TOP 10 PRE-PLUG METHANE MEASUREMENT TECHNOLOGIES

FOR ORPHANED, ABANDONED, MARGINAL, IDLE & UNDERPERFORMING OIL & GAS WELLS

1 STATIC FLUX CHAMBER

Direct enclosure with gas accumulation

SCHEMATIC / HOW IT WORKS

1. Enclose emission source
2. Methane accumulates
3. Analyzer measures concentration rise
4. Flux calculated from rise rate, chamber area & conditions

INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- Bacharach ECA 1000
- Flux Lab Static Chamber
- ANTEA® Static Chamber
- RKI Eagle 2

2 DYNAMIC CHAMBER & HIGH-FLOW SAMPLING

Enclosure with active airflow for high fluxes

SCHEMATIC / HOW IT WORKS

1. Chamber placed over source
2. Air pulled through at constant rate
3. Analyzer measures CH_4 concentration
4. Flux = Concentration × Flow Rate

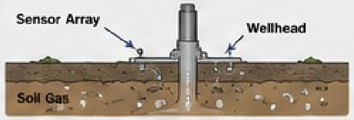
INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- Flux Lab Dynamic Chamber
- Ventis™ High-Flow Sampler (Industrial)
- TSI Incorporated Samplers
- SKC High-Flow Pump Systems

3 IN-SITU ELECTROCHEMICAL SENSOR ARRAYS

Continuous wellhead & soil gas monitoring

SCHEMATIC / HOW IT WORKS



1. Sensors installed around wellhead and in soil gas points
2. Electrochemical sensors detect CH_4 in real time
3. Data logged continuously for trends and variability

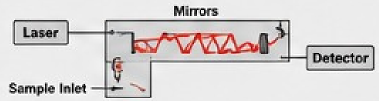
INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- GasClip Technologies MGC-Simple+
- Aeroqual Series 500/500+
- City Technology ALTAIR® (Options with EC sensors)
- RKI Instruments GX-6000

4 CAVITY RING-DOWN SPECTROSCOPY (CRDS)

High-precision gas concentration measurement

SCHEMATIC / HOW IT WORKS



1. Laser light bounces between mirrors
2. Sample gas absorbs light
3. Ring-down time measured
4. CH_4 concentration calculated

INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- Picarro G2401-m / GS310
- LGR (Los Gatos Research) Ultra-Portable
- Tiger Optics Halo Photonics
- Aerodyne Research QCL Systems

5 HANDHELD & GROUND-BASED OPTICAL GAS IMAGING (OGI)

Visual leak detection and localization

SCHEMATIC / HOW IT WORKS

1. OGI camera detects IR-absorbing methane plume
2. Plume visualized in real time
3. Operator locates and quantifies (leak rate estimation)

INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- FLIR GF320 / GF620
- Teledyne API TDLAS IR Camera
- SeekOps Reveal / Optima Plus
- QOGI (Quantitative OGI) Systems

6 UAV-MOUNTED OGI / OGI-Q

Aerial detection and quantification

SCHEMATIC / HOW IT WORKS

1. UAV flies planned transects
2. OGI sensor detects methane plume
3. Plume mapped and quantified (when OGI-Q enabled)
4. Source location identified

INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- SeekOps SkyCORE / SkyFASTM
- Bridger Photonics MethaneAIR (OGI-Q)
- Sensia G2 Cloud
- GHGSat Airborne Solutions

7 TRACER DILUTION

Quantification using tracer gas

SCHEMATIC / HOW IT WORKS

1. Tracer gas released into enclosure
2. Mixes with methane emission
3. Analyzer measures tracer & CH_4
4. Flux calculated from dilution ratio

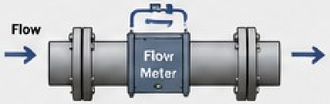
INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- GTI (Gas Technology Institute) Tracer Kits
- Permian Global Tracer System
- Mesa Solutions Tracer System
- Certification Services International (CSI)

8 MASS-FLOW & THERMAL-MASS FLOW METERS

Direct measurement of vented flows

SCHEMATIC / HOW IT WORKS



1. Meter installed inline at vent or flow path
2. Measures mass flow rate directly
3. Combined with CH_4 concentration
4. Emission rate calculated

INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- Sierra Instruments Mass Flow Meters
- Endress+Hauser t-mass / Proline t-mass
- Bronkhorst EL-FLOW / IN-FLOW
- TSI 4040 Thermal Mass Flow Meter

9 MOBILE GROUND SURVEY (VEHICLE-MOUNTED CRDS)

High-sensitivity ground mapping

SCHEMATIC / HOW IT WORKS

1. Vehicle drives transects
2. Air sampled continuously
3. CRDS measures CH_4 concentration
4. Plume mapping & source flags

INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- Picarro Mobile Laboratory
- Aeris Technologies Mobile Monitoring
- Tetratech Mobile Emissions Lab
- Scientific Aviation / ARES Solutions

10 AIRCRAFT-BASED SURVEYS

Regional scale detection & mapping

SCHEMATIC / HOW IT WORKS

1. Aircraft flies survey pattern
2. Air sampled or measured remotely
3. Methane enhancements detected
4. Regional plume mapping

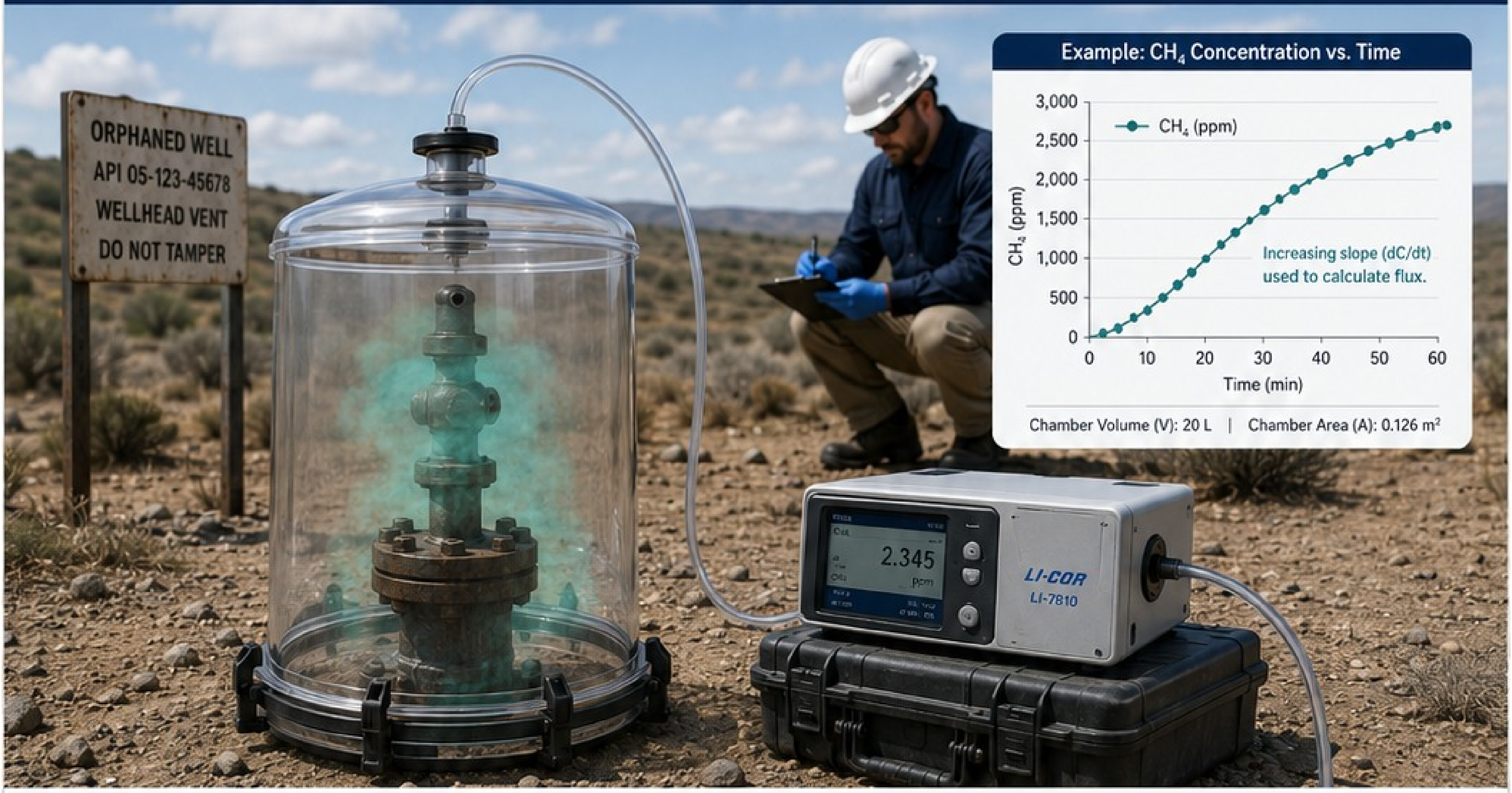
INDUSTRY-LEADING PLATFORMS (EXAMPLES)

- Scientific Aviation (Caravan Aircraft Lab)
- GHGSat Airborne Campaigns
- Earth Networks Airborne
- University / Government Aircraft Labs

Note: Schematics are simplified for clarity. Equipment selection subject to project requirements, calibration, and verification under the QECM measurement equipment standards.

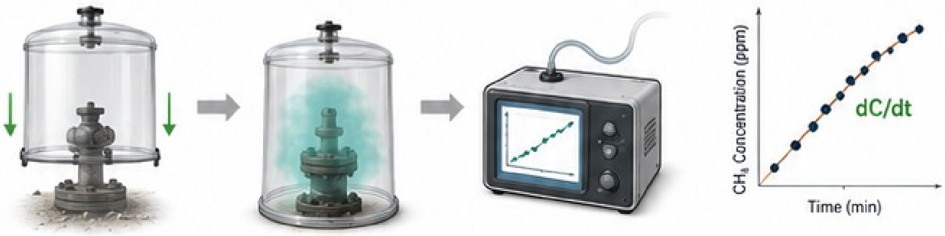
1. Static Flux Chamber

Primary baseline quantification for low-flow diffuse-emission wells.



HOW IT WORKS

1. **Enclosure over source**
2. **Methane accumulates**
3. **Analyzer measures concentration rise**
4. **Flux calculated from slope**



1. Place chamber over wellhead or vent and ensure good seal.
2. CH_4 accumulates in the chamber; concentration increases over time.
3. Sample air is drawn to analyzer; CH_4 concentration recorded over time.
4. Flux = dC/dt × V / A
   Units: g CH_4 m^{-2} h^{-1}

STRENGTHS

- Direct well-specific quantification
- Very low detection limit
- Repeatable across multiple events
- Strong fit for primary crediting

WEAKNESSES

- Labor intensive
- Single-visit measurements miss temporal variability
- Diffuse emissions outside chamber footprint may be missed
- Back-pressure must be managed

OVER-CREDITING RISK

Low with multi-event EMP;
Moderate if single-visit only.

EMP FIT

Repeated 24-hour events distributed across 7–30 days to capture temporal variability.

One of the primary dual-method tools in the EMP.

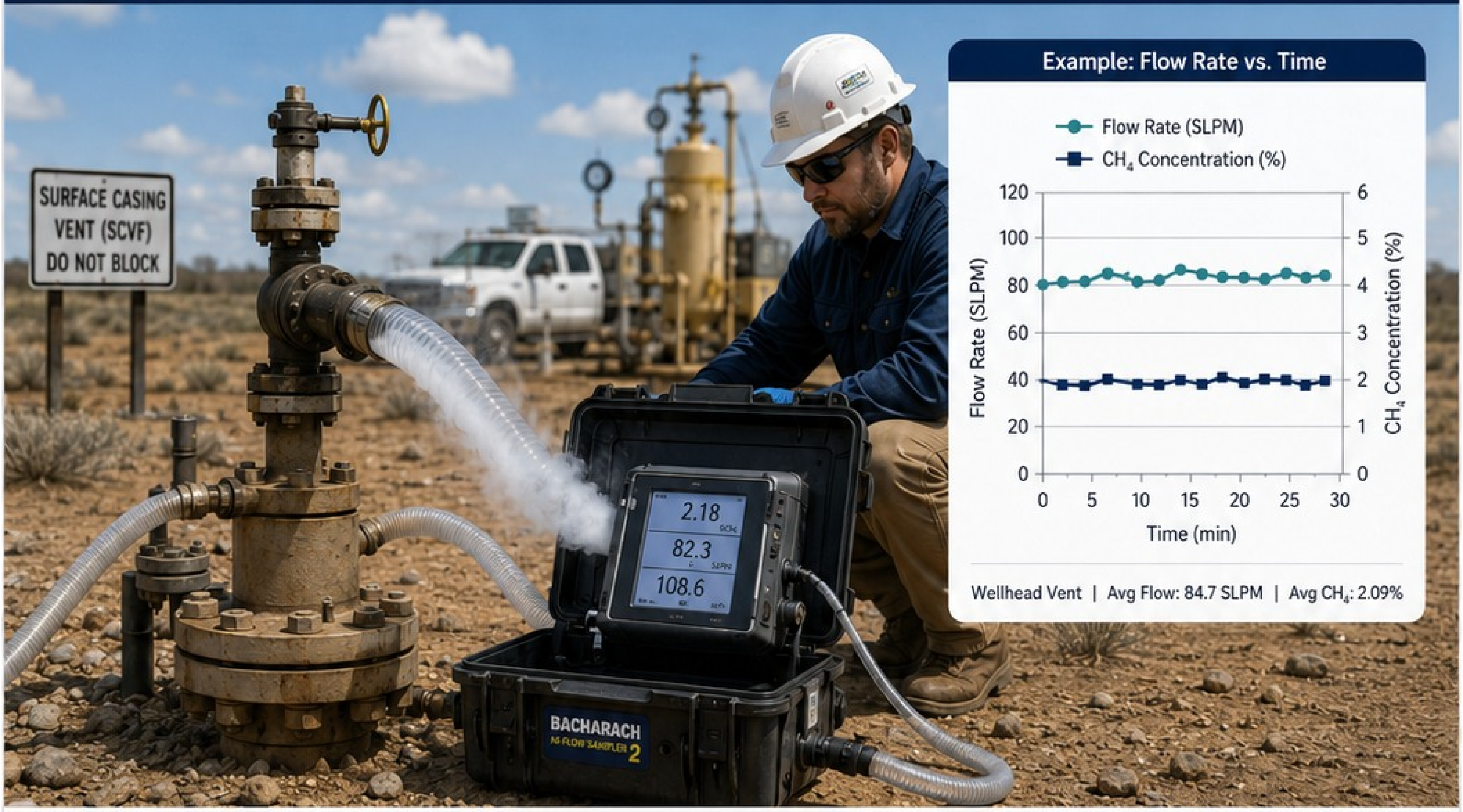
REPRESENTATIVE PLATFORMS

- LI-COR LI-7810 + Smart Chamber 8200-01S
- Eosense eosAC / eosFD
- PP Systems EGM-5
- Picarro chamber-coupled configurations

Best Practice: Use a level surface, verify chamber seal, monitor temperature/pressure, and document all field conditions to support data quality and reproducibility.

2. Dynamic Chamber & High-Flow Sampler

Primary baseline quantification for vented wells and SCVF.



HOW IT WORKS

1 **Connect sampler to routed vent.**

Ensure a leak-tight connection and approved routing.

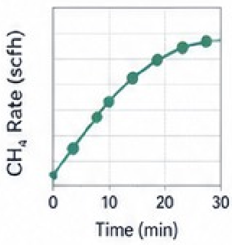
2 **Pull gas through sampler.**

High-flow pump draws gas through the system at a controlled rate.

3 **Measure methane concentration and flow.**

Analyzer and flow meter record concentration and volumetric flow.

4 **Calculate volumetric methane rate.**



CH_4 Rate = Flow × CH_4
Units: scfh, std m^3/h

STRENGTHS

- Direct volumetric quantification
- Strong fit for vented wells and SCVF
- Established field standard
- Good accuracy within instrument range

WEAKNESSES

- Can saturate on super-emitters
- Not suitable for diffuse soil emissions
- Range-transition errors near bounds
- Requires an identifiable flow path

OVER-CREDITING RISK

LOW within instrument range; higher if saturation or off-path emissions are ignored.

EMP FIT

Primary across repeated events or continuous deployment during the Extended Measurement Period.

Ideal for repeated measurements to assess stability and variability.

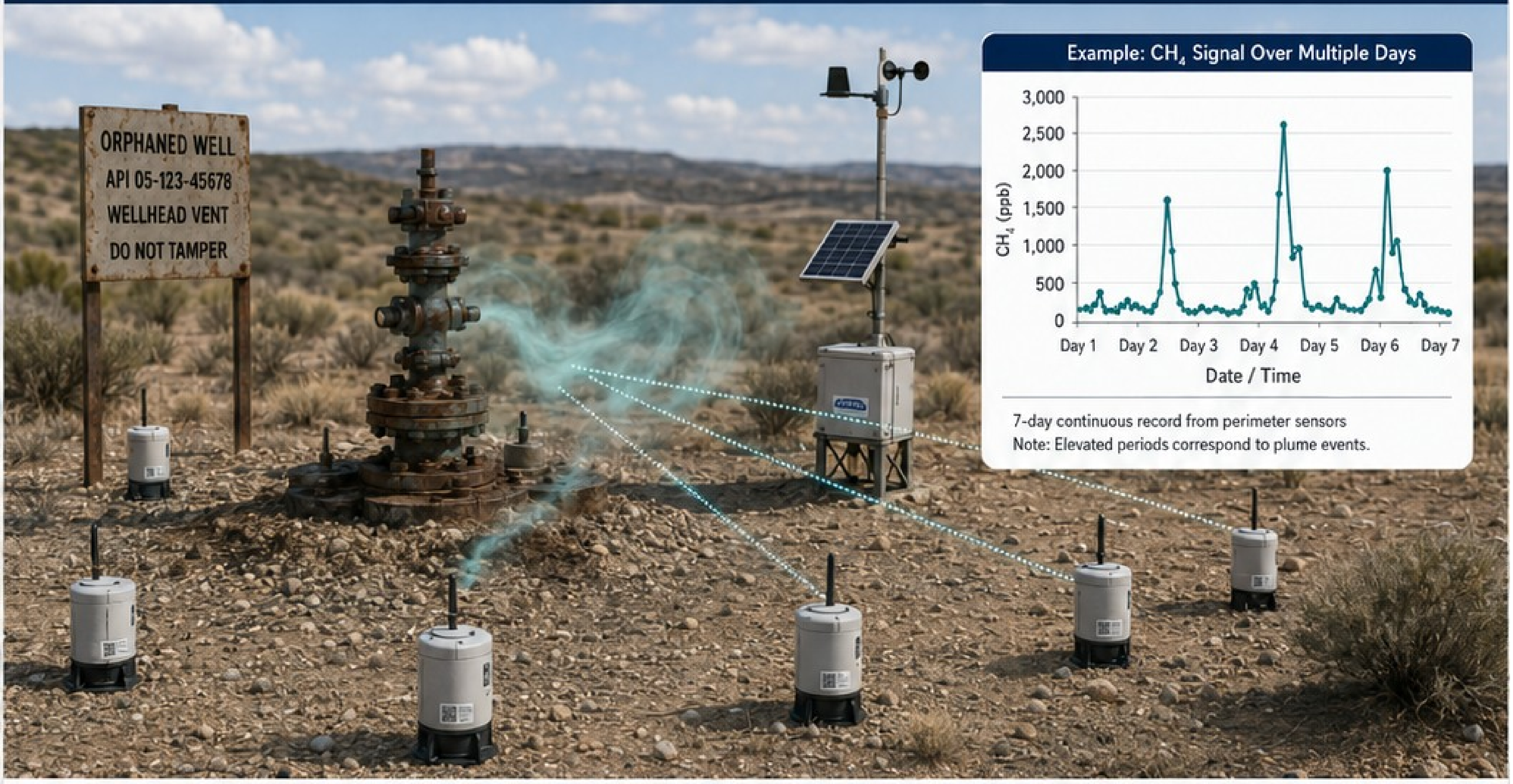
REPRESENTATIVE PLATFORMS

- Bacharach Hi-Flow Sampler 2
- Heath SmartLeak / DP-IR derivatives
- Sensit PMD with flow integration
- Equivalent high-flow sampling systems

Best Practice: Verify flow path integrity, confirm the instrument range matches expected emissions, and document repeated measurements across the EMP.

3. In-Situ Electrochemical Sensor Arrays

Continuous methane monitoring across the Extended Measurement Period.



7-day continuous record from perimeter sensors
Note: Elevated periods correspond to plume events.

HOW IT WORKS

1. **Deploy sensors around the source.**
2. **Record methane concentrations continuously.**
3. **Pair with enclosure or wind/dispersion context.**
4. **Analyze stabilization and temporal variability.**

1. Place robust methane sensors downwind and crosswind of the source.
2. Sensors log CH_4 at short intervals (e.g., 1–10 sec) 24/7 across the EMP.
3. Collect wind speed, wind direction, and stability to interpret plume behavior.
4. Use continuous data to quantify episodes, assess stability, and derive flux statistics.

$$\text{Flux} = \frac{dC}{dt} \times \frac{1}{V} \times A$$

Units: $g\ CH_4\ m^{-2}\ h^{-1}$

Where:

dC/dt = rate of change in CH_4 (ppm/s)
V = wind speed (m/s)
A = effective cross-sectional area (m^2)

STRENGTHS

- Continuous temporal capture
- Detects episodic and weather-driven emissions
- Supports stabilization analysis
- Strong dual-method partner

WEAKNESSES

- Sensor drift requires calibration
- Dispersion-derived flux adds uncertainty
- Lower precision than CRDS
- Site layout matters

OVER-CREDITING RISK

LOW

Low when paired with a second approved method.

EMP FIT

Primary workhorse across **7–30 days** of continuous deployment.

REPRESENTATIVE PLATFORMS

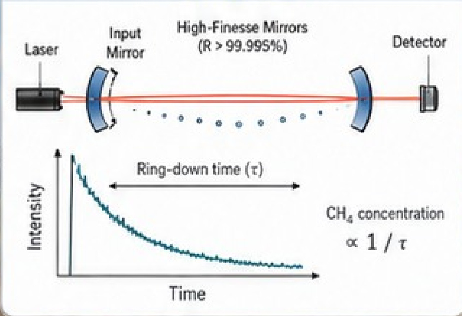
- Project Canary – Canary X
- SeekOps – ground stations
- Aeris – MIRA Ultra
- Sensit / ABB – continuous nodes
- SLB – emissions sensor stack

Best Practice: Calibrate before and after deployment, colocate wind data, and use continuous records to confirm stability before crediting.

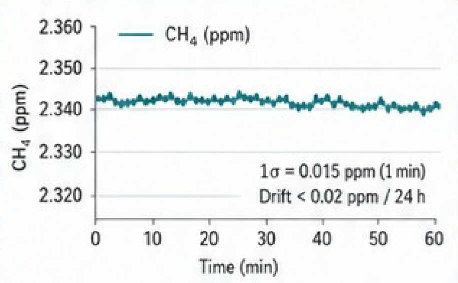
4. Cavity Ring-Down Spectroscopy (CRDS)

High-precision methane concentration measurement for paired flux derivation.

CRDS CONCEPT



Example: High-Precision CH_4 Concentration Trace



1-min average | Allan deviation at 100 s: 8 ppb

HOW IT WORKS

1 Draw sample into optical cavity.

Sample is drawn from chamber headspace or tracer system into the CRDS analyzer.

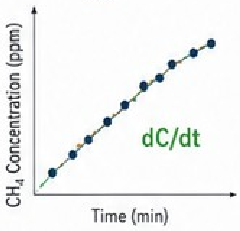
2 Laser ring-down measures CH_4 concentration.

Ring-down time is measured and converted to high-precision CH_4 concentration.

3 Pair with chamber or tracer method.

Use paired method to relate concentration change to flux.

4 Derive well-specific flux.



Flux = dC/dt × V / A

Units: g CH_4 m^{-2} h^{-1}

STRENGTHS

- Highest precision concentration measurement
- Low drift
- Multi-species capability
- Valuable validation tool

WEAKNESSES

- High equipment cost
- Skilled operation required
- Flux is indirect without pairing
- More complex field logistics

OVER-CREDITING RISK

LOW when paired.
MODERATE if ambient concentration is misused as standalone flux.

EMP FIT

Primary when paired with chamber or tracer.

Validation tool at high-scrutiny wells.

REPRESENTATIVE PLATFORMS

- Picarro G2301 / G2401 / G4302
- Aeris MIRA Pico / Ultra
- LGR Ultraportable Greenhouse Gas Analyzer
- Aerodyne TILDAS

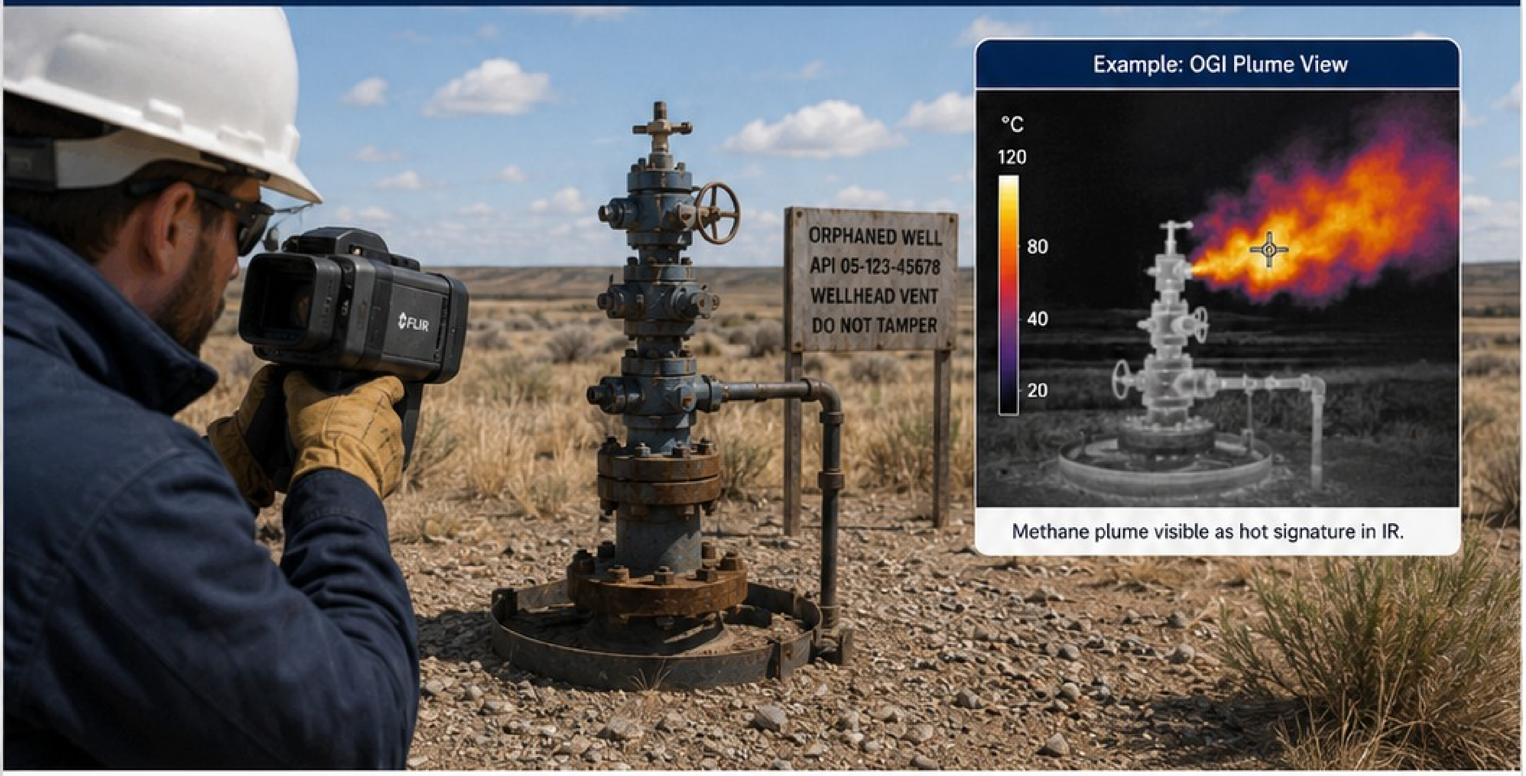
Best Practice: Use CRDS as the precision analyzer inside a paired method, retain calibration logs, and add it under escalation when standard dual-method correlation fails.

CALIBRATION LOGS

ESCALATION WHEN NEEDED

5. Handheld & Ground-Based Optical Gas Imaging (OGI)

Visual plume detection and source localization for corroboration.



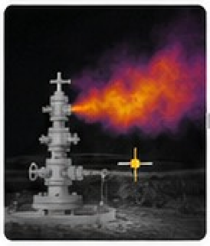
Methane plume visible as hot signature in IR.

HOW IT WORKS

1. **Scan target wellhead with IR camera.**

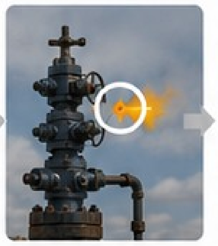
Position camera and scan area of interest.

2. **Detect methane plume visually.**



Methane plume appears as bright signature (methane absorbs IR).

3. **Localize leak source.**



Identify and localize source based on plume origin and behavior.

4. **Corroborate with primary measurements.**

Verify and quantify using chambers, sensors or flow meters.

STRENGTHS

- Rapid screening
- Strong visual evidence
- Good for leak localization
- Useful for QIDL / VVB support

WEAKNESSES

- Mostly qualitative
- Detection threshold misses many low emitters
- Performance depends on weather and operator skill
- Not suitable as primary crediting method

OVER-CREDITING RISK

HIGH if used as primary;
LOW as corroborative only.

EMP FIT

Corroborative only during measurement events.

Supports visual verification and source localization.

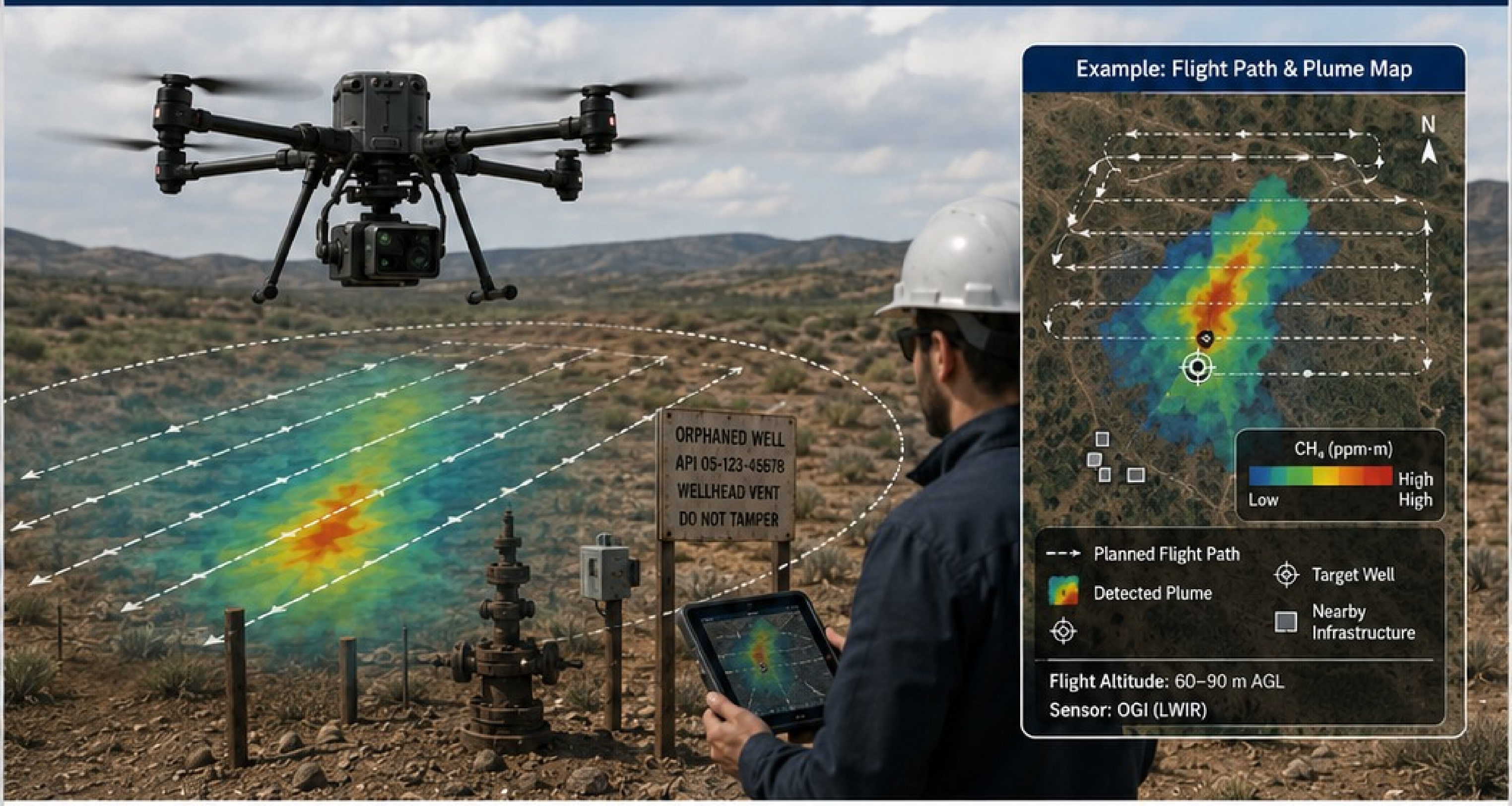
REPRESENTATIVE PLATFORMS

- FLIR GF320 / GF77a
- Opgal EyeCGas 2.0
- Sierra-Olympia Ventus OGI
- Workswell GIS-320
- Providence Photonics QL320 for OGI-Q

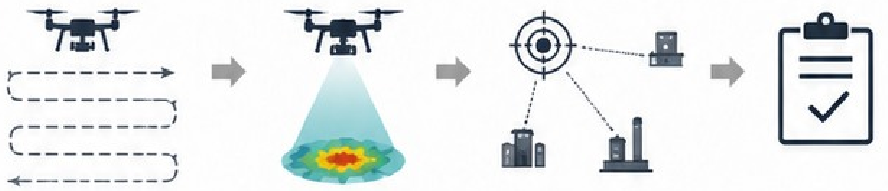
Best Practice: Use OGI to confirm plume origin and document visual evidence, but rely on chambers, sensors, or flow meters for credit calculations.

6. UAV-Mounted OGI / OGI-Q (QASV)

Aerial plume verification and source attribution around the well.



HOW IT WORKS



1. **Fly planned survey pattern.** Execute orthogonal passes to ensure complete coverage.
2. **Detect plume from above.** OGI sensor detects methane signatures across the site.
3. **Attribute emissions to target well versus nearby sources.** Use wind, location, and plume behavior to assign the source.
4. **Corroborate the ground-based baseline.** Results corroborate chamber or flux data from the well.

OGI-Q (QASV): Quantitative Aerial Survey Vehicle methods are used for supportive / corroborative attribution—NOT as the primary quantification method.

STRENGTHS

- Expanded aerial coverage
- Helps with source attribution
- Detects offset migration and nearby infrastructure
- Strong corroborative evidence

WEAKNESSES

- Weather constrained
- Limited flight time
- Quantification remains emerging
- Not used as primary calculation method

OVER-CREDITING RISK

Low because it is used as a corroborative method.

EMP FIT

Mandatory corroborative role with at least two flights per EMP campaign.

Supports source attribution and cross-validation.

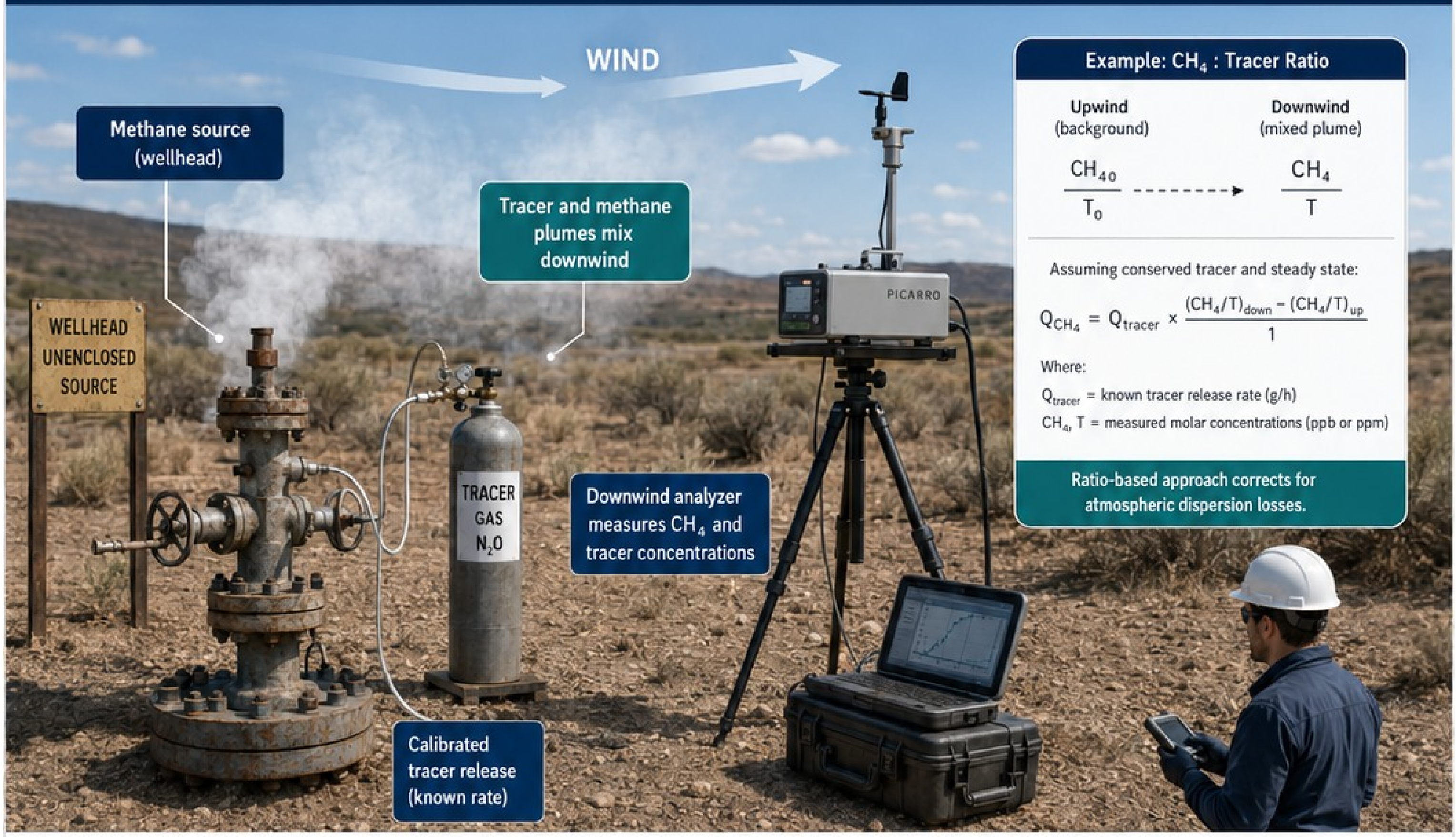
REPRESENTATIVE PLATFORMS

- SeekOps SeekIR on DJI Matrice 300 / 350 RTK
- ABB HoverGuard
- Sierra-Olympia Ventus OGI on UAV
- Bridger drone configurations
- Percepto autonomous drone systems

Best Practice: Fly orthogonal passes in suitable weather and use the drone survey to confirm source attribution and identify nearby confounders.

7. Tracer Dilution

Supplementary quantification for super-emitters and unenclosed sources.



Example: CH_4 : Tracer Ratio

Upwind (background)		Downwind (mixed plume)
$\frac{CH_{4\,0}}{T_0}$	- - - - - →	$\frac{CH_4}{T}$

Assuming conserved tracer and steady state:

$$Q_{CH_4} = Q_{tracer} \times \frac{(CH_4/T)_{down} - (CH_4/T)_{up}}{1}$$

Where:

Q_{tracer} = known tracer release rate (g/h)

CH_4, T = measured molar concentrations (ppb or ppm)

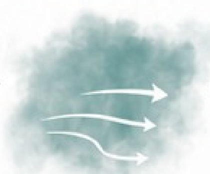
Ratio-based approach corrects for atmospheric dispersion losses.

HOW IT WORKS

1. Release tracer gas at a known rate near source.

Calibrated tracer (e.g. N_2O, SF_6) released adjacent to the emission source.

2. Allow tracer and methane plumes to mix downwind.

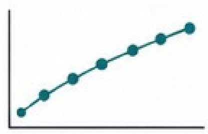


Plumes advect and disperse downwind under prevailing meteorological conditions.

3. Measure methane-to-tracer ratio.

Downwind analyzer measures CH_4 and tracer concentrations simultaneously.

4. Calculate methane flux from the known tracer release.



$Q_{CH_4} = Q_{tracer} \times (CH_4/T)_{down} - (CH_8/T)_{up}$

Flux derived using ratio change and known tracer release rate.

STRENGTHS

- Useful when enclosure is infeasible
- Corrects for atmospheric dispersion
- Valuable for super-emitters
- Independent of source geometry

WEAKNESSES

- Complex setup
- Requires stable wind and tracer colocated with source
- Accuracy falls at low rates
- Residual uncertainty is higher than chamber methods

OVER-CREDITING RISK

Moderate due to uncertainty propagation and environmental variability.

EMP FIT

Supplementary method used when methods disagree or for super-emitter validation.

Strengthens data credibility in the EMP.

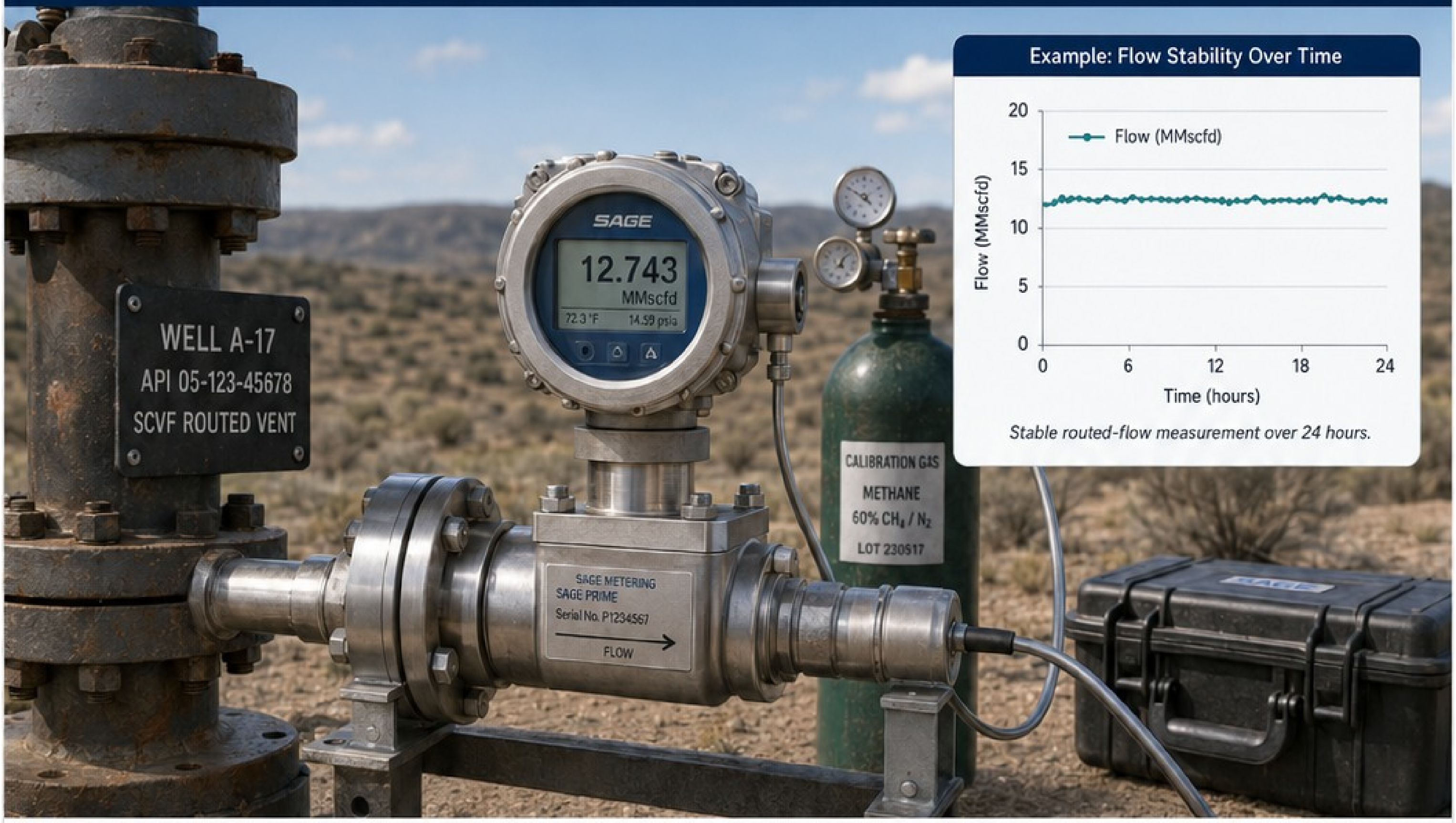
REPRESENTATIVE PLATFORMS

- Picarro G2308 / G2204 with tracer release systems
- Aerodyne TILDAS
- NPL tracer-correlation setups
- Academic tracer-dilution platforms

Best Practice: Use tracer dilution when enclosure is infeasible, ensure precise tracer colocating, and apply a conservative uncertainty deduction.

8. Mass-Flow & Thermal-Mass Flow Meters

Direct routed-flow measurement for SCVF and vented wells.



Stable routed-flow measurement over 24 hours.

HOW IT WORKS

1. **Install meter in-line on vent or flow path.**
2. **Measure volumetric or mass flow directly.**
3. **Confirm calibration and gas composition assumptions.**
4. **Record continuous routed-flow rate.**

Ensure proper orientation and straight-run per manufacturer requirements.

Meter measures flow rate in real time without relying on atmospheric dispersion.

Verify calibration gases, pressure, temperature, and gas composition used in calculations.

Log flow rate and conditions continuously throughout the monitoring period.

STRENGTHS

- Direct measurement without atmospheric dispersion uncertainty
- De facto standard for SCVF
- Continuous-monitoring capable
- Strong accuracy with proper installation

WEAKNESSES

- Requires a defined flow conduit
- Not applicable to diffuse emissions
- Installation sensitivities matter
- Composition and particulates can affect performance

OVER-CREDITING RISK

LOW for correctly installed routed-flow applications.

EMP FIT

Primary for SCVF and vented wells with continuous deployment during the EMP.

Best used where flow is routed, measurable, and attributable.

REPRESENTATIVE PLATFORMS

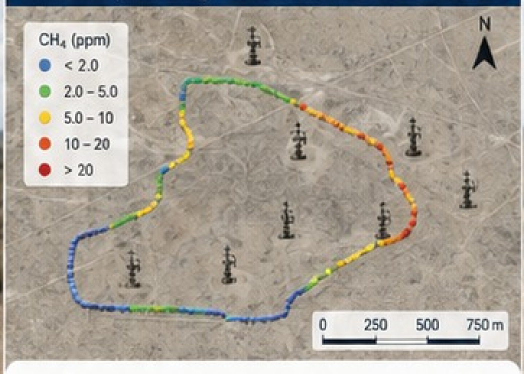
- Sage Metering Sage Prime
- Sierra Instruments QuadraTherm 640i / 780i
- Fox Thermal FT4A
- Endress+Hauser t-mass T 150 / Proline 300
- Emerson Micro Motion Coriolis meters

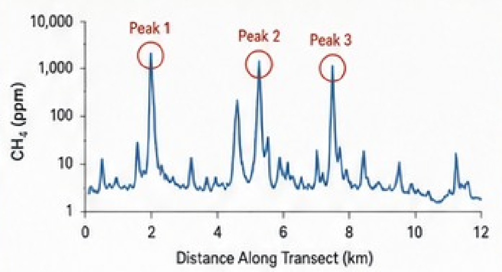
Best Practice: Install meters with proper straight-run requirements, verify calibration gases, and use them only where the vent flow is truly routed and attributable.

9. Mobile Ground Survey (Vehicle-Mounted CRDS)

Inventory screening and super-emitter triage, not primary crediting.

Example: Survey Transect & Concentration Peaks





Peaks indicate candidate sources for follow-up.

HOW IT WORKS

1. **Drive roads near target wells.**

Follow accessible routes to pass near multiple wells.

2. **Continuously sample ambient methane.**

Vehicle-mounted CRDS analyzer measures CH_4 in real time.

3. **Flag concentration spikes and map them.**

Spikes are detected and geolocated to candidate sources.

4. **Use results for screening and triage.**

Prioritize wells for detailed follow-up and mitigation planning.

Mobile surveys are optimized for detection and ranking, not for single-well attribution or quantification.

STRENGTHS

- Screens many wells quickly
- Efficiently identifies super-emitters
- Low screening cost per well
- Valuable for site selection

WEAKNESSES

- Poor single-well attribution in dense fields
- Requires road access
- Misses many low emitters
- Not accurate enough for primary baseline crediting

OVER-CREDITING RISK

HIGH if used as primary because of attribution and detection-limit bias.

EMP FIT

Pre-EMP screening and inventory characterization only.

Not suitable to establish crediting baselines.

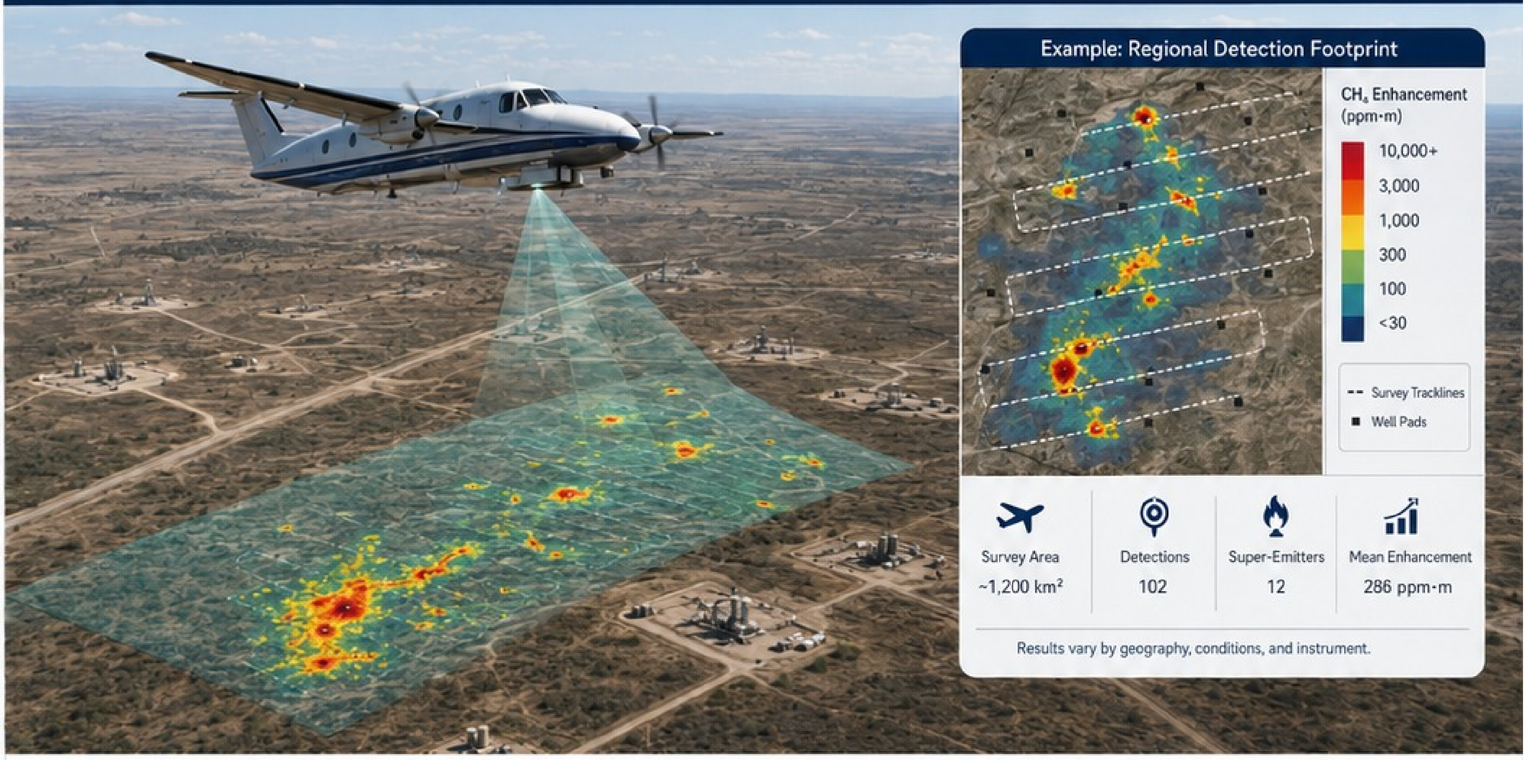
REPRESENTATIVE PLATFORMS

- Picarro Surveyor
- ABB MobileGuard
- Aclima vehicle networks
- Bridger ground-mobile systems
- SeekOps GroundOps

Best Practice: Use mobile survey to prioritize wells for detailed EMP campaigns, not to establish crediting baselines.

10. Aircraft-Based Surveys

Regional methane mapping and super-emitter detection, not per-well baseline crediting.

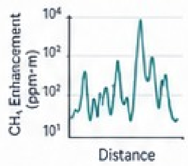


HOW IT WORKS

1. Fly survey grid over basin.

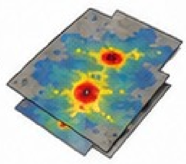
Planned flight lines collect backscatter or absorption data across the basin.

2. Measure methane enhancements remotely.



Sensors measure methane column enhancements relative to background.

3. Map regional detections.



Enhancements are mapped to surface location to identify plumes and hot spots.

4. Use detections to guide follow-up field work.

Teams investigate detections on the ground to confirm sources and quantify.

Aircraft systems (LiDAR, imaging spectrometers, or TDLAS) provide broad-area coverage efficiently but cannot reliably attribute emissions to individual wells.

STRENGTHS

- Covers thousands of wells per campaign
- Finds super-emitters in remote areas
- Useful for regional inventory characterization
- Supports portfolio design

WEAKNESSES

- Detection threshold misses most lower-emitting wells
- Severe attribution challenges in dense fields
- Single-well accuracy is weak
- Not suitable for primary baseline crediting

OVER-CREDITING RISK

High if used as primary due to strong detection-limit bias.

EMP FIT

Pre-EMP regional screening tool only. Not appropriate as a primary measurement method in the EMP.

Use to prioritize areas, then deploy well-specific methods for crediting.

REPRESENTATIVE PLATFORMS

- Bridger Photonics Gas Mapping LiDAR
- Kairos LeakSurveyor
- Carbon Mapper aerial systems
- Scientific Aviation / ChampionX airborne deployments
- MethaneAIR

Best Practice: Use aircraft surveys to screen regions and identify priority follow-up sites, then shift to well-specific ground methods for crediting.