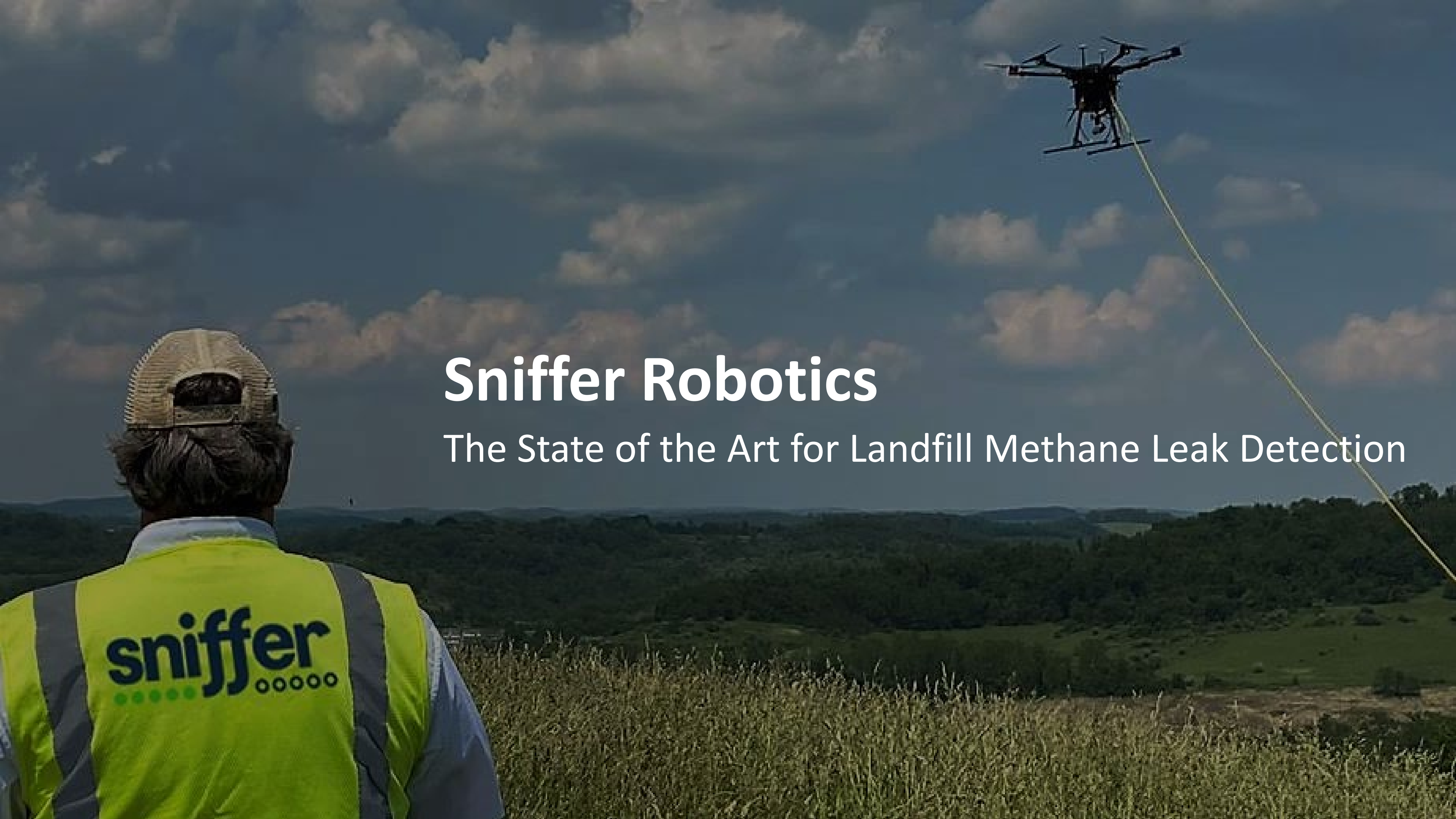
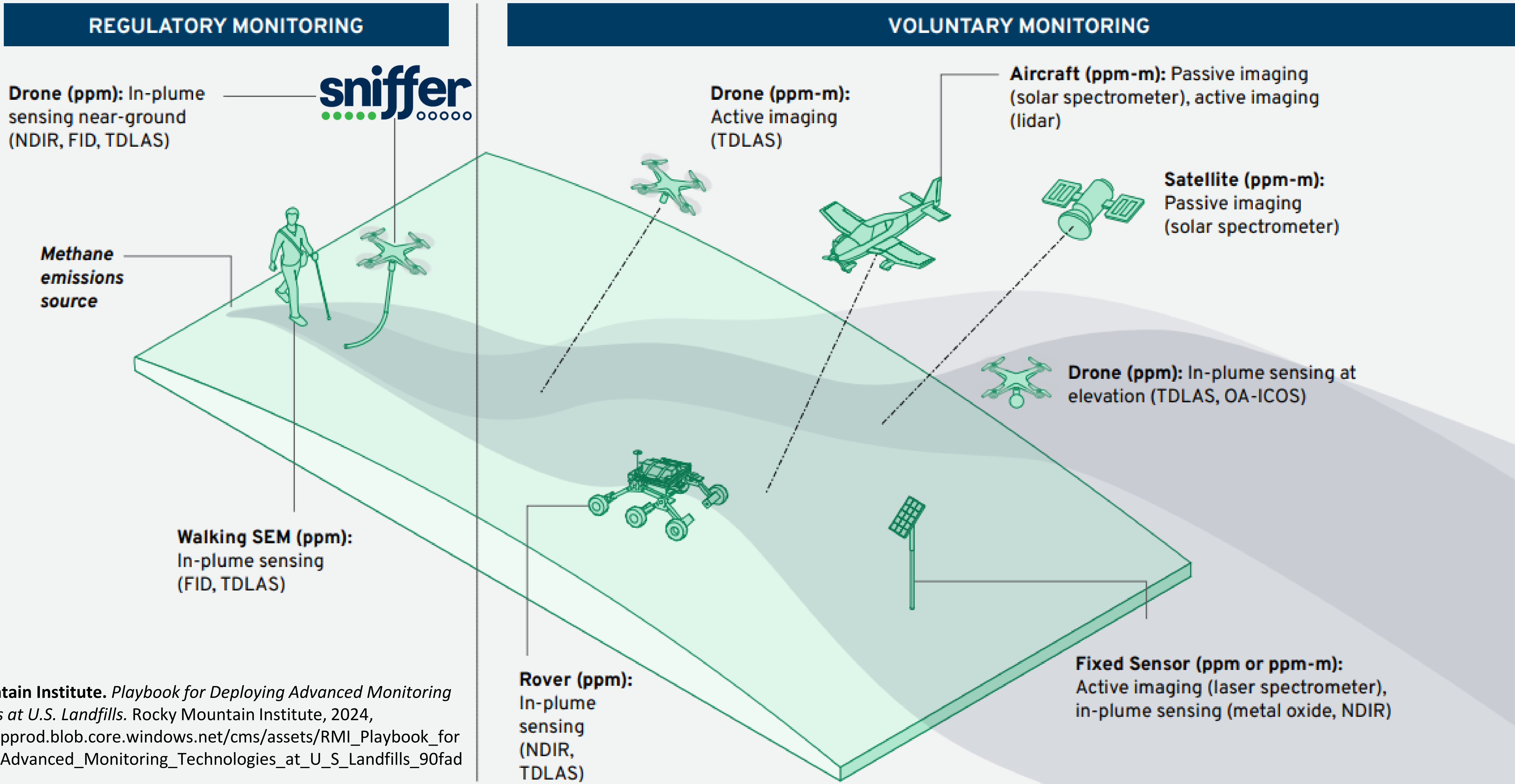
Sniffer Robotics

The State of the Art for Landfill Methane Leak Detection



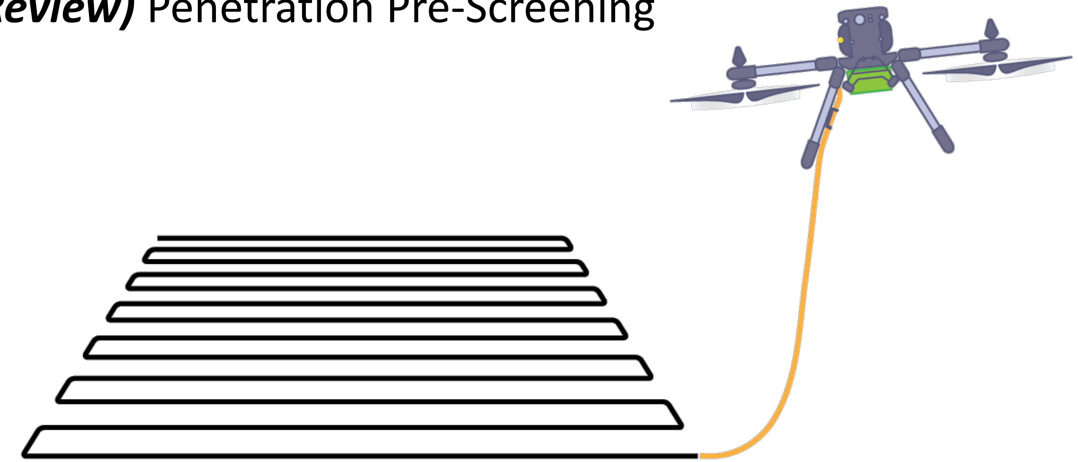
Advanced methane monitoring technologies deployed today



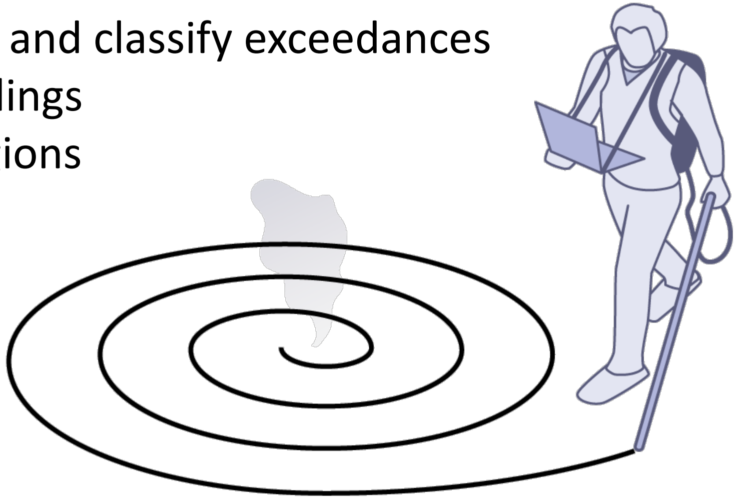
Rocky Mountain Institute. *Playbook for Deploying Advanced Monitoring Technologies at U.S. Landfills.* Rocky Mountain Institute, 2024, rmiwastemapprod.blob.core.windows.net/cms/assets/RMI_Playbook_for_Deploying_Advanced_Monitoring_Technologies_at_U_S_Landfills_90fad7ccf5.pdf.

OTM-51 Sampling Method

1. Traverse Landfill at 30m (or better spacing) with Drone (D-SEM)
   - Identify locations of increased meter readings
   - Visual observations indicating elevated landfill gas concentrations
   - ***(In Review)*** Penetration Pre-Screening



2. Manually Inspect (G-SEM) and classify exceedances
   - Increased meter readings
   - Visually indicated regions
   - Penetrations



https://www.epa.gov/system/files/documents/2022-12/Barron%20Sniffer%20Alt%20with%20OTM%2051%20attached_signed.pdf

OTM-51 *is* Method 21.. From a Drone

- Identical unit of measure - ppm
- Identical sample collection at ground level
- Familiar detection technology (NDIR or closed path closed cavity TDLAS)
- Identical CONOP – 30m serpentine paths, further (manual) inspection of increased meter readings

BUT

- Computer controlled path spacing
- Laser enforced nozzle above ground level
- Rigid, programmatic enforcement of "Increased Meter Reading" for secondary inspection
- Faster detector response time

YIELDING

- **~2.27x more located exceedances per site**

METHOD 21
SURFACE EMISSIONS MONITORING (SEM)

OTM-51
DRONE SURFACE EMISSIONS MONITORING (DSEM)

Comparison of Serpentine Path Inspection

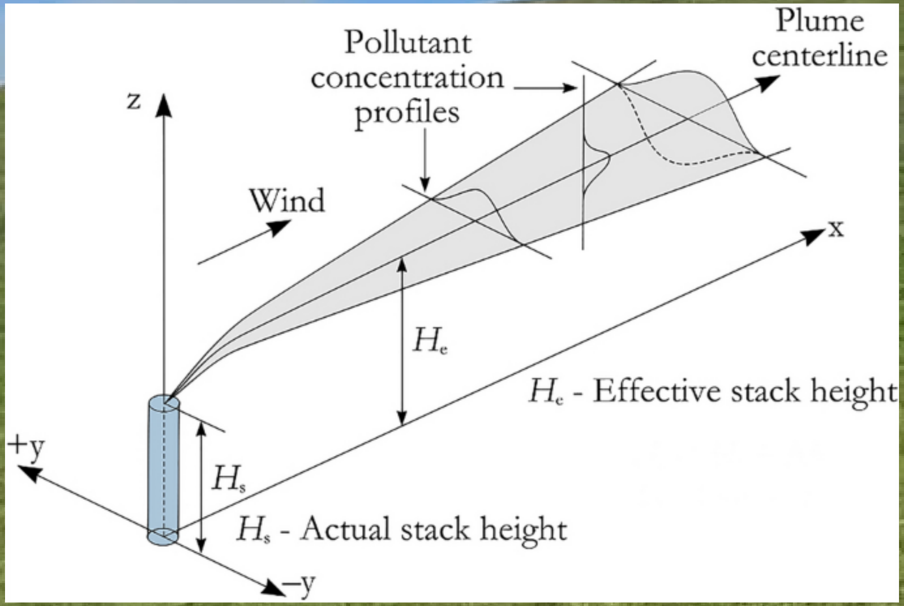
Operator defined paths yields source discrimination between the active face, intermediate cover, final cover

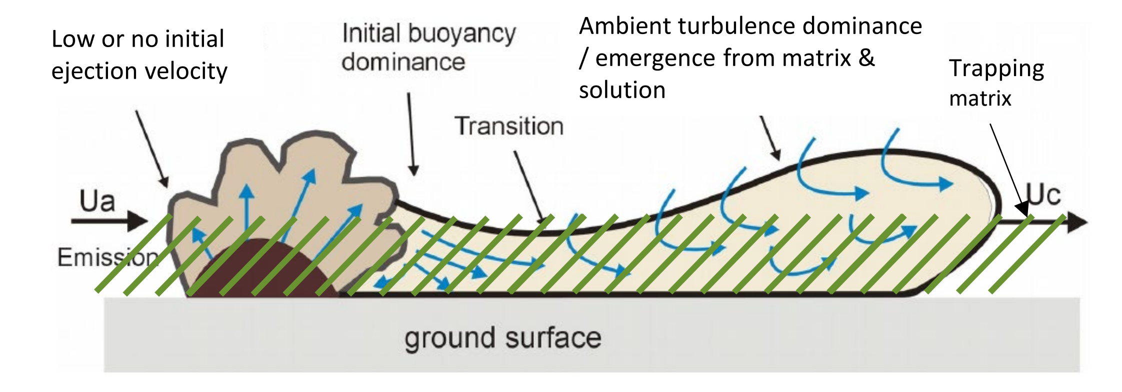
Certainty of Full Landfill Performance

Site ID	D-SEM Date	Projected Exceedances*	M-SEM Date	Reported Exceedances	Difference: Exceedance Count
A	2/19/2020	58	3/11/2020	3	55
B	3/3/2020	31	3/10/2020	10	21
B	5/11/2020	6	6/17/2020	28	-21
A	6/13/2020	17	6/11/2020	2	145
B	8/7/2020	33	9/15/2020	11	22
A	9/25/2020	13	9/22/2020	4	9
A	11/23/2020	28	11/11/2020	4	35
B	4/22/2021	41	5/5/2021	15	26
C	5/12/2021	29	6/16/2021	5	24
D	5/10/2021	7	5/12/2021	0	7
B	7/15/2021	10	8/24/2021	22	-14
B	9/1/2021	16	8/24/2021	22	-8
		289		**126**	**227%**

- Programmatic control of traversed path
- Definition of increased meter reading for enhanced inspection.
- Strict control of nozzle AGL

Heavy Landfill Gas Must be Sampled at Ground Level





Natural Gas:
97% CH_4, higher order alkanes, trace
Molecular Weight: **17.16 g/mol** [2]
Nominally leaking from elevated pressure
Equipment Emissions @ > 0m AGL in air

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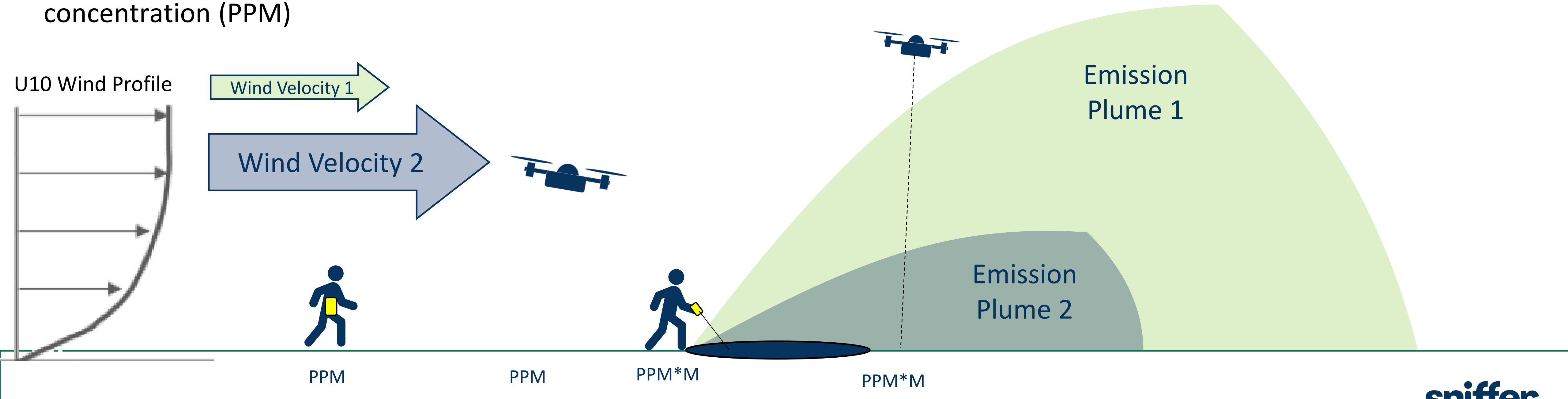
Landfill Gas:
CO_2, CH_4, trace
Molecular Weight: **30.03 g/mol** [1]
Nominally Leaking at ~ambient pressure
Surface Emissions @ 0m AGL in vegetation/terrain

1) https://www3.epa.gov/ttncatc1/dir1/landgem-v302-guide.pdf
2) https://group.met.com/en/media/energy-insight/composition-of-natural-gas

PPM is the most direct unit for Landfill Emissions

- Units Options:
  - PPM is a direct measurement of concentration at the source location (pipe vent, surface leak, etc)
  - PPM-M is a path integrated measurement with a higher degree of influence from environmental parameters (wind velocity, pressure, etc)
  - Kg/hr is a calculated value conflating uncertainties in methane detection, wind velocity and plume model assumptions
- Any given emission, in two different wind environments, will produce different path integrated concentrations (PPM*M)
- Given wind shear drives wind velocity at the emission location to zero – severity of leaks can be approximated using true concentration (PPM)



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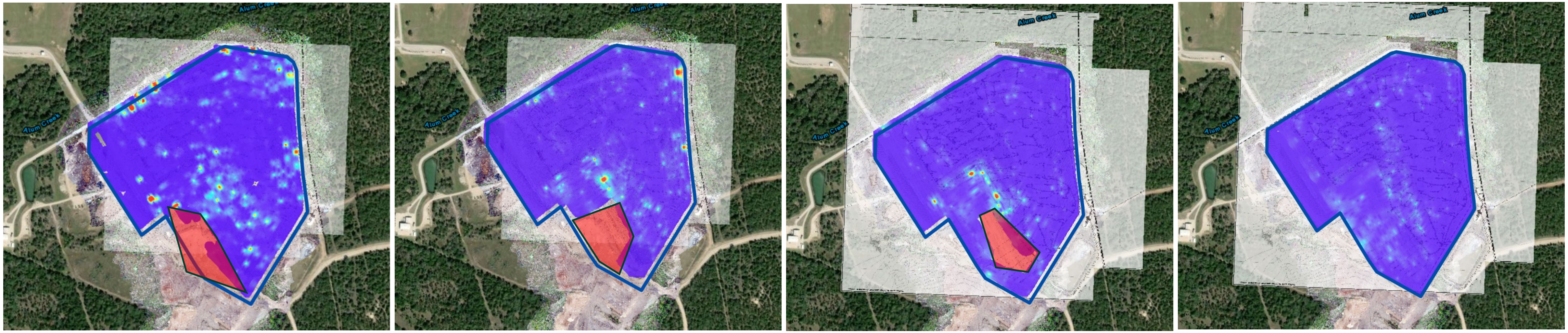
Operating conditions	• 14°F to 104°F • <8m/s (18mph) ground wind speed • Ground level sampling minimizes wind impact • No precipitation • Agnostic to terrain – active laser-based terrain following • NDIR/TDLAS/etc Methane Detector – specific to methane (and higher order alkanes) • Cost competitive with M-SEM with superior detection performance	6400+ Completed SnifferDRONE™ Flights >1100 SnifferDRONE™ Flight Hours 127 Unique Landfills/BioGas CY2024 to date

Case Study: D-SEM insights yielded 200scfm Product Gas



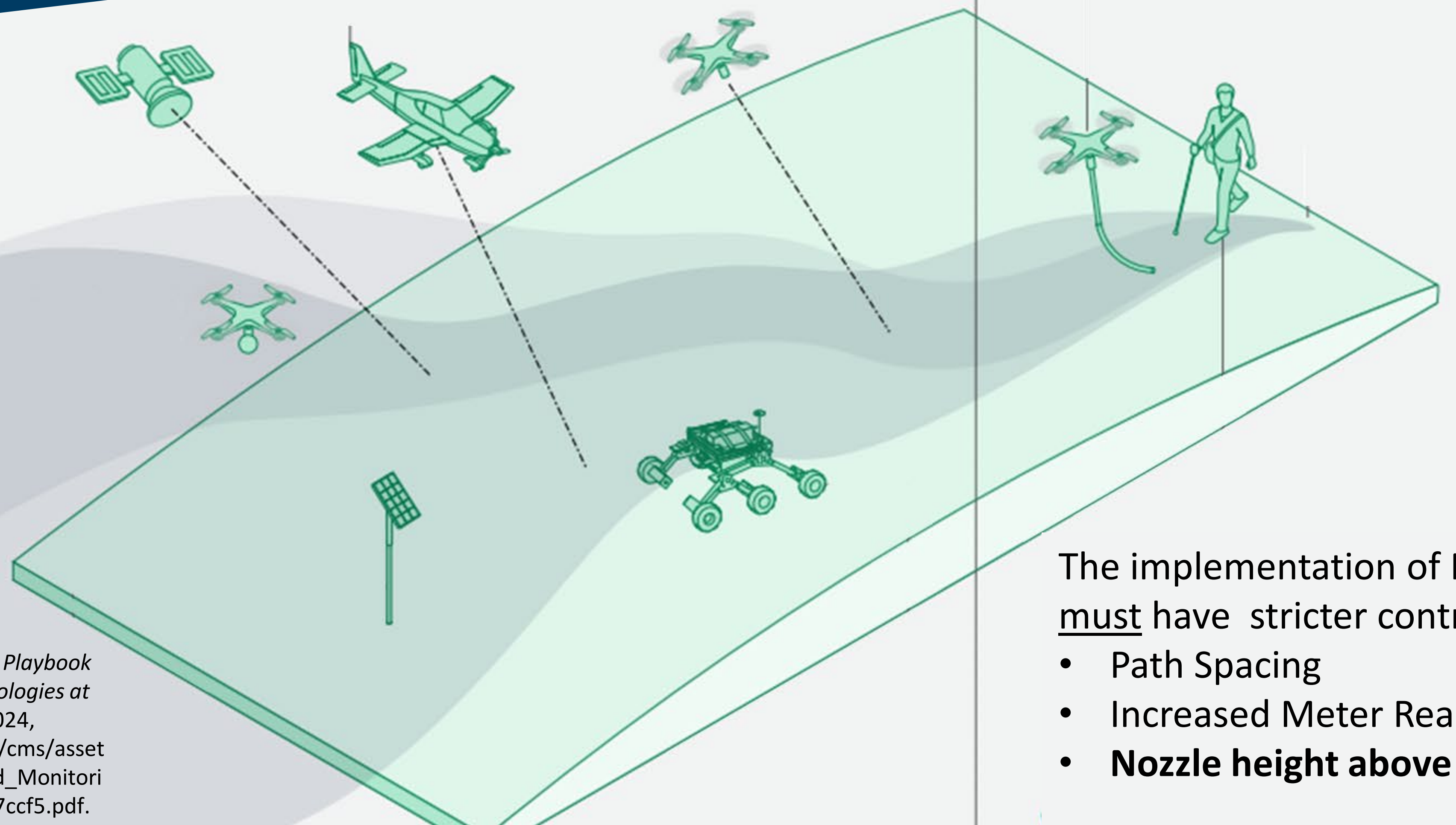
Month	January	February	March	June
Leak Count	19	6	5	0
Mean PPM (whole site)	10.02	5.64	4.74	3.92
Std. Dev. PPM (whole Site)	36.8	21.5	20.6	9.1
Est. scfm (SEM2Flux)	283.6	178.3	204.2	133.5

Additional 200 SCFM Product Gas Generated by RNG Facility (scfm in the pipelline)

A Regulatory Framework Enforcing a Cascade of Localization

Leverage the scalability of remote sensing advanced technologies to trigger SEM surveys for pinpointing and driving remediations of individual exceedance level leaks

- Tighten M21 to alleviate shortfalls
- Regulate active area emissions by limiting active surface area



Adapted from: Rocky Mountain Institute. *Playbook for Deploying Advanced Monitoring Technologies at U.S. Landfills.* Rocky Mountain Institute, 2024, rmiwastemapprod.blob.core.windows.net/cms/assets/RMI_Playbook_for_Deploying_Advanced_Monitoring_Technologies_at_U_S_Landfills_90fad7ccf5.pdf.

The implementation of M21 for SEM must have stricter control of:

- Path Spacing
- Increased Meter Reading Definition
- **Nozzle height above ground**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Seed Questions/topics for the Presenters

1. M21 Comparisons:
   - How does your method compare to EPA Method 21? Method is identical – sampling is performed by drone vs human
   - How does it demonstrate an advancement over the current approach? 227% more located exceedances per landfill
   - Could it be used in place of EPA Method 21 for surface emissions monitoring? Yes – an approved alternative per ALT-150
2. How do you manage variable winds and other complex environmental conditions? Active terrain following enforces ground level sampling which is significantly less sensitive to wind and atmospheric stability when compared to standoff technologies.
3. How do you manage complicated terrain? Active terrain following means the drone is agnostic to the terrain.
4. Is your resolution sufficient to distinguish between allowable emissions (working face) and those that are not allowed? Yes – ground level sampling via the drone is specific to the location sampled; paths in/out of the working face distinguish emissions
5. Has the technology been tested for any potential chemical interferences from other species present in emissions from landfills, and if so, what were the results? Yes – NDIR/TDLAS is specific to the methane absorption spectra
6. What are the similarities between advanced technologies applicable to detecting methane from landfills and those employed in the oil and natural gas production field? Are the significant differences that EPA should be aware of? The composition of gas, source geometries and significant differences in ejection velocity/location drives significant deltas to emission dynamics and therefore detection techniques/algorithms. They should be viewed as entirely distinct.
7. How could this technology be incorporated into the current NSPS and EG? How could the technology be used to reduce emissions from the landfill? OTM-51 is broadly applicable today via ALT-150 and drives discovery of 227% more exceedances
8. What are the required environmental conditions (wind conditions, topography etc.) for your technology to be useful? No deltas to Method 21 for wind, precipitation and atmospheric stability, expanded capability (and removal of bias) for full surface coverage inclusive of steep terrain, erosion rills, mud and other areas traditionally classified as hazardous.
9. Can you please explain the financial feasibility of your technology for landfill emission monitoring? On par with M21
10. What are the results of uncertainty analysis of the technology? >2x more exceedances per landfill vs M21.