The Continuing Evolution of Air Emissions Monitoring

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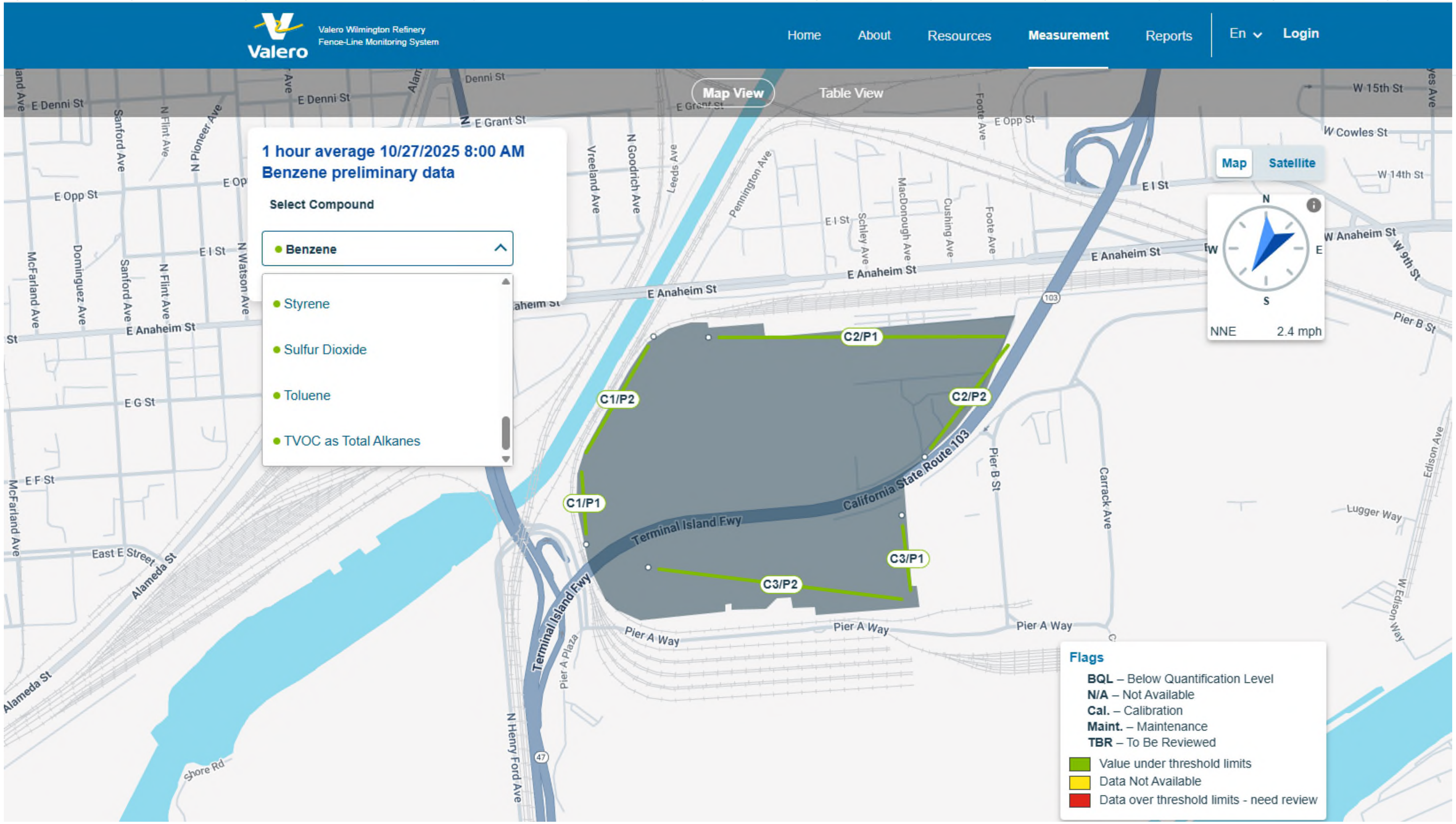
The Future is Now!

Mass adoption of advanced air measurement systems has been two years away – for the past 30 years.

The Future is Now! – In California



Pollutants Monitored:

- 1,3-Butadiene
- Acetaldehyde
- Acrolein
- Ammonia
- Benzene
- Black Carbon
- Carbonyl Sulfide
- Ethylbenzene
- Formaldehyde
- Hydrogen Cyanide
- Hydrogen Fluoride
- Hydrogen Sulfide
- M-Xylene
- O-Xylene
- P-Xylene
- Nitrogen Dioxide
- Styrene
- Sulfur Dioxide
- Toluene
- Total Alkanes

The Air Toxics Fenceline Monitoring Landscape in the U.S.

Petroleum Refineries:

- 2015 Petroleum Refinery Sector Rule.
- 130 petroleum refineries in the United States.
- All of them are required to conduct continuous fenceline monitoring for benzenes starting in 2018.

Chemical Plants:

- Per AFPM, there are 311 petrochemical manufacturing facilities in the United States.
- Per EPA, between 200 and 220 of these sites are subject to the requirements of the Hazardous Organic NESHAP, or HON, regulatory framework.
- Fenceline monitoring is required for six pollutants: benzene, 1,3-butadiene, 1,2-dichloroethane, vinyl chloride, ethylene oxide and chloroprene.
- Starting dates for the fenceline monitoring programs range from September 2024 to July 2026.

Source: Royalty-Free Image from Shutterstock

EPA Reference Methods

Method 325A/B – Refinery MACT & HON:

- Use of passive diffusive sorbent tubes along the fenceline.
- At least 12 samplers around the facility perimeter.
- 14-day integrated samples.
- Gas chromatography lab analysis.
- Action levels:

    Benzene = 9 µg/m^3

    1,3-Butadiene = 3 µg/m^3

    Chloroprene = 0.8 µg/m^3

    Ethylene dichloride = 4 µg/m^3

Source: CAMSCO

Method 327 - HON:

- Use of TO-15 style or equivalent sampling canisters.
- 8 or more canister sampling stations along the fenceline.
- 24-hour samples.
- Lab analysis per Reference Method TO-15.
- Action levels:

    Ethylene oxide = 0.2 µg/m^3

    Vinyl chloride = 3 µg/m^3

Source: Restek

Comparative Analysis

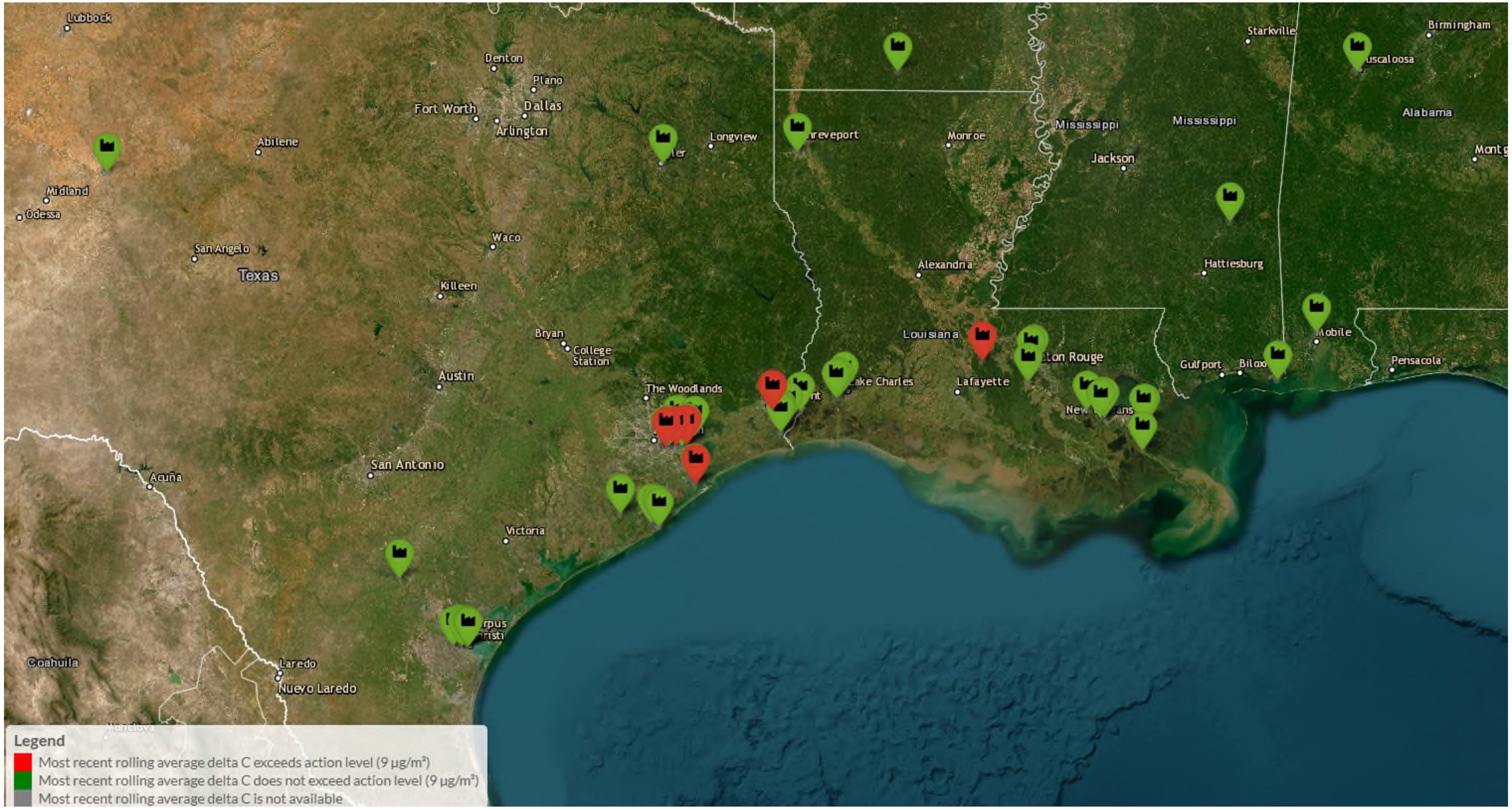
	Relative Advantages	Relative Disadvantages
Method 325 A/B	+ Low cost + Simple and standardized + Focused on specific HAPs of concern + Lower data management burden	- No temporal or spatial resolution on sources - Data is of limited value in root cause investigations - Requires large number of samplers, even for small sites
Method 327	+ High sensitivity (sub ppb detection) + Better resolution (24-hr v. 14-day) + More supportive of root cause investigations + Established laboratory infrastructure	- Higher cost - Logistically complex - More complex QA/QC requirements - Greater infrastructure needs

Neither method provides actionable, real-time information.

Neither method provides insight into the location of the emission source(s). The source of emissions resulting in concentrations above an action level could be off-site.

Neither method provides information on quantities released, just concentrations.

Monitoring Results are Available to the Public



Source: Environmental Integrity Project

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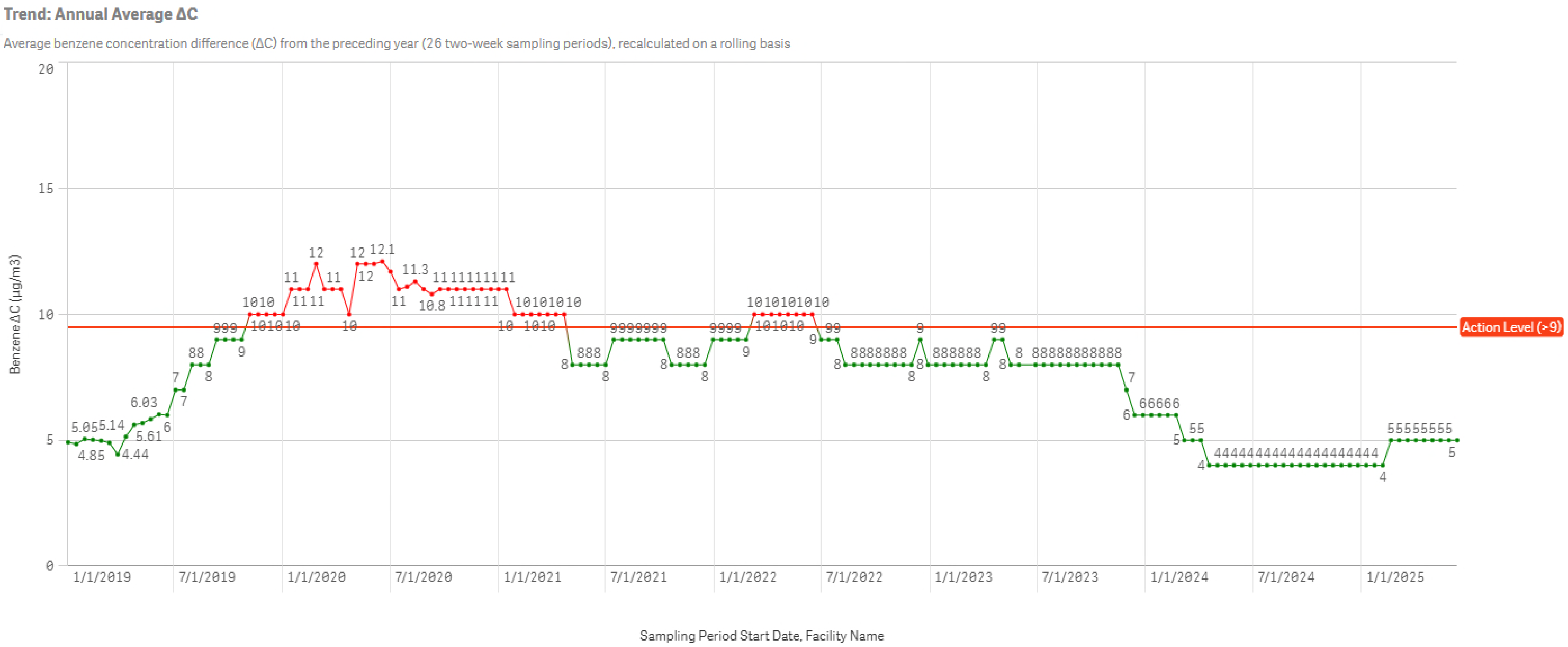

Source: US EPA

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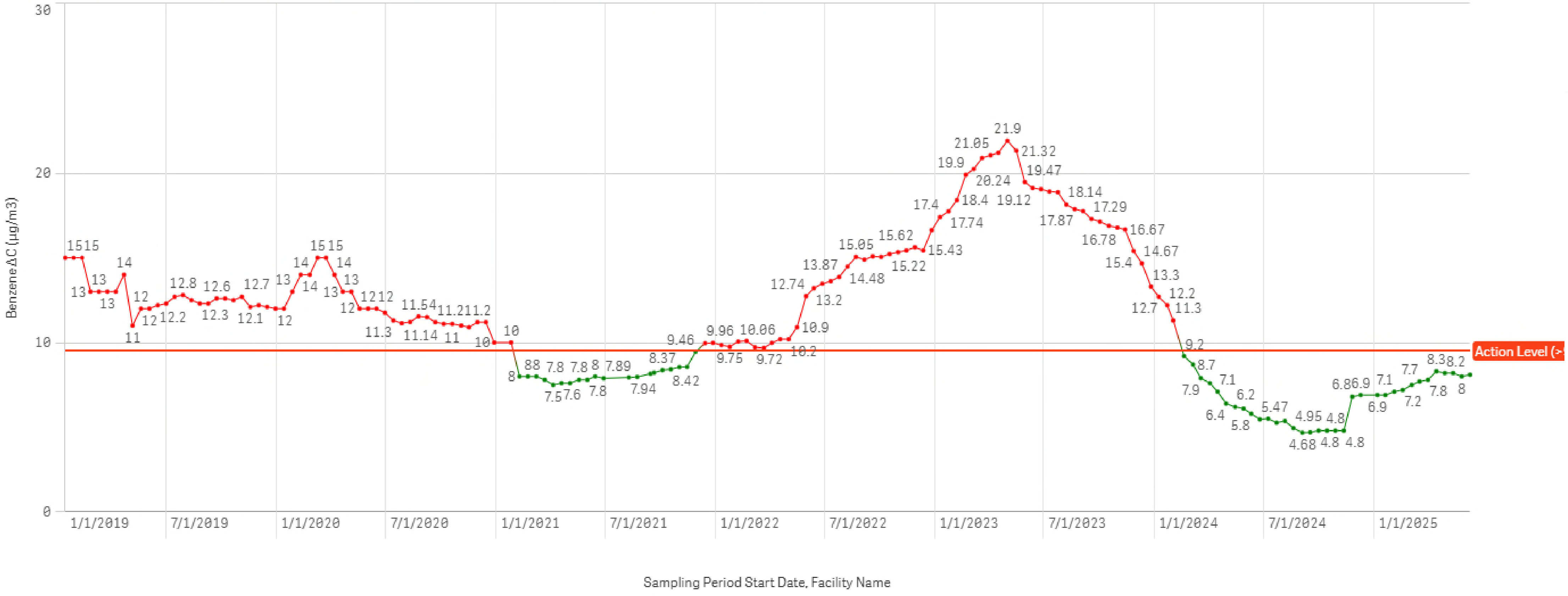
Monitoring Results are Available to the Public

Trend: Annual Average ΔC

Average benzene concentration difference (ΔC) from the preceding year (26 two-week sampling periods), recalculated on a rolling basis



Source: US EPA

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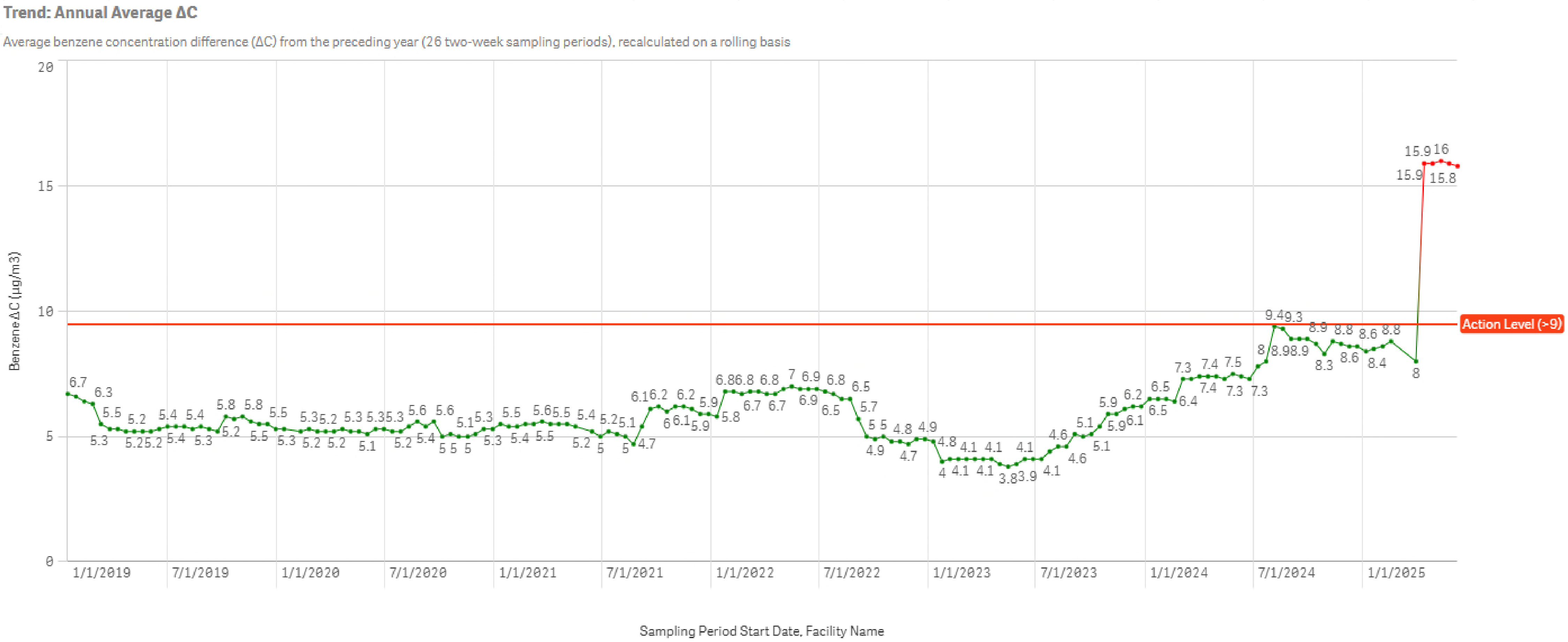

Source: US EPA

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Actionable Data Augmentation Options

The Hardware

Low-Cost Technologies:

- Metal Oxide Sensors (MOS)
- Photoionization Detectors (PID)

Mid-Cost Technologies:

- Extractive Tunable Diode Laser Spectrometers (TDLAS)
- Limited speciation mini AutoGCs

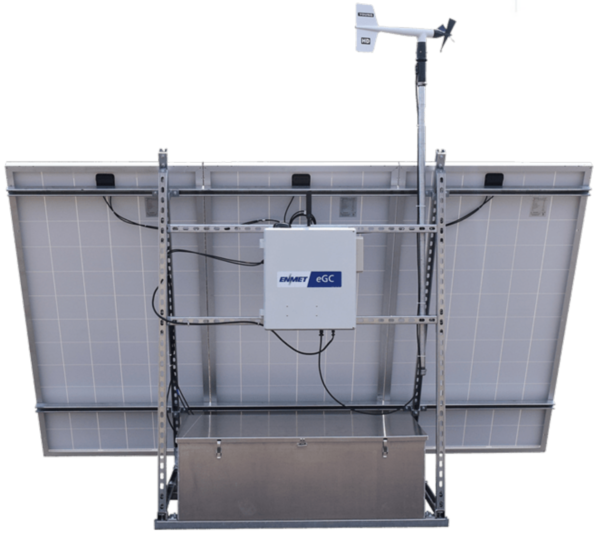
Mid/High-Cost Technologies:

- Extractive Cavity Ring-Down Spectroscopy (CRDS)

High-Cost Technologies:

- Full speciation AutoGCs.
- Open-Path Systems:
  - ✓ Fourier Transform Infrared (FTIR)
  - ✓ Ultraviolet Differential Optical Absorption Spectroscopy (UV-DOAS)
  - ✓ TDLAS

Source: SENSIT



Source: ENMET

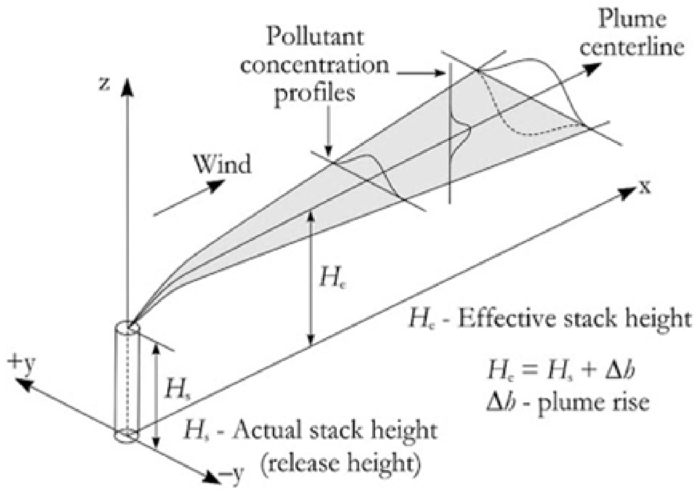
Source: CEREX

Actionable Data Augmentation Options:

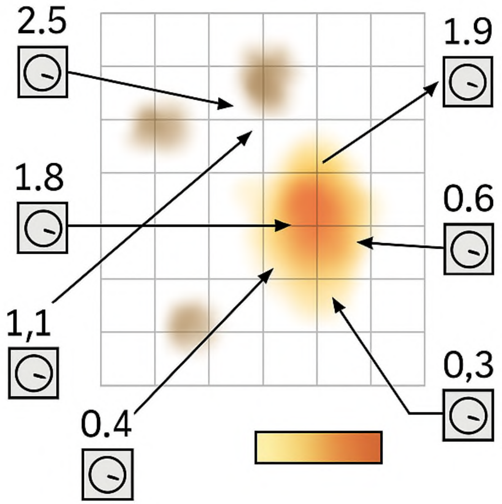
The Data Analytics

- Simplest approach is back trajectory from wind direction data. Gives you no information on distance or quantity released.
- More precise location using:
  - Inverse Gaussian distribution,
  - Bayesian multi-source inversion modeling, or
  - Convolutional neural networks.
- These methods can be used to locate emission sources and estimate emission rates in real or near-real time.
- The issues are system cost, system reliability, data quality, and actual data utility.

Inverse Gaussian Analytical



Bayesian Multi-Source Inversion: Probability



Source: ResearchGate

AI Use Cases

- **Source Localization via Plume Modeling + Machine Learning**
  AI can ingest meteorological data, topography, and real-time concentration fields from fenceline or mobile monitors to reverse-model emission source locations using pattern recognition and optimization algorithms.

- **Signature Recognition Using Hydrocarbon Fingerprints**
  Machine learning models can be trained to identify speciated VOC “fingerprints” associated with specific units (e.g., delayed coker vs. catalytic reformer), allowing systems to match field samples to likely operations or release points.

- **OGI Video Analytics for Emission Quantification**
  AI-enabled computer vision tools can analyze OGI camera footage in real time or post-process mode to detect, track, and quantify gas plumes, improving detection sensitivity and reducing false negatives in LDAR programs.

- **Sensor Fusion for Enhanced Attribution**
  AI can combine data from multiple sensor types—including passive samplers, open-path analyzers, lidar, and drone-mounted detectors—to triangulate emissions and distinguish between overlapping sources or background noise.

- **Continuous Learning from Emissions History**
  AI models can learn from historical emission events, maintenance logs, and environmental conditions to build predictive models of when and where leaks are likely to occur, helping prioritize inspections and optimize sampling locations.

- **Real-Time Anomaly Detection in Monitoring Streams**
  Streaming AI algorithms can flag deviations in concentration or plume shape in real time—providing early warning for super-emitter events and helping operators reduce response time.

AI Limitations and Challenges

- **Data Access & Confidentiality**
  Facilities may restrict access to raw emissions data, operational logs, or sensor feeds due to proprietary process information, regulatory sensitivity, or fear of enforcement or litigation exposure.

- **Inconsistent or Low-Quality Data**
  Sensor drift, noise, downtime, or irregular sampling intervals can degrade model performance.AI models—especially deep learning—require large, clean, and labeled datasets to perform well. These are rarely available in early-stage deployments.

- **Lack of Ground-Truth Data**
  AI models often need verified emissions data to learn effectively (e.g., source location and release rate).

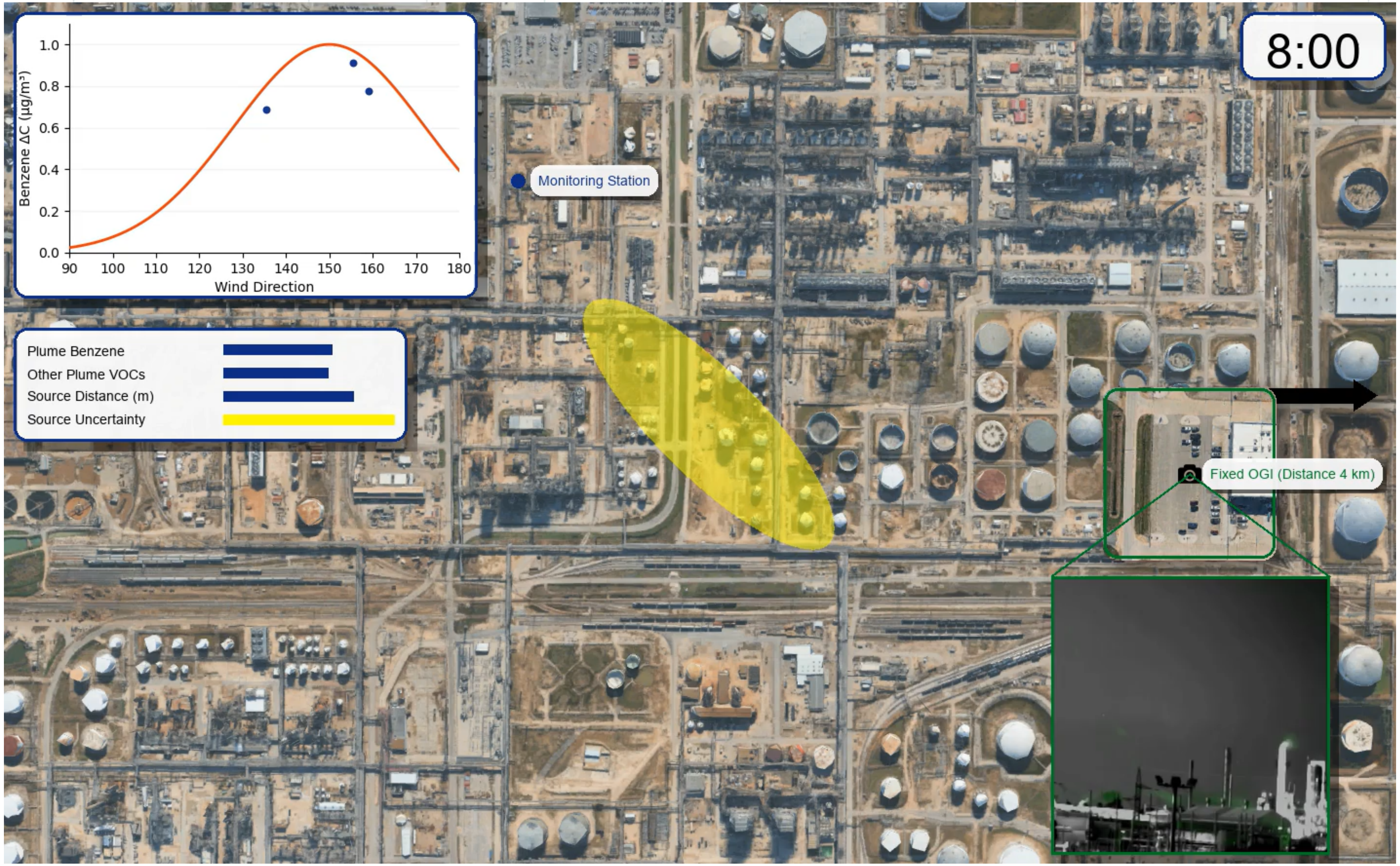
- **Site Complexity and Variability**
  Facilities are heterogeneous—equipment layouts, emissions profiles, and meteorology differ significantly. AI models trained on one site will likely not generalize to others without retraining or adjustment.

- **Resistance to Operational Disruption**
  Facility operators may be reluctant to install new instrumentation, share real-time control system data, or integrate AI outputs into compliance or operational decisions.

- **Trust & Interpretability**
  Many AI models (especially deep learning) operate as “black boxes”, making it hard for environmental engineers or regulators to understand how predictions were made, and to validate or audit the system.

- **Cost & ROI Uncertainty**
  Initial cost of AI deployment—sensors, infrastructure, data handling, integration—can be perceived as high. The business case for AI in emissions monitoring often hinges on regulatory credit (e.g., SIP reduction recognition), O&M savings, or reduced enforcement risk. Without clear ROI, adoption is slow.

Example of What is Possible with A Single Point Monitor



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Machine Learning Requires Teaching

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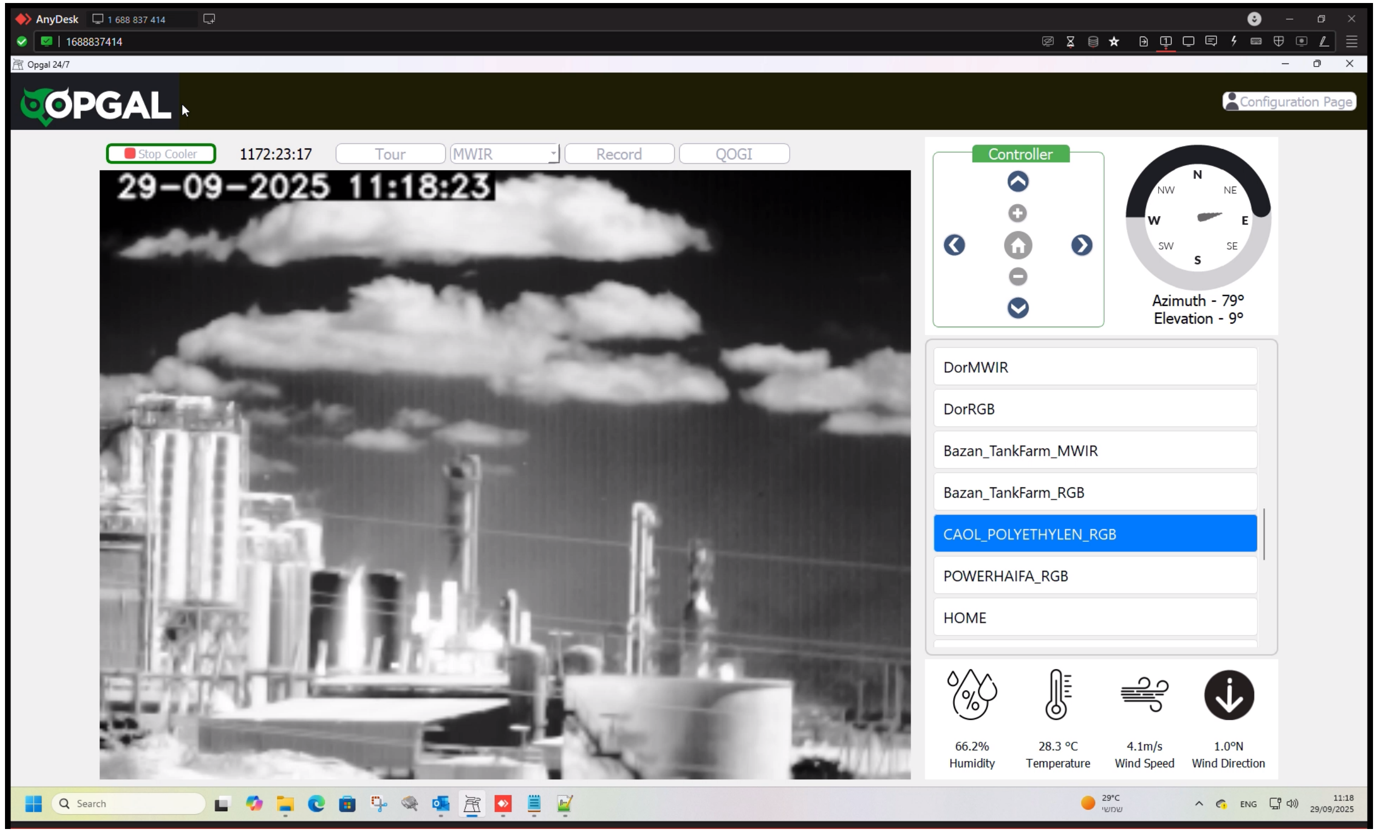


Source: Opgal

Compelling Reasons to Conduct Fenceline Monitoring

Risk Management:

- ✓ Identifies fugitive emissions or leaks before they escalate into reportable events, citizen complaints, or regulatory violations.
- ✓ Provides early detection of abnormal conditions.
- ✓ Reduces the likelihood of enforcement actions, litigation, or shutdowns.

"It's cheaper if you find it before the drone finds it."

Marketplace Signaling:

- ✓ Demonstrates a commitment to environmental stewardship and community safety
- ✓ Supports corporate sustainability claims around air quality, emissions transparency, or net-zero targets.
- ✓ Attracts shareholders, investors and customers who value environmental performance.

"You can't say you're serious about the environment if you don't know what's leaving your property boundary."

Community Trust & Social License to Operate:

- ✓ Improves community relations, especially in fenceline neighborhoods with historic concerns about exposure and lack of transparency.
- ✓ Voluntary disclosure of fenceline data (even in summary form) builds goodwill and credibility.
- ✓ MAY reduces pressure from NGOs, media, and local environmental justice groups.

"It's not just what you emit—it's what people think you emit."

Compelling Reasons to Conduct Fenceline Monitoring

Operational Intelligence:

Continuous or high-frequency fenceline data can:

- ✓ Reveal unplanned emissions patterns.
- ✓ Help prioritize maintenance and inspection.
- ✓ **Keep product in the process: More to sell, less to go "boom."**

"You can't manage what you don't measure."

Insurance and Liability Management:

- ✓ May reduce exposure to toxic tort claims, nuisance lawsuits, and property value reduction claims.
- ✓ May reduce business interruption risk.
- ✓ May enhance a company's reputation and perception of business stability.
- ✓ May reduce insurance premiums.

"Demonstrating real-time boundary control reduces uncertainty—and insurers love that."

Preparedness for Future Regulations:

- ✓ Staying ahead of EPA and state regulations, or international initiatives relevant to market access.

"Today's regulatory climate won't last forever."

And Why They Still Say “No”

Short-Term Mindset:

- Decisionmakers are often focused on quarterly results, not multi-year risk mitigation.
- **Capital is prioritized for projects that increase throughput, reduce energy use, or have a clear financial return**.
- Fenceline monitoring is seen as a cost center, not a value generator—especially if it doesn’t tie directly to production or compliance obligations.

Bad Experiences:

- Technology that didn’t do what the suppliers said it would do.
- Technology that was unreliable.
- Technology that generated false positives that just created more work for staff.
- **Technology that couldn’t discern between permitted, routine emissions and unplanned, unpermitted emission events**.

Siloed Decision-Making:

- EHS, legal, operations, and finance often operate in silos with misaligned incentives.
- EHS may advocate for proactive monitoring, but Ops resists the complexity, Legal fears discoverability, and Finance sees sunk cost.

Unclear ROI:

- The value of avoided emissions or avoided enforcement is hard to quantify until after an incident occurs.
- “Show me a clear business case or it is just a science project.”

Fear of Data:

Companies may fear that fenceline or continuous monitoring data will reveal:

- Emissions that they weren’t aware of.
- **Actionable data that regulators, NGOs, or the public could use against them**.

Lack of External Pressure:

- **If the regulators aren’t demanding it, if the community isn’t demanding it, if the competitors aren’t doing it, Then why would we?**

Other Considerations

- SIP creditable emission reductions must be :
  1. **Surplus:** The emission reduction must be beyond what is already required by federal, state, or local laws, rules, or regulations, including other SIP elements.
  2. **Quantifiable:** The amount of the emission reduction must be capable of being reliably determined and calculated.
  3. **Permanent:** The emission reduction must be guaranteed to last for the duration of the time needed to demonstrate attainment or maintenance of the National Ambient Air Quality Standards (NAAQS).
  4. **Enforceable:** The emission reduction must be assured and legally binding, usually through a measure that is enforceable by the state, the EPA, and citizens.
- Fenceline monitoring's main use is in actionable, real-time identification of unplanned, unpermitted, or otherwise unknown emissions. These emissions fail one or more of the SIP creditability tests.
- Establishing fenceline monitoring as a SIP creditable emission reduction strategy under existing EPA policy is effectively impossible. It would require a regulatory paradigm shift.
- However, ozone standard design values are climbed in Houston and elsewhere. Mass-adopted voluntary initiatives to reduce actual precursor loading to an airshed could make the difference between attainment and additional, high-cost SIP requirements.
- Fenceline monitoring could also be used to inform temporal variability in emissions for use in SIP demonstration photochemical modeling.

My thoughts on the fenceline monitoring marketplace

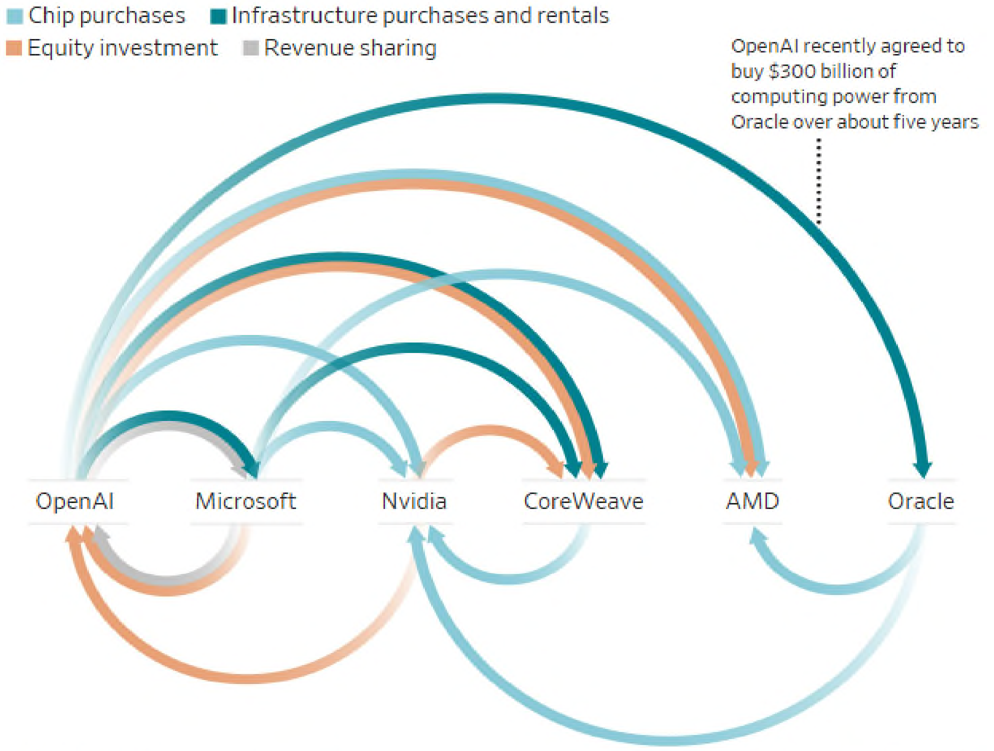
Too many people chasing too few dollars

- Total Addressable Market: It can't be more than $100 million per year at this time.
- Short of additional regulatory mandates, market growth is expected to be less than 10% per year.
- The number of technology companies that provide hardware, software, and other infrastructure support for fenceline monitoring projects is likely more than 100.
- Downsides of a highly fragmented market:
  1. Lack of resources to fund truly meaningful R&D.
  2. Lack of resources to educate the market and strongly promote brand visibility.
  3. Lack of resources to effectively support customer projects.
  4. Lack of resources to effectively engage with the regulatory process.
  5. Lack of trust in a market dominated by startups and Mom-and-Pop companies.
  6. Lack of standardization.
  7. Everyone is reinventing the wheel. How many different cloud dashboards do we need?
- How to "fix" this problem:
  1. Grow the market via more regulatory mandates. Not a popular option with the regulated community.
  2. Hope for more voluntary adoptions. Is hope a strategy?
  3. Consolidation through strategic acquisitions of smaller companies by larger companies.
  4. Industry cooperation and collaboration.

My thoughts on the fenceline monitoring marketplace

Collaboration, Consolidation, Standardization

Select capital flows among six AI-industry companies



Note: Some chip purchases are through intermediaries. Some investments and other arrangements subject to conditions.
Sources: staff reports; Morgan Stanley
Nate Rattner/WSJ

- Market Capitalization:

OpenAI =	$500 billion
Microsoft =	$4,000 billion
NVidia =	$4,700 billion
CoreWeave =	$66 billion
AMD =	$420 billion
Oracle =	$800 billion
TOTAL =	$10.5 trillion

- Can this market learn something from the world's largest companies working together in one of the greatest technology development efforts in human history?

Thank You

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