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6 Years of Natural Gas Field Measurement & Solution Testing *What Have We Learned?*

Daniel Zimmerle, Colorado State University

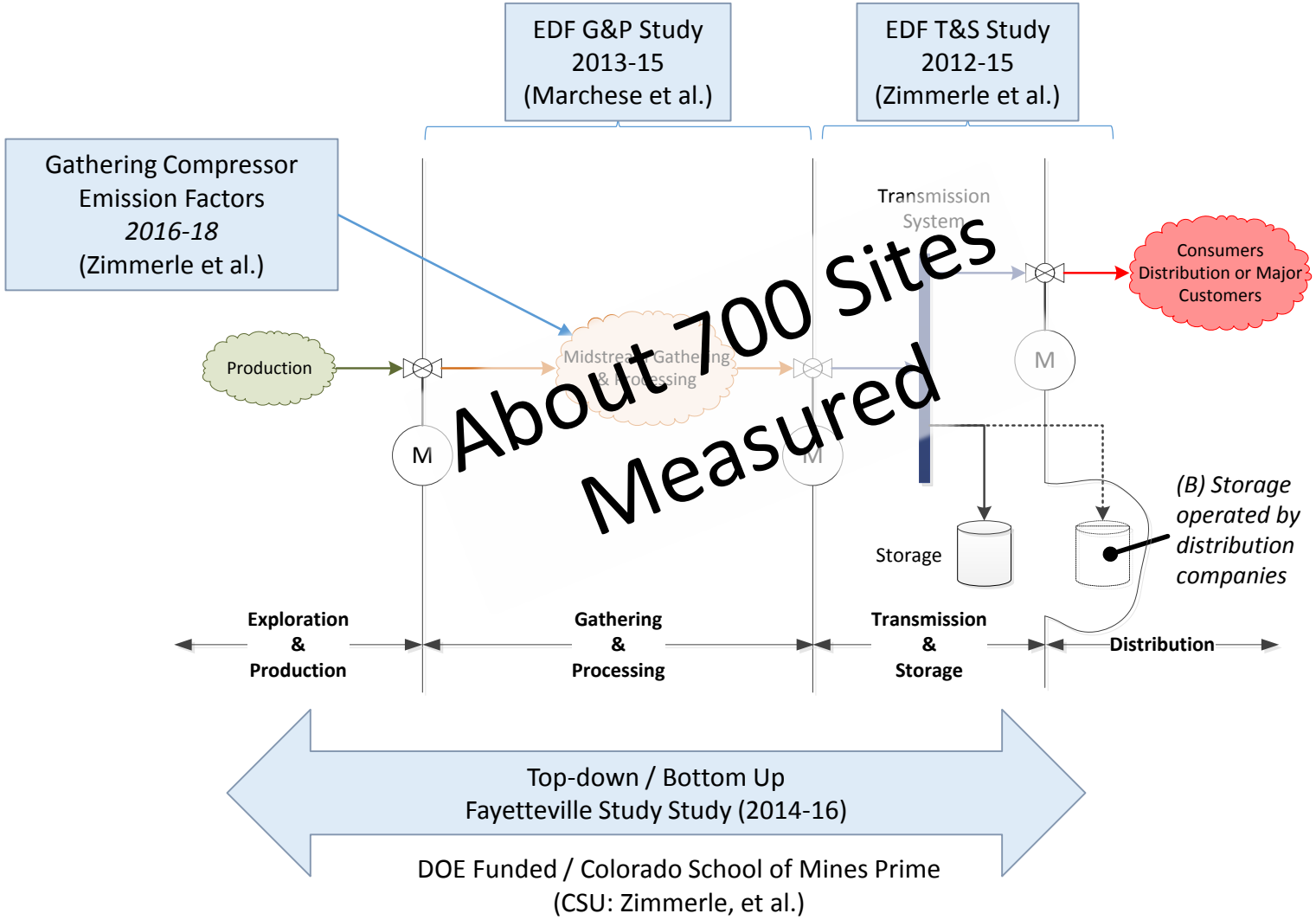
Agenda

- CSU - Who we are
- Adopting new technologies for leak detection
- How we're testing new technologies
- What recent test results indicate

Time Permitting …

- Natural gas emissions: What do we know?

CSU's Background in Methane Measurement



Papers: CSU & Partners

1.Ravikumar, A. P. et al. "Good versus Good Enough?" Empirical Tests of Methane Leak Detection Sensitivity of a Commercial Infrared Camera. Environ. Sci. Technol. (2018). doi:10.1021/acs.est.7b04945

2.Zimmerle, D. J. et al. Gathering pipeline methane emissions in Fayetteville shale pipelines and scoping guidelines for future pipeline measurement campaigns. Elem Sci Anth 5, (2017).

3.Zavala-Araiza, D. et al. Super-emitters in natural gas infrastructure are caused by abnormal process conditions. Nature Communications 8, 14012 (2017).

4.Yacovitch, T. I. et al. Natural gas facility methane emissions: measurements by tracer flux ratio in two US natural gas producing basins. Elem Sci Anth 5, (2017).

5.Vaughn, T. L. et al. Comparing facility-level methane emission rate estimates at natural gas gathering and boosting stations. Elem Sci Anth 5, (2017).

6.Schwietzke, S. et al. Improved Mechanistic Understanding of Natural Gas Methane Emissions from Spatially Resolved Aircraft Measurements. Environ. Sci. Technol. (2017). doi:10.1021/acs.est.7b01810

7.Robertson, A. M. et al. Variation in Methane Emission Rates from Well Pads in Four Oil and Gas Basins with Contrasting Production Volumes and Compositions. Environ. Sci. Technol. (2017). doi:10.1021/acs.est.7b00571

8.Bell, C. et al. Comparison of methane emission estimates from multiple measurement techniques at natural gas production pads. Elem Sci Anth 5, (2017).

9.Zimmerle, D. et al. Reconciling Top-down and Bottom-up Methane Emission Estimates from Onshore Oil and Gas Development in Multiple Basins: Report on Fayetteville Shale Study. (2016).

10.Zimmerle, D. & Manning, D. Potential for Methane Emissions Reductions by Addressing Large Emitters. in (5th Energy Policy Research Conference, 2015).

11.Zimmerle, D. J. et al. Methane Emissions from the Natural Gas Transmission and Storage System in the United States. Environ. Sci. Technol. 49, 9374–9383 (2015).

12.Zavala-Araiza, D. et al. Reconciling divergent estimates of oil and gas methane emissions. PNAS 112, 15597–15602 (2015).

13.Subramanian, R. et al. Methane Emissions from Natural Gas Compressor Stations in the Transmission and Storage Sector: Measurements and Comparisons with the EPA Greenhouse Gas Reporting Program Protocol. Environ. Sci. Technol. 49, 3252–3261 (2015).

14.Roscioli, J. R. et al. Measurements of methane emissions from natural gas gathering facilities and processing plants: measurement methods. Atmos. Meas. Tech. 8, 2017–2035 (2015).

15.Mitchell, A. L. et al. Measurements of Methane Emissions from Natural Gas Gathering Facilities and Processing Plants: Measurement Results. Environ. Sci. Technol. 49, 3219–3227 (2015).

16.Marchese, A. J. et al. Methane Emissions from United States Natural Gas Gathering and Processing. Environ. Sci. Technol. 49, 10718–10727 (2015).

17.Lyon, D. R. et al. Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region. Environ. Sci. Technol. 49, 8147–8157 (2015).

18.Quinn, C., Zimmerle, D. & Olsen, D. B. Flare Gas Utilization at Combined Oil-Gas Well Sites. 279–284 (2010). doi:10.1115/ES2010-90041

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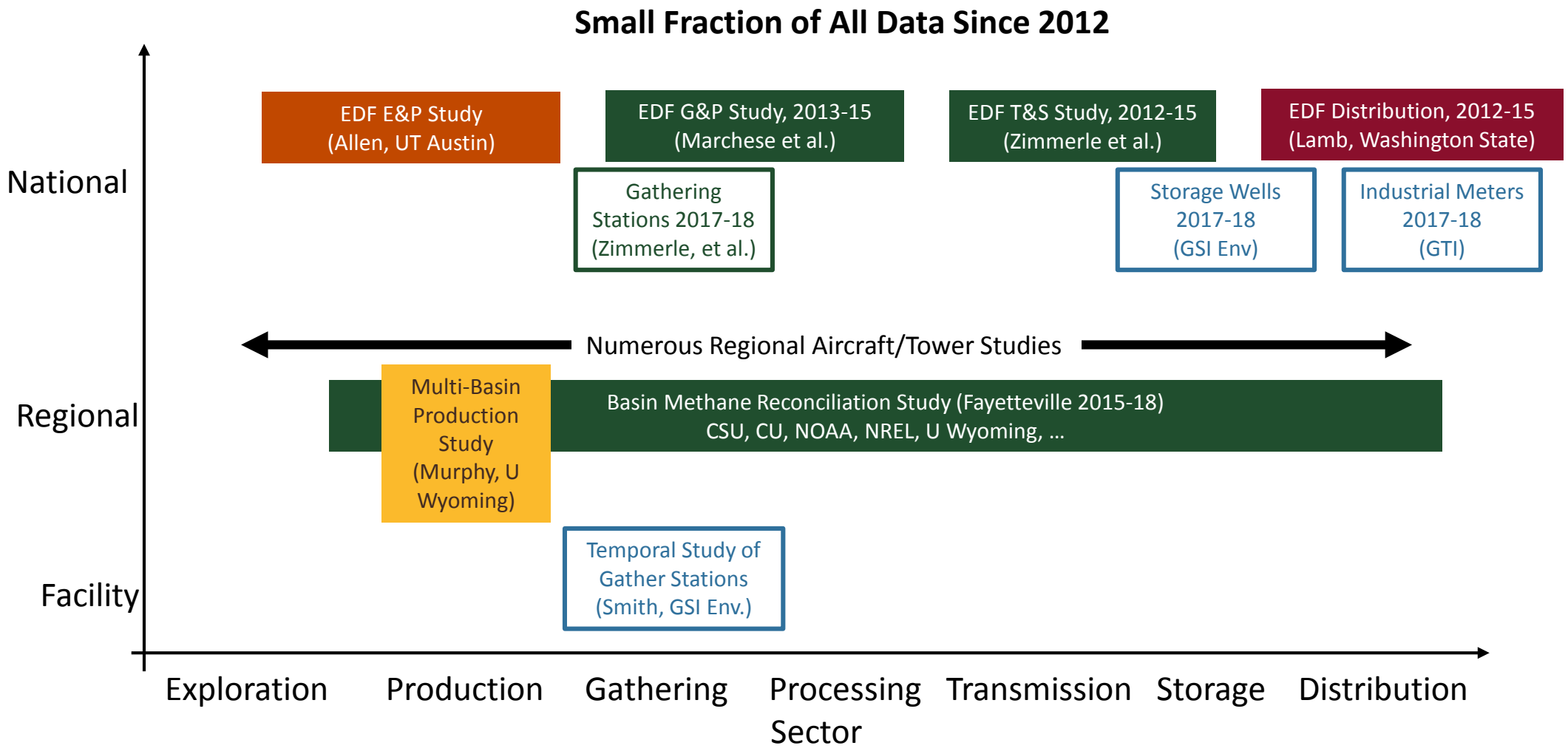
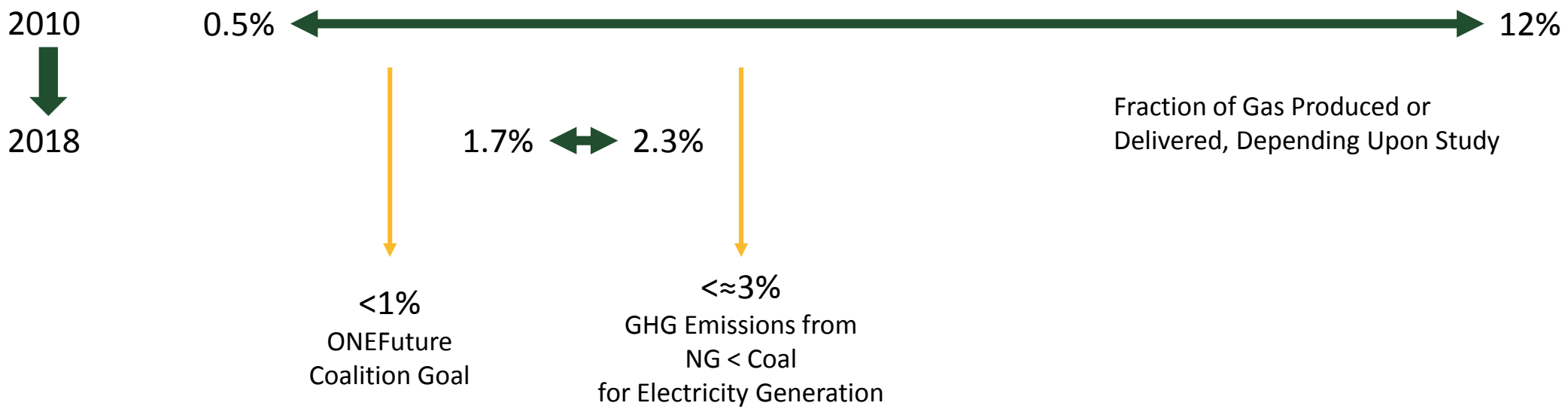
Natural Gas Emissions: What Do We Know?

Where's the Data?



Uncertainty in Methane Emissions Decreasing



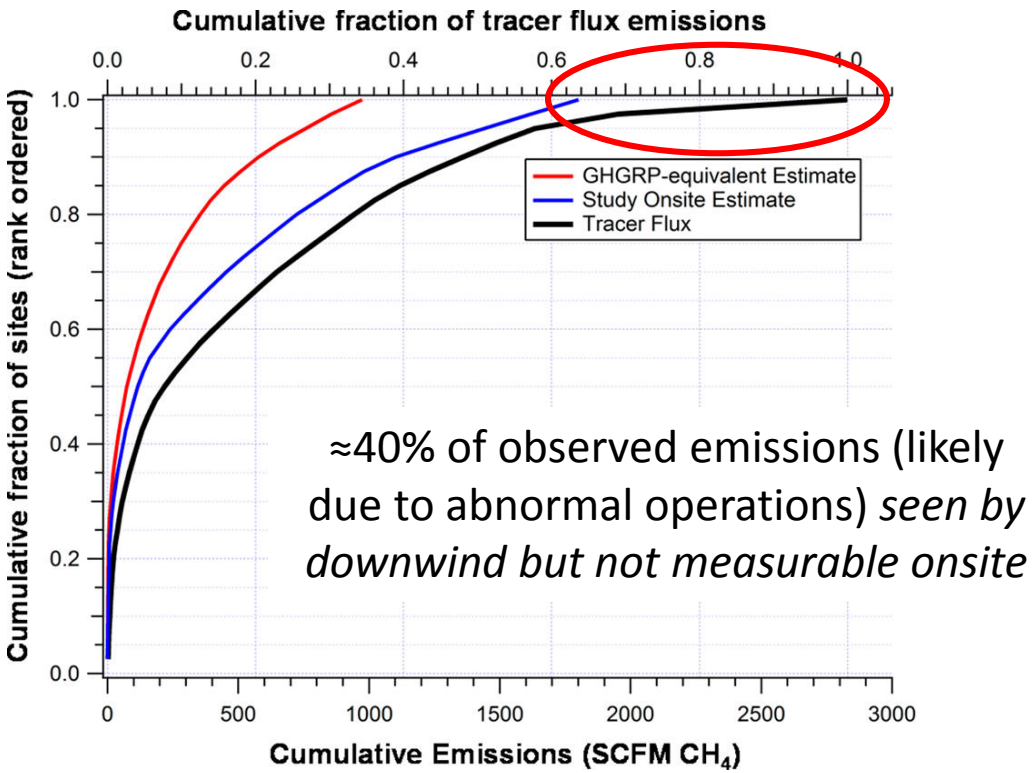
- Missing from or weak in current analysis:
  - Poor understanding of leakage rate *inside the meter*
  - New facility designs not reflected in emissions data
  - Unexplained excess emissions in urban areas
  - Under-sampled portions of supply chain: Marginal wells, geologic seeps, coal mines, abandoned wells …

1. Littlefield, J. A., Marriott, J., Schivley, G. A. & Skone, T. J. Synthesis of recent ground-level methane emission measurements from the U.S. natural gas supply chain. *Journal of Cleaner Production* doi:10.1016/j.jclepro.2017.01.101
2. Alvarez, R. A. *et al.* Assessment of methane emissions from the U.S. oil and gas supply chain. *Science* eaar7204 (2018). doi:10.1126/science.aar7204
3. Karion, A. *et al.* Methane emissions estimate from airborne measurements over a western United States natural gas field. *Geophys. Res. Lett.* **40,** 4393–4397 (2013).
4. Howarth, R. W., Santoro, R. & Ingraffea, A. Methane and the greenhouse-gas footprint of natural gas from shale formations. *Climatic Change* **106,** 679 (2011).

Large Emitters at Every Scale of Measurement

Example: Compressor Stations

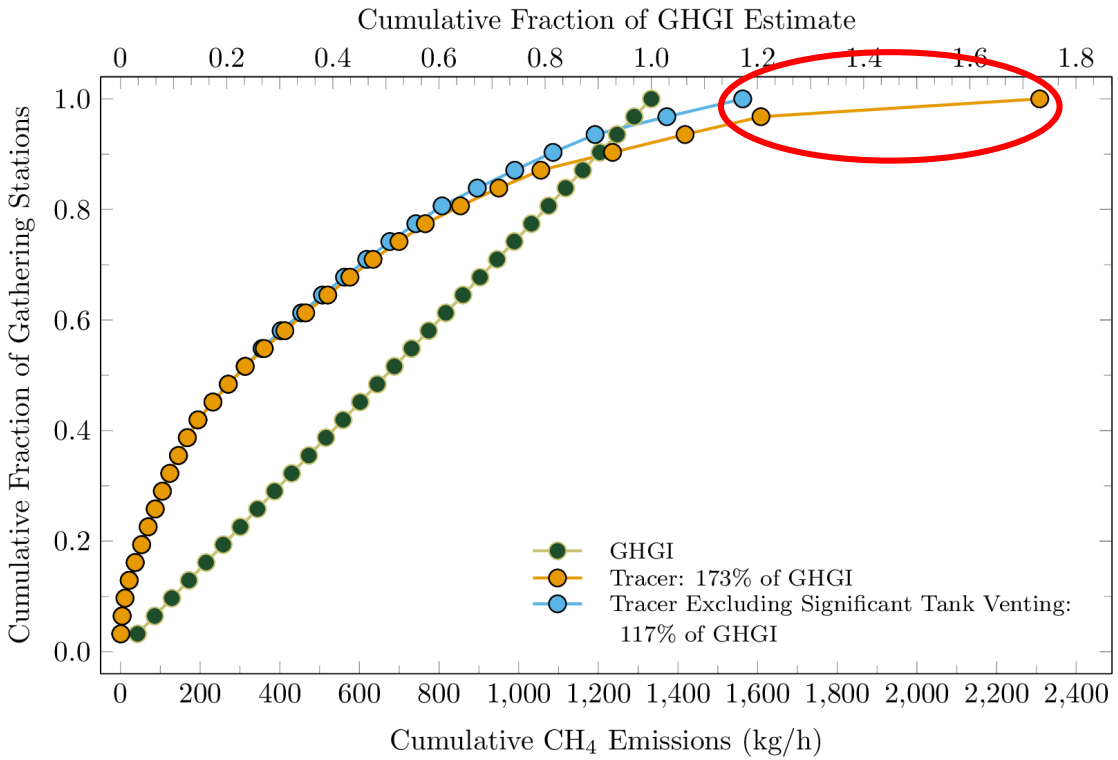
Transmission & Storage Stations



≈40% of observed emissions (likely due to abnormal operations) *seen by downwind but not measurable onsite*

Subramanian R, Williams LL, Vaughn TL, Zimmerle D, Roscioli JR, Herndon SC, Yacovitch TI, Floerchinger C, Tkacik DS, Mitchell AL, et al. 2015. Methane Emissions from Natural Gas Compressor Stations in the Transmission and Storage Sector: Measurements and Comparisons with the EPA Greenhouse Gas Reporting Program Protocol. Environ Sci Technol 49(5): 3252–3261. doi: 10.1021/es5060258

Gathering Stations



Vaughn TL, Bell CS, Yacovitch TI, Roscioli JR, Herndon SC, Conley S, Schwietzke S, Heath GA, Pétron G, Zimmerle D. 2017. Comparing facility-level methane emission rate estimates at natural gas gathering and boosting stations. Elem Sci Anth 5(0). doi: 10.1525/elementa.257

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Emission Factor Estimates *Do Include* Corrections for "Super Emitters"

Estimates are not always used correctly →

- Need to adapt national-scale inventories to use study estimates

Data is sparse and estimates are highly uncertain →

- Need long-duration studies to determine *how often and how big*

- Zavala-Araiza D, Alvarez RA, Lyon DR, Allen DT, Marchese AJ, Zimmerle DJ, Hamburg SP. 2017. Super-emitters in natural gas infrastructure are caused by abnormal process conditions. *Nature Communications* **8**: 14012. doi: 10.1038/ncomms14012
- Zavala-Araiza D, Lyon DR, Alvarez RA, Davis KJ, Harriss R, Herndon SC, Karion A, Kort EA, Lamb BK, Lan X, et al. 2015. Reconciling divergent estimates of oil and gas methane emissions. *PNAS* **112**(51): 15597–15602. doi: 10.1073/pnas.1522126112
- Zimmerle DJ, Pickering CK, Bell CS, Heath GA, Nummedal D, Pétron G, Vaughn TL. 2017. Gathering pipeline methane emissions in Fayetteville shale pipelines and scoping guidelines for future pipeline measurement campaigns. *Elem Sci Anth* **5**(0). doi: 10.1525/elementa.258
- Zimmerle DJ, Williams LL, Vaughn TL, Quinn C, Subramanian R, Duggan GP, Willson B, Opsomer JD, Marchese AJ, Martinez DM, et al. 2015. Methane Emissions from the Natural Gas Transmission and Storage System in the United States. *Environ Sci Technol* **49**(15): 9374–9383. doi: 10.1021/acs.est.5b01669

Better Understanding of Regional Estimates

- Regional aircraft (mass balance) methods agree well with facility- and component-level measurements … with *proper temporal assumptions*
  - Detailed, time-resolved activity data required
  - Additional recommendations for aircraft operation

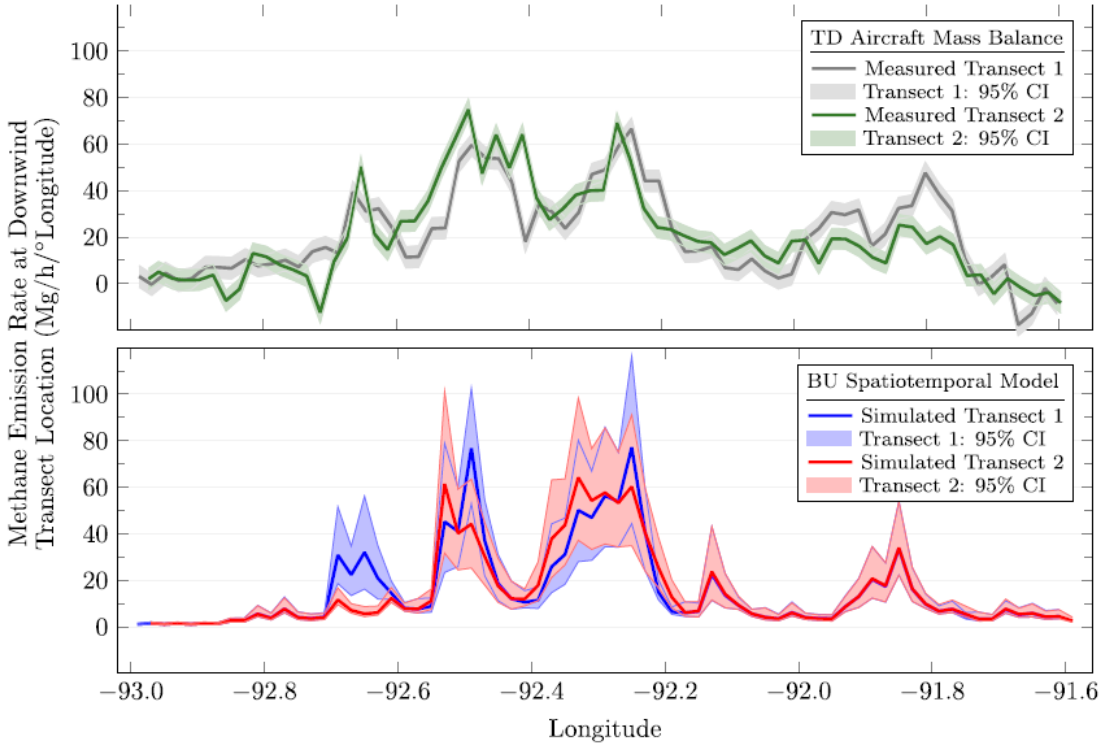
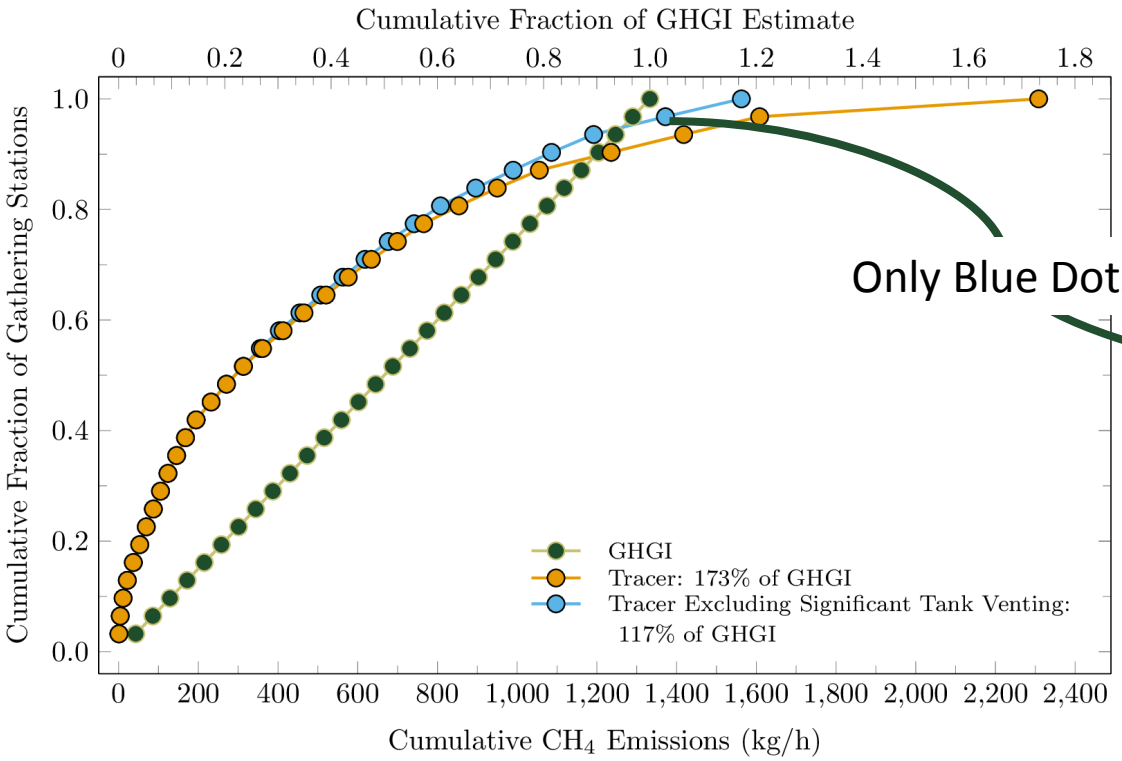


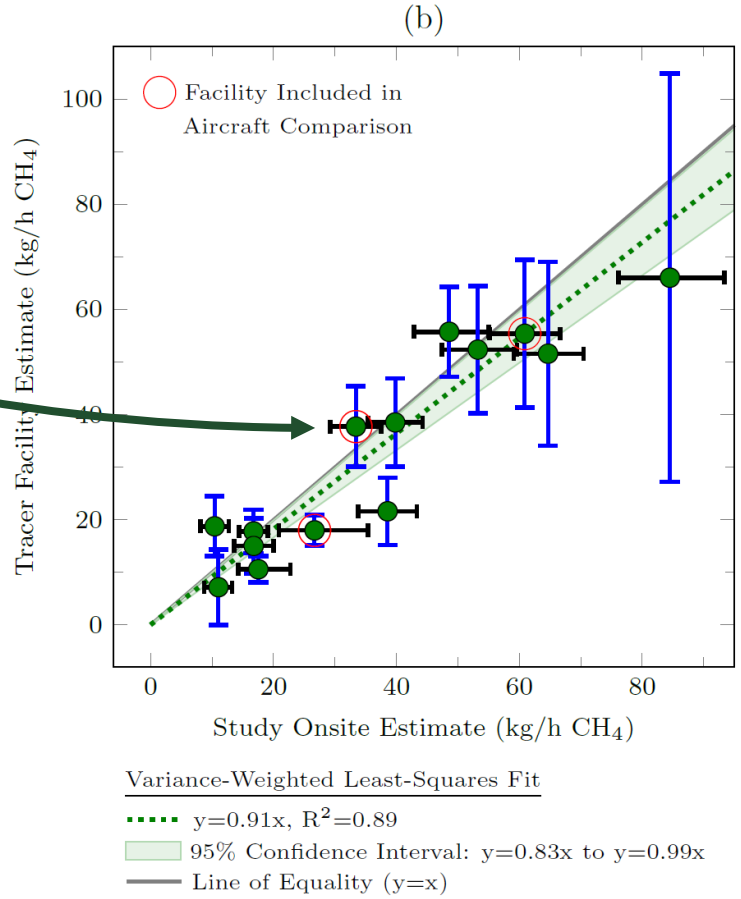
Figure 5: Comparison of longitudinal emission profiles. Top panel: measured top-down West-to-East CH_4 emission profiles (in Mg per hour or tonnes per hour; normalized to a one degree longitude wide swath) from two individual aircraft transects at the downwind (southern) edge of the study area. Bottom panel: corresponding simulated bottom-up transects. Basin-level emission rates in this sensitivity analysis were simulated at two-minute intervals for the duration of each top-down transect and propagated downwind using a Gaussian dispersion model. Simulated bottom up transects were aligned temporally at 2-minute resolution such that each longitudinal bottom-up data point corresponds to the same time that the aircraft measures at the same longitude.

- Schwietzke S, Vaughn T, Zimmerle D, Pétron G, Conley S, Mielke-Maday I, Wolter S, Dlugokencky E, Tans PP, Bell C, et al. 2018. Evolution, current state of the art, and interpretation of aircraft-based methane emission quantification at the natural gas basin-level. 2018 Jun 26. World Gas Conference 2018; Washington, D.C.
- Vaughn TL, Bell CS, Pickering CK, Schwietzke S, Heath GA, Petron G, Zimmerle D, Schnell RC, Nummedal D. n.d. Temporal Variability Largely Explains Difference in Top-down and Bottom-up Estimates of Methane Emissions from a Nat- ural Gas Production Region. *Proceedings of the National Academy of Sciences* **In publication**: 37.

Solid Facility-Scale Estimates



Only Blue Dots



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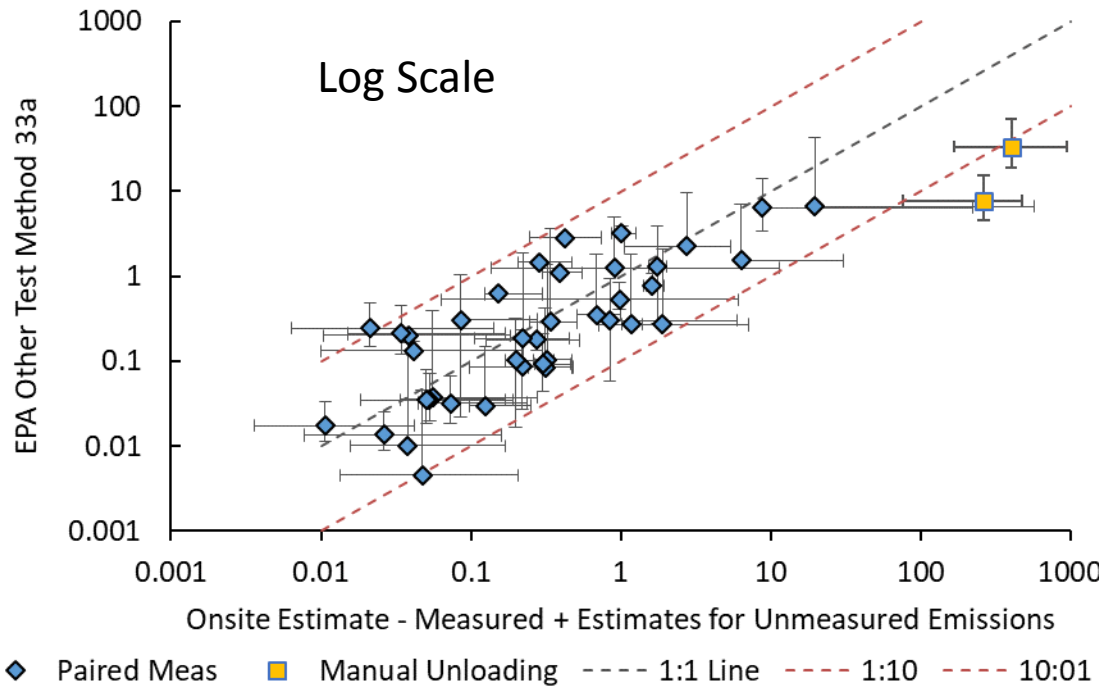
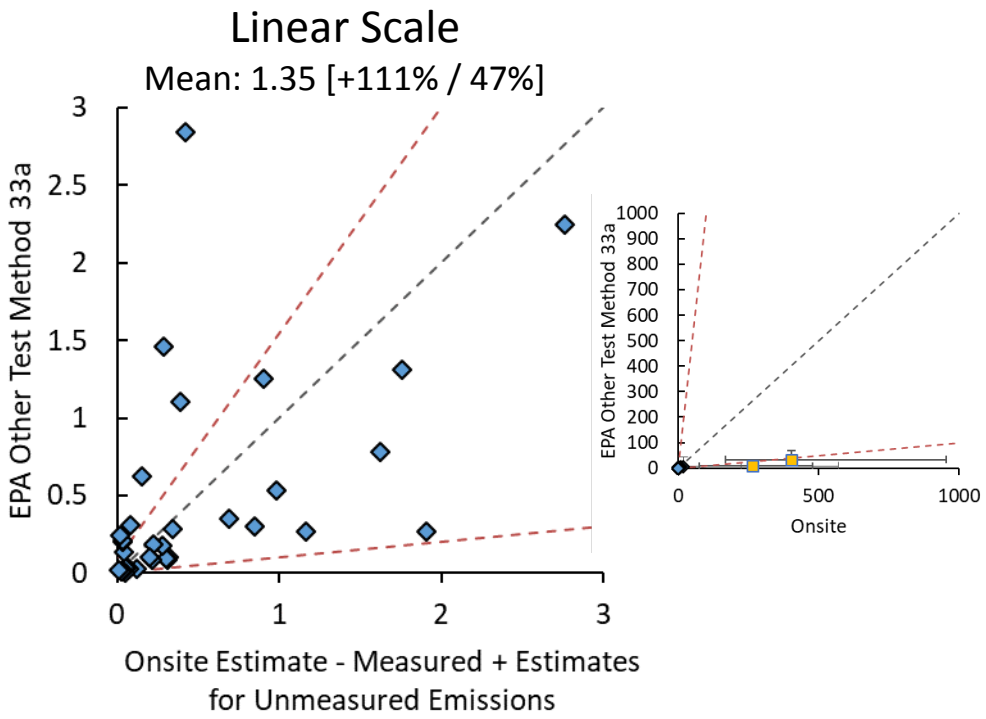
Component-level & down wind match well … if right methods used both on-site & downwind

- On-site must include "hard to measure" sources & remove large emitters from comparisons

… and Not All Methods Are Working Well

Comparison of near-simultaneous production site measurements in Fayetteville Shale





Measurements in kg/h

Bell C, Vaughn T, Zimmerle D, Herndon S, Yacovitch T, Heath G, Pétron G, Edie R, Field R, Murphy S, et al. 2017. Comparison of methane emission estimates from multiple measurement techniques at natural gas production pads. *Elem Sci Anth* **5**(0). doi: 10.1525/elementa.266

New Leak Detection and Quantification Tech: A Path to Equivalency

What's New in the Solution Approaches

Deployment Methods

Fixed Scanning Mobile …

Sensor Technologies

Thermal
Chemical
Laser
Optical
…

+

Deployment Protocol

- Staff training
- Usage frequency
- Data integration
- Response thresholds

…

Existing types … new combinations

Typical Output from an OGI* Survey

Camera operator identified leak-type emissions from a tubing connector at this location

Dispatched repair team:

1) Found tag
2) Stopped leak by replacing damaged union and tubing

Detection & isolation

*** OGI = Optical Gas Imaging** → Natural gas is visible in mid-IR wavelengths and can be seen with specialized cameras

Typical Output from New Technologies

Using data from the last N hours …

There is a >70% probability of an emissions > 10 SCFH in this 2x2x2 m cube

Dispatched repair team:

1) Used OGI camera to identify *leaking fitting*
2) Stopped leak by replacing damaged union and tubing

Separate detection from isolation

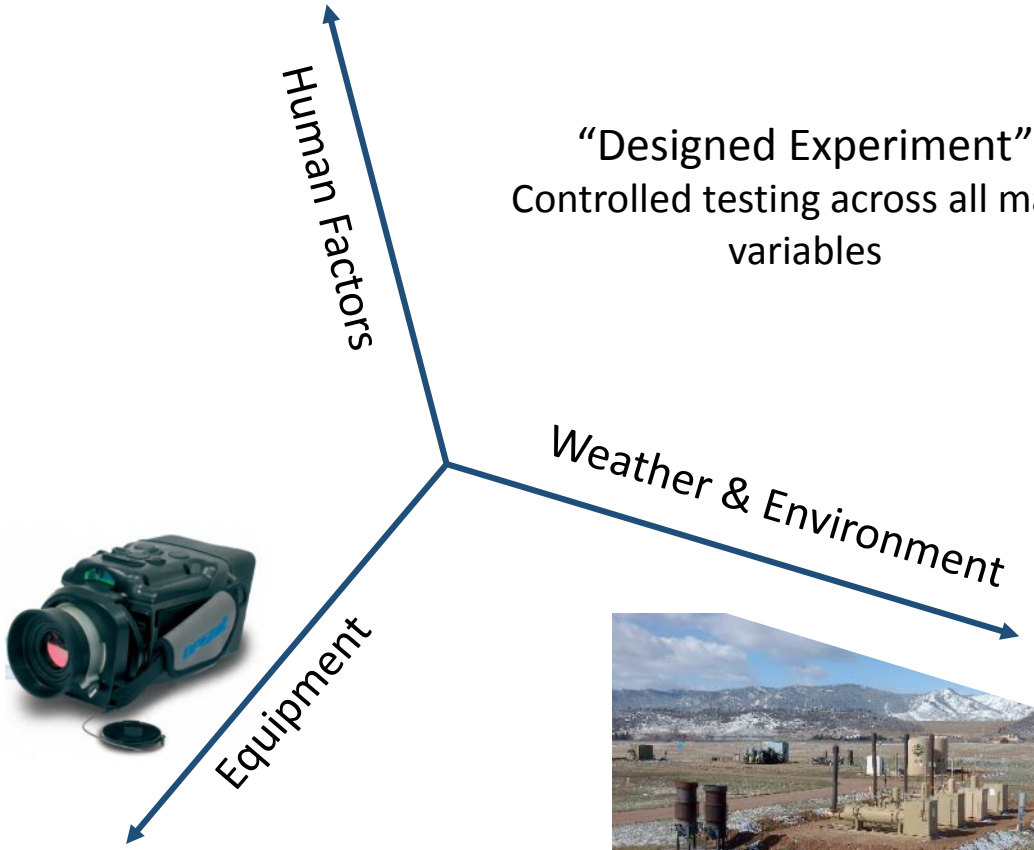
Outlining a Potential Path To Equivalence

1. Establish a quantitative efficacy baseline for currently approved methods
2. Develop a technology-independent method to quantify equivalent emissions control and reduction
3. Develop a test & acceptance protocol for technology/method combinations.
4. *Stakeholder preparation for the regulatory and policy adoption cycle*

Possible to work in parallel on multiple steps

1) Establish Baseline

- Objective:
  - Understand *practical* performance of existing methods – primarily OGI – in real conditions.
- Concept:
  - Controlled, realistic, test environment
  - Professional OGI operators
  - Full range of weather

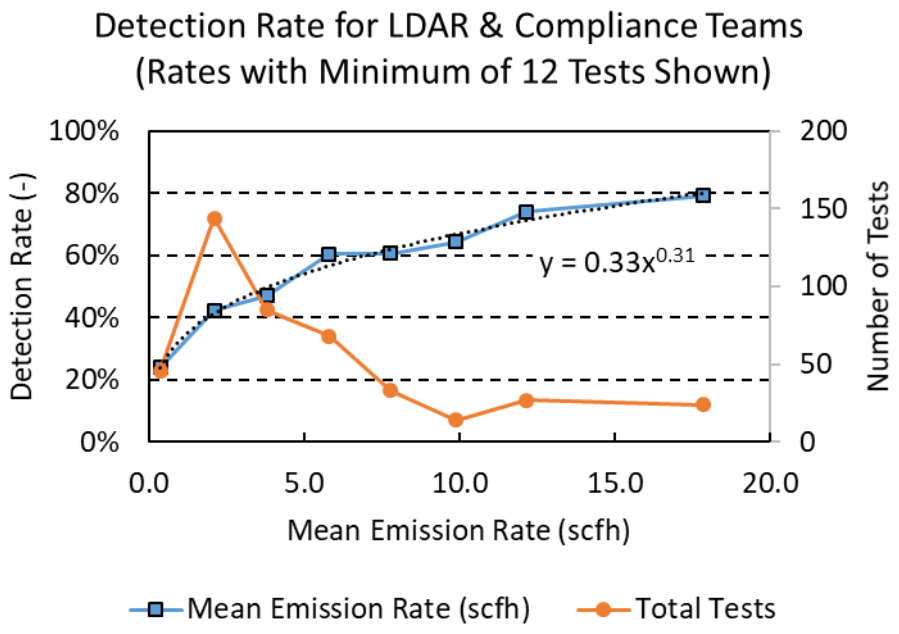


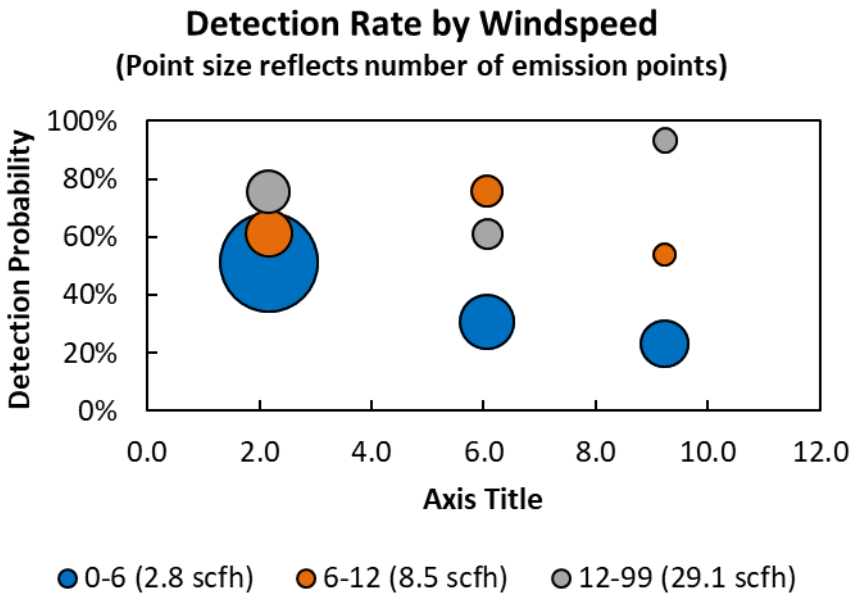
"Designed Experiment"
Controlled testing across all major variables

Testing underway with sponsorship from EPA & Environmental Partnership
Looking for industry participation in October/November 2018. Contact us!

Preliminary OGI Results

9 of 19 test days shown, 30-days total, Feb-Nov 2018

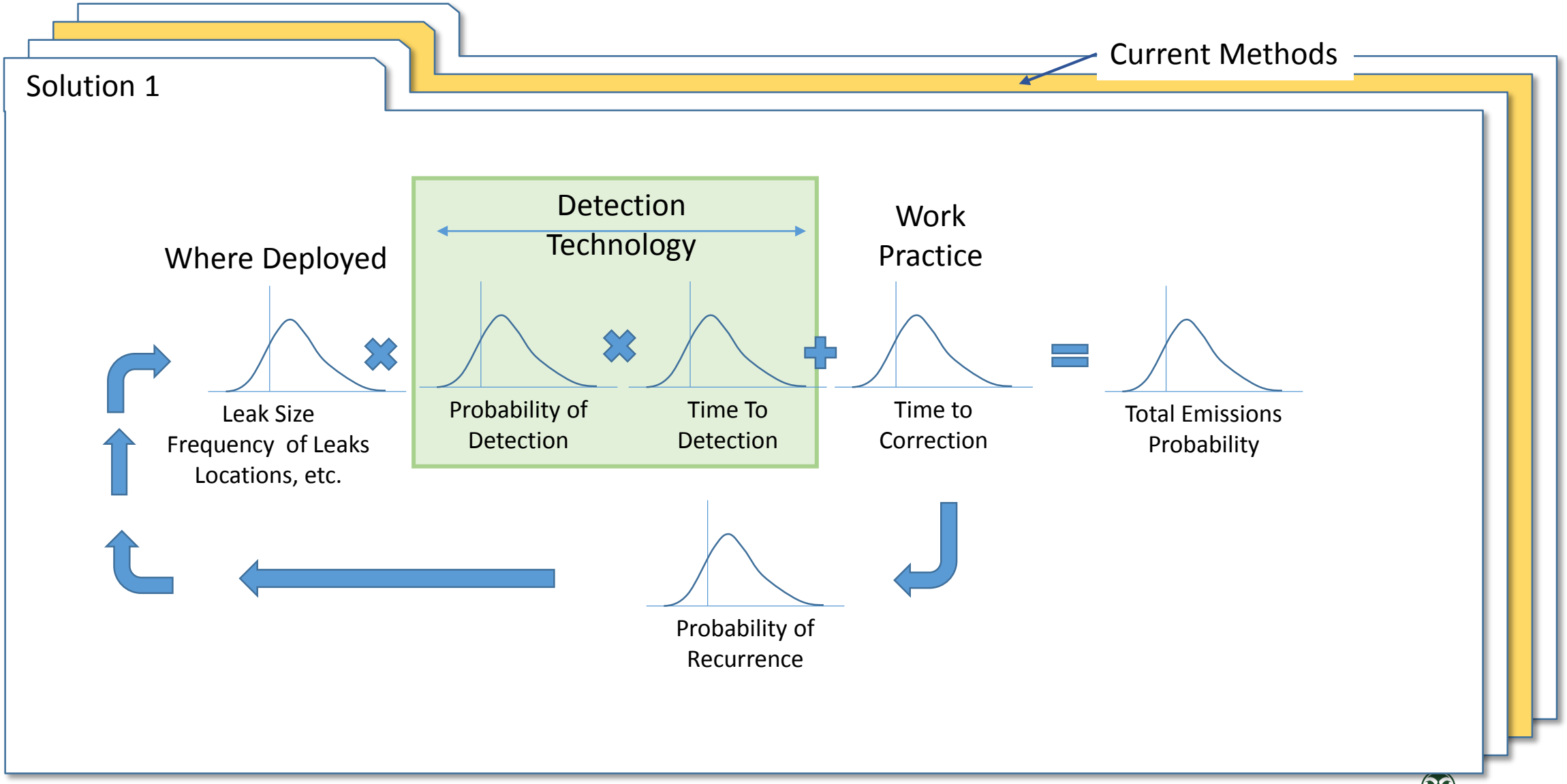




2) Define Equivalency: Assess Results in a Tech-independent Way

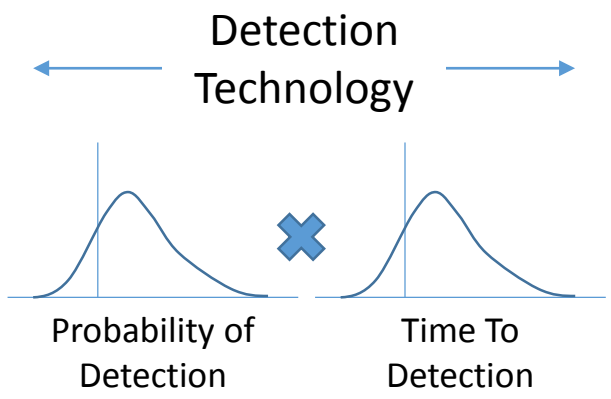
- Objective:
  - Understand performance of dramatically different methods … and build buy-in from stakeholders
- Concept:
  - Solidify deployment *methods*
  - Merge with company/industry processes
  - Develop test protocols *per method*
  - Stochastic comparison between methods

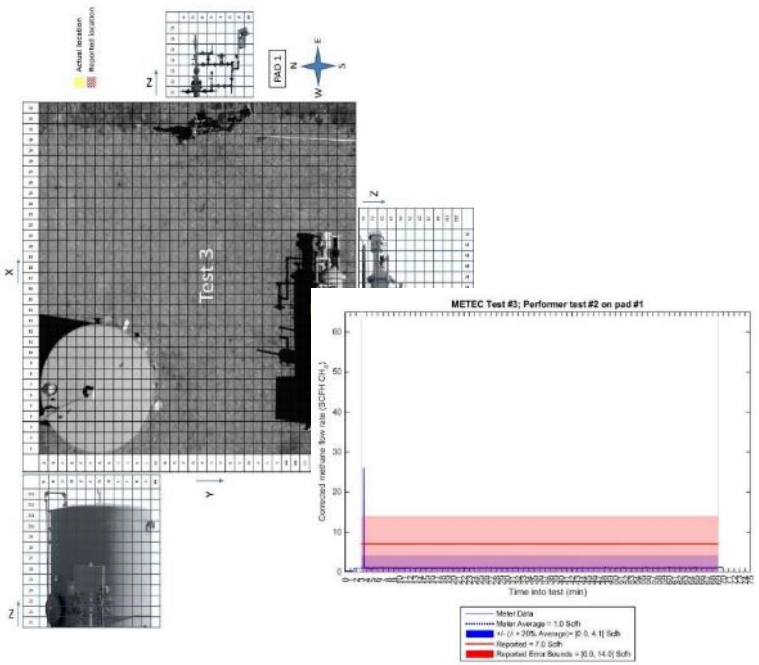
Comparing Emissions Reduction Requires a Model



3) Assessment Protocol

- Objective:
  - Agreed test protocol for each method
- Concept:
  - Convene inclusive working groups
    - Operators
    - Solution developers
    - Regulators
    - Environmental community
  - Identify common methods
  - Develop test protocols
  - Perform “standard” tests that are stable and comparable over time





4) Adoption

- Objective:
  - Broad engagement through process leads to cooperation in rule-making
- Concept:
  - Facilitate strong science
  - Include broad stakeholder group
  - Testing that is independent of rule-type

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Methane Emission Technology Evaluation Center

Colorado State University

https://energy.colostate.edu/metec/

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METEC$_{H_4}$ … Testing Leak Detection Solutions

ARPA-E MONITOR … developing innovative technologies to cost-effectively and accurately locate and measure methane emissions associated with natural gas production

METEC:

- **Goal 1: Gauge technical performance**
- **Goal 2: Engage stakeholder community**

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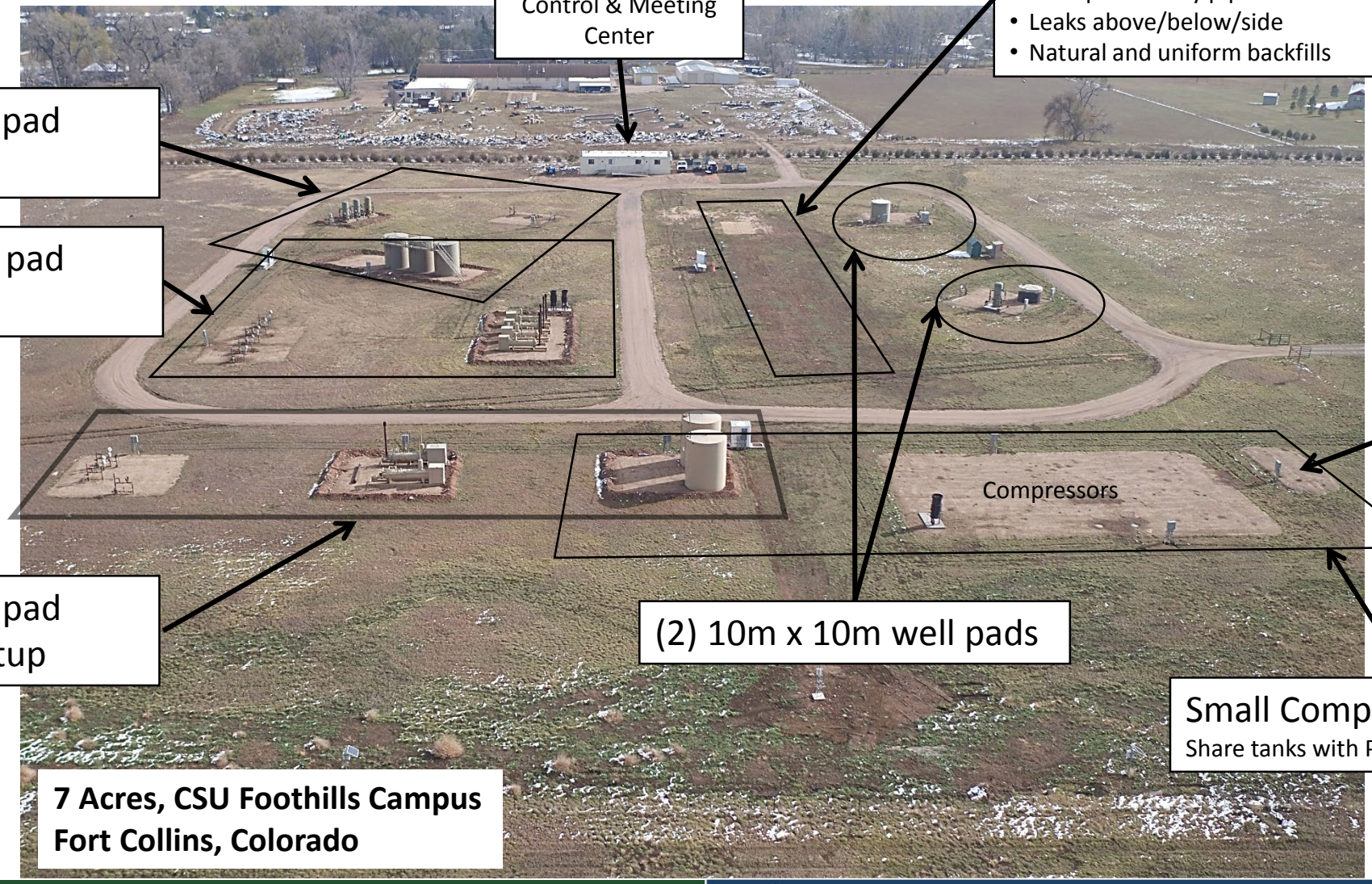
METEC Facilities



Pipeline Test Bed
- Multiple dummy pipes
- Leaks above/below/side
- Natural and uniform backfills

45m x 60m well pad
Dry setup

45m x 60m well pad
Wet/Dry setup

Dehydrator

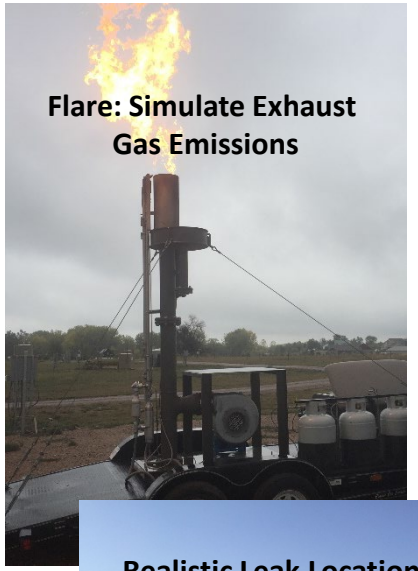
10m x 60m well pad
Wet/Dry Gas Setup

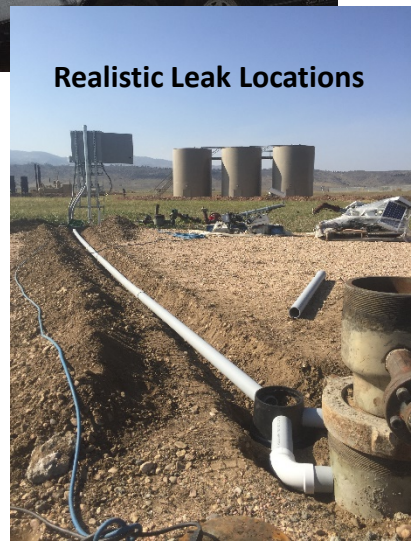
(2) 10m x 10m well pads

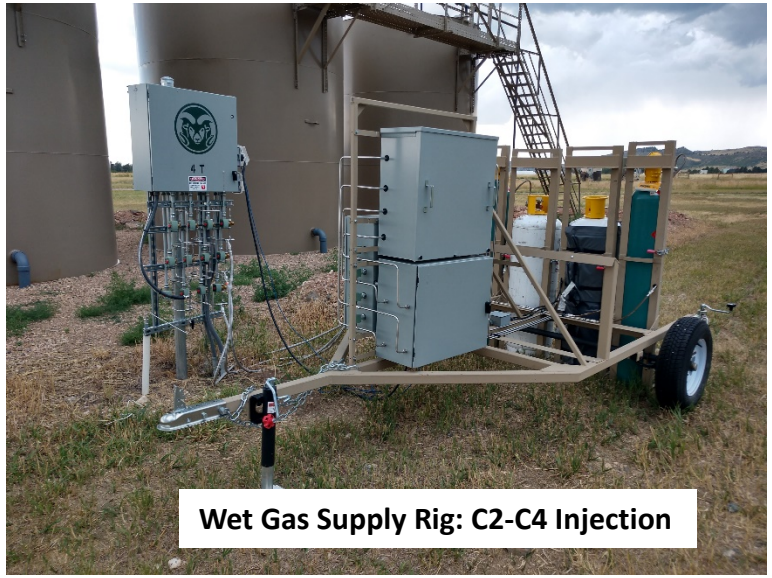
Small Compressor Station
Share tanks with Pad 3

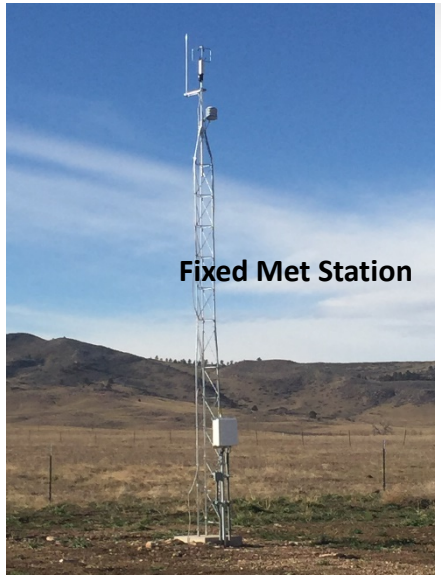
7 Acres, CSU Foothills Campus
Fort Collins, Colorado

MeTeC$_{H_4}$ Analytic and Advanced Capabilities



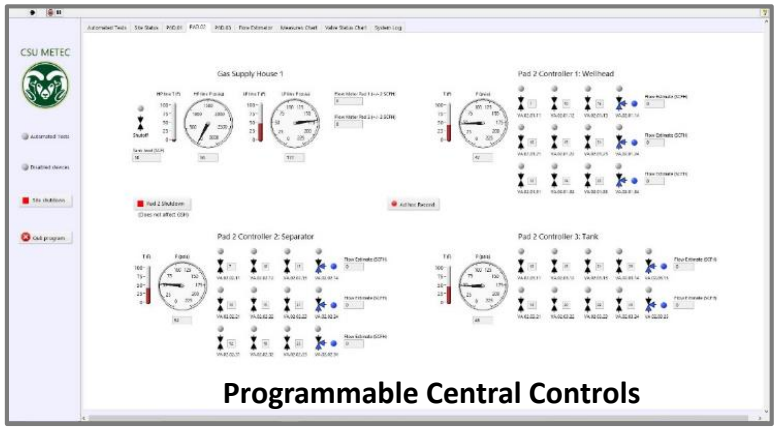






G2210-i iCH_4/C_2H_6

Ethane and Isotopic Methane



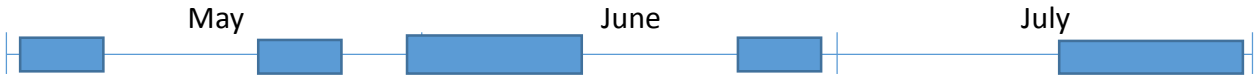
Round 2 Testing Overview

Focus of R2 Test Protocols

Deployment

- Basin Survey
- Continuous Monitoring

Repeatability



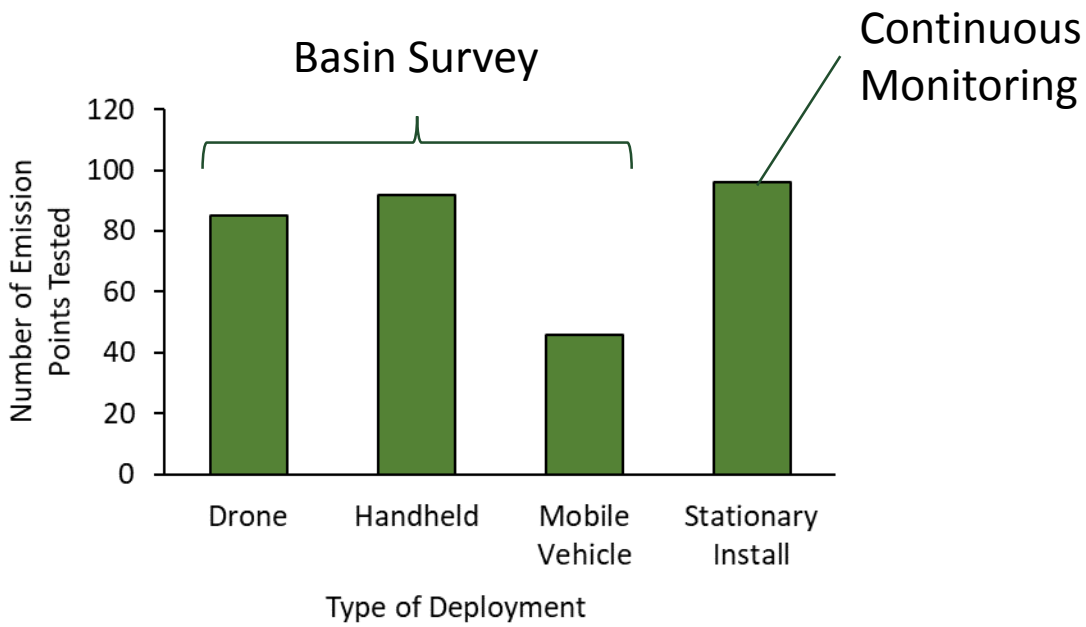
Technology Readiness

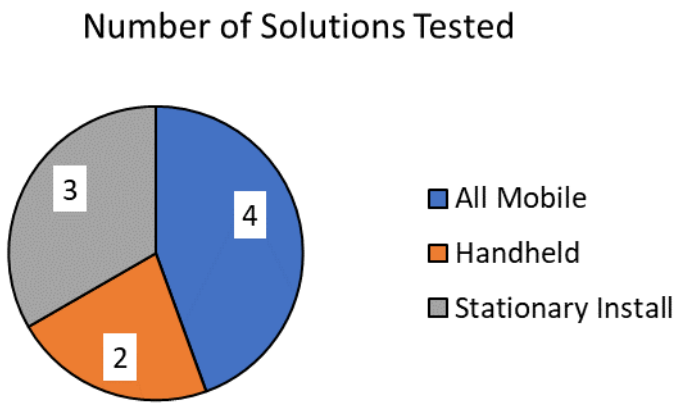
- Graded complexity: A / B / C

Fine Print: Detection "Grades"

- <u>Detected</u>
  - Emission point reported on same equipment *unit* as an emission point: "Pad 4 / Wellhead 2"
  - 15% of difficulty "C" test points had two emitters close together: Detected if one reported.
- <u>Same Group</u> *(Important for some stationary solutions)*
  - Emission point reported on same *equipment group* as an emission point: "Pad 4 / Wellhead 2" but emission was on "Pad 4 / Wellhead 1"
- <u>Not Detected</u>
  - No reported point on same equipment or same group
- <u>False Positive</u>
  - Reported emission on equipment group with no emission point

Who & How Many …





- Categories are “hazy”
  - Several levels of “mobility” / several degrees of “stationary”

Complex Scenarios Are Harder …

- Detection rates drop when multiple emission points are present
- Type of multi-point emissions has less impact than “if there are multiple points”

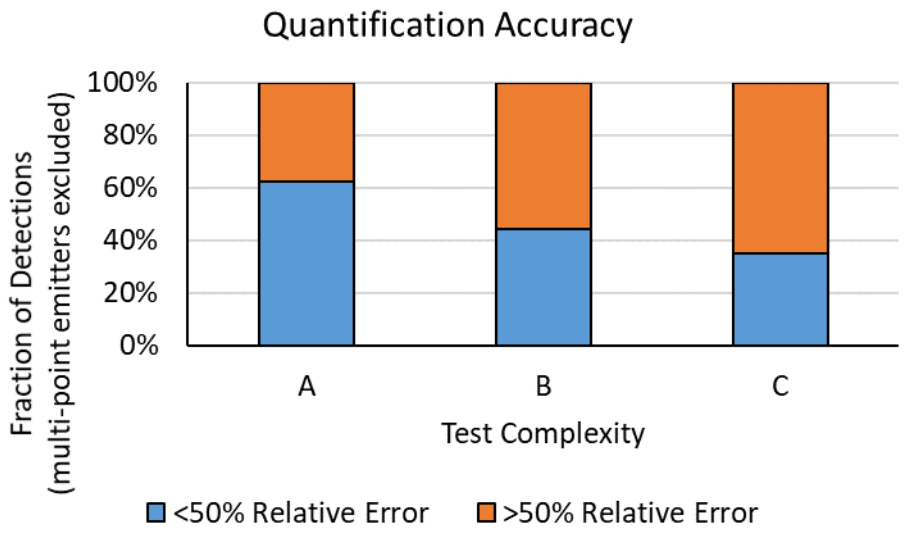
3-Level Test Complexity

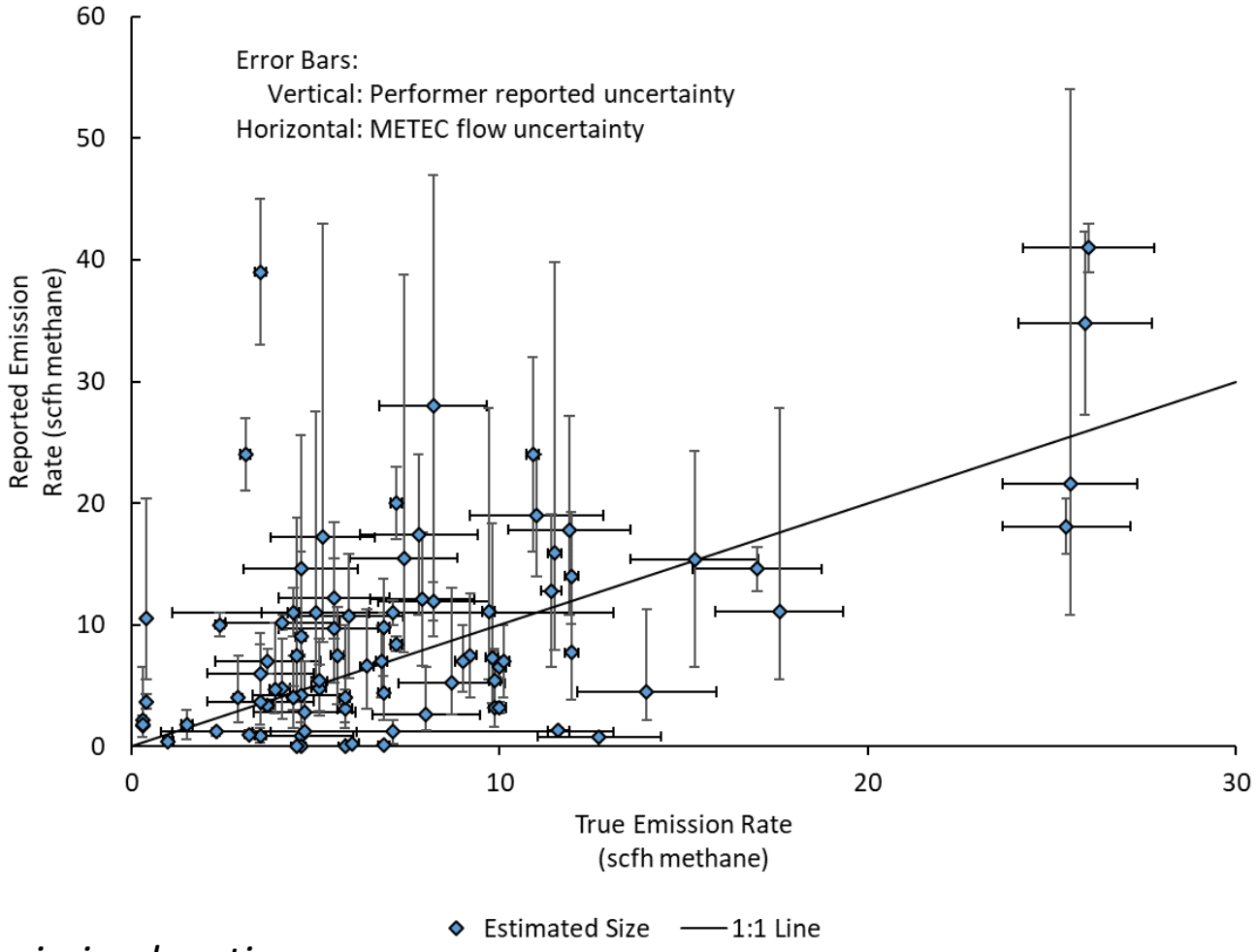
A – Single emission point per pad, Steady emission rate

B – Multiple emission points per pad, Steady emission rate

C – Multiple emission points per pad, Steady & intermittent rates

Quantification remains problematic

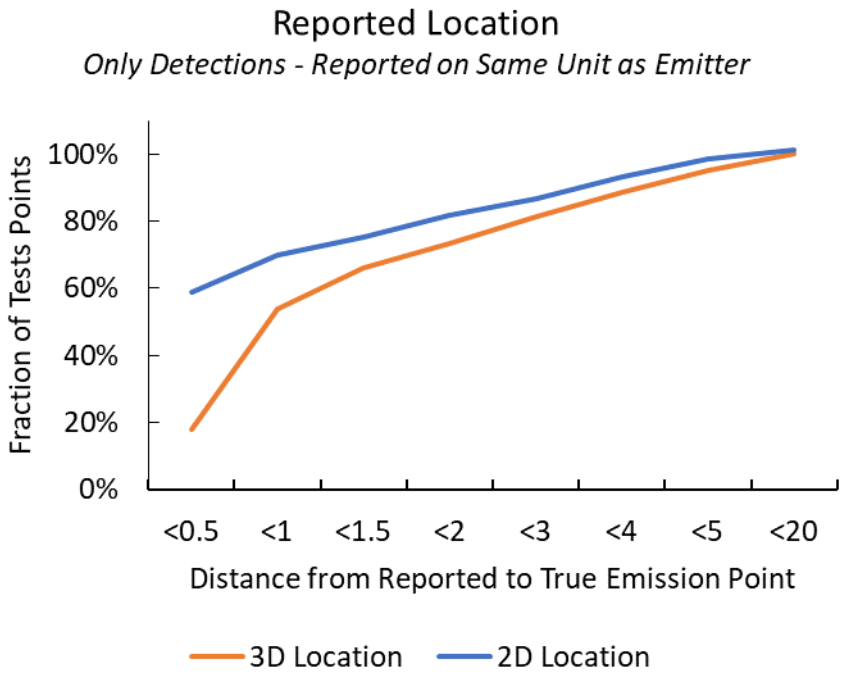




Single point emission locations
Detected emitters only

Localization looks promising

- 2D – 70% within 1 meter
- 3D – 54% within 1 meter



- Recommend automated capture of leak locations
  - In solution design
  - In SCADA tracking systems

What Have We Learned From Testing?

- Testing – even in simplified METEC environment – distinguishes differences in performance

- Nuances challenge comparisons
  - Variation in deployment methods
  - Amount of human interaction with automated solutions → translates to cost
  - Amount of labor in post-measurement analysis → translates to cost

- Protocols are informative, but need more development
  - More repeat testing
  - Standardized reporting – with time limits
  - Tracking practical performance metrics: time/site, up-time, etc.

Summary

What we know

1. Emission estimates are dramatically improved over last 8 years
2. We now understand multi-scale measurement methods much better
3. New technologies heading to market have real & useful capabilities

What's next:

1. Apply better measurement methods uniformly
2. Fill in gaps in emissions knowledge … including new facility types
3. *Path to Equivalency* for new technologies

Thank You

Contact

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