Landfill Emissions Measurement Industry & Research Panel

Amy Banister, Sr. Director of Air Programs (WM)
Dr. Dave Risk, Research Chair in Climate Science & Policy (St. Francis Xavier Univ. FluxLab)
Mike Thomson, Environmental Innovation Program Manager (GFL)
Niki Wuestenberg, Sr. Manager of Air Compliance (Republic Services)

Moderator: Dr. Bryan Staley, CEO (Environmental Research & Education Foundation)

Background & Current Targets

Corporate Sustainability Targets

WM

1) Reduce absolute scope 1 and 2 GHG emissions 42% by 2031
2) Increase beneficial use to 65% by 2026
3) Have a methane measurement system by 2025

Republic Services

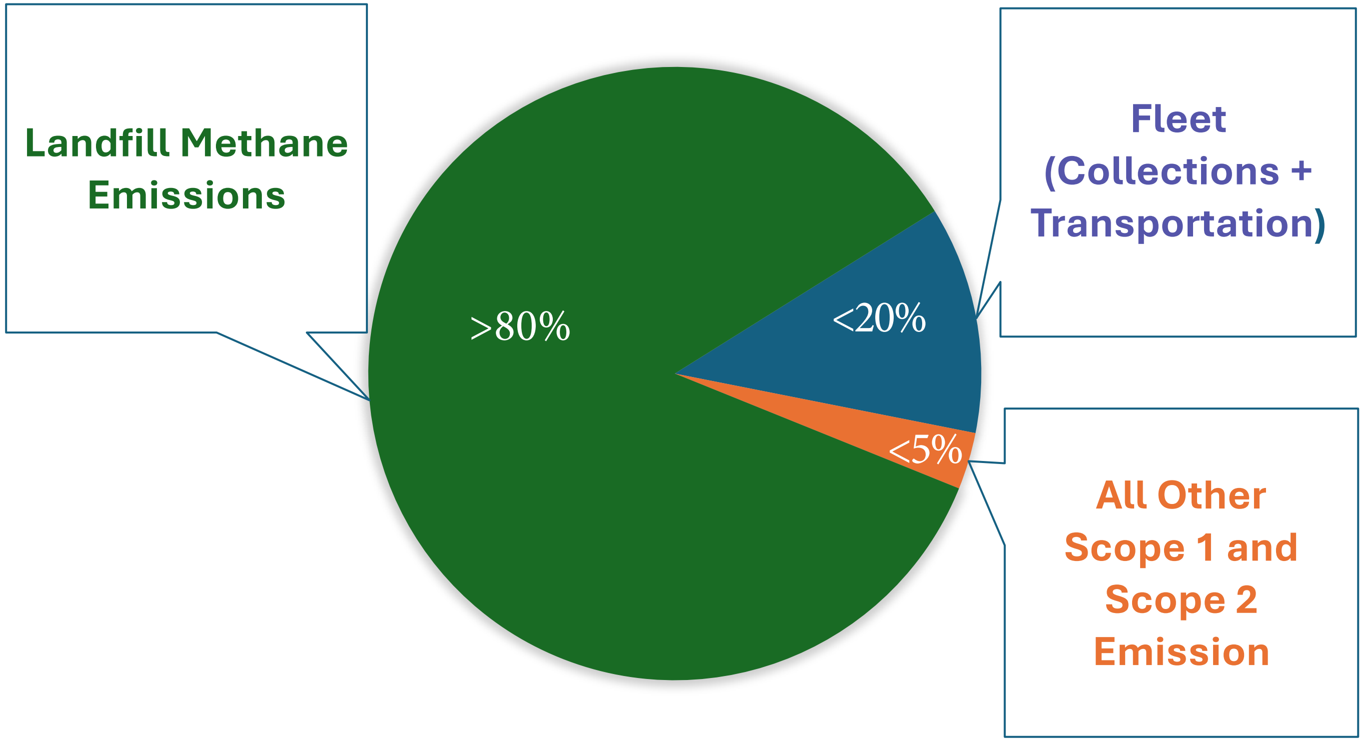
1) Reduce absolute scope 1 and 2 GHG emissions 35% by 2030
2) Increase recovery and circularity of key materials by 40% on a combined basis by 2030
3) Increase biogas sent to beneficial reuse by 50%

GFL

1) Increase beneficial use of biogas from landfills 2x by 2030
2) Decrease scope 1 and 2 emissions 15% by 2030

Waste Management Sector Emissions

- Landfill methane emissions account for >80
- Fleet accounts for < 20%
- All other Scope 1 and Scope 2 emission <5%



Industry Research and Experiences with New Technologies

GFL's Sustainability Value Initiatives (SVIs)

Focus Areas for **Next Generation** and **Incubator** SVIs

Fugitive Emissions and Energy resource Management

- Next generation surface emission monitoring using satellite aircraft, drones and fix sensors
- Data Management and analytics for optimalization of gas collection and control systems
- Support research, policy development and sector advocacy into landfill gas measurement and monitoring techniques and technologies by industry associations

Customer Sustainability Pilots

- Tailored services to improved collection of data and understanding of scope 3 emissions
- Service specific performance monitoring and reporting (such as vehicle distance travelled, emissions avoided)

Advance Wastewater Management

- Leverage expertise to manage leachate and deliver best in class services
- Pilot leachate treatment technologies for emerging contaminants

Advance Material Recovery

- Develop emerging, high volum industrial material recycling
- Continue investments in advanced MRFs and organics recycling

Zero emissions Vehicles

- Continue to pilot latest advancements in electric and hydrogen powered vehicles
- Develop roadmap to zero emission fleet

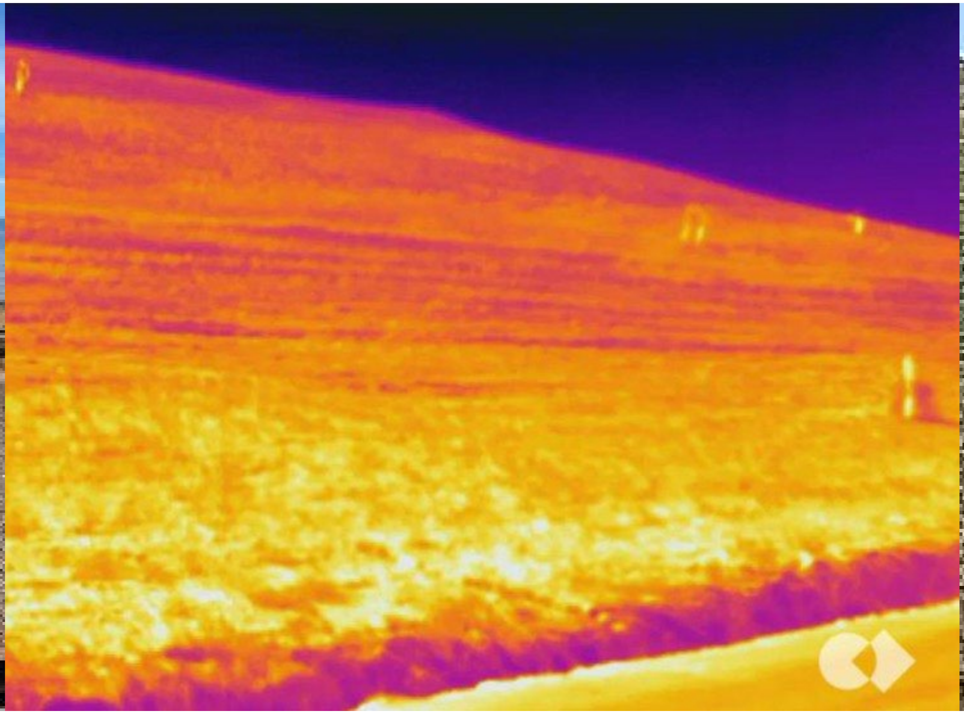
Fugitive Emissions and Energy Resource Management

- Next generation surface emissions monitoring using satellites, aircraft, drones and fixed sensors
- Data management and analytics for optimization of gas collection and contrail systems
- Support research, policy development and sector advocacy into landfill gas measurement and monitoring techniques and technologies by industry associations

Supporting Technology Development

- Provided landfill access and operator expertise (e.g. SnifferDRONE™ , as well as Andium)
- Incorporated fixed fence-line sensors for methane into odour management
- Supporting FluxLab Remote Mobile Sensor Emission Assessment (RMSEA) at Canadian landfills, and controlled releases
- Ongoing collaboration with South Wake County Landfill to work with US EPA Office of Research and Development field work Next Generation Emission Measurements (NGEM)
- GFL's Greenlight Innovation Workshop brought together technical and operations personnel to develop solutions

Andium OGI Video Solution



- Proprietary Optical Gas Imaging (OGI) to detect and visualize methane
- Machine learning algorithm to identify methane leaks, and notify operations
- Continuous monitoring
- Solar powered skid with telemetry for remote operation

Challenges and Opportunities

- Standard methods and clarity of deliverables
- Cost effective deployment at scale
- Organizing Next Generation data with conventional information
- Converting data to actionable information
- Building a track record to show progress

Emissions Measurement & Analytics

Find Fix and Manage

- *Collect more gas*
- *Reduce GHG emissions*
- *Minimize Observations*

Amy Banister, Sr. Dir Air Programs, WM

USEPA Technical Workshop – October 29, 2024

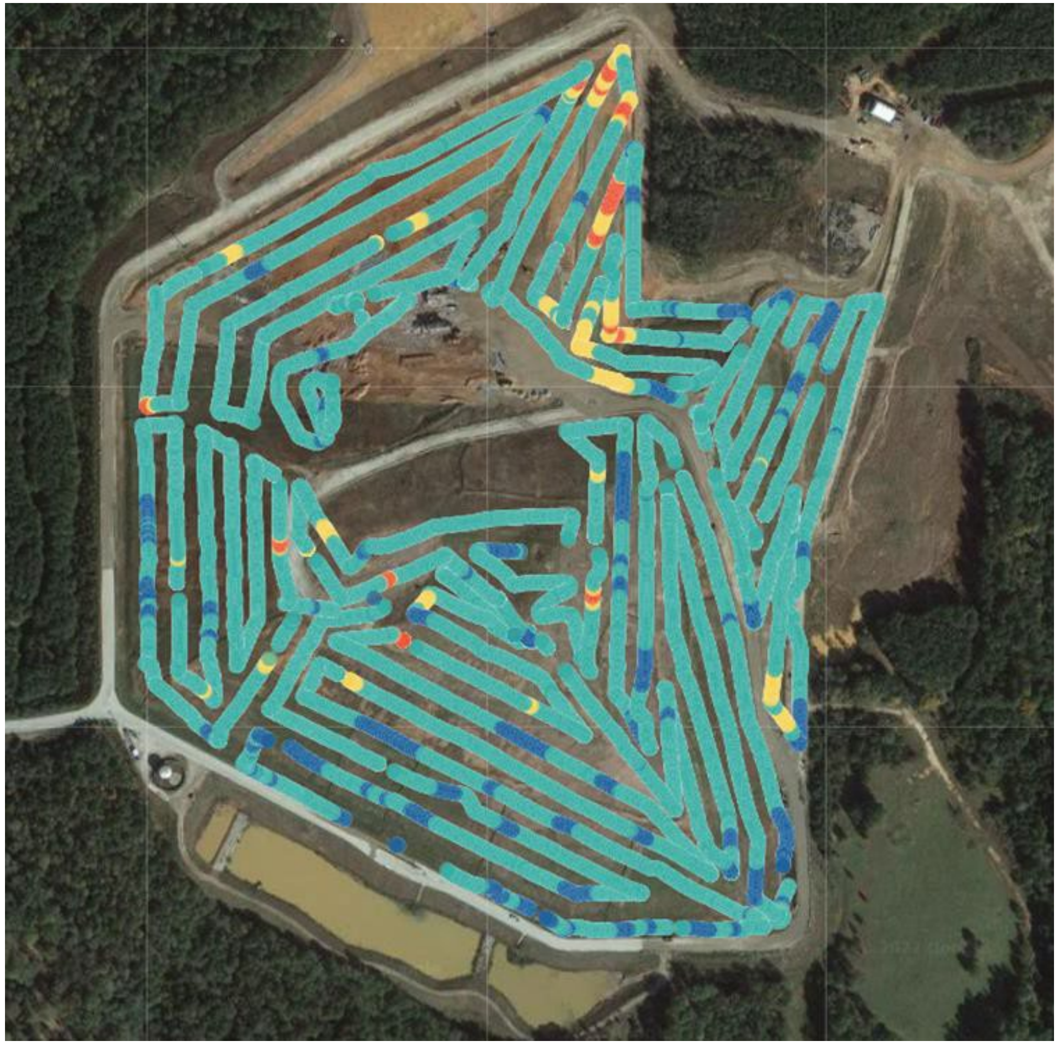
What are we trying to achieve with landfill emissions measurements?

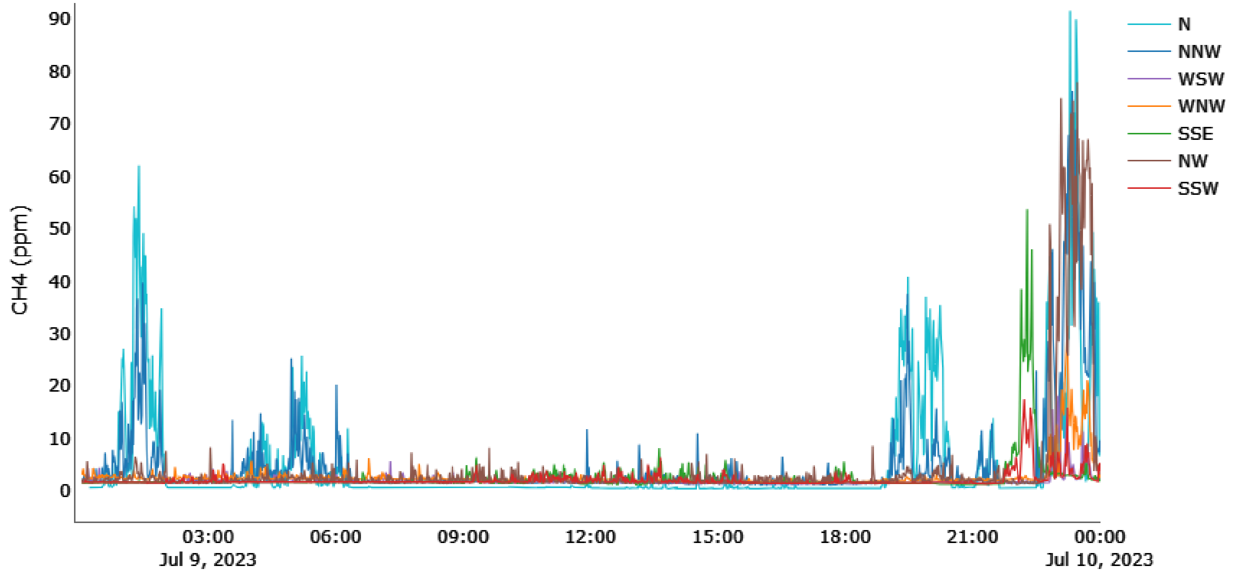
Localize – identify the physical location of emission sources to facilitate remediation and understand root causes.

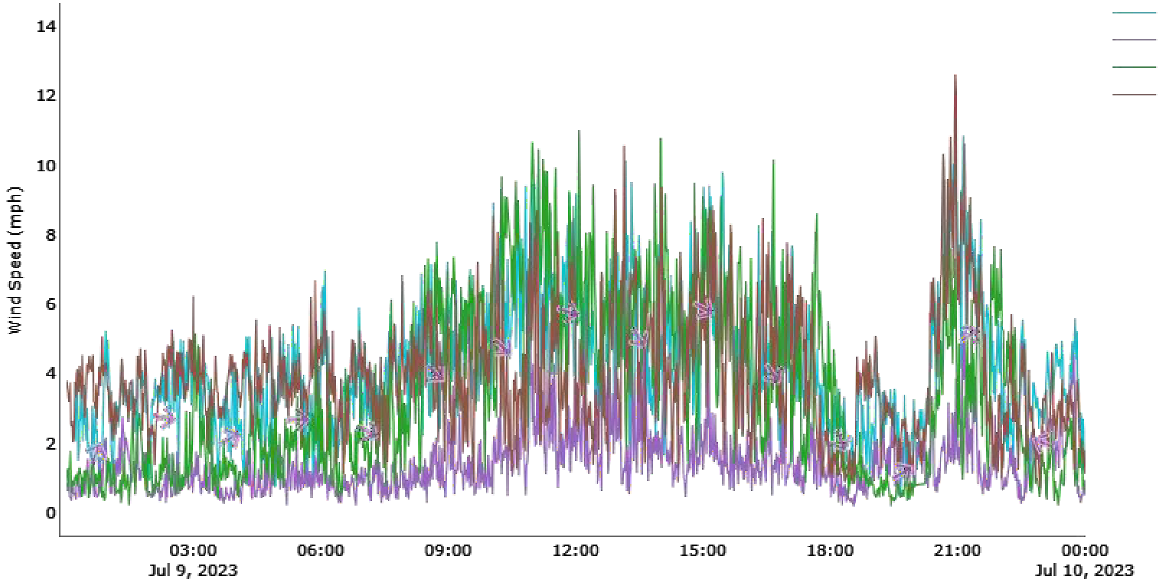
Quantify – determine the mass emission rate to compare to model and inventory values and gauge emissions mitigation actions.

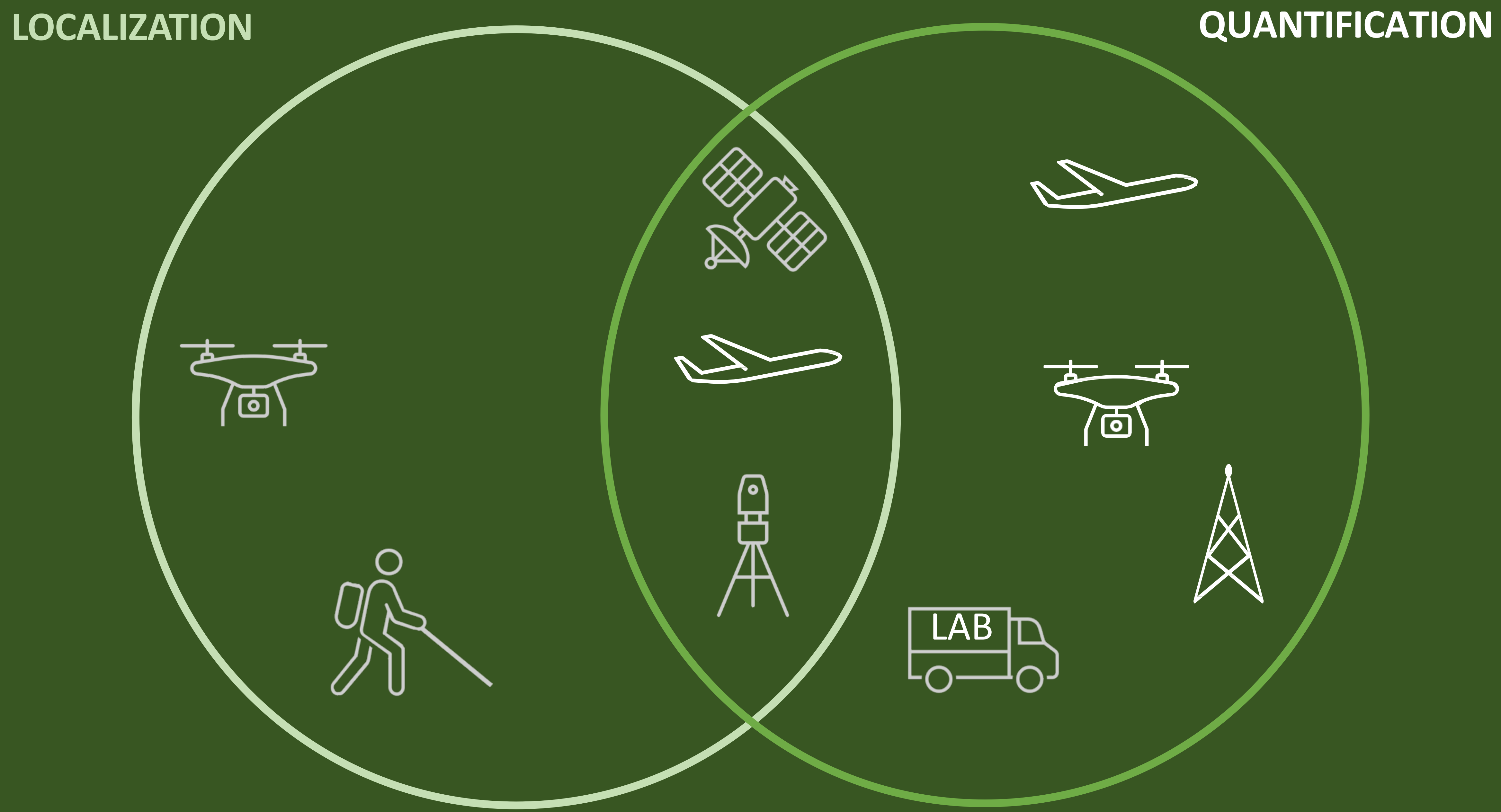
Evaluate and Deploy – compare methods with whole landfill measurements to understand what combination of approaches is accurate and scalable. Develop and assess best practices to operationalize information for mitigation.

Emissions Vary in Space and Time (concentration values shown)









LOCALIZATION
QUANTIFICATION
LAB

Measurement and Technology Evaluation Approach

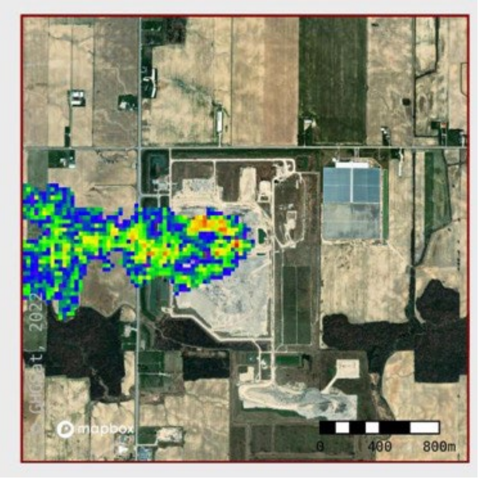
Continuous

fixed sensors

Source: Champion X/Scientific Aviation

Monthly

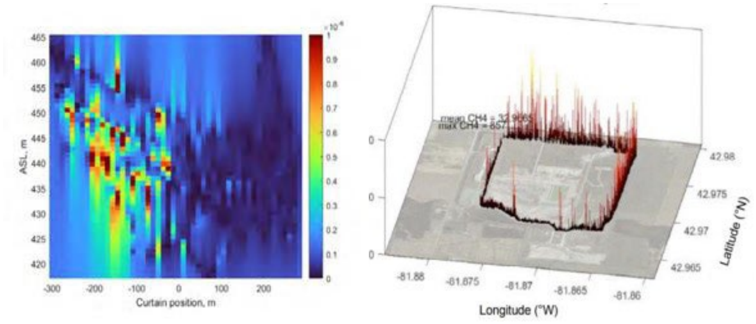
satellite observations



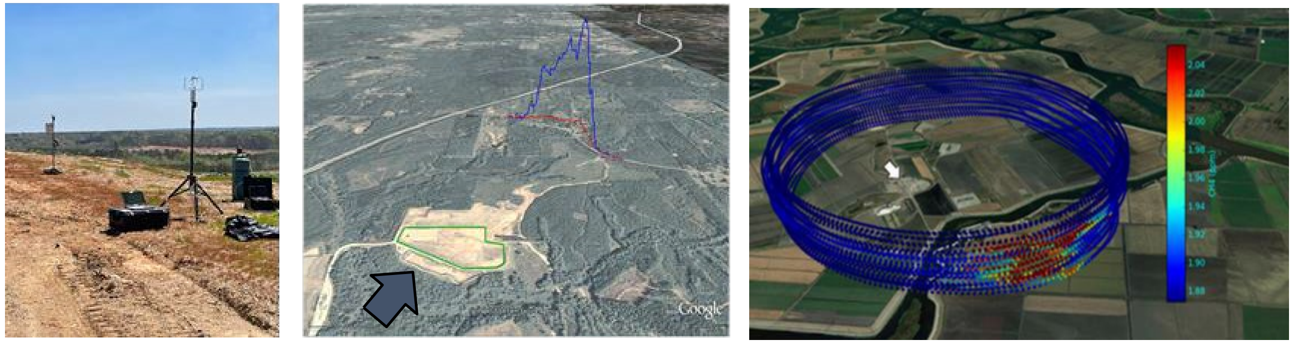
Source: GHGSat, Inc.

Quarterly

SEM and flux measurements (mobile, drone, aircraft)

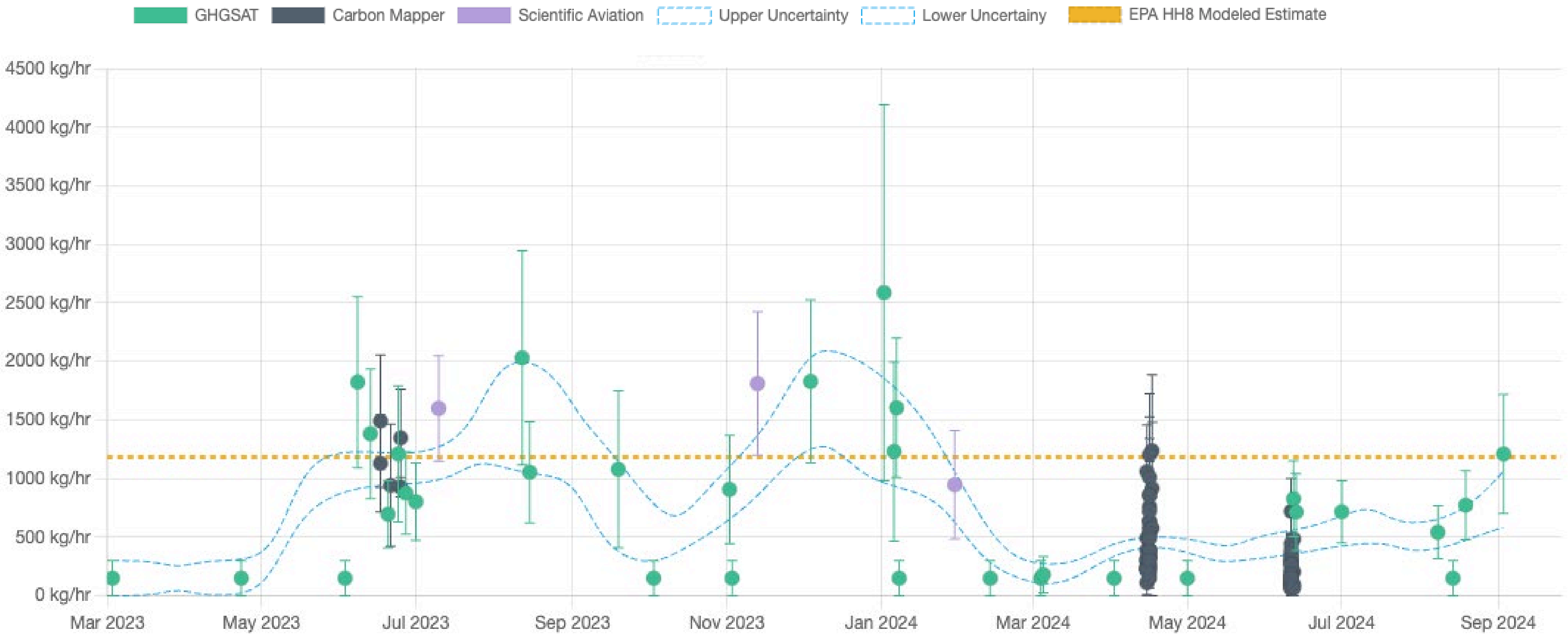


tracer correlation measurements (WM-FSU)



Source: Champion X/Scientific Aviation

Example West Coast Landfill Emission Rates Over Time



"Find it - Fix It"

Three distinct sources observed by satellites and aircraft.

Source A (Active fill area)

- 14 observations June 2023-January 2024
- Ongoing GCCS expansion, wells damaged due to filling operations, and anomalous heavy rains.

Source B (GCCS construction)
Observed in June 2023.

- Installation of trench collectors during satellite observations. Satellite detects ceased once trenching completed.

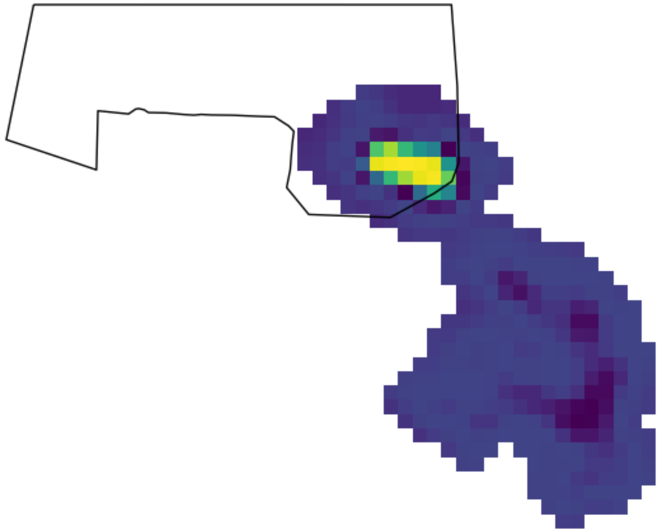
Source C (Flare downtime)

- Observed Jan 2 and 6, 2024 – correlated to a flare downtime

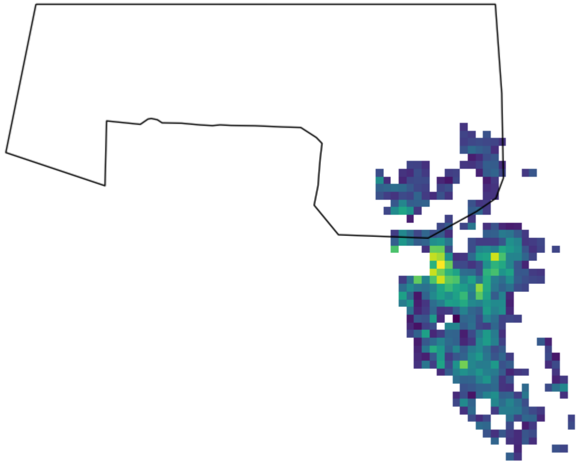
2024 observations indicate emissions were significantly lower

Need to standardize emission rates from satellites

Large variance in emission rate from different providers



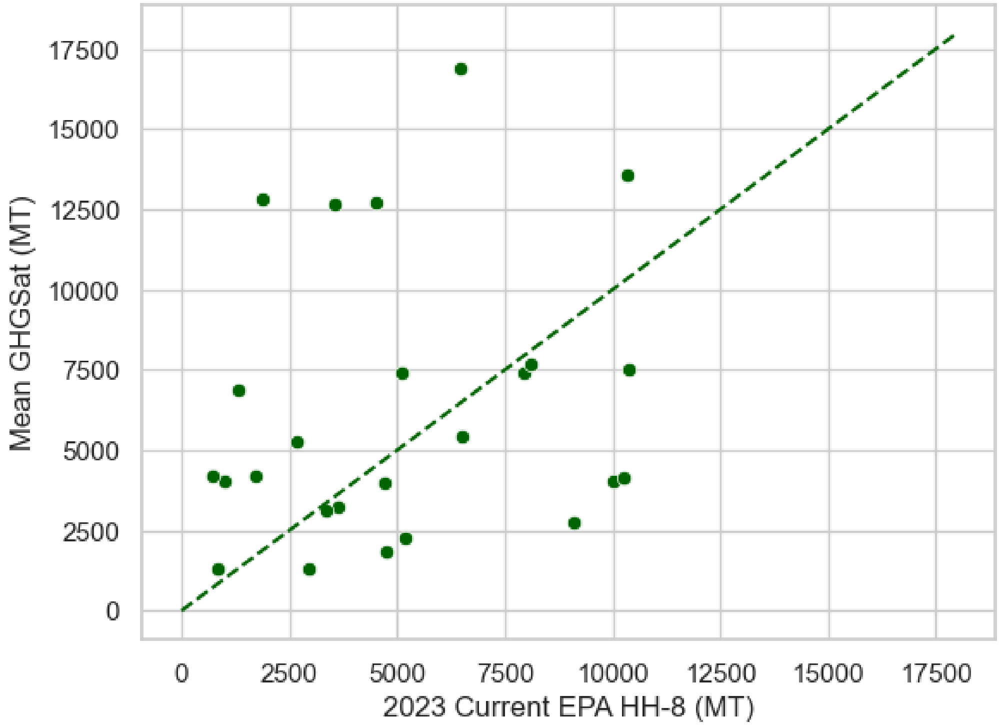
10:30 AM
4,300 kg/hr
Windspeed: 3.01 m/s (from HRRR)



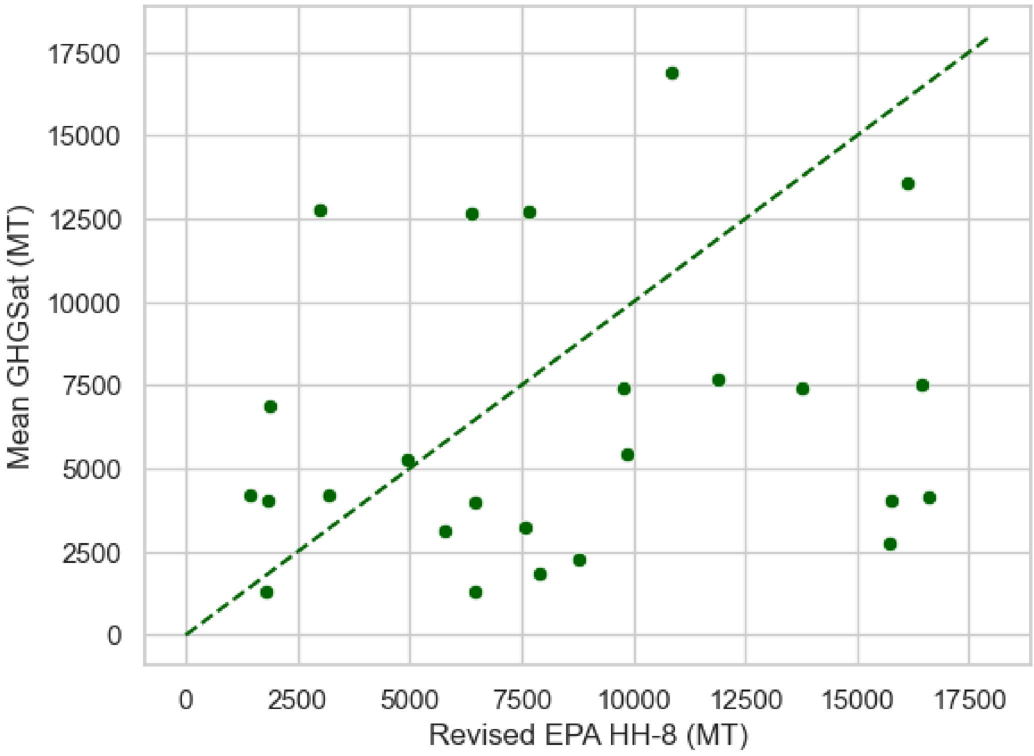
11:45 AM
560 kg/hr
Windspeed: 2.3 m/s (from GEOS-FP)

Satellite Measurements Versus GHGRP Subpart HH Model

EPA GHGRP 2023



EPA GHGRP 2024 Changes*



Satellite measurements were tasked monthly from Feb 2023 to April 2024

Need many measurements over time to be able to estimate emission rate of a site.

* Fed Reg@31802, April 25, 2024

Lessons Learned

WM Landfill Methane Measurement Study

There is no silver bullet, one-size-fits-all approach.	Some combination of measurement approaches that capture temporal variability in emissions and provide reasonably accurate quantitation will be needed.
Technologies developed and used for the oil and gas sector are not directly transferrable to landfills.	Fixed sensors and drone flux approaches show promise. However, quantitation and localization needs additional development and study.
Understanding the status of the landfill is key to understanding the potential sources of emissions	• LF Gas System status & Construction activity • Cover type and distribution (optical imagery can be very useful in this context) • Local MET data (wind speed, direction, atmospheric pressure)
2023 EPA Reported emissions compared to measured emissions at 25 sites are highly variable.	
Executing studies combining multiple measurements is complex, expensive and challenging.	We need to find more ways to collaborate and leverage expertise and reduce the cost of this work.

Automated Wellheads Lessons Learned

- Over 700 wells from two vendors installed across 11 WM sites
- Found to increase flows and sustain LFG composition
- Cost effective for sites with current and planned RNG plants
- Not all wells are good candidates

Thank You!

WM Contacts:

- *Amy Banister (abaniste@wm.com)*
- *Roger Green (rgreen2@wm.com)*
- *Halley Brantley (hbrantle@wm.com)*

Emission Quantification & Identification Evaluation

Niki Wuestenberg; Sr. Air Programs Manager

USEPA Technical Workshop - October 2024

Framework

- Measure and quantify emissions
  - Transparency – measure with data
  - Identification – allows ability to mitigate
  - Actionable – measurement provides ability to remediate
- Finding cost effective technology options
  - Deployable
  - Non-proprietary
- Trust
  - Measurement builds confidence in the data for regulators, investors, stakeholders

Executive LFG Methane Technology Pilot Summary

Pilot Project – Midwest & South

- Evaluating Quantification Emission and Leak Technologies
- Two-week study evaluation of methane drone sensor testing capabilities of drone to determine threshold and emission rates for data integrity.

2022
Evaluate Tech's

Q4 2022
Initial Pilot Testing

Q3 2023
Stationary Sensors
Methane Leak Scans

Q1 2024
Added more Leak Scans

Q3 2024
2 week sensor study

Final Pilot tests
Q4 2024

Q4 2024
Evaluate Next steps

Satellite

- **Insights:**
- Diffuse emissions not detected
- Provides snapshot in time emissions
- Detects larger point sources
- High altitude imaging to provide broad measurement on atmospheric columns

Plane

- **Insights:**
- 360º flux emission curtain
- Provides snapshot in time emissions
- EPA is developing test method OTM-58

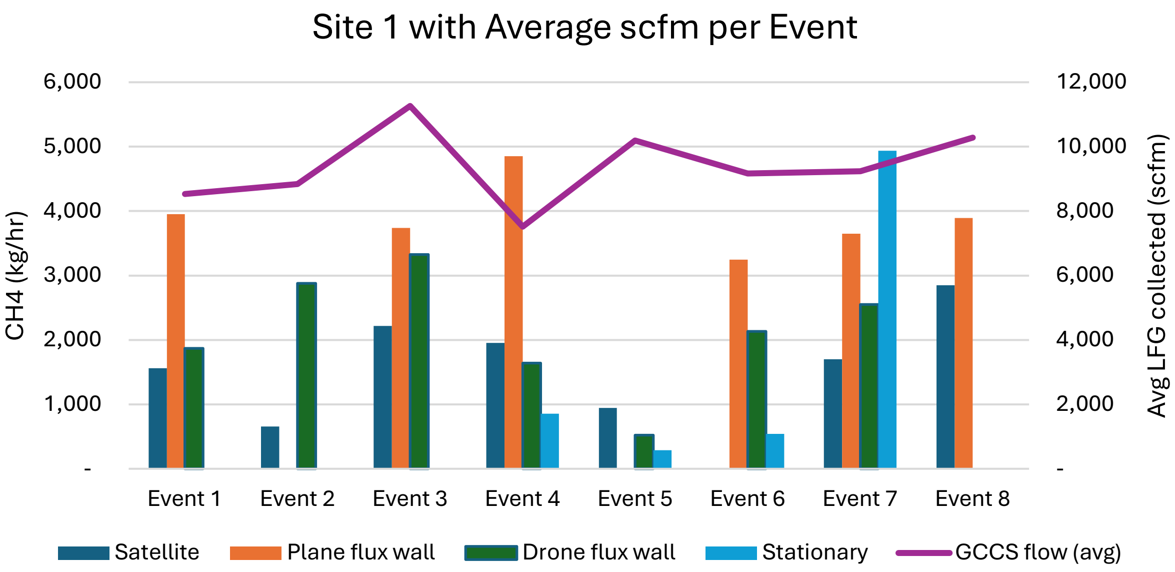
Drone

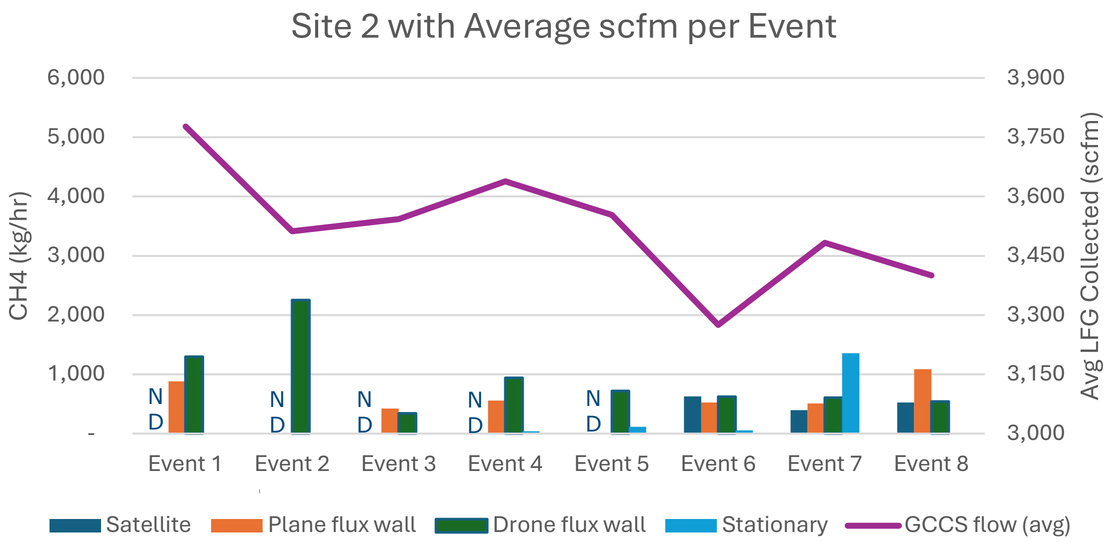
- **Insights:**
- Lower deployment complexity
- Create a flux emission curtain for snapshot in time emissions
- Deployable for "leak" detection
- Identifies large & small emissions sources with greater degree of nuance and precision

Stationary

- **Insights:**
- 24/7 monitoring frequency
- Quadrant emissions focus
- Fixed metal oxide sensors

Preliminary Results- Pilot Emissions





Site Located South
Approximately 400 acres
>500 gas collectors

Site Located Midwest
Approximately 160 acres
>180 gas collectors

Note: Aircraft used only for events 1, 3, 4, 6, 7 & 8; Stationary began event 4

Only in 2 cases did the emissions findings correlate to reduced GCCS flow; Aircraft in Round 4 at Site 1, and Drone in Round 2 at Site 2

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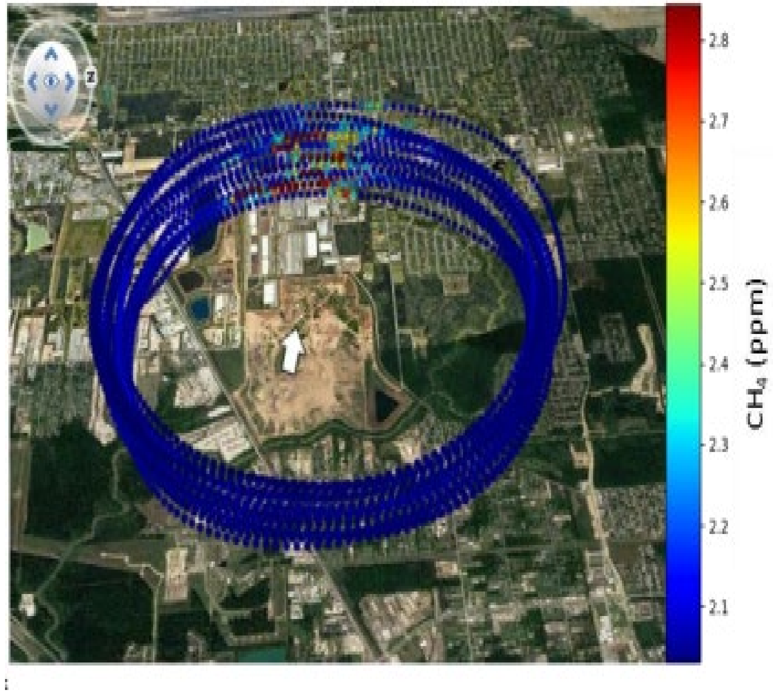
Flux Wall Technologies



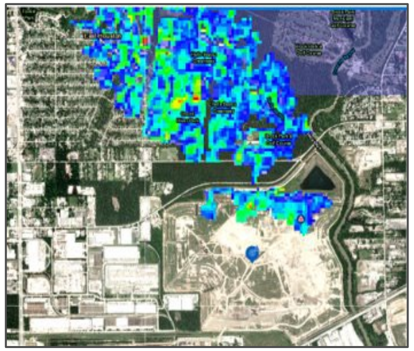
Aircraft includes potential emissions beyond the landfill

Quantification Challenges

Methane Emissions Quantification Comparisons

- Competing technologies providing inconsistent results for same site conditions
  - Unique algorithms for processing atmospheric data (e.g., wind)
- Detection limits vary by technology
- No approved standard methods developed

Satellite

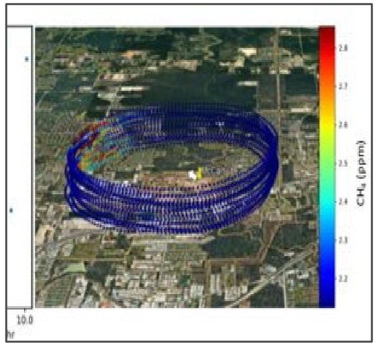


Satellite emissions plume

Drone

Drone emission flux

Airplane



Flux Wall Concentrations at various altitudes

Fixed Sensor

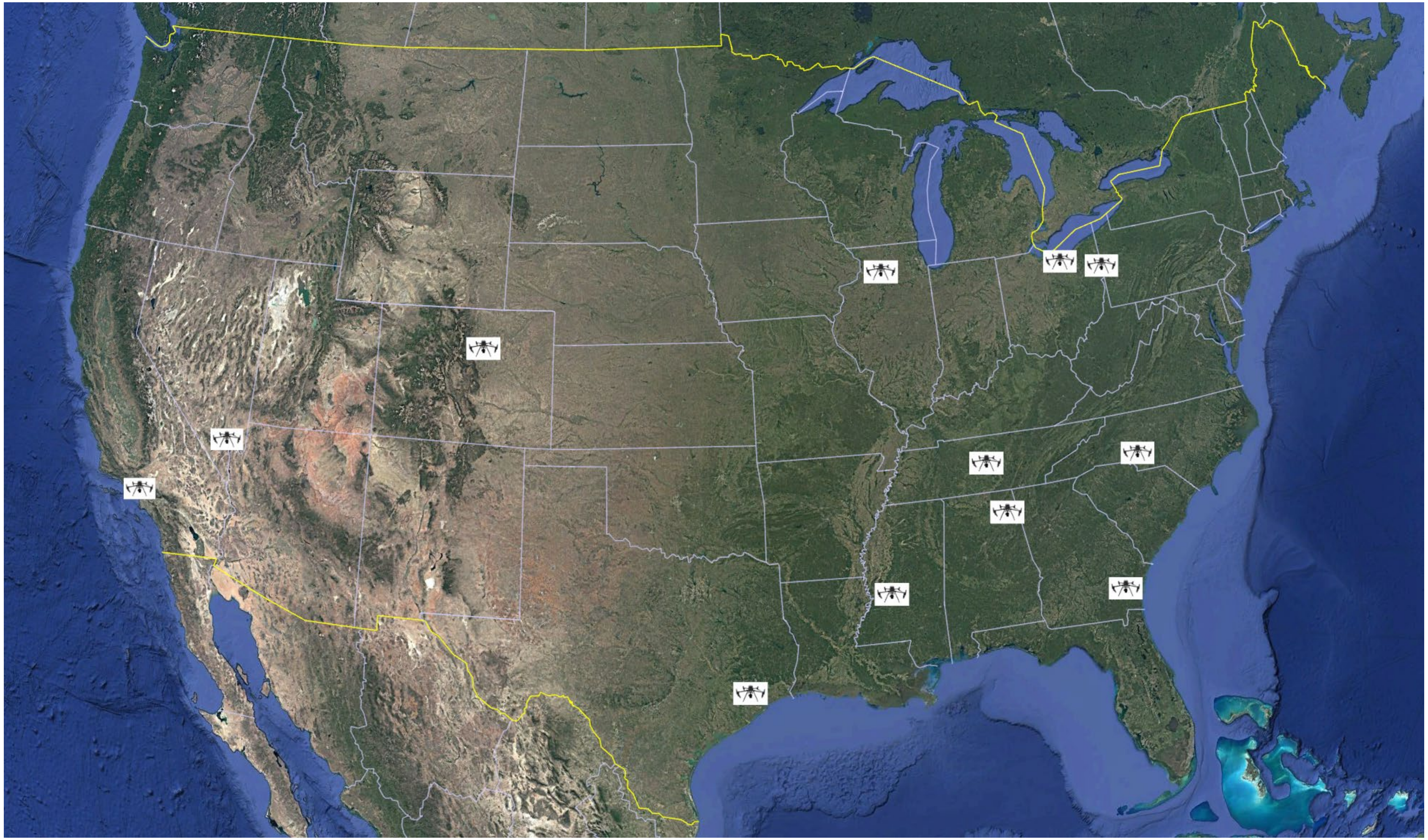
Continuous

Key Takeaways

- Weather patterns (wind, clouds, rain, snow) limits
- Topography complex
- Difficult to assume yearly emissions with snap shots
  - Construction on-going
  - Diurnal Impacts
- Landfill topography/emission source location can impact
- Difficult to stack technologies on same day

Variability between quantification technology pilot; continued data analysis required

Drone Leak Detection – 2023 Pilot Locations



2023

Sites: **12**

Flights: **21**

Focus Areas

- Gas Expansion
- Localization Opportunities
- Capping Events
- New Gas System Install
- RNG plant startup

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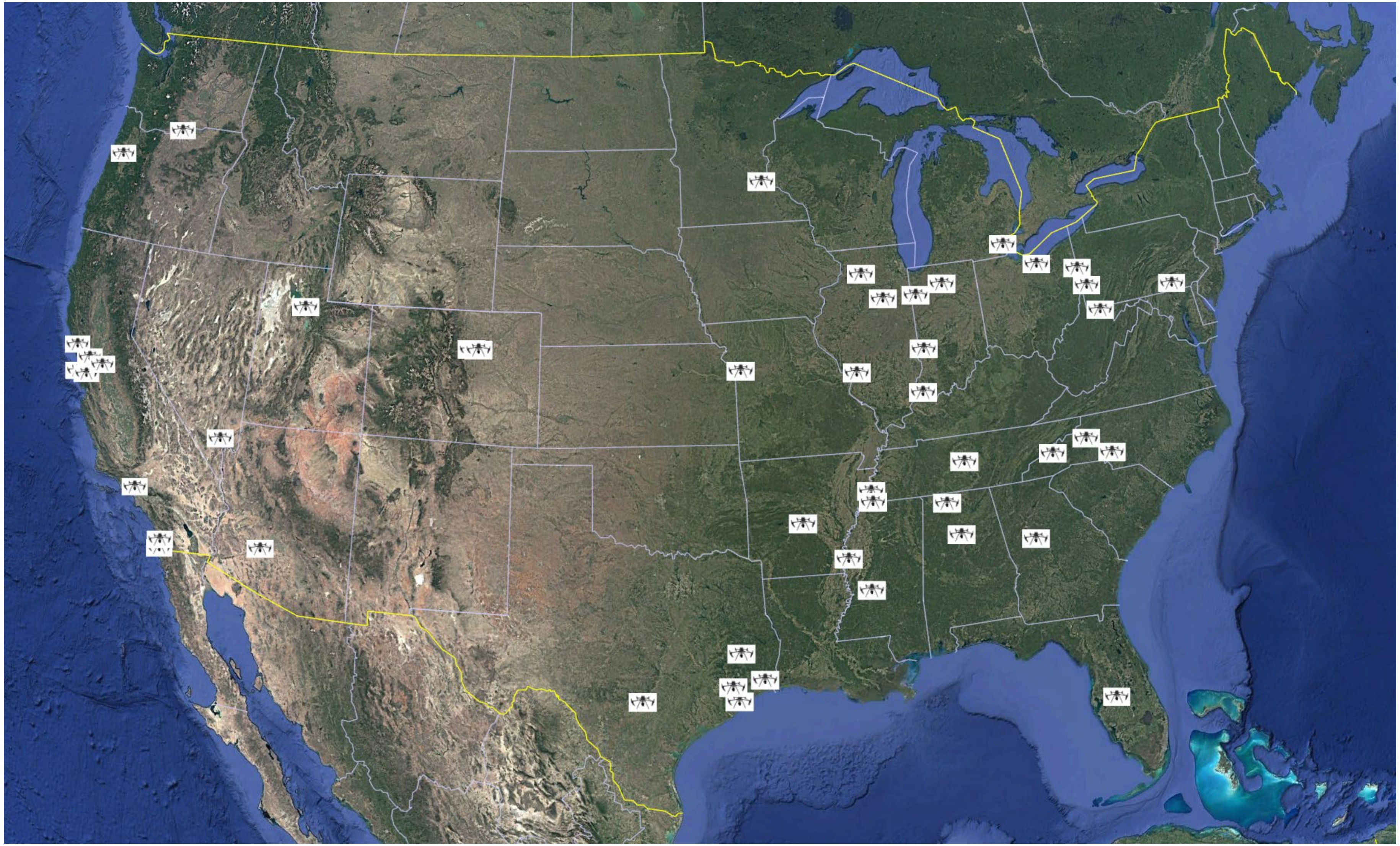
Drone Leak Detection – 2024 Pilot Locations



2024
Sites: **49**
Flights: **167**

Focus Areas

- Gas Expansion
- Localization Opportunities
- Capping Events
- New Gas System Install
- RNG plant startup

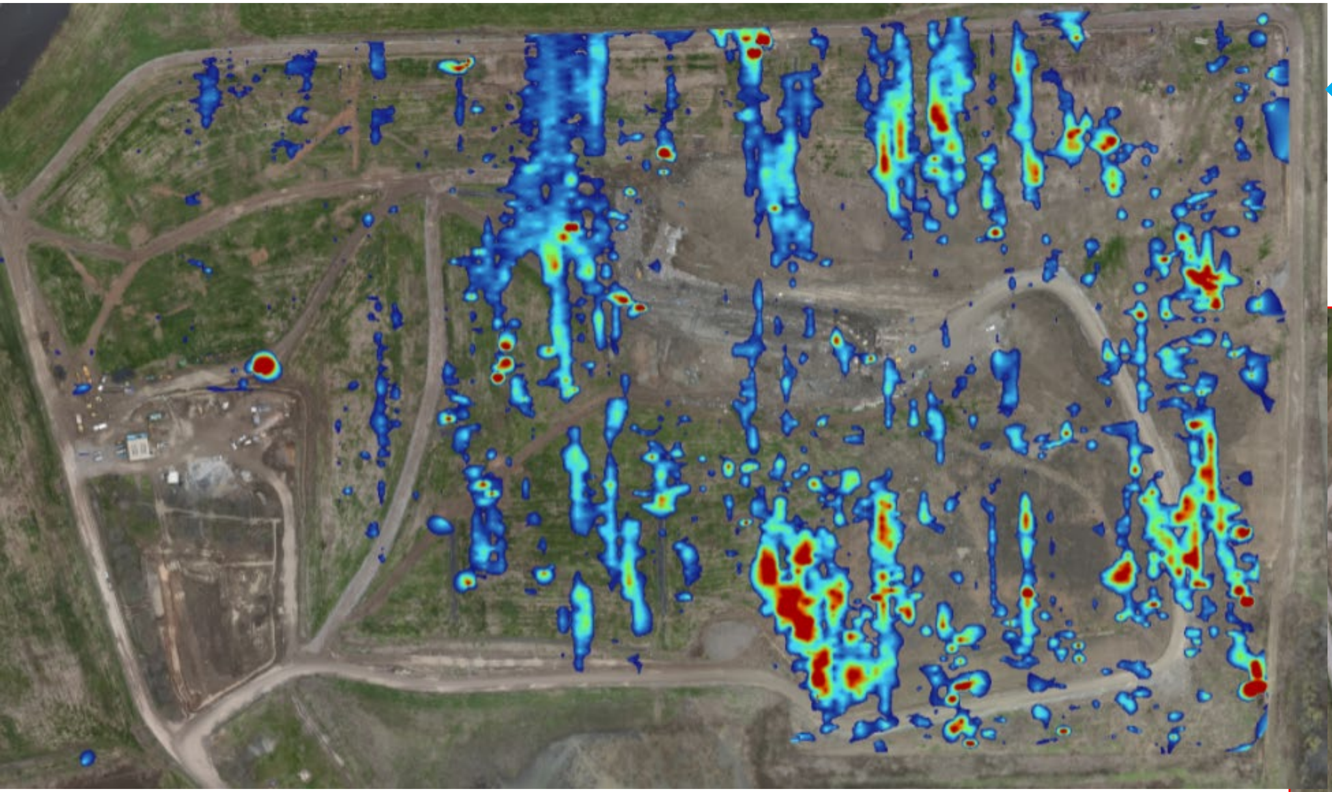
GCCS Before and After

Before Gas System Installed – April 2024

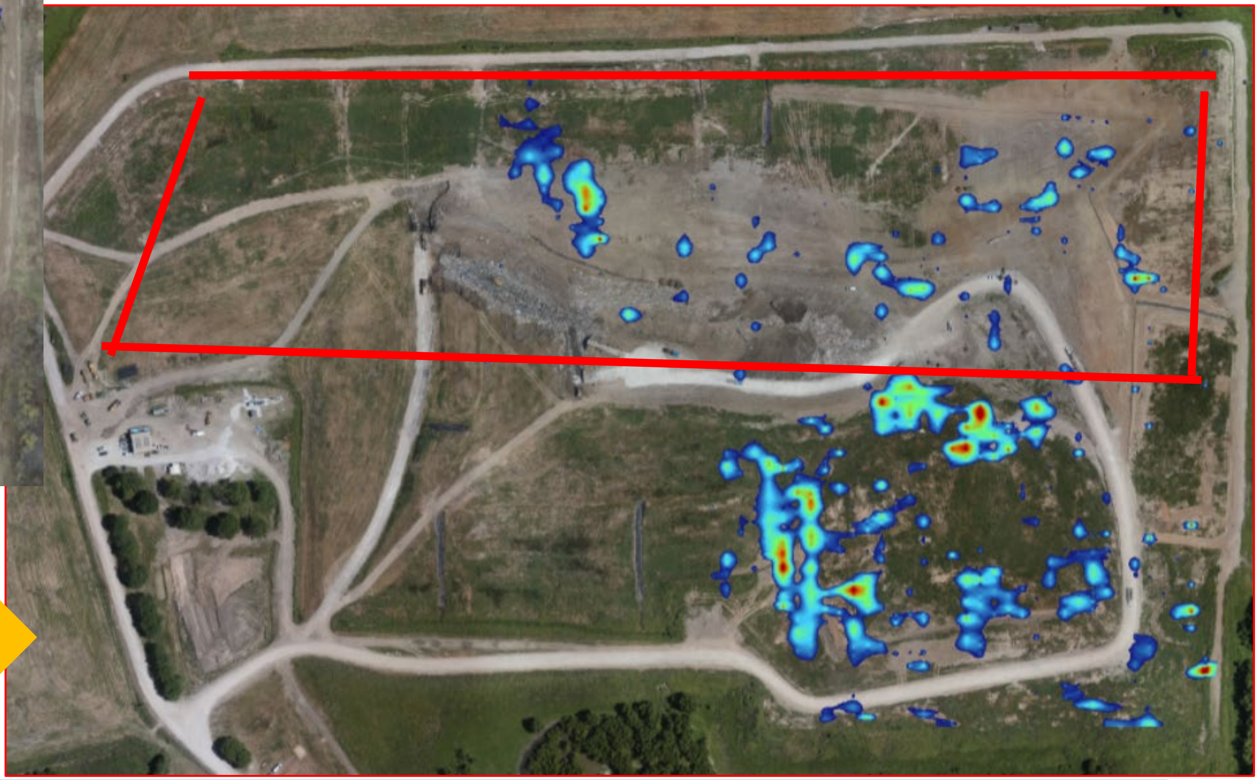
After Gas System Installed – August 2024

Utilizing imaging to affect gas design for future expansion in 2025

Impacts of Gas Collection System Installation



Before Gas System Installed – March 2024



After Gas System Installed – June 2024

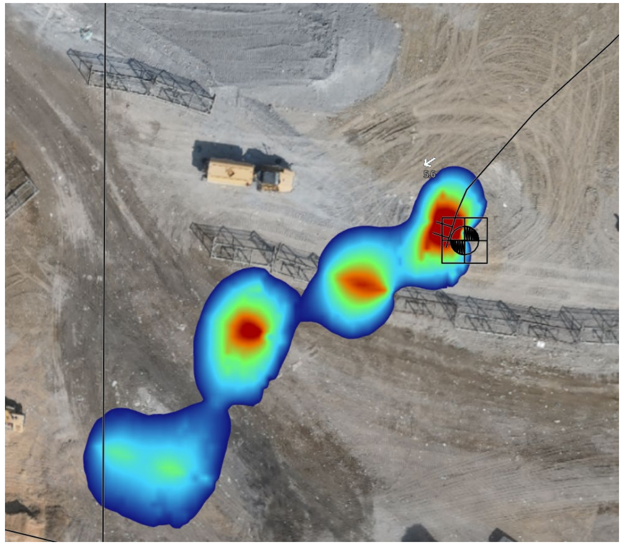
Opportunity to identify areas to remediate & expand the GCCS

Localization Detection

Area identified with drone saved time & money

Localization/Leak Detection

- Provides actionable data
  - Value for GCCS installation/expansion
  - Identifies areas to remediate



More to come….

- Two Week Study (Purway sensor)
  - Consistency
  - Repeatability
- Active area
- Whole site emissions
  - Wind measurements

Need to determine when scan data for localization becomes actionable?

Next Steps to Support Technology

- Leverage Republic data collected into other similar studies
- Conduct another drone methane sensor study to verify capabilities
  - Repeatability/precision
  - Wind correction factor
  - Correlations to 500 ppmv (Method 21)
- More stacking of technologies at landfills
- Continue collaboration with industry group on EREF Canada project

Additional Data Supports Understanding Landfill Emissions

Thank you!

Republic Contacts:

Niki Wuestenberg

David Penoyer

REPUBLIC SERVICES

Applied University Research with New Technologies

FluxLab

St. Francis Xavier University

- **Dave Risk PhD**
- St. Francis Xavier University
- Antigonish, Nova Scotia
- ~30 team members at FluxLab
- Specialize in **detection + measurement** of methane
- Conduct **large** national-scale programs for government and industry
- Extensive contract work for tech companies. Spinouts.

ELEMENTA
Science of the Anthropocene

Methane emission rate estimates of offshore oil platforms in Newfoundland and Labrador, Canada

scientific reports

Methane emissions from upstream oil and gas production in Canada are underestimated

Methane emissions were measured at 6650 sites across six major oil and gas producing regions in Canada to examine regional emission trends, and to derive an inventory estimate

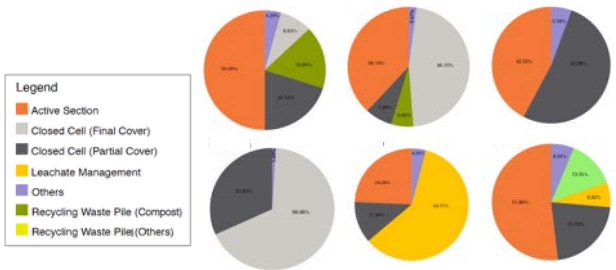
communications earth & environment

Hybrid bottom-up and top-down framework resolves discrepancies in Canada's oil and gas methane inventories

FLUX LAB
gas detection measurement

Waste

- ~100-site **inventory examination**
- **Source-apportionment** study, 12 landfills



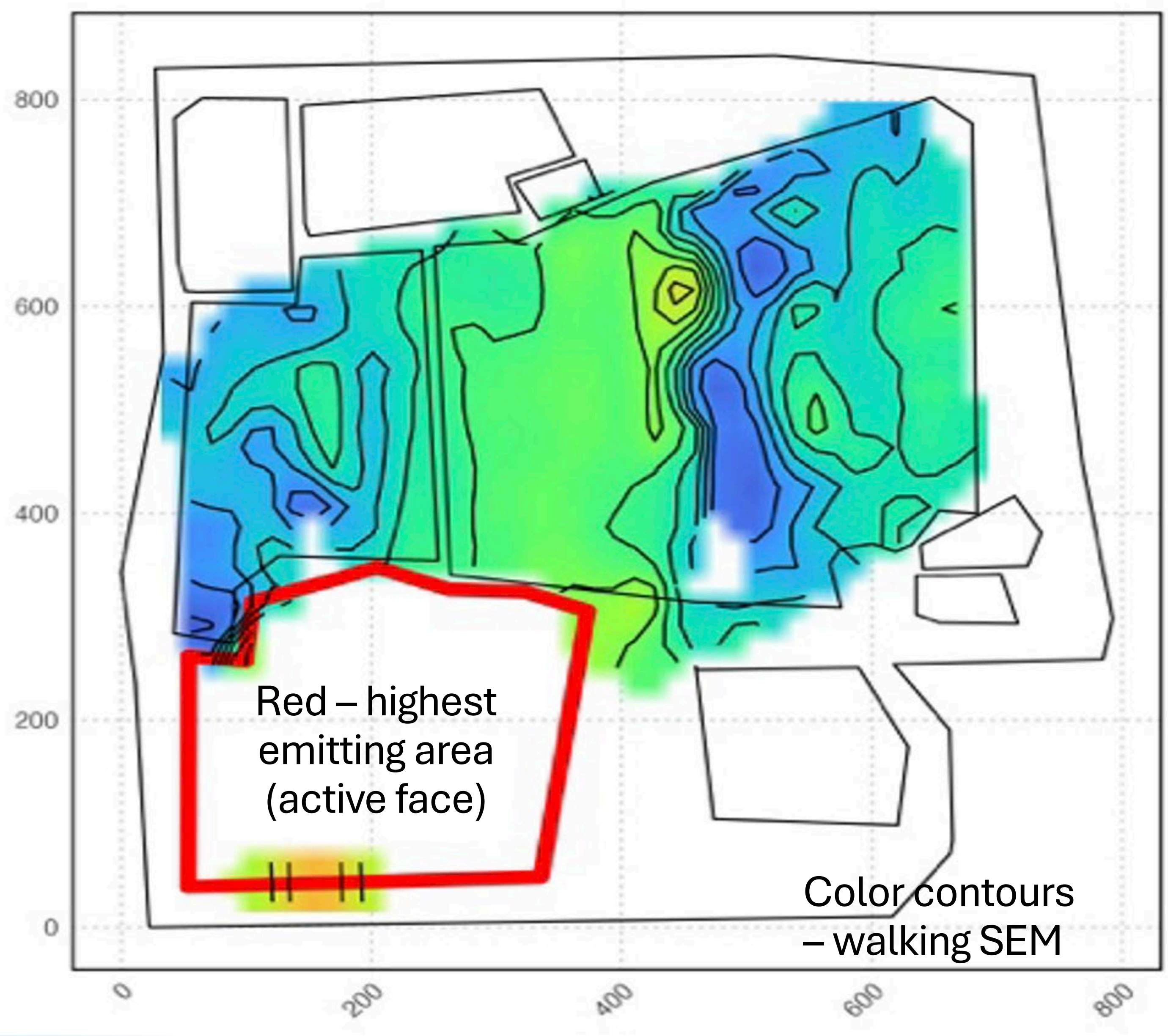
- **Regulatory** development, **standard methods**
- **Simulation Facility for Landfill Emission Experiments** (SIMFLEX)
  - "Landfill METEC"
  - CR1 Nov 2023
  - Tarek Abichou co-PI

FLUX LAB gas detection measurement

EREF

Regulated Foot SEM – Status Quo…or Go?

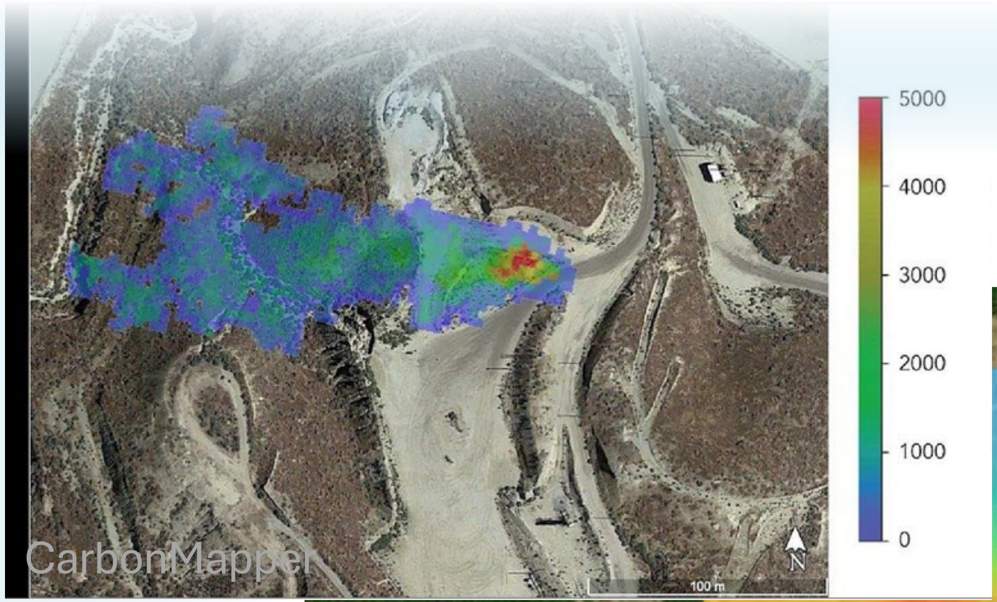
- **Easy, but coverage is fractional**
- Canadian studies show **rate % coverage 10-50%** for active sites
- Puts **little of the emissions are under measurement-informed management**
  - Canadian OG methane rules erred on this initially - US benefitted – vent vs fugitive problem
- **Indirect.** Concentration ≠ Severity
  - (Concentration * wind * area)
- **Repeatability? MDL unknown.**
- If kept, could be followed by source quantification (like OG)
  - **OG methods for points**
  - **CR-validated methods for areas**

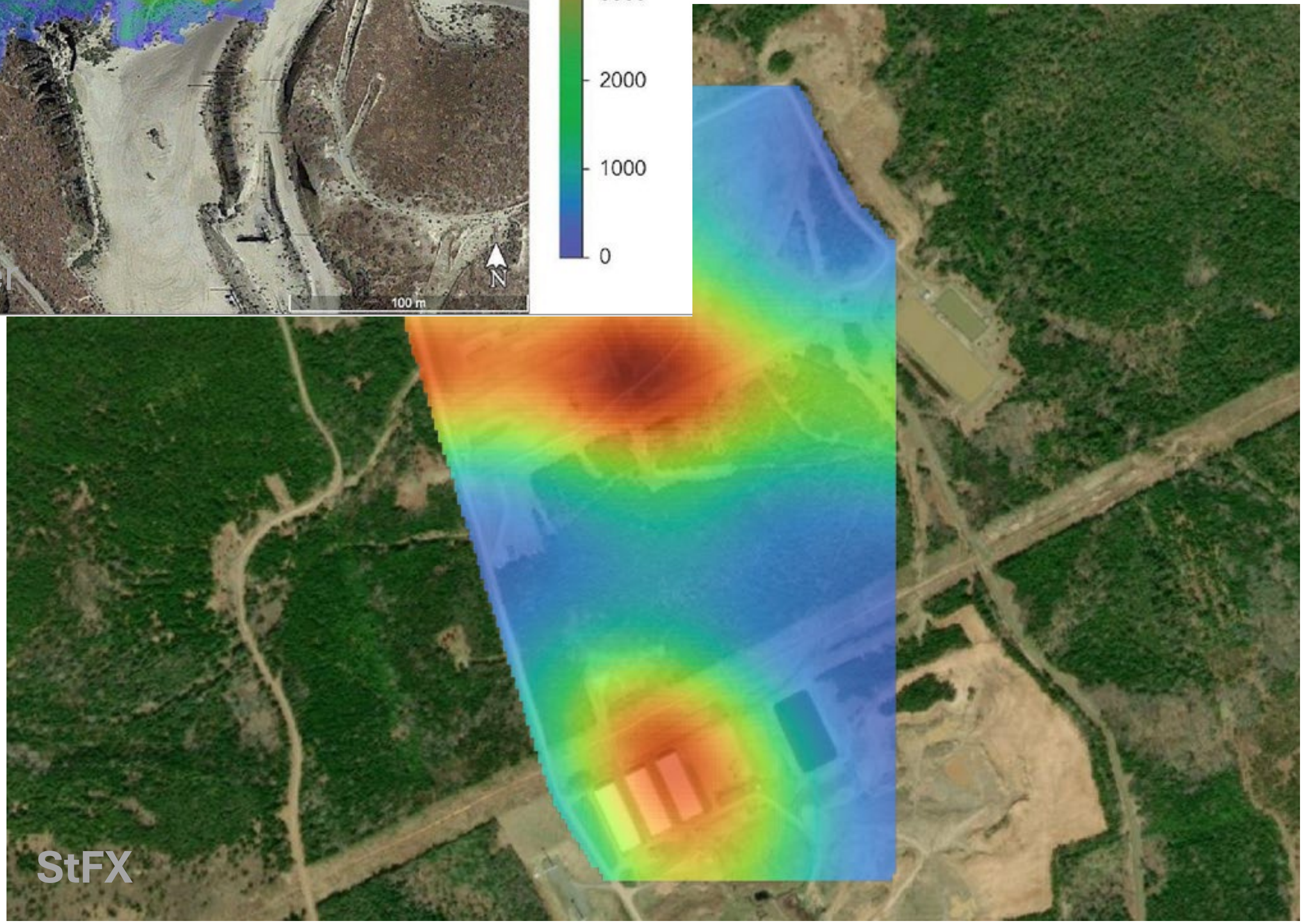


FLUX LAB gas detection measurement

Quantification Opportunities – “Rate Based”

- **Whole site quantification – CR1**
  - Tracer Correlation <5% bias
  - Low bias -LiDAR, drone flux plane
  - Virtually all within +-40%
    - Not bad when compared to models, or temporal variation
  - **Not all methods work at every site, or all the time.** For annual inventory assessments, methods need to be combined by site.
- **Source-based quantification**
  - Trucks and some continuous sensors, LiDAR, drone flux plane, Tracer Correlation can work for point or area-based source quantification
  - Many SEM tools have potential
  - **We haven’t asked for it!**
    - What size emission is important to manage?





FLUX LAB gas detection measurement

SEM Alternatives – CR1 and Other

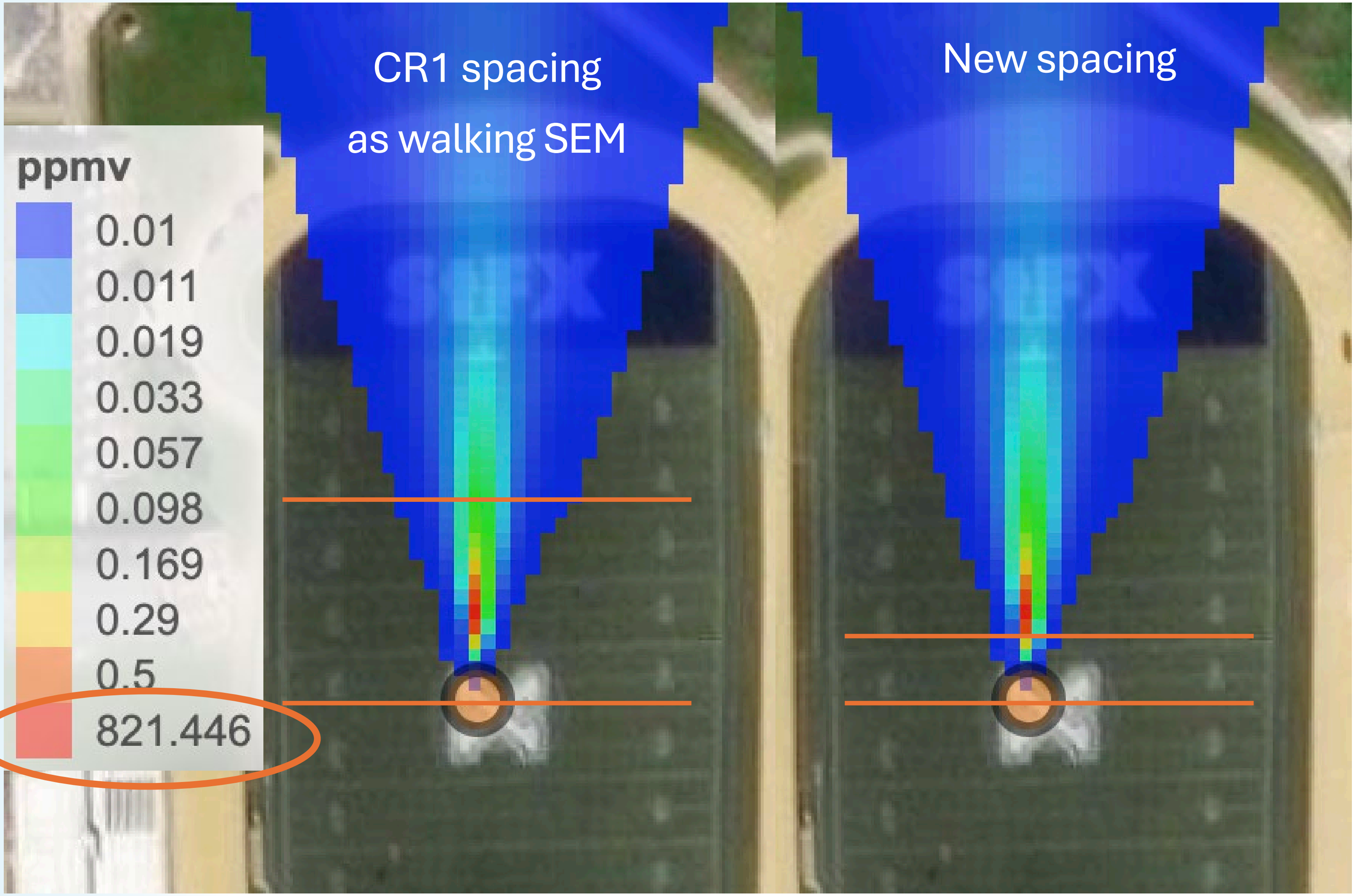
CR1 Tested

- LiDAR – excellent performer
- CTDLAS drones weak in CR1
  - Workpractice issue in part?

Not CR1 Tested but Options

- OTM51 tube drone
  - Foot SEM equivalence
- Aerial and satellite imagers
  - Not yet area source validated

- Some already quantify sources, all have near-term potential for this. Move to rate-based.
- But what size source matters?
  - 1 kg/hr? 10 kg/hr? 100 kg/hr?



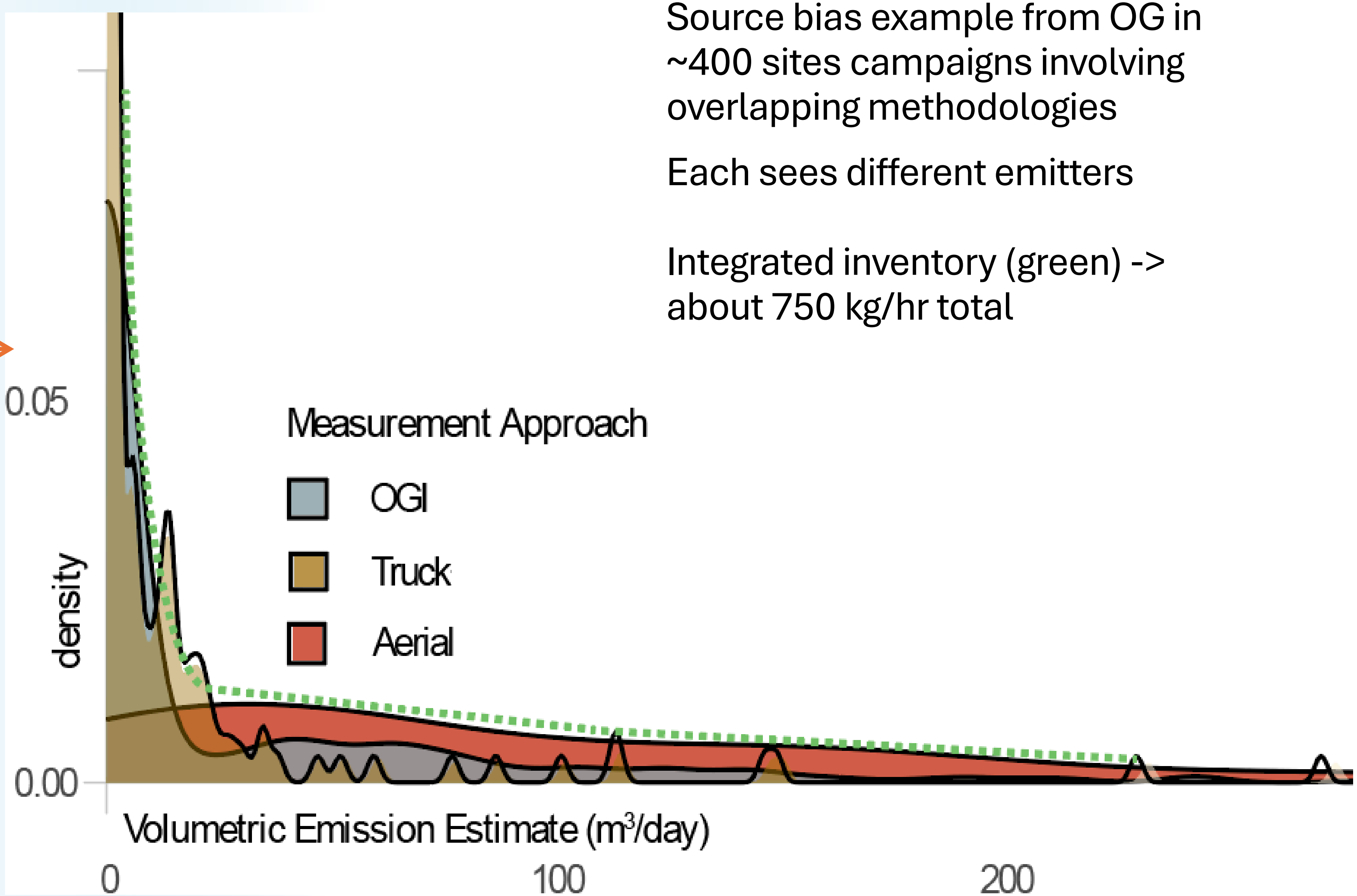
80 kg/hr Gaussian, 0 m agl source, 1 m agl detect, 20 km/h wind, Pasquill D

Rate-based tuning: Detection success and MDL are related to spacing.

FLUX LAB

Understanding Error

- **Variability** – Repeat more
- **Bias** – True rates
- Regardless of claims, **every methodology has BOTH**
- **Bias Types: Quantification** and **Source**. Even a low rate-biasing method will miss some source types or sizes.
- **Error is workable** for **simple** outcomes like **over/under**
    - O&G regulation sets out **different program roles for methodologies** across a wide **30x range** (matrix)



Source bias example from OG in ~400 sites campaigns involving overlapping methodologies

Each sees different emitters

Integrated inventory (green) -> about 750 kg/hr total

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Working with Error for Different Purposes

Purpose	Involves	Used For	Difficulty	Tolerable error	Who
Over/under Threshold	**A measurement** with reasonable error for the outcome	**Management**	**Easy**	100% fine **IF** the range is large. 0 kg/hr? 1 kg/hr? 10 kg/hr? 100 kg/hr?	Typically used by **regulators** to define corrective action thresholds
Reconciliation	**A process** with several types of measurements as input	**Understanding how to make better decisions** in measurement design	**Hard**	Varying, because multiple measurement methods used	Typically used by **expert operators**, in **market-based community developed standards** that go **beyond regulation**, for some **ROI**. e.g. GTI Veritas, EO, MiQ, etc.
Measurement-Based Annual Inventory	**A process** involving several types of measurement, EFs, statistics.	**Commitments to Transparency, and/or Market Access or Competitiveness.** Not a management tool.	**Hardest**	Varying because multiple measurement methods and EFs are used to be comprehensive	Typically used by **expert operators**, in **market-based community developed standards** that go **beyond regulation**, for some **ROI**. e.g. GTI Veritas, EO, MiQ, etc.

FLUX LAB gas detection measurement

Working with Error for Different Purposes

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Regulatory Considerations - Measurement

My comments informed by measurements and regulatory experience in OG, and waste

- Regulate where measurements contribute under a flexible rate-based system
  - **Understand rate contribution of sources**, and **allocate resources to the biggest problems**
  - **Consider flexible rate-based performance approaches** as in O&G
  - Errors are workable – if we build simple management and response frameworks that minimize their impact
- Consider Rewards for
  - Implementing annual inventory measurements (would benefit GHGRP) or developing advanced collection processes
  - Encourage industry to develop its own community standards – can SWICS remodel as Veritas equivalent?
- Hybrid Measurement-Informed Inventories by Gov
  - Should be done by experts / national or state orgs, to inform policy, and not to police sites
  - Takes more than just measuring with one tech – in Canada we do it for OG nationally – took years to develop
  - Need to get inventories right. Gov owns the inventory error from the process but industry gets the black eye.
- Tech Agnostic Rules
  - Avoid a restrictive system that picks winners amongst the many techs that will arrive
  - Define performance-based criteria (rate-based), establish pathways for approval

LANDFILL CONTROLLED METHANE RELEASE STUDY

- Final report published
- Evaluated 16 commercial and R&D technologies for the ability to detect and quantify emissions from point and non-point releases.
- First round conducted by St. Francis Xavier University (FluxLab) in November 2023 at the 60-acre closed WM Petrolia Landfill in Ontario.
- Sponsored by the Environmental Research and Education Foundation (EREF).
- Second round of testing planned for Q4 2024 with work in progress for a more permanent setup.

FLUX LAB gas detection measurement

EREF Environmental Research & Education Foundation™ *Lighting a path to sustainable waste management practices*

Landfill Controlled Release: Localization Results Summary

Technology	Method Identifier	False Positive Fraction	False Negative Fraction	True Negative Rate	Localization Accuracy	Survey Time (mins)
Aerial – Drone (UPSEA-TDLAS)	C	1	1	0.70	0	40
Aerial – Helicopter (LIDAR)	G	0	0	1	1	20
Satellite (Spectrometer)	H	-	-	-	-	0.3
Aerial – Drone1 (UCSEA-TDLAS/Laser)	L	0.83	0.63	0.28	0.17	50
Aerial – Drone2 (UCSEA-TDLAS/Laser)	M	0.79	0.50	0.52	0.21	60
Ground – Truck (MGPA-LGR)	N	0.79	0.85	0.54	0.1-0.5	15

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Controlled Release: Quantification Results Summary

Technology Identifier	Technology	% Deviation from True Value (Range)	Average % Deviation from True Value	Std Dev.
H	Satellite (Spectrometer)	No Detection	-	N/A
F	Aerial – Airplane (APSEA)	-77 – -1 %	-40%	24 %
G-1	Aerial – Helicopter (LIDAR)	-11 – 128 %	44%	45 %
G-2	Aerial – Mass Balance	-12 – 130 %	36%	43 %
C	Aerial – Drone (UPSEA-TDLAS)	-33 – 66 %	14%	35 %
D	Aerial – Drone (UPSEA- IR LDS)	-74 – 96 %	3%	62 %
E	Ground – Truck (MTCA "Tracer Corr.")	-44 – 31%	-11%	20 %
B	Ground – Truck (MGPA-LICOR)	-88 – 68 %	-34%	40%
A	Ground – Truck (MGPA-LGR)	-74 – 160 %	-33%	48%
N	Ground – Truck (MGPA-LGR)	-70 – 215 %	62%	88 %
K	Ground – Fixed (RPSEA-Metal Oxide)	-96 – 70 %	-58%	39 %
J	Ground – Fixed (RPSEA-Metal Oxide)	-35 – 306 %	78%	96 %
I	Ground – Fixed (RPSEA-EM27)	1 – 3597 %	743%	975 %

Top 3 Performers

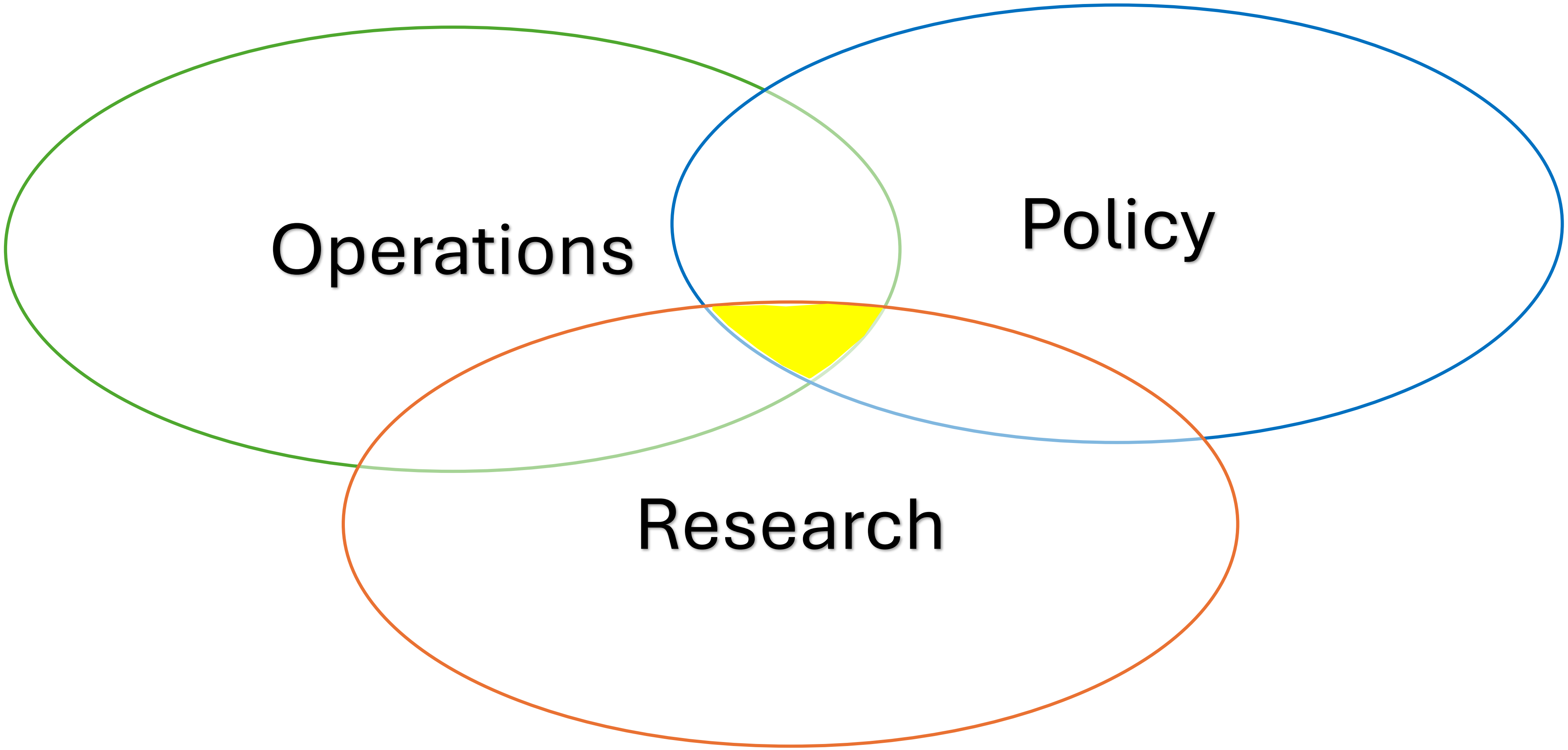
3 (F)

2 (C)

1 (E)

The Path Forward

Path Forward



To inform emission estimates:

and

To support methods development:

How to address emissions variation throughout the day/night as most measurements are taken during clear daytime conditions?

How to weight episodic (construction, maintenance) events?

How to reconcile differences in measurements of emissions using same technologies (e.g., satellite vendors) and then different technologies (drones v portable analyzers)?

Can a 'one size fit's all' approach work for landfills?

How to modernize equivalency demonstration for alternative monitoring/measurement technologies?

How to determine what is actionable versus observable?