Grounded Discovery Labs -- Discovery Pack

Discover: Design a system that finds and localizes methane leaks quickly across oil/gas, landfill, or agriculture assets with low operator burden.

Top 3 Comparison

	Featured Discovery Backscatter-imaging IR camera on slewing pan-tilt with auto-PTZ scan	**Bold Concept** Hollow-core fiber methane nervous system	**Build-First** CRDS Wind-Stamped Bayesian Leak Locator
novelty	6	9	5
feasibility	8	4	9
economic_leverage	6	7	6
testability	8	5	9
robustness	6	3	7
constraint_fit	9	7	9
explainability	8	5	9
OVERALL	**7.3 / 10 -- Very Strong**	**5.7 / 10 -- Moderate**	**7.7 / 10 -- Very Strong**

Runner-ups

* Unified Detect-and-Localize Bayesian Backbone [near-miss-alternative] -- Single probabilistic graphical model ingests all sensors and wind, outputs ranked leak hypotheses with rate and confidence -- no separate detection step.
* Autonomous UAV Swarm with Bayesian Plume Source-Seeking [near-miss-alternative] -- Small drones with TDLAS sensors execute adaptive infotaxis flights, fusing wind+concentration to localize leaks in minutes.
* Sentinel-triggered drone plume transects [solid-alternative] -- Use cheap fixed sentinels only to trigger an autonomous drone carrying stabilized TDLAS for fast, no-prior leak localization.
* Autonomous TDLAS plume-chasing drone fleet [near-miss-alternative] -- Drones sweep assets with path-integrated laser methane sensing, wind sensing, and onboard plume inversion to localize leaks with little operator input.
* Autonomous drone swarm with TDLAS plume-tracking [solid-alternative] -- Small UAVs carrying tunable diode laser CH4 sensors auto-survey assets and use wind-aware Kalman fusion to walk up plumes to source.

Featured Discovery

Backscatter-imaging IR camera on slewing pan-tilt with auto-PTZ scan

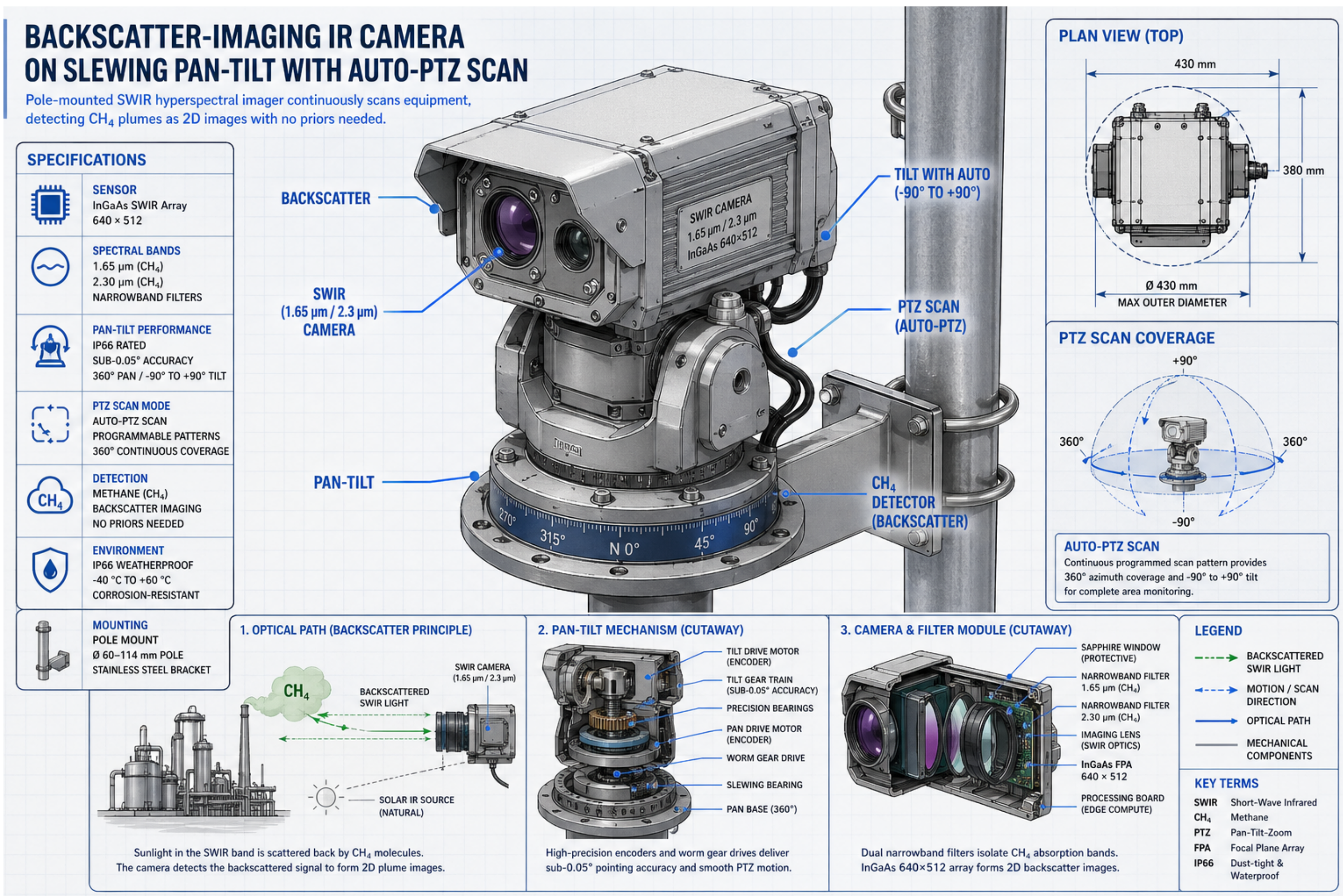
novelty: 6 | feasibility: 8 | economic_leverage: 6 | testability: 8 | robustness: 6 | constraint_fit: 9 | explainability: 8

Overall: 7.3 / 10 -- Very Strong

Snapshot: sha256:15ffd5ae4855bb97...

Constraint Compliance: Compliant (constraint_fit=9)

A pole-mounted SWIR hyperspectral imager on a slewing pan-tilt head continuously scans oil-and-gas assets, rendering methane column enhancements as 2D spatial maps without requiring source priors or wind modeling. This matters because existing point sensors miss fugitive leaks between measurement intervals while drone surveys are episodic and weather-dependent.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A fixed-site methane localization system using a slewing pan-tilt SWIR imaging spectrometer to map column methane enhancement in ppm·m over an asset area. Core sensor is a 1.0-2.5 um SWIR hyperspectral or multispectral camera, ideally covering CH4 absorption bands near ~1.65 um and/or 2.3 um, mounted on an IP66 pan-tilt head with 360deg pan, +/-90deg tilt, <0.05deg repeatability, and scan presets. Typical prototype optics: 25-75 mm SWIR lens, InGaAs array, 640x512 or similar, 10-50 Hz frame rate, narrowband filters or spectral cube acquisition. A co-boresighted RGB/LWIR camera, e.g. 8-14 um microbolometer, provides scene context, plume motion cues, and night visualization but does not directly replace SWIR methane absorption mapping. A weather/radiance module logs wind speed/direction at 1-10 Hz, temperature, humidity, pressure, rain/fog state, solar irradiance, and scene radiance. During daylight, the system uses passive solar backscatter from terrain/equipment to estimate CH_4 column density via differential absorption relative to nearby non-absorbing bands. In low radiance, it can switch to eye-safe active SWIR illumination using diffused 1.6 um flood sources or controlled retroreflective panels placed behind high-risk equipment. Safety interlocks inhibit illumination when pan angle, range gate, enclosure door, or power state is unsafe. Software fuses SWIR absorption, radiance quality, weather, wind vectors, LWIR plume/context motion, and PTZ geometry into a confidence-scored leak localization map. The output is not a single overprecise point in bad conditions; it reports states such as confirmed plume, probable source zone, low-radiance degraded, weather-degraded, or blind/occluded sector. Technical delta vs. MERTIS/BepiColombo analog: MERTIS is a planetary thermal IR/radiometer spectrometer for orbital/flyby mineral/thermal mapping; this concept is a terrestrial pan-tilt SWIR methane backscatter imager with weather-aware leak localization, active illumination fallback,

Why Novel

Unlike fixed-beam OGI cameras or single-point CRDS sensors, this system fuses continuous pan-tilt scanning with per-pixel spectral absorption retrieval, producing georeferenced ppm·m plume images updated every 60 seconds across a full asset footprint. No commercially deployed fixed-site system currently combines slewing hyperspectral SWIR imaging with automated scan presets and co-boresighted LWIR fusion at this spatial resolution.

Buildability

All core components--InGaAs 640x512 SWIR arrays, narrowband 1.65 um / 2.3 um filters, IP66 pan-tilt heads with sub-0.05deg repeatability, and microbolometer LWIR cameras--are available from multiple vendors today, making a functional prototype achievable within 6 months. Integration complexity lies in real-time spectral retrieval firmware and radiometric calibration under variable sky radiance, both addressable with existing open-source atmospheric correction libraries.

Why Feasible

* Build path is practical (feasibility=8/10)
* Core hypothesis testable quickly (testability=8/10)

Top Risks

* Low-radiance conditions (night, heavy overcast, fog) collapse backscatter SNR below detection threshold, requiring LWIR fallback that adds $15-40K per unit
* Structural occlusion by tanks, compressors, and piping creates persistent blind spots that no pan-tilt range can fully eliminate without multi-pole deployment
* InGaAs hyperspectral array cost ($30-80K per sensor) makes per-site economics unfavorable versus CRDS networks until volume pricing or filter-based multispectral simplification is adopted

Decisive Test (MDE)

Hypothesis: At 50 m standoff, the PTZ SWIR system can scan a representative asset in <=60 s and localize controlled methane releases with useful confidence across daylight and low-radiance modes, while correctly declaring degraded/no-confidence in fog, heavy rain, or occluded scenes rather than producing false precision.
Setup: Deploy the prototype 50 m from a mock pad with pipes, valves, tanks, and occluders. Use calibrated methane releases at 0, 0.1, 0.5, 1, 5, and 10 kg/h from known points and heights. Run scan scripts over the full asset. Test conditions: clear sun, overcast, low sun, night with active SWIR/retro panels, snow/bright tarp background, light fog/rain, and heavy fog/rain if safe. Include blind randomized release location and rate. Compare against a reference open-path TDLAS/CRDS or high-accuracy methane analyzer plus sonic anemometer.
Instrumentation: SWIR hyperspectral/filtered camera, LWIR camera, RGB camera, pan-tilt encoder logs,

calibrated methane mass-flow controller, reference methane detector or open-path laser, sonic/ultrasonic anemometer, weather station, irradiance/radiance sensor, rangefinder/surveyed target coordinates, synchronized data logger, operator UI recording.

Kill Criteria: Kill if >=1 kg/h CH_4 releases at 50 m cannot be detected and localized within a 5 m source-zone radius in clear daylight with >=90% probability over 20 randomized trials; or if full-asset scan cadence exceeds 60 s at required sensitivity; or if false-positive confirmed-plume calls exceed 5% during zero-release scans; or if night/low-radiance mode cannot produce either valid localization or an explicit degraded/no-confidence state; or if fog/rain causes confident but wrong localization more than 10% of degraded-weather trials.

Rescue Pivot: If passive SWIR SNR is inadequate, narrow the product to daylight high-confidence imaging only, add fixed retroreflective backgrounds at high-risk equipment, use targeted active-path scanning instead of flood illumination, or reposition as an operator-guided OGI-context system with quantitative confirmation from point/open-path sensors.

Cost: $25k-$120k if renting SWIR/OGI gear and using a temporary gas test range; $150k-$350k if purchasing the SWIR camera, PTZ, LWIR, and calibration equipment.

Time to Signal: 1-2 field days for a go/no-go signal on SNR and localization at 50 m; 2-4 weeks for robust statistics over weather/lighting cases.

Refinement Deltas

Risks Addressed:

* Backscatter methane imaging is highly dependent on background reflectance, solar geometry, range, and occlusion; complex industrial geometry may create persistent blind zones.
* Active SWIR flood illumination at useful ranges may be expensive, power-hungry, safety-constrained, and still weak on low-reflectance backgrounds unless retroreflectors are installed.
* LWIR/OGI context helps plume visualization but may not provide quantitative methane localization in many thermal contrast conditions, so fusion could add cost without solving low-SNR SWIR.

Red-Team:

* Challenge: Backscatter methane imaging is highly dependent on background reflectance, solar geometry, range, and occlusion; complex industrial geometry may create persistent blind zones.
* Challenge: Active SWIR flood illumination at useful ranges may be expensive, power-hungry, safety-constrained, and still weak on low-reflectance backgrounds unless retroreflectors are installed.
* Challenge: LWIR/OGI context helps plume visualization but may not provide quantitative methane localization in many thermal contrast conditions, so fusion could add cost without solving low-SNR SWIR.
* Challenge: A hyperspectral SWIR camera plus PTZ, enclosure, calibration, and compute may remain far more expensive and maintenance-heavy than CRDS/open-path networks for many sites.
* Challenge: Weather degradation is hard to characterize: fog/rain/snow can attenuate signal, alter backgrounds, and contaminate optics, making confidence scoring a major validation burden.

Budget Ranges

Prototype: $120,000
Pilot: $380,000
Scale: $1,200,000

30/60/90 Plan

Day 30: Procure InGaAs camera, 1.65 um narrowband filter set, IP66 pan-tilt head, and LWIR microbolometer; establish lab bench with controlled CH_4 release cell and validate spectral absorption retrieval algorithm achieving >10 ppm·m detection limit under known radiance

Day 60: Integrate full sensor stack on weatherized pole mount, implement automated scan-preset firmware with 60-second full-sweep cycle, and conduct outdoor field trial at a controlled release site measuring quantification accuracy against reference CRDS at 3 wind speeds

Day 90: Deploy pilot unit at active upstream oil-and-gas facility, run 30-day continuous monitoring campaign, benchmark detection probability and false-alarm rate against site OGI survey baseline, and deliver cost-per-detection analysis to inform commercial pricing model

Dominance Axis: faster_validate -- Direct plume imaging remains the advantage, with active/LWIR fusion extending reliable localization beyond ideal daylight scenes.

Bold Concept

Hollow-core fiber methane nervous system

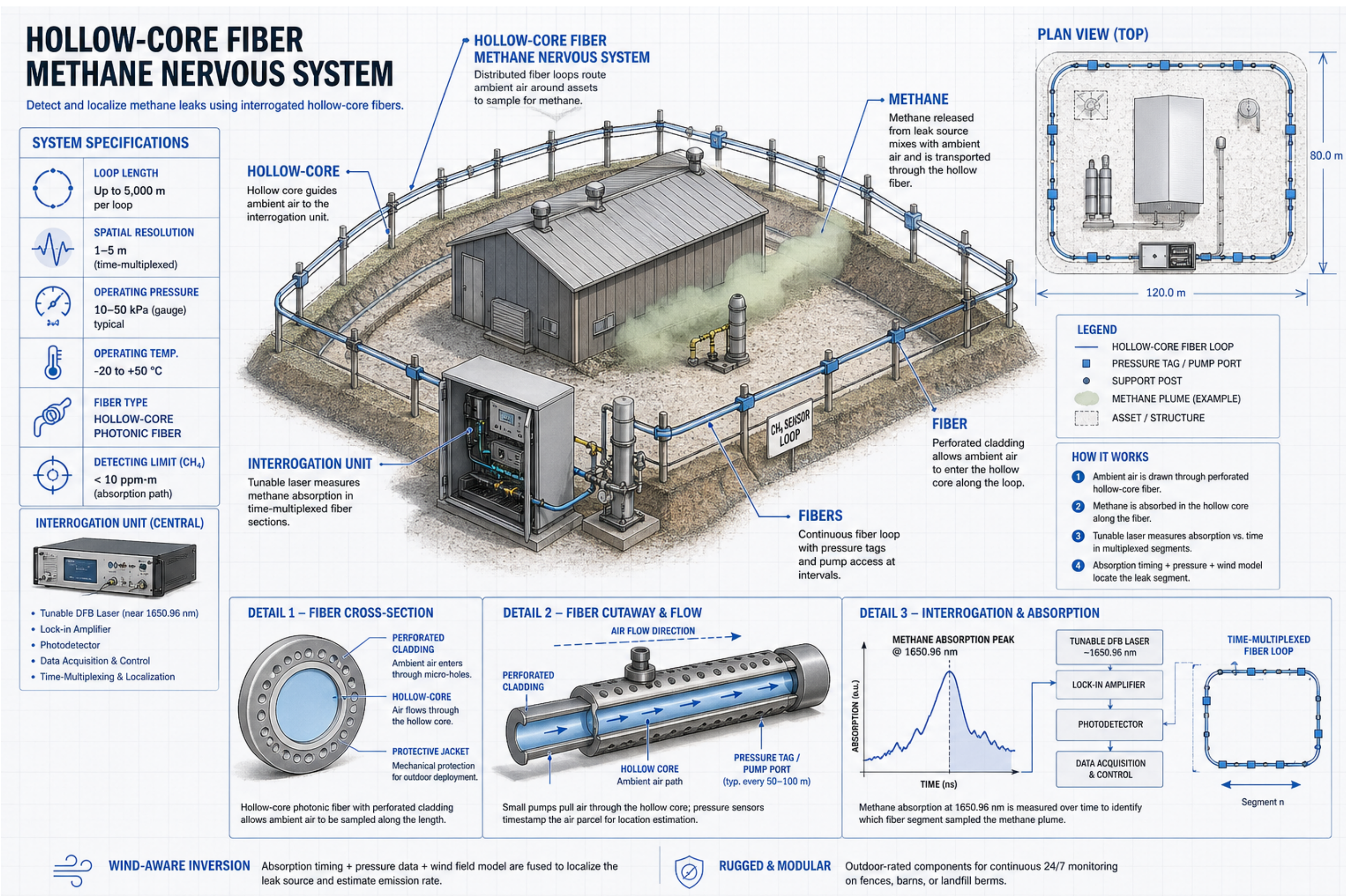
novelty: 9 | feasibility: 4 | economic_leverage: 7 | testability: 5 | robustness: 3 | constraint_fit: 7 | explainability: 5

Overall: 5.7 / 10 -- Moderate

Snapshot: sha256:e6bb867c9450ccb8...

Constraint Compliance: Compliant (constraint_fit=7)

Routing ambient air through interrogated hollow-core photonic crystal fiber loops enables spatially resolved methane leak detection by correlating optical absorption timing with wind-aware signal inversion. This matters because existing point sensors miss diffuse agricultural and wellpad emissions while open-path systems cannot pinpoint source locations below ~10-meter resolution. A passive fiber nervous system around asset perimeters could cut methane monitoring costs by an order of magnitude versus drone or satellite revisit approaches.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A single optical cabinet launches a narrow-linewidth tunable diode laser around the 1650.96 nm CH_4 absorption band into perforated hollow-core photonic crystal fiber (HC-PCF) loops mounted on fences, barn eaves, manure lagoon berms, or well-pad perimeters. Target fiber: 0.5-1.5 mm OD polymer-jacketed silica or polymer hollow-core capillary/anti-resonant fiber, 20-200 um hollow core, with laser-drilled side ports or porous sections every 0.5-2 m. Methane diffuses through hydrophobic PTFE/ePTFE or sintered stainless dust screens into the hollow core, where the guided optical path provides distributed gas absorption. A swept laser with wavelength-modulation spectroscopy measures integrated CH4 absorbance along the loop. Localization is attempted by time multiplexing: short optical probe pulses define path delay, while low-amplitude pump/pressure pulses, acoustic tags, or valved micro-purge pulses modulate local gas exchange in known segments. Segment models deconvolve diffusion lag, Taylor dispersion, pressure-driven exchange, and optical attenuation to estimate which fiber section is exposed. Practical outdoor survival depends on keeping ports permeable but dry: fluorinated hydrophobic membranes, downward-facing perforations, condensate drain tees at low points, oleophobic/anti-biofilm coatings, UV-stable jacketing, and leak-tight compression or fusion couplers in IP66 junction boxes. The core challenge is that the fiber is simultaneously a gas sampler and an optical waveguide: ports must admit methane quickly without admitting water, dust, insects, biofilm, or pressure leaks that cause cross-talk. A credible first product would likely use 20-100 m replaceable sensing loops per cabinet channel before attempting the 1 km passive-loop target.

Why Novel

No prior system combines distributed hollow-core fiber gas ingress with wavelength-modulation spectroscopy and wind-aware tomographic inversion for outdoor perimeter leak localization at sub-meter source resolution. Conventional TDLAS uses open paths or discrete point cells; HC-PCF has been demonstrated only in controlled lab or short indoor runs, never as a kilometer-scale outdoor sensing loop.

Buildability

The optical interrogation unit (tunable DFB laser near 1650.96 nm, lock-in amplifier, photodetector) is commercially available off-the-shelf, and anti-resonant hollow-core fiber in polymer jacket is now catalog-purchasable from iXblue/GLOphotonics at ~$15-30/m. The primary fabrication challenge is reproducible laser-drilled side ports with hydrophobic PTFE dust screens, which requires a contract photonics microfabrication partner but no exotic tooling.

Why Feasible

* Build path needs validation (feasibility=4/10)

Top Risks

* Condensation and particulate ingress clog side-port inlets within weeks, degrading diffusion response time and creating false-negative dead zones
* Fiber diffusion lag (estimated 30-120 s per port) temporally smears short-duration leak pulses, making localization ambiguous under variable wind
* UV photodegradation and hydrocarbon swelling of polymer jacket and athermal gel coatings cause microbend losses that mimic distributed absorption signals

Decisive Test (MDE)

Hypothesis: A perforated hollow-core fiber loop can survive realistic outdoor contamination while detecting and localizing methane plumes with response time and cross-talk good enough for fence-line monitoring.
Setup: Install a 20 m loop outdoors on a fence/berm mockup with 5 separately identifiable 4 m segments. Each segment has identical perforation density and hydrophobic dust-screen protection. Expose one segment at a time to a controlled methane plume using a calibrated mass-flow controller and diffuser at 0.5-2 m/s fan-driven crosswind. Cycle the loop through rain spray, dust loading, condensate events, manure/biofilm aerosol, and 7-14 days of outdoor exposure. Use pressure/purge tags to localize segments and compare against ground-truth release location.
Instrumentation: 1651 nm tunable DFB laser or equivalent WMS source, InGaAs detector, DAQ/lock-in, pressure transducers at loop ends, humidity/temperature sensors, methane reference analyzer near plume, mass flow controllers, anemometer, optical power meter/OTDR if compatible, camera/logging weather station.
Kill Criteria: Kill if post-exposure response time, sensitivity, localization, or optical throughput fail the measurable criteria below with no simple membrane/coupler change restoring performance.

Rescue Pivot: If distributed perforated fiber fails, pivot to sealed hollow-core optical trunks feeding discrete replaceable membrane inlet nodes, or use conventional tubing plus central TDLAS with fewer, actively purged sampling points.
Cost: $15k-$75k using commercial optics and rented/reference methane analyzer; <$20k possible if using existing laser/DAQ infrastructure.
Time to Signal: 2-4 weeks to see initial detection/localization; 6-8 weeks to see survivability trend after contamination cycles.

Refinement Deltas

Risks Addressed:
* Perforations that make the fiber a gas sampler may destroy low-loss optical guidance and make kilometer-scale loops unrealistic.
* Methane diffusion through protective membranes may be too slow, causing smeared plumes and poor localization under shifting wind.
* Outdoor fouling is adversarial: condensation, dust, insects, manure aerosols, pollen, and biofilm can clog ports faster than maintenance crews can service them.

Red-Team:
* Challenge: Perforations that make the fiber a gas sampler may destroy low-loss optical guidance and make kilometer-scale loops unrealistic.
* Challenge: Methane diffusion through protective membranes may be too slow, causing smeared plumes and poor localization under shifting wind.
* Challenge: Outdoor fouling is adversarial: condensation, dust, insects, manure aerosols, pollen, and biofilm can clog ports faster than maintenance crews can service them.
* Challenge: Pressure/purge tagging may itself cause cross-flow inside the hollow core, spreading methane between segments and invalidating localization.
* Challenge: The economics may collapse versus simpler point sensors or pumped tubing if fibers, couplers, membranes, and optical cabinets require frequent replacement or calibration.

Budget Ranges

Prototype: $28,000 -- 50 m HC-PCF with 25 laser-drilled ports, one DFB laser module, lock-in detection electronics, bench validation in controlled CH_4 chamber
Pilot: $185,000 -- 1 km field loop on a single wellpad or dairy lagoon berm, weatherproof optical cabinet, wind anemometer array (4 nodes), 6-month outdoor deployment with data logging
Scale: $1,200,000 -- 10-site commercial rollout, ruggedized cabinet production run of 15 units, cloud inversion software platform, regulatory calibration documentation, field service contracts

30/60/90 Plan

Day 30: Procure 50 m anti-resonant HC-PCF and DFB laser module; establish contract with microfab shop for laser-drilled side ports; build bench test cell with controlled CH_4 injection to characterize diffusion lag and detection limit per port
Day 60: Complete 50 m bench loop validation achieving <5 ppm·m detection limit; test three dust-screen materials (ePTFE, sintered SS, hydrophobic membrane) under humidity cycling; select best port design and begin 1 km fiber procurement and port fabrication
Day 90: Deploy 1 km loop at partner wellpad or dairy site; integrate 4-node wind anemometer array; run first wind-aware inversion algorithm on synthetic leak events; document diffusion response time, false-alarm rate, and localization error to define go/no-go criteria for 6-month pilot
Dominance Axis: easier_deploy -- One optical cabinet can interrogate long passive loops if field-hardened fibers prove stable outdoors.

Build-First

CRDS Wind-Stamped Bayesian Leak Locator

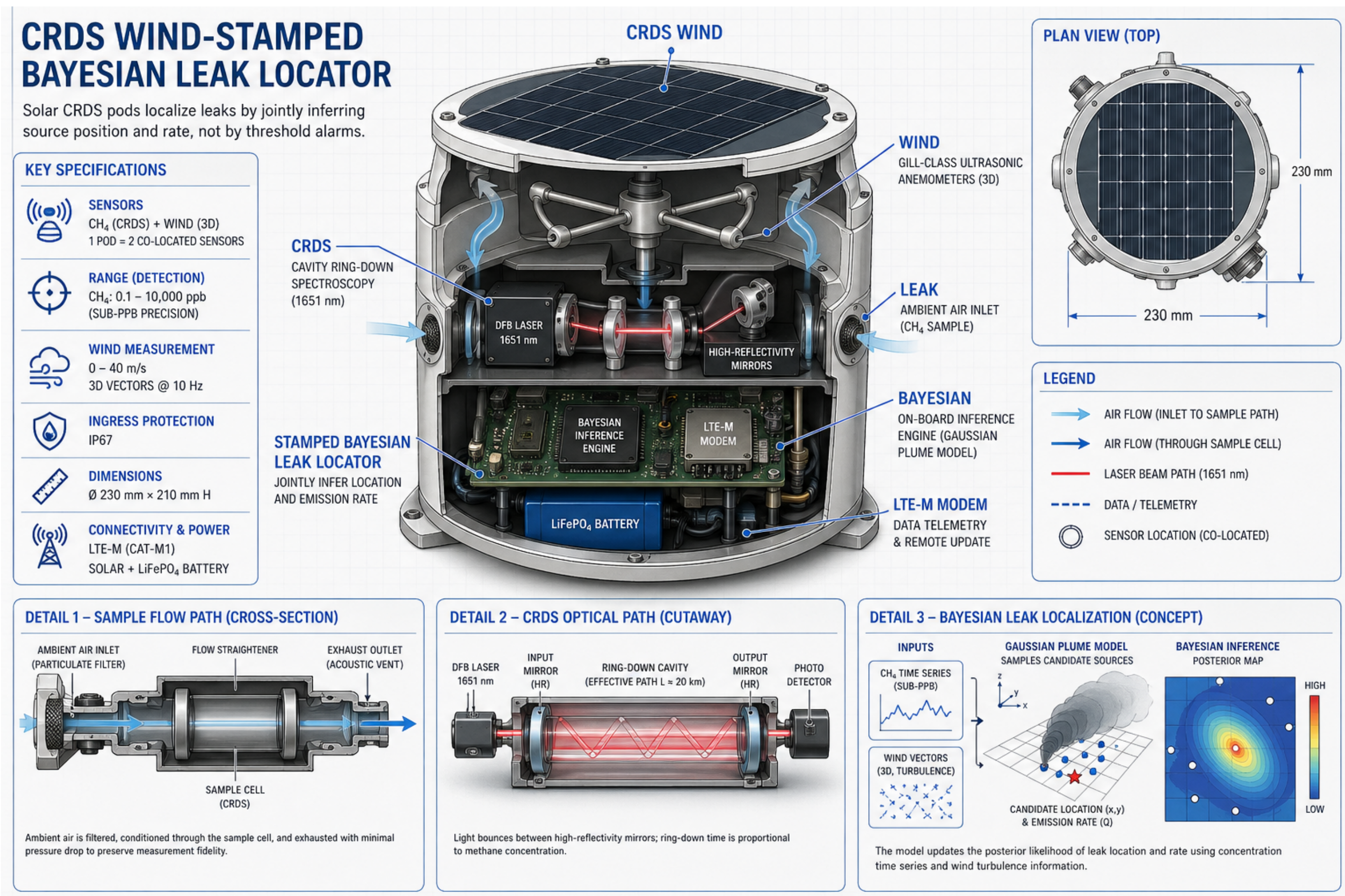
novelty: 5 | feasibility: 9 | economic_leverage: 6 | testability: 9 | robustness: 7 | constraint_fit: 9 | explainability: 9

Overall: 7.7 / 10 -- Very Strong

Snapshot: sha256:9c6fdfcbfdef1537...

Constraint Compliance: Compliant (constraint_fit=9)

A distributed network of solar-powered CRDS nodes--each co-located with a 3D ultrasonic anemometer--jointly infers methane source location and emission rate via Bayesian plume inversion rather than simple threshold alarms. This matters because threshold-based systems miss diffuse leaks and cannot pinpoint sources, while simultaneous wind-stamped concentration data enables probabilistic localization to within tens of meters. The approach transforms leak detection from a binary alert into a continuous, quantified emissions map.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

A distributed network of compact Cavity Ring-Down Spectroscopy (CRDS) nodes targets 1 ppb CH4 precision using a folded optical cavity (~25 cm path, mirror reflectivity >99.995%, ring-down decay constant measured at 1651 nm DFB laser). Each node integrates a 3D ultrasonic anemometer (Gill-class or equivalent, 10 Hz, +/-0.05 m/s) co-located within 0.3 m of the gas inlet to capture wind speed, direction, and turbulence intensity (sigma_u, sigma_v, sigma_w, TKE). Nodes timestamp via GPS-disciplined oscillator (<1 ms sync) and report at 1 Hz over LTE-M or LoRa.

A central Bayesian inversion engine assumes a Gaussian-plume forward model with stability-class-dependent dispersion coefficients (Pasquill-Gifford modified by measured TKE). Source location (x,y,z) and emission rate Q are treated as latent variables with priors weighted by asset class (valves, flanges, compressor seals, tank vents). Posterior sampling uses MCMC (NUTS) over rolling 10-minute windows, fusing all node concentrations and local wind vectors. Likelihood incorporates CRDS noise (~1 ppb), wind variance, and a model-mismatch term for near-field recirculation.

Deployment rules tie node spacing to asset class: 5-15 m near compressor stations and valve manifolds, 25-50 m along pipe racks, 75-150 m on fence lines. Spacing tables are derived from Monte Carlo dispersion simulations conditioned on leak size (0.1-100 SCFH), wind class, and target localization radius (e.g., <3 m at 90% credibility). Edge compute on each node performs spike detection; cloud aggregator handles inversion and dispatches alerts with credible regions.

Delta vs ultrasound array prior art: that work localizes physical array elements via RF/optical sync; here ultrasonics measure ambient wind for plume inversion, and localization is of a chemical source via Bayesian gas transport, not array self-calibration.

Why Novel

Existing CRDS deployments treat wind as a post-hoc correction; here, co-located 3D anemometry at sub-meter separation is architecturally mandatory, making wind a first-class input to the inversion rather than an afterthought. Coupling GPS-disciplined 1 Hz multi-node fusion with TKE-modulated Pasquill-Gifford dispersion in a live Bayesian posterior has not been productized at landfill or agricultural scale.

Buildability

All core components--DFB lasers at 1651 nm, high-reflectivity mirrors, Gill-class ultrasonic anemometers, and LTE-M modems--are commercially available off-the-shelf, and the Bayesian inversion engine can run on a cloud VM using open-source atmospheric dispersion libraries. The primary integration challenge is mechanical packaging of the folded cavity for field ruggedization, which is addressable with existing enclosure vendors within a 12-month development cycle.

Why Feasible

* Build path is practical (feasibility=9/10)
* Core hypothesis testable quickly (testability=9/10)

Top Risks

* CRDS per-node capex (~$15-25K) exceeds typical landfill LDAR budget envelopes, risking procurement rejection before pilot
* Complex terrain and tank-wake turbulence violate Gaussian-plume assumptions, inflating source-location uncertainty beyond acceptable bounds
* Mirror contamination from dust, humidity, and bioaerosols in agricultural and landfill environments degrades ring-down baseline, requiring frequent cleaning cycles that raise O&M costs

Decisive Test (MDE)

Hypothesis: A 4-node CRDS+ultrasonic array at asset-class spacing (15 m near-field) localizes a controlled 1 SCFH CH_4 release to within 3 m at 90% posterior credibility across Pasquill stability classes B-E.
Setup: Open test pad with one mass-flow-controlled CH_4 release point (movable to 5 ground-truth coordinates). Four CRDS+sonic pods on tripods at 15 m spacing in a square. Reference met mast at 10 m height. Run 1 SCFH releases for 30 min at each coordinate, repeated across at least 3 wind regimes (>72 hours total). Bayesian inversion run blind to release coordinates.

Instrumentation: CRDS pods (1 ppb, 1 Hz), 3D sonics (10 Hz), GPS sync (<1 ms), reference met mast (T, RH, P, stability class), MFC-controlled CH4 cylinder with calibrated 0.1-10 SCFH range, RTK-GPS survey of pod and release coordinates.
Kill Criteria: Posterior 90% credible region exceeds 10 m radius for >30% of release trials, OR systematic position bias >5 m under stable nighttime conditions, OR rate estimate error >50% across wind classes.
Rescue Pivot: If near-field plume inversion fails due to recirculation, pivot to a CFD-informed forward model (precomputed QUIC-URB response surfaces per asset geometry) replacing analytic Gaussian, or fall back to coarse zone-localization (which asset, not which point) at lower spec.
Cost: $40k-$70k (rental pods, MFC rig, site fees, 1 FTE-month)
Time to Signal: 3-4 weeks from setup to inversion results

Refinement Deltas

Risks Addressed:
* CRDS capex (~$15-25k/node today) is hard to amortize across landfill or dairy sites with thin margins; competing TDLAS or low-cost MOS sensors may dominate on $/leak-found even with worse precision
* Gaussian-plume assumptions break down within 3-5 obstacle heights of tanks, compressors, and buildings -- exactly where leaks concentrate -- biasing Bayesian inversion in the highest-value zones
* Co-located point-wind measurement does not capture the 3D flow field driving near-field transport; turbulence statistics at the node tell you little about a recirculation eddy 20 m upwind

Red-Team:
* Challenge: CRDS capex (~$15-25k/node today) is hard to amortize across landfill or dairy sites with thin margins; competing TDLAS or low-cost MOS sensors may dominate on $/leak-found even with worse precision
* Challenge: Gaussian-plume assumptions break down within 3-5 obstacle heights of tanks, compressors, and buildings -- exactly where leaks concentrate -- biasing Bayesian inversion in the highest-value zones
* Challenge: Co-located point-wind measurement does not capture the 3D flow field driving near-field transport; turbulence statistics at the node tell you little about a recirculation eddy 20 m upwind
* Challenge: Mirror contamination, temperature drift, and laser aging will degrade the 1 ppb spec in field conditions; without automated zero/span the network accuracy claim is fragile
* Challenge: Asset-class spacing tables risk being either too sparse (missing small leaks) or collapsing to dense grids near complex equipment, eroding the 'bounded cost' value proposition

Budget Ranges

Prototype: $120,000
Pilot: $480,000
Scale: $2,800,000

30/60/90 Plan

Day 30: Finalize node hardware BOM; procure DFB laser modules, mirror sets, and Gill anemometers; stand up cloud Bayesian inversion engine with synthetic plume test cases; identify pilot site (landfill or gas processing facility) and execute site access agreement.
Day 60: Assemble and bench-validate three prototype nodes--confirm 1 ppb CH4 sensitivity, ring-down stability over 72-hour continuous run, and anemometer-to-gas-inlet co-location within 0.3 m; deploy two nodes at pilot site perimeter and validate GPS time-sync and LTE-M telemetry pipeline end-to-end.
Day 90: Deploy full six-node pilot array at site; run Bayesian inversion against known controlled-release events (calibrated CH4 cylinder releases at measured rates); report source-location RMSE, emission-rate bias, and false-localization rate; document mirror contamination interval and define automated cleaning maintenance schedule.
Dominance Axis: lower_failure -- Co-located wind and gas reduce false localization while asset-based spacing keeps network cost bounded.

Top Uncertainties & Assumptions

* Low-radiance conditions (night, heavy overcast, fog) collapse backscatter SNR below detection threshold, requiring LWIR fallback that adds $15-40K per unit
* Structural occlusion by tanks, compressors, and piping creates persistent blind spots that no pan-tilt range can fully eliminate without multi-pole deployment
* InGaAs hyperspectral array cost ($30-80K per sensor) makes per-site economics unfavorable versus CRDS networks until volume pricing or filter-based multispectral simplification is adopted
* Condensation and particulate ingress clog side-port inlets within weeks, degrading diffusion response time and creating false-negative dead zones
* Fiber diffusion lag (estimated 30-120 s per port) temporally smears short-duration leak pulses, making localization ambiguous under variable wind

C4.46 L1 T228,234