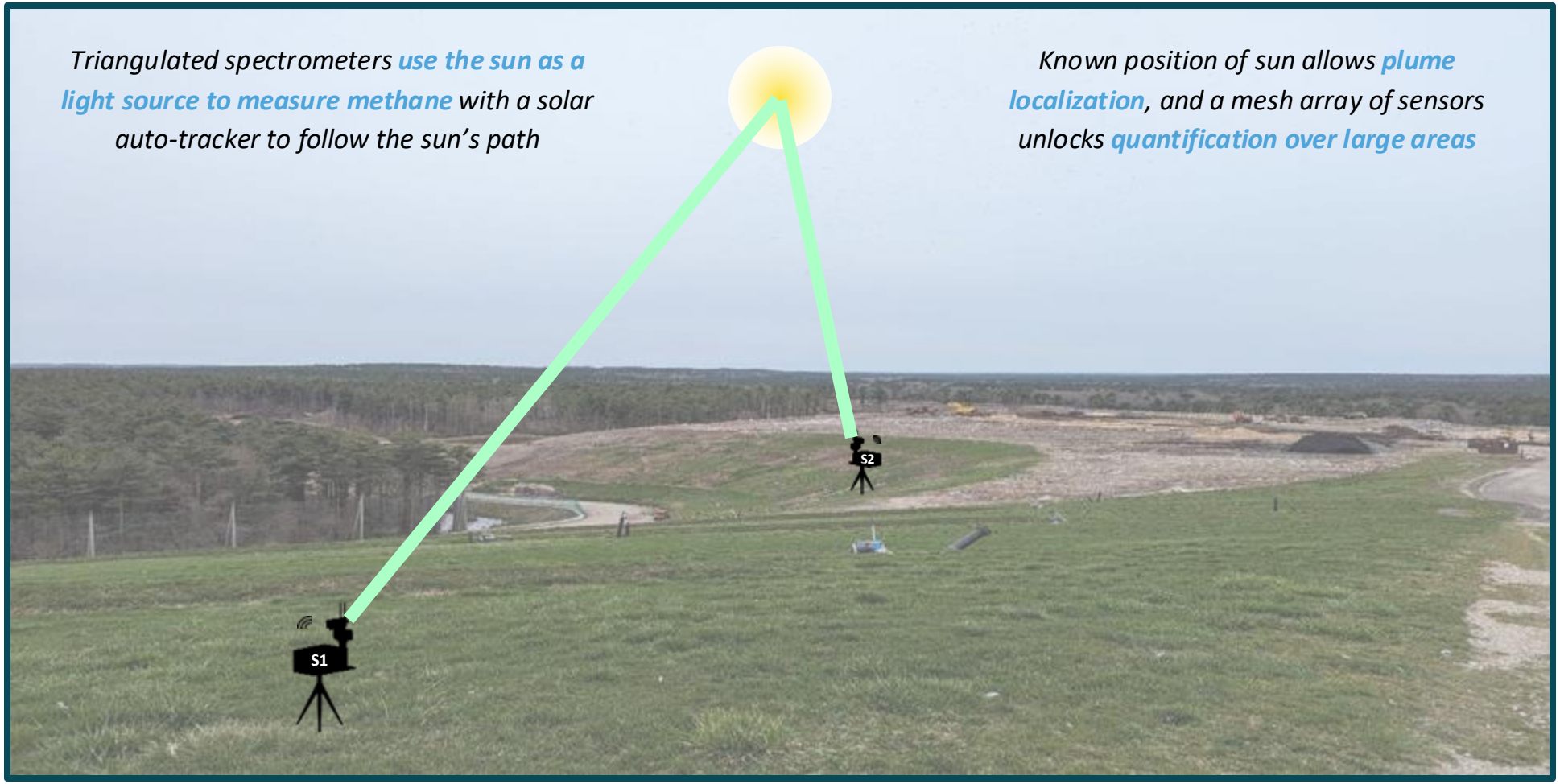
Non–visible light source is beamed at retroreflectors placed up to 300 meters away to create multiple lines of sight through areas of concern



The sensor rotates, beaming non-visible light off of the retroreflectors back to the sensor, capturing path-integrated GHG concentration data

TRELLISENSE

“TrelliSun” || Methane Radar

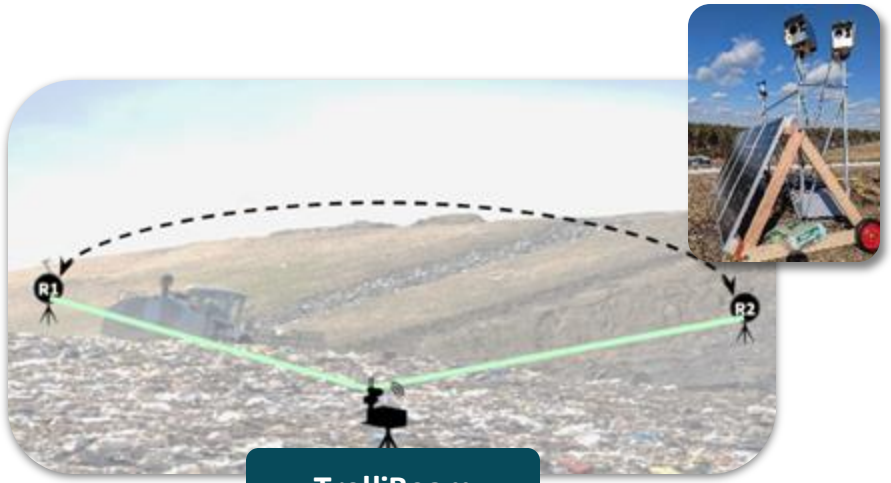


TRELLISENSE

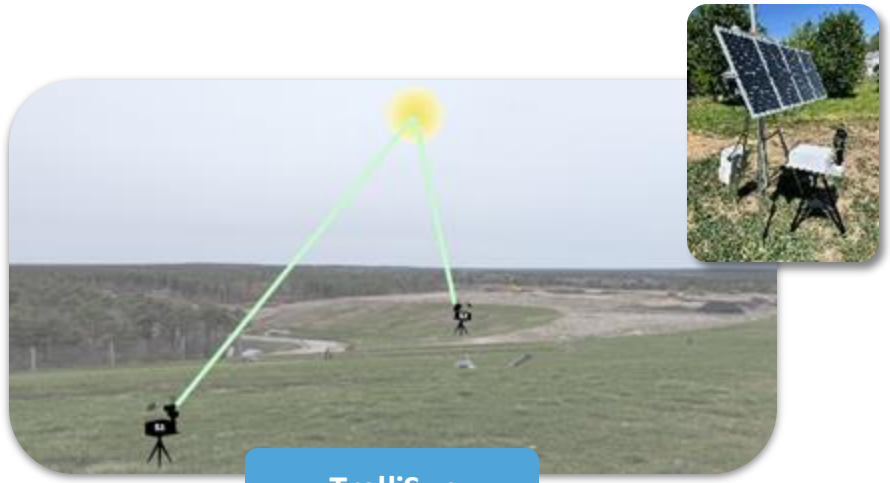
Proprietary and Cost-Effective

Methane Intelligence as a Service

- Proprietary quantum spectroscopy technology
- Continuous
- Modular & portable
- Sensitive (<0.4 kg/hr)
- Low maintenance
- Zero calibration needed
- Weather sensors onboard
- Real-time alerts
- Direct-to-cloud upload
- Zero-CapEx contracts
- CH_4 today; CO_2, NH_3, and more tomorrow



TrelliBeam



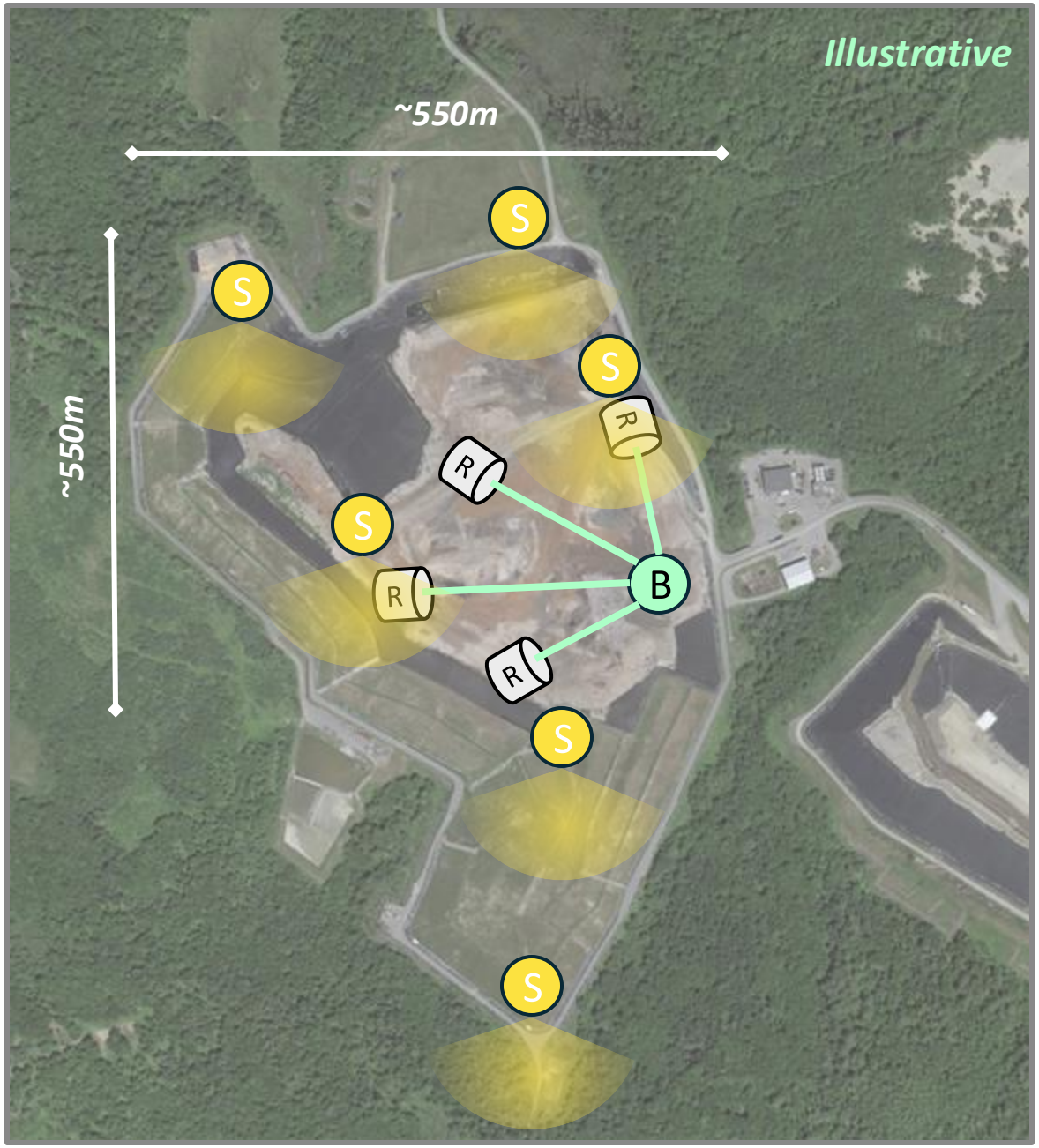
TrelliSun

TrelliBeam		TrelliSun
Invisible Laser	**Light Source**	Sunlight
24/7/365	**Operation**	Daytime Only
300 meters	**Range**	1+ sqkm
<30 meters	**Localization**	<10 meters
Active Face	**Primary Target**	Permanent & Intermediate Cover

Custom Fit for Landfills

KEY

- S — TrelliSun sensor
- B — TrelliBeam sensor
- R — Retroreflector of laser
- Fixed measurement path



TRELLISENSE

Scrappy (and Nerdy) Veteran Team

Small team combines **science, engineering and operations** with experience in **waste, power and oil & gas**

Ben Silton
CEO

- First business hire at food waste RNG startup Divert (exit 2021)
- Venture & innovation consulting for utilities & energy companies
- MBA
- A.B. Math & Economics

ADL VENTURES · Northwestern Kellogg · divert · Middlebury

Dr. Andrew Sappey
CTO

- 2x founder & 1x exit (2020)
- 30+ years of scientific product development
- Former national lab researcher
- Ph.D. Physical Chemistry
- A.B. Chemistry

JOHN ZINK HAMWORTHY COMBUSTION · WISCONSIN · Kenyon · Los Alamos NATIONAL LABORATORY

Dr. Pat Masterson
Chief Scientist

- 30+ years as Electro-Optics engineer, leading sensor engineering and product development
- Ph.D. Physics
- A.B. Physics

MELLES GRIOT · JOHN ZINK HAMWORTHY COMBUSTION · University of Colorado Boulder · PRINCETON UNIVERSITY

Lee Sutherland
Optomechanical Engineer

- 30+ years of hardware engineering and product development leadership
- Former CEO, CTO, Founder & Inventor
- B.S. Mech Engineering

NCAR · ExtractCraft · MONTANA STATE UNIVERSITY · CHURCHILL NAVIGATION

TRELLISENSE

Thank You

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Landfill Methane Emissions Management

Ali Lashgari Ph.D.

Project Canary
Denver, Colorado

PROJECTCANARY.COM

Complexities – compared to upstream oil and gas

- Large areas
- Complex terrain
- A combination of point and diffuse sources
- Higher background emissions
- Weather dependency of emissions

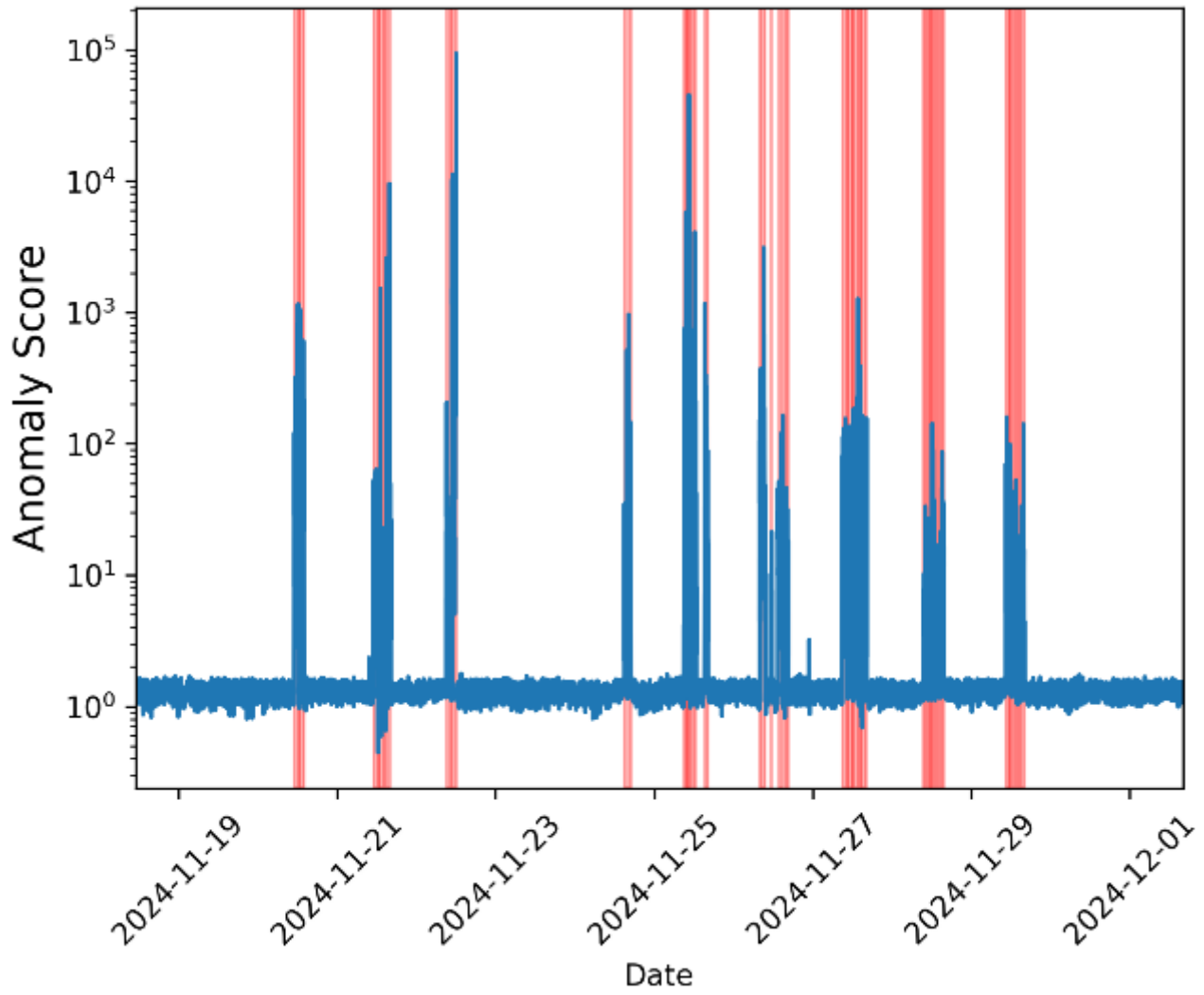
Application of Continuous Monitoring Systems (CMS)

- **Working face and total site emissions** measurement and quantification
- Comprehensive understanding of **temporal variability** of emissions (including nighttime emissions)
- Continuous stream of data to help **anomaly detection**
- Differentiate **allowable emissions from leaks**
- Determine **beyond-fenceline impact** of the landfill operation with high temporal resolution
- Complement and **inform other measurement modalities** (early detection, duration and frequency)
- Informs **frequency of additional surveys** using other methods
- Provides **site-specific atmospheric measurements**

ANOMALOUS EMISSION DETECTION

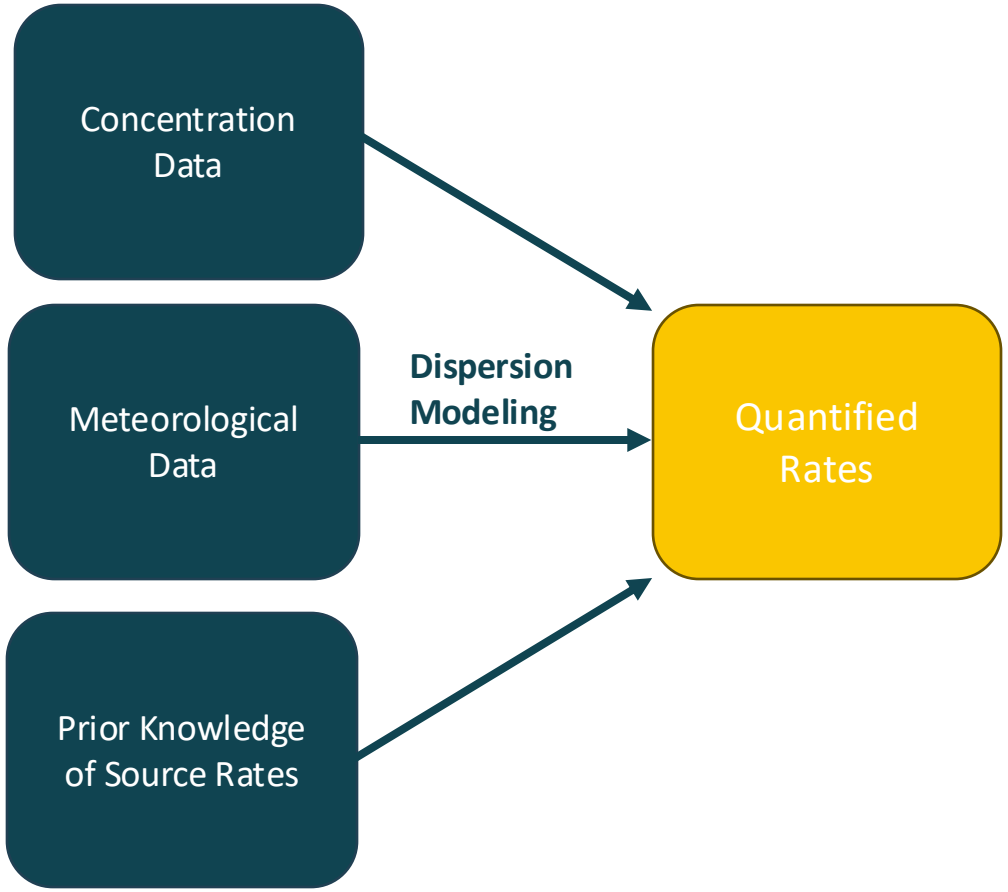
Alerting algorithms capable of detecting periods of time when there is evidence of unusual emissions.

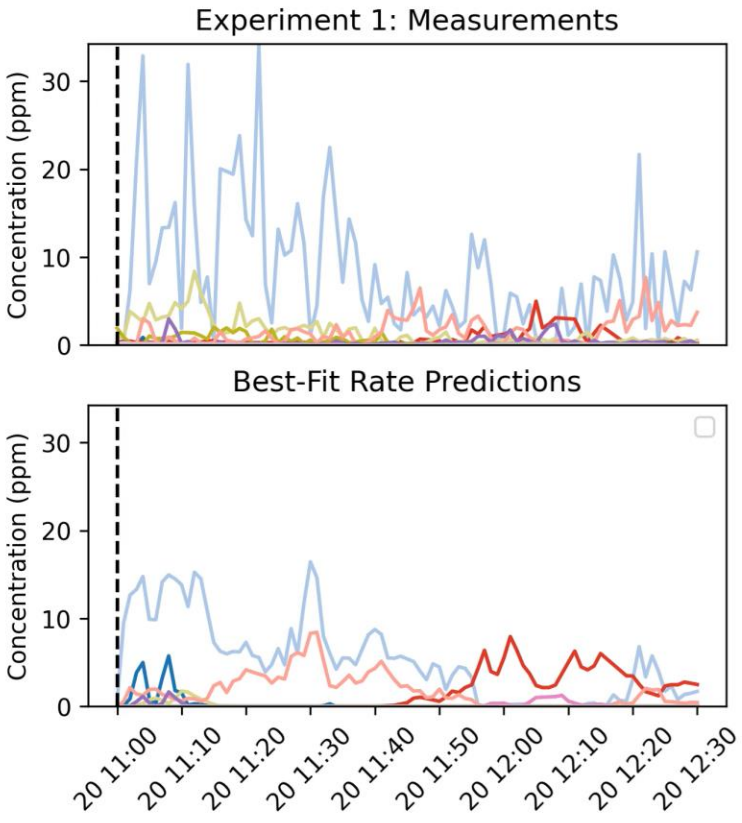
Red Shaded Regions: Controlled Release Times

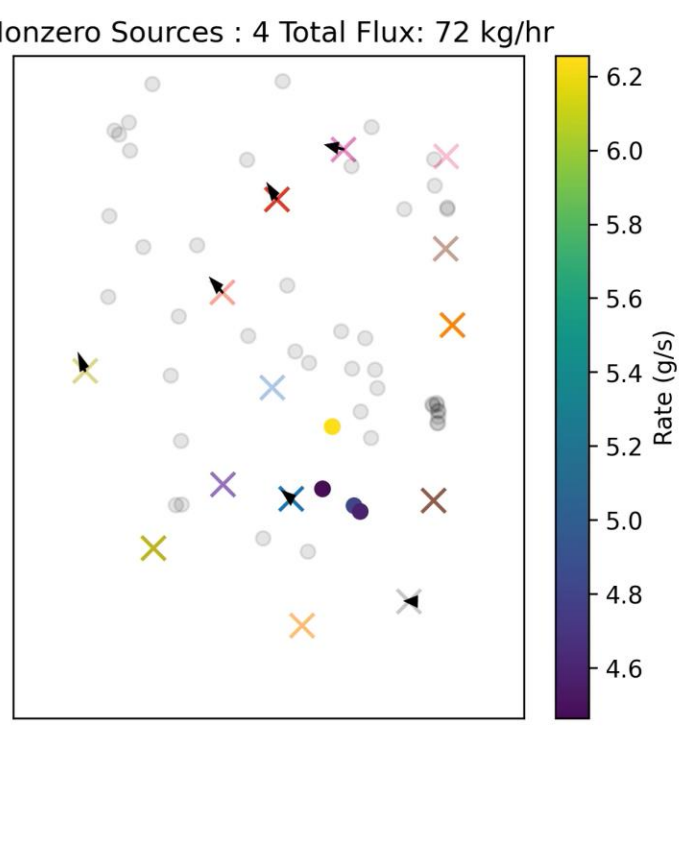


Quantification Model in Action

Project Canary's quantification employs a probabilistic model to iteratively update source rate estimates





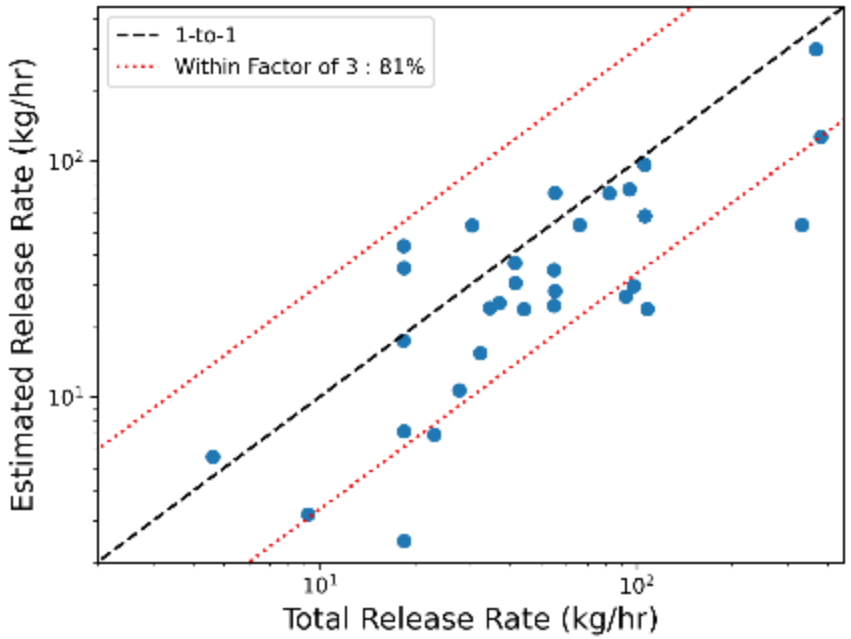


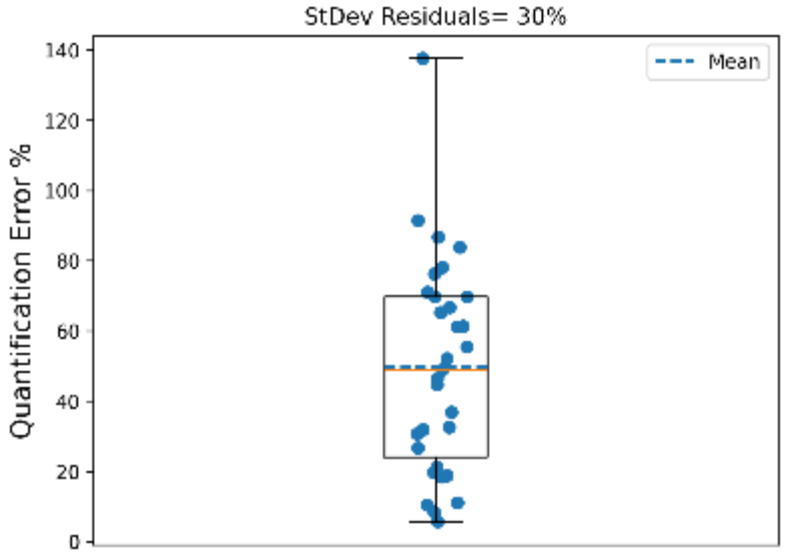
BLIND RESULTS: QUANTIFICATION

Key Metrics:

- 81% of estimates were within a factor of 3 of actual release rate
- Mean absolute percent error: 45%
- Standard Deviation of Residual: 30%

Plenty of room for improvement, especially regarding the bias of the system, but showing a lot of promise for providing reasonably consistent estimates regarding order of magnitude of cumulative emissions (i.e., the system can fairly reliably distinguish between small, medium, and large leaks)





Universal Compatibility with Other Measurement Technologies

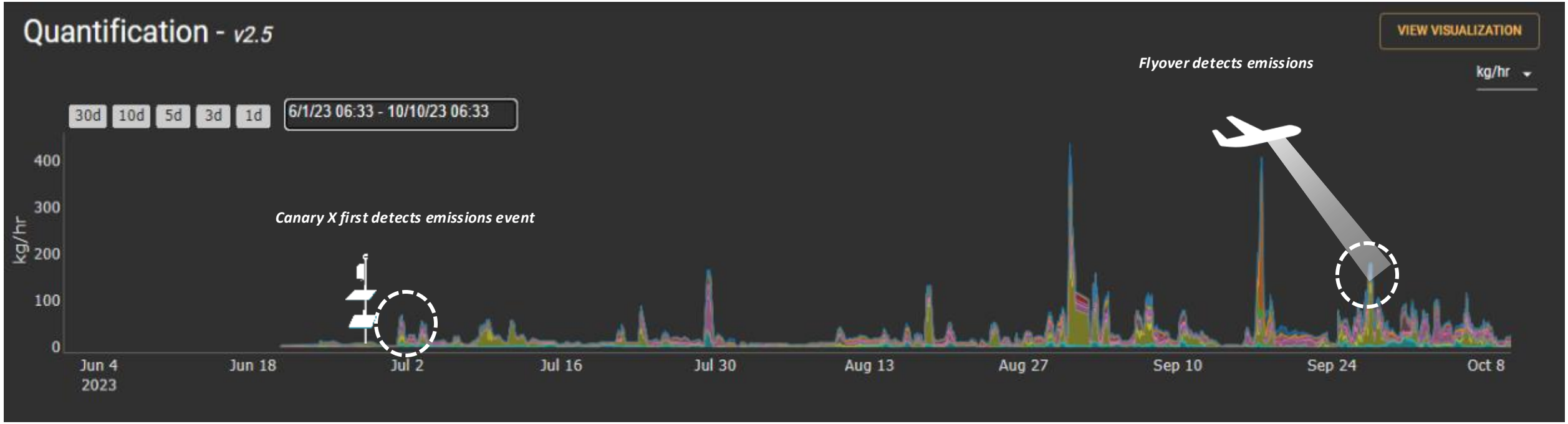
Currently taking in data collected by:

BRIDGER PHOTONICS · SENSIRION · EARTHVIEW · sniffer · KUVA Methane Mitigation Simplified · INSIGHT M METHANE MANAGED · GHGSAT

WE WORK WITH THE DATA YOU ALREADY HAVE

Multiscale Measurement in Practice – data-driven approaches vs employing statistical methods

CMS provides temporal resolution for emission events



Duration of Event Estimated by Approach

- Flyover emissions rate applied since last detection – 599,280 kg
- Canary X quantified emissions over same time period – 66,757 kg

At Time of Flyover – 09/27/2023

- Flyover quantified emissions estimate – 227 kg/hr
- Canary X quantified emissions estimate – 181 kg/hr

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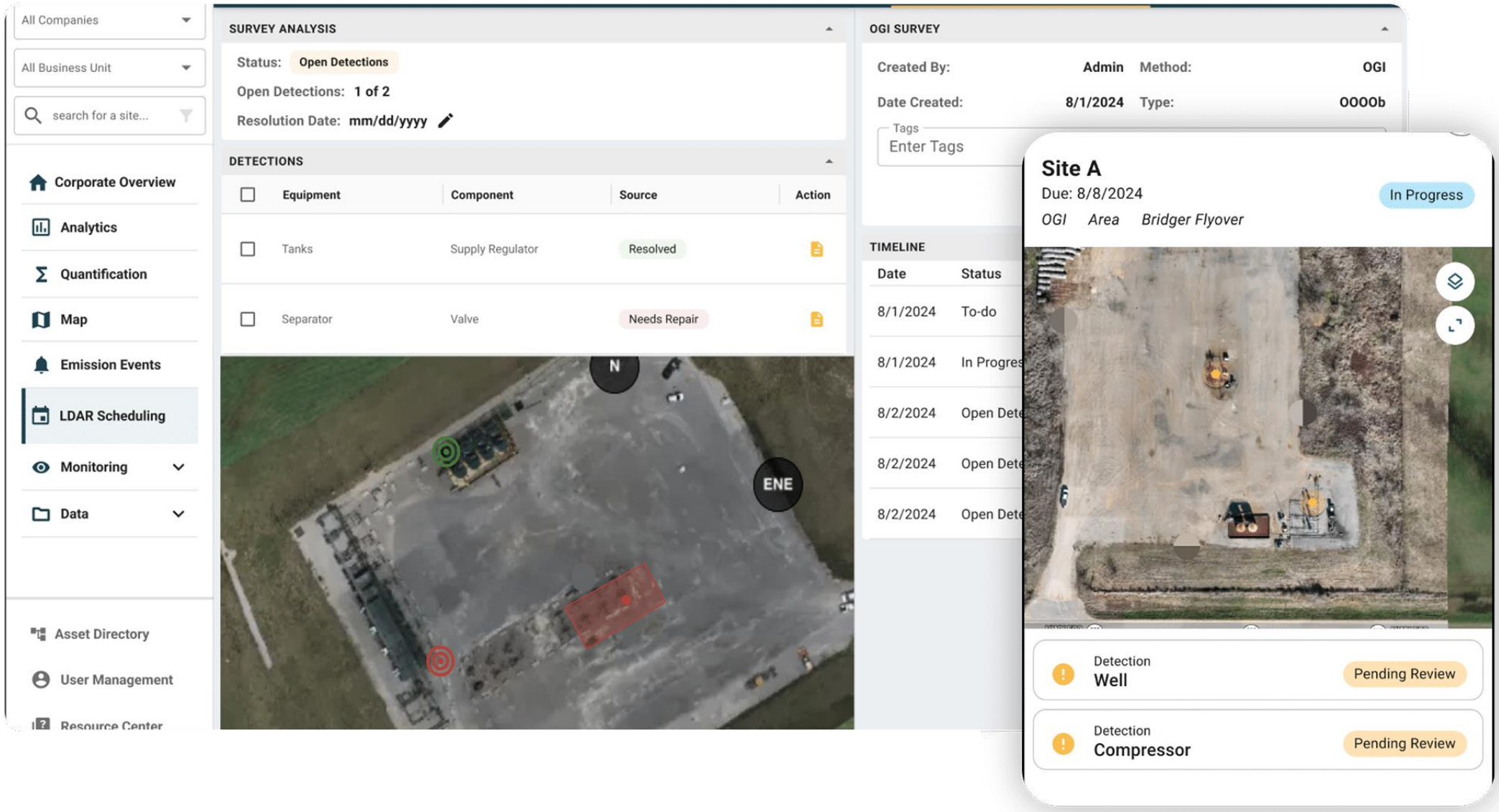
Operational Tools



Q&A

MACKENZIE SMITH
Director of Airborne Operations
ChampionX

GREG RIEKER
Co-founder &
Chief Technology Officer
LongPath Technologies

RIKKI COOK
Co-Founder
Grand Valley Instrumentation

BEN SILTON
Chief Executive Officer
TrelliSense

ALI LASHGARI
Senior Scientist
Project Canary

What's Next for Landfill Methane in Colorado

August 5: Written Public Comment Deadline for Landfill Methane Regulation 31
Written comments will be accepted until 5 p.m. MT on August 5th at cdphe.aqcc@state.co.us.

August 8: Clean Air Program (CAP) Grant Funding Opportunity Closes
Grants are available now to help landfills cover the cost of critical upgrades, but the clock is ticking. Counties and landfill operators can apply by August 8th for CAP funding to modernize monitoring and methane capture.

August 20-22: AQCC Hearing for Regulation 31
Members of the public can register on Zoom to provide public comment at https://cdphe.colorado.gov/aqcc.

August–September: Story Window
Colorado could become a national leader in managing one of the most overlooked sources of climate and health-harming pollution. Behind the data are real communities, real stakes and a rulemaking process unfolding in real time.

Thank You!

Further Questions?

Please reach out to:
Ellie Garland (egarland@rmi.org) or
Madison Hall (mhall@rmi.org)