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Facility Comparison Data
GHGI Stakeholders Meeting
10/27/17

Daniel Zimmerle

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Synopsis: 4 Points & a Plug

New Data Presented Here

Reconciling Basin-Scale Top-Down and Bottom-Up Methane Emission Measurements for Onshore Oil and Gas Development (RPSEA 12122-95)

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NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

CIRES
Cooperative Institute for Research in Environmental Sciences

JISEA Joint Institute for Strategic Energy Analysis

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NETL

RPSEA
Research Partnership to Secure Energy for America

Colorado Energy Research Collaboratory
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AGA American Gas Association

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XTO ENERGY
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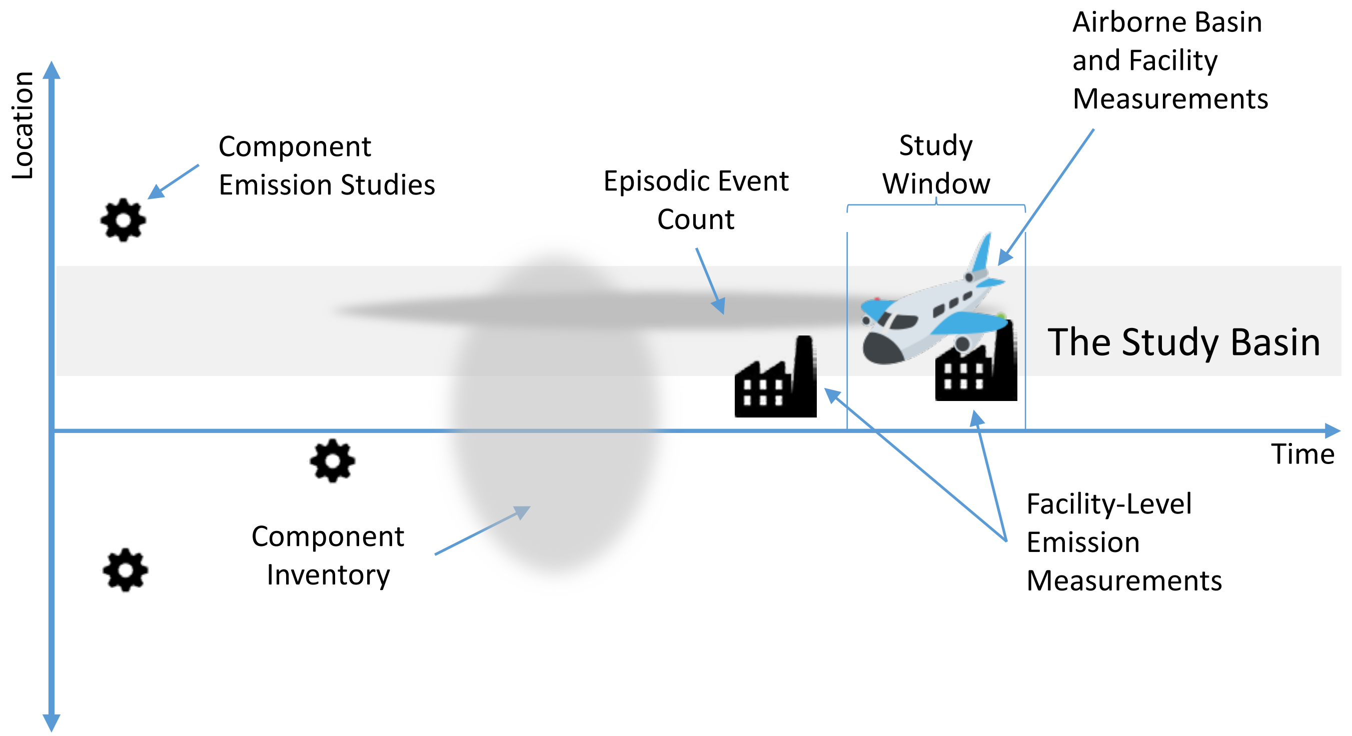
Chevron

What Has Been Compared in Past Studies



From past studies …

Aircraft (top down) estimated emissions

≈1.5 times

Inventory-based (bottom up) estimate

- Facility measurements not statistically representative
- Episodic data from annualized counts aggregated at basin level (at best)
- Vague component inventory values
- Component measurements from distant times & places

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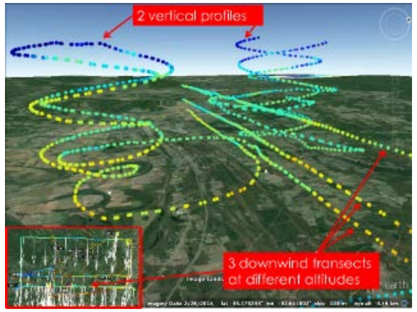
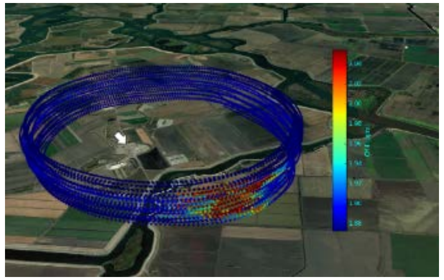
Measurement @ 3 Levels

Basin

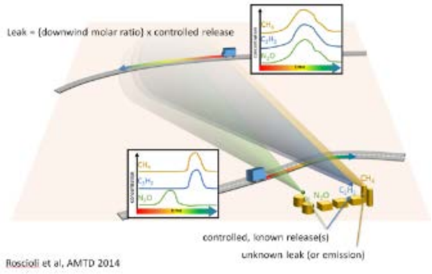


Regional Mass Balance

Facility



Facility "Spiral Flight"



Tracer Flux

OTM33A

Device

Onsite

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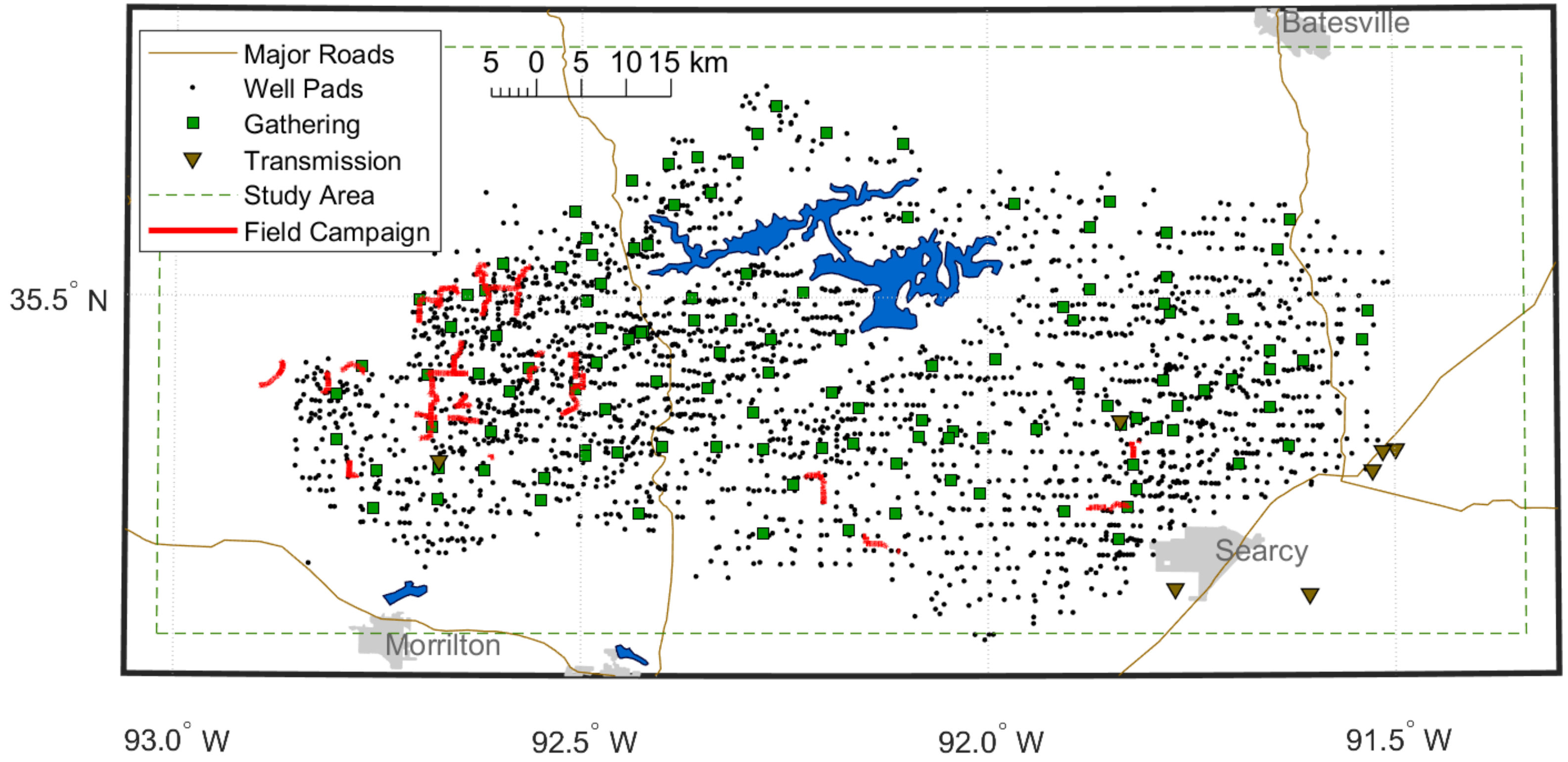
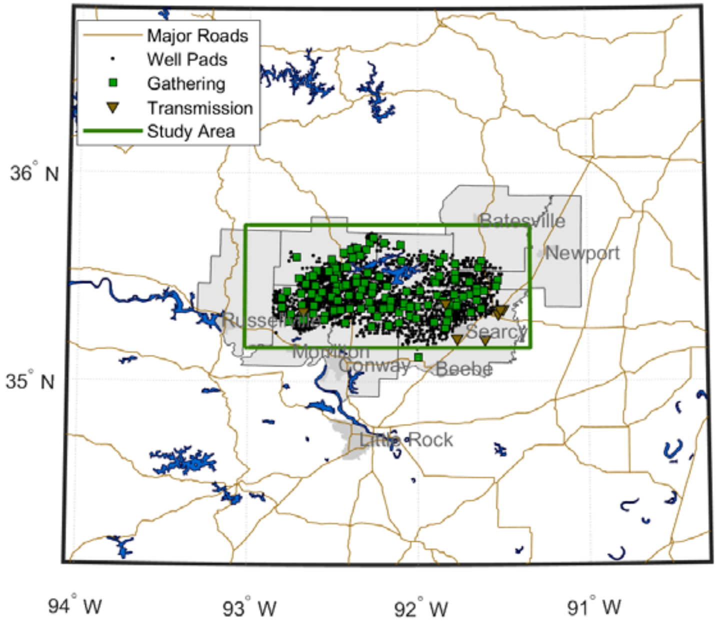
Study Area





Fayetteville Shale play in northern Arkansas

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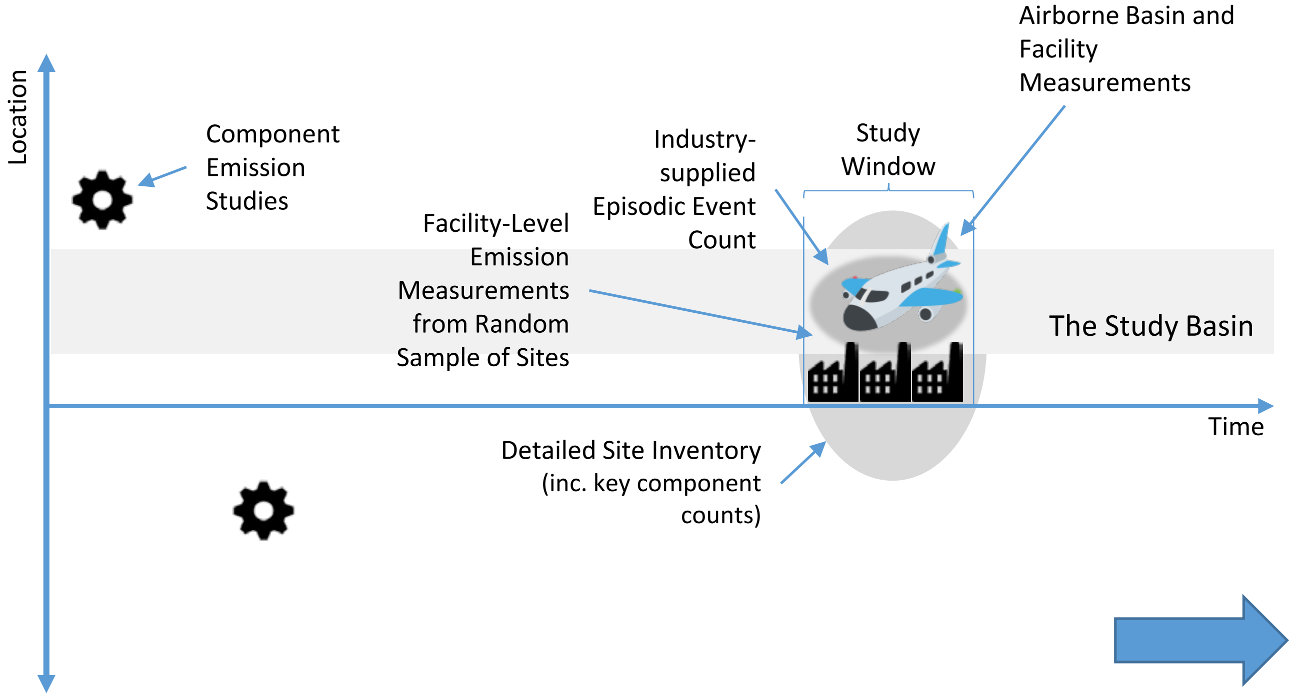
What is Unique: Aligned Measurements



Study Accomplishments

- Statistically representative facility measurements
- Episodic data resolved at fine detail *during aircraft measurement window*
- Basin-specific, high-resolution facility inventory and key component counts (we have data for ≈98% of O&G facilities)
- **Multiple measurement approaches utilized and compared for facilities**

Compromise Areas ($ vs completeness)

- Robust, empirically-based uncertainty estimates for all estimates **(**missing some**)**
- Component measurements from distant times & places (couldn't measure some key sources)

Papers

Released:

- Conley S, Faloona I, Mehrotra S, Suard M, Lenschow DH, Sweeney C, Herndon S, Schwietzke S, Pétron G, Pifer J, et al. 2017. Application of Gauss's theorem to quantify localized surface emissions from airborne measurements of wind and trace gases. *Atmospheric Measurement Techniques; Katlenburg-Lindau* **10**(9): 3345–3358. doi: http://dx.doi.org/10.5194/amt-10-3345-2017
- Robertson AM, Edie R, Snare D, Soltis J, Field RA, Burkhart MD, Bell CS, Zimmerle D, Murphy SM. 2017 Jun 19. Variation in Methane Emission Rates from Well Pads in Four Oil and Gas Basins with Contrasting Production Volumes and Compositions. *Environ Sci Technol*, in press. doi: 10.1021/acs.est.7b00571
- Schwietzke S, Pétron G, Conley S, Pickering C, Mielke-Maday I, Dlugokencky EJ, Tans PP, Vaughn T, Bell C, Zimmerle D, et al. 2017 May 26. Improved Mechanistic Understanding of Natural Gas Methane Emissions from Spatially Resolved Aircraft Measurements. *Environ Sci Technol*, in press. doi: 10.1021/acs.est.7b01810
- Vaughn TL, Bell C, Zimmerle DJ, Pickering C, Pétron G. 2017. Reconciling Facility-Level Methane Emission Rate Estimates Using Onsite and Downwind Methods at Natural Gas Gathering and Boosting Stations. *Elem Sci Anth* **accepted**.
- Yacovitch TI, Daube C, Vaughn TL, Bell C, Roscioli JR, Knighton B, Nelson DD, Zimmerle D, Pétron G, Herndon SC. 2017. Natural gas facility emission measurements by dual tracer flux in two US natural gas producing basins. *Elem Sci Anth* **accepted**.
- Zimmerle DJ, Pickering C, Bell C, Heath G, Pétron G, Nummedal, D, Vaughn TL. 2017. Methane Emissions from Gathering Pipeline Networks in the Fayetteville Shale Play. Elem Sci Anth, in press.

In Progress:

- Mielke-Maday I, Pétron G, Schwietzke S, Schnell R. n.d. → Improved attribution of emissions estiamtes
- Vaughn TL, Bell C, Pickering C, Heath G, Murphy SM, Pétron G, Robertson AM, Pickering C, Roscioli JR, Yacovitch TI → Basin-level comparison between bottom-up and top-down estimates

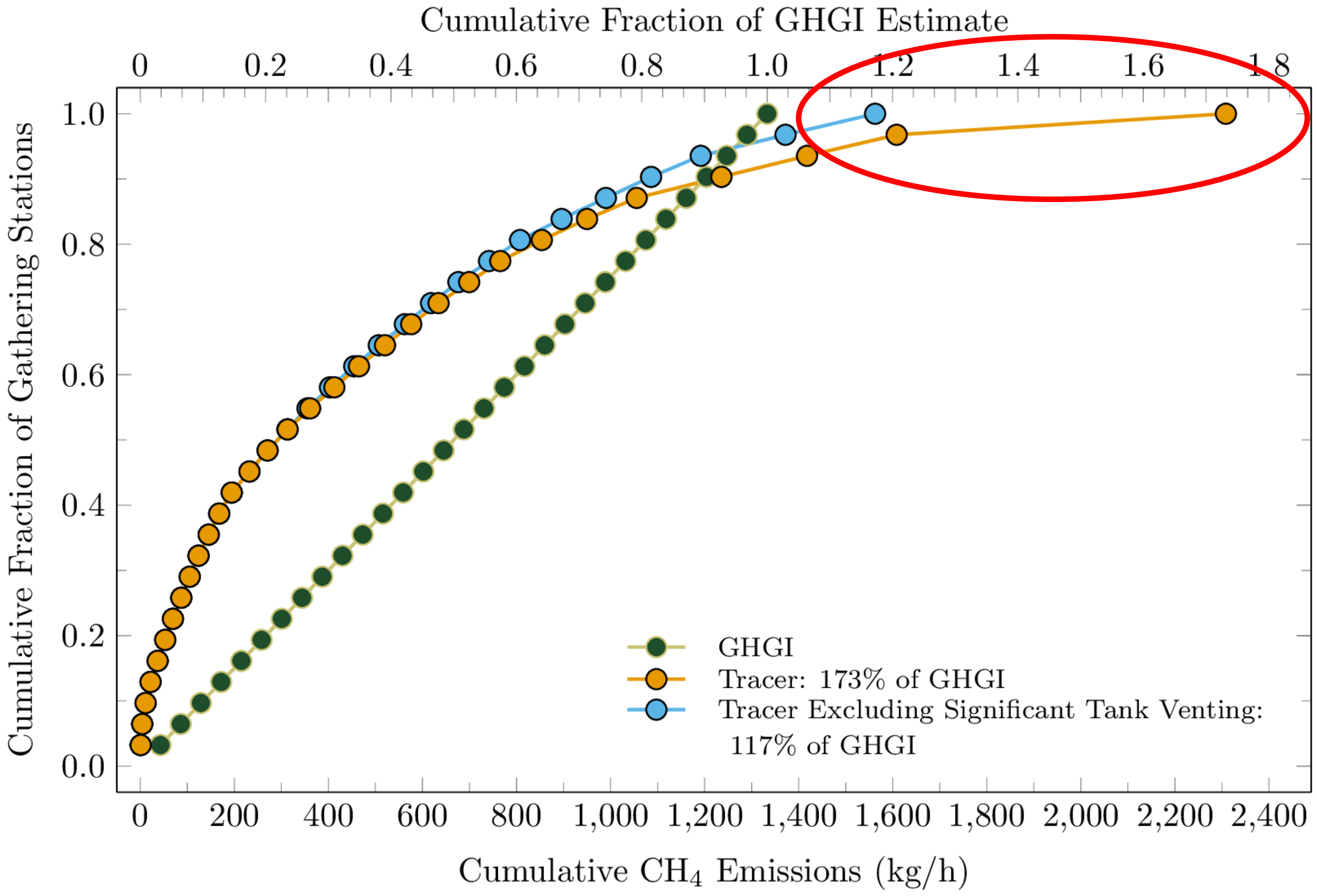
Facility-Level Comparisons of Gathering Compressor Stations

Vaughn TL, Bell C, Zimmerle DJ, Pickering C, Pétron G. 2017. Reconciling Facility-Level Methane Emission Rate Estimates Using Onsite and Downwind Methods at Natural Gas Gathering and Boosting Stations. *Elem Sci Anth,* in press.

Fayetteville Study: Gathering Compressor Stations

- Data:
  - Contemporaneous downwind (dual tracer flux) and onsite device leak measurements + recent combustion slip from standard tests
- Analysis:
  1. Remove sites where major sources could not be measured by onsite methods
  2. Assemble "best estimate" for total emissions from both downwind & on-site methods.
  3. Pairwise comparison of measurement results

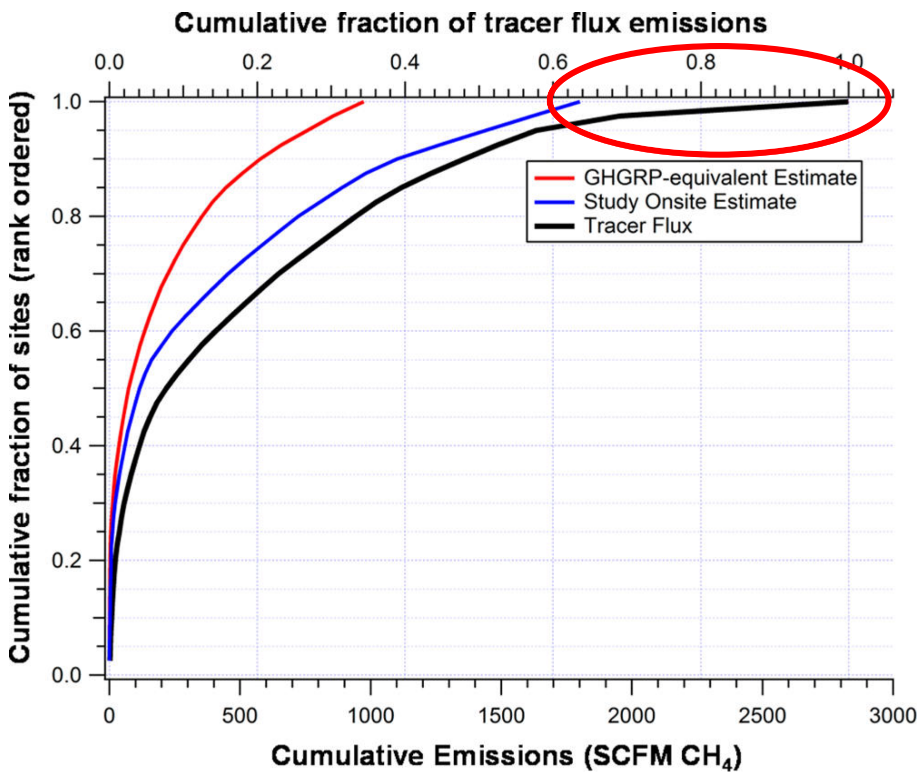
Step 1: Remove Onsite Measurement Gaps



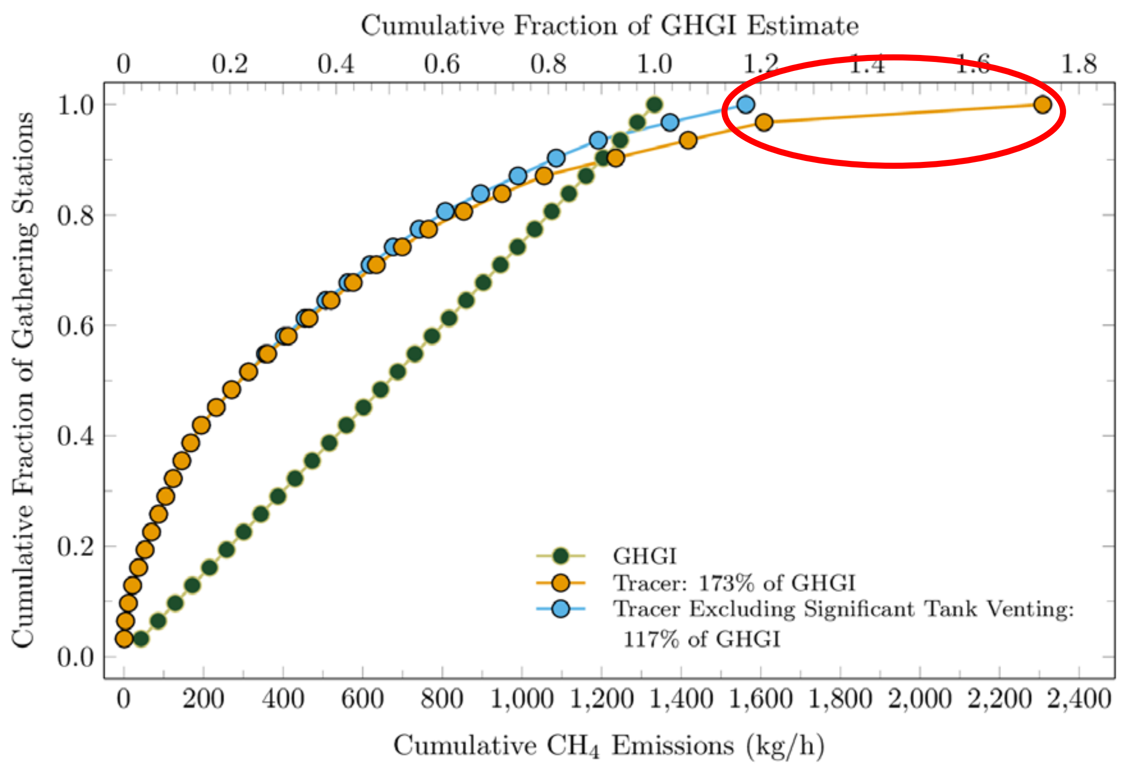
- Facilities where downwind methods captured emissions that could not be measured by on-site methods.

Facility-Level Reconciliation: Normal / Abnormal Operations

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



T&S Study (Subramanian et al., Zimmerle, et al.)



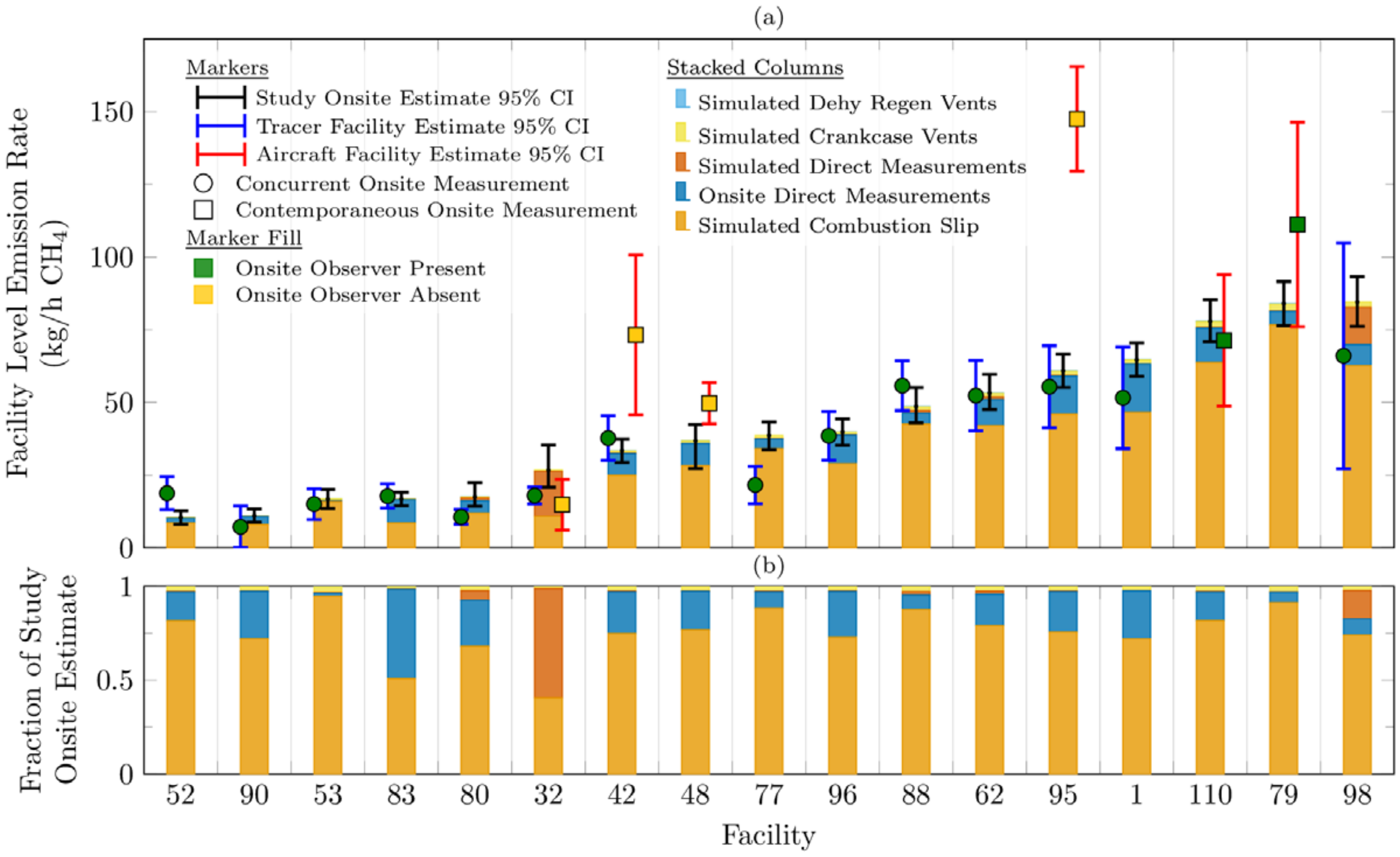
Fayetteville Study (Vaughn et al.)

* 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).

Point #1: Include Exceptional Emissions in GHGI

- Beginning to develop a consistent pattern:
  - *at compression facilities* (possible that other facilities are similar)
  - a substantial portion of emissions measured in field campaigns (≈40% of emissions)
  - is **visible only using downwind methods** … i.e. not caught by on-site measurement methods due to primarily to safety concerns
  - And … the source of these emissions cannot be consistently attributed to any one equipment type and is not correlated to system size, age, paint color, etc.
- Therefore:
  - Need to have a category to capture these larger, *uncategorized,* emissions

Step 2: Assemble Best Estimate



Exhaust methane: 78% / measured fugitives: 15% / simulated fugitives: 7%

Source

- Onsite measurements:
  - OGI detection
  - High-flow + some add'l methods
- Partner data from recent exhaust measurements
- Estimates when measurements could not be made

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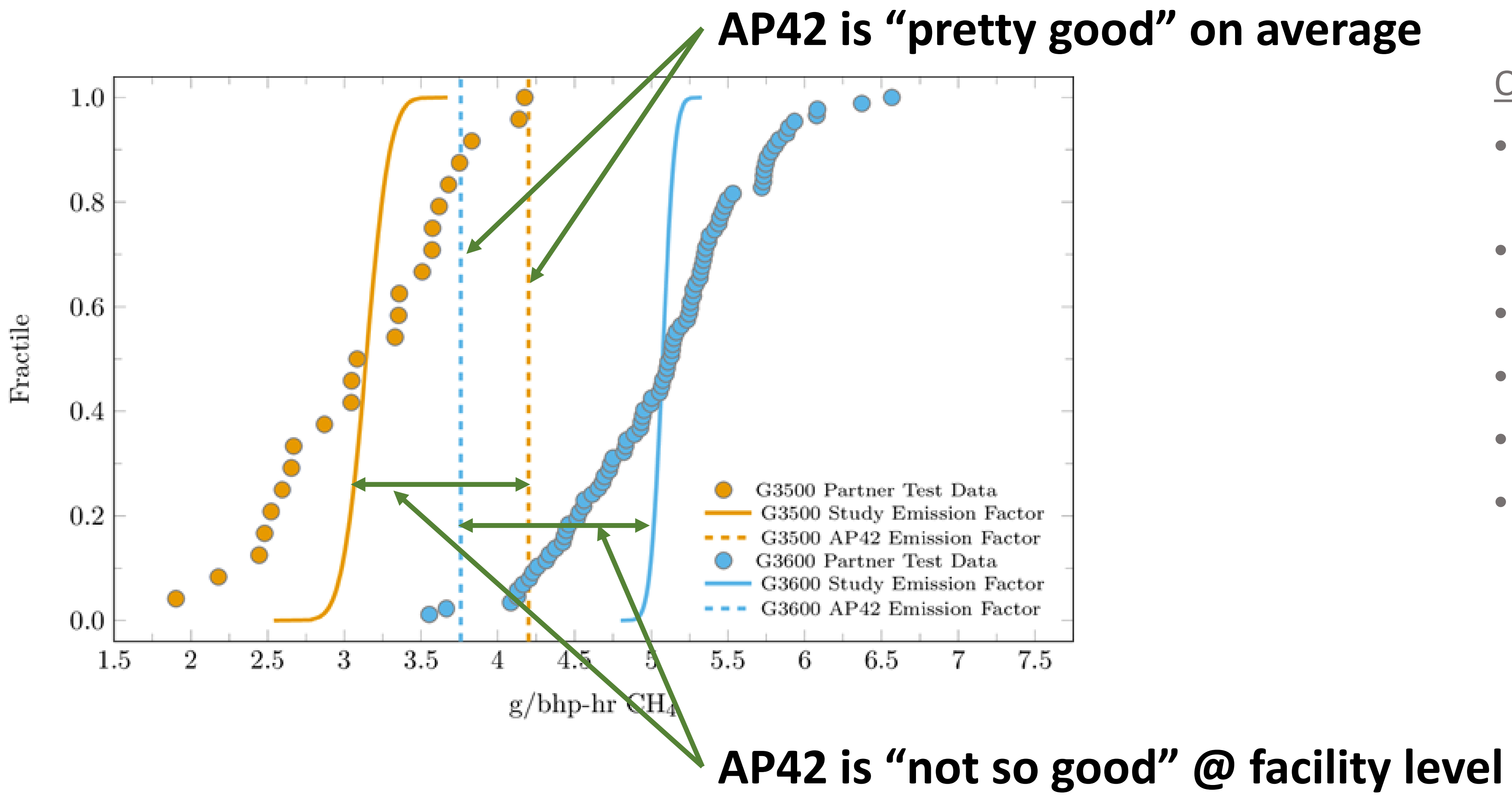
Exhaust is large fraction … therefore … Exhaust data is important



Qualifiers:

- Recent, lean burn engines
- Two types only
- One manufacturer
- One basin
- Two partners
- Emissions data < 1 year old from company-conducted tests (JJJJ or ZZZZ type)

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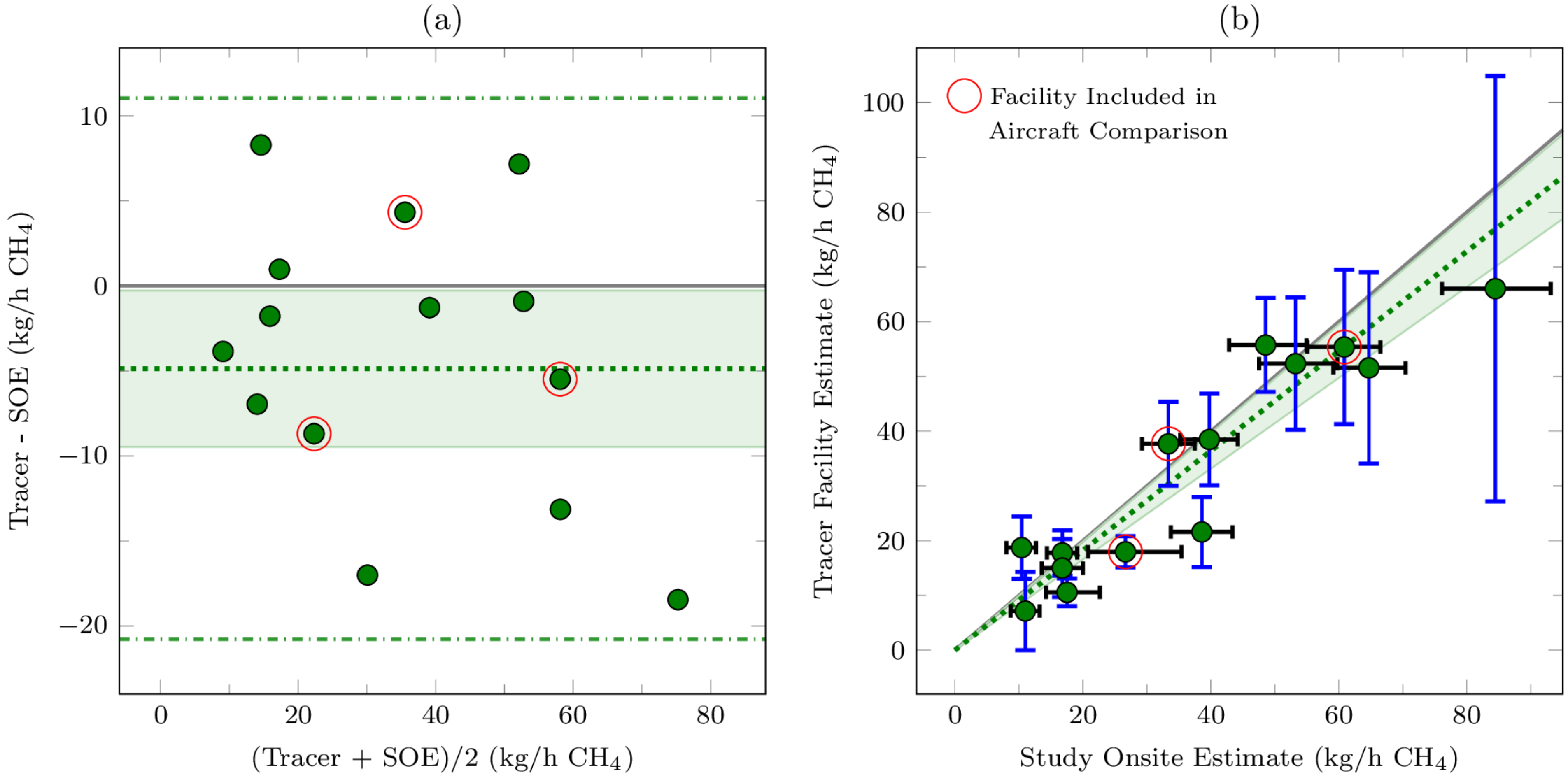
Point #2: Know Your Exhaust

- Even within single class of engine there are significant difference in exhaust methane emissions (g/bhp-hr)
- In aggregate … over large populations … AP42 emission factors are “*not bad*”
- For small populations … e.g. basins or facilities … AP42 emission factors *are not sufficiently representative for good comparisons between methods*

Plug: Substantial FTIR-based exhaust emissions measurements done every year → is there a way to collect and update AP42?

Step 3: Pairwise Comparison



Bland-Altman Difference Plot

- Bias: -4.9 kg/h
- Bias 95% CI: -9.5 to -0.3 kg/h
- Limits of Agreement: -4.9 (+/-15.9) kg/h

Variance-Weighted Least-Squares Fit

- y=0.91x, R^2=0.89
- 95% Confidence Interval: y=0.83x to y=0.99x
- Line of Equality (y=x)

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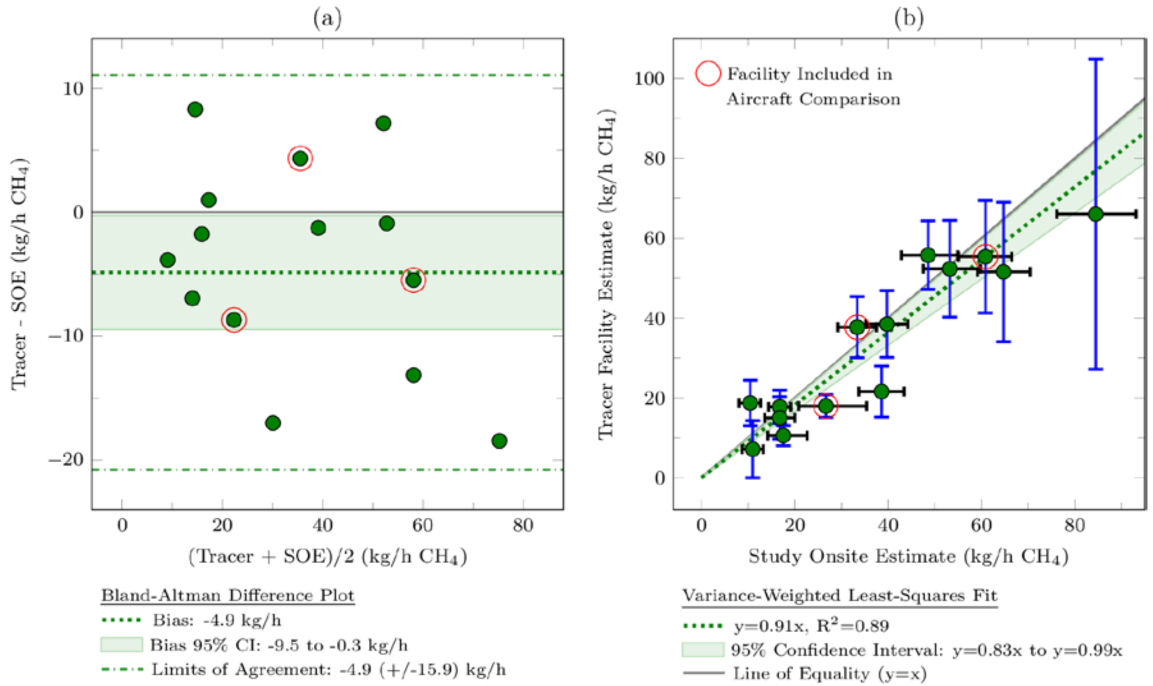
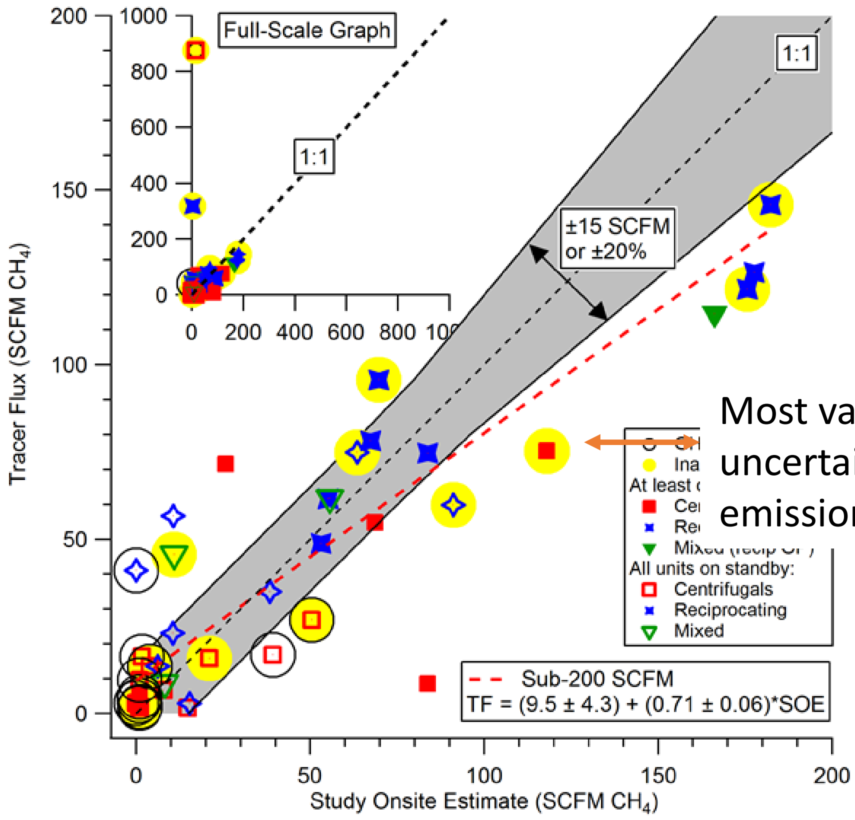
Comparison Notes

- Very strong agreement between onsite and tracer
- Onsite emissions dominated by exhaust … strong support that emission tests are representative.
- Comparison indicates that tracer systematically indicates lower emissions than onsite
  - Tracer *may* miss some exhaust emissions



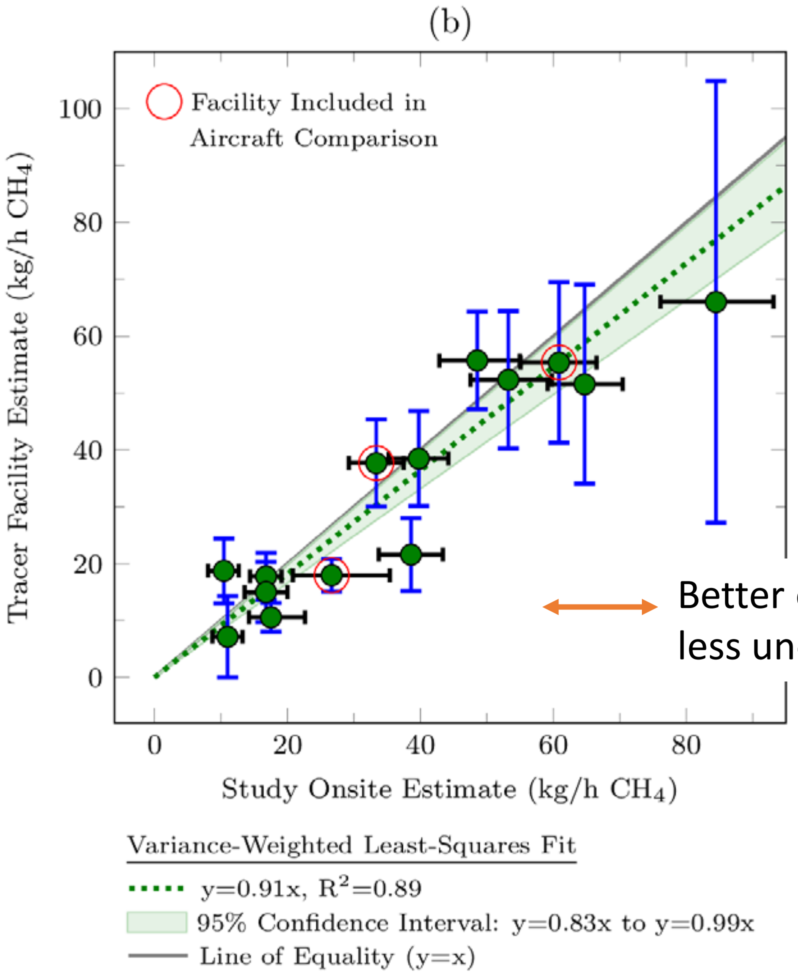
Exhaust Data Impacts Comparisons

T&S Study*:
Engine Emissions from AP42



Most variance due to uncertainty in exhaust emissions

Fayetteville Study / Gathering Stations
Engine Emissions from Recent Tests



Better exhaust data … less uncertainty

* 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).

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Point 3: Properly Developed Onsite Estimates Likely Represent True Emissions

Observations:

- Exhaust dominates emissions at these facilities
- Tracer matches onsite closely

Conclude:

- Recent exhaust measurements are likely representative.
- Facility-level comparisons enhanced by engine-specific … ideally unit-specific … emissions measurement
- Onsite fugitive survey is not systematically missing large emission sources

Cautions

- One basin
- Limited # of operators
- Comprehensive leak survey & meas.
- One type of engine (lean burn)
- Tracer may systematically miss some emissions
- Exhaust methane dominates emissions … difficult to see changes in fugitives

Gathering Pipelines

Zimmerle DJ, Pickering C, Bell C, Heath G, Pétron G, Nummedal, D, Vaughn TL. 2017. Methane Emissions from Gathering Pipeline Networks in the Fayetteville Shale Play. , in press.

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Leak Detection Method

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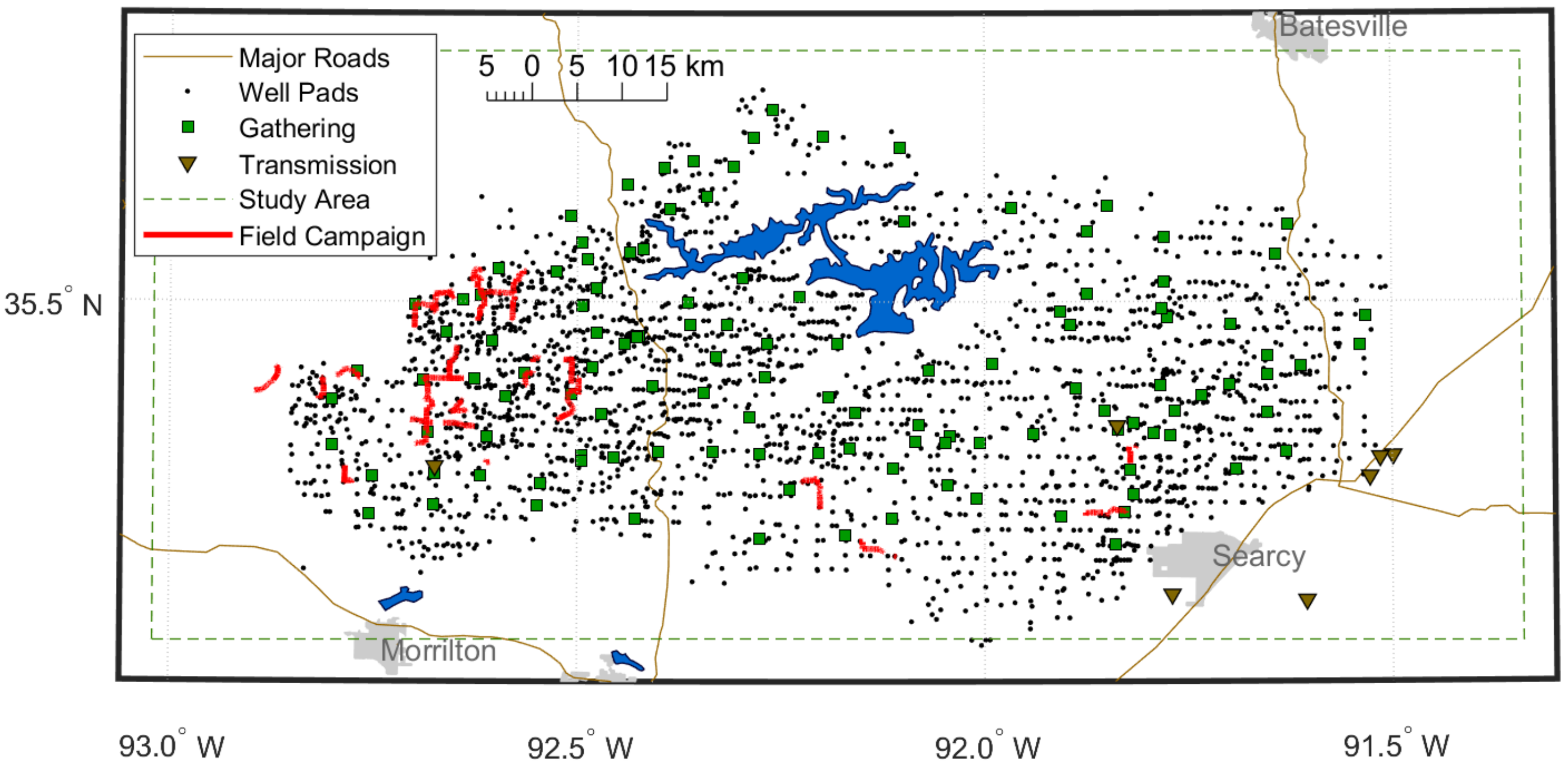
Pipelines

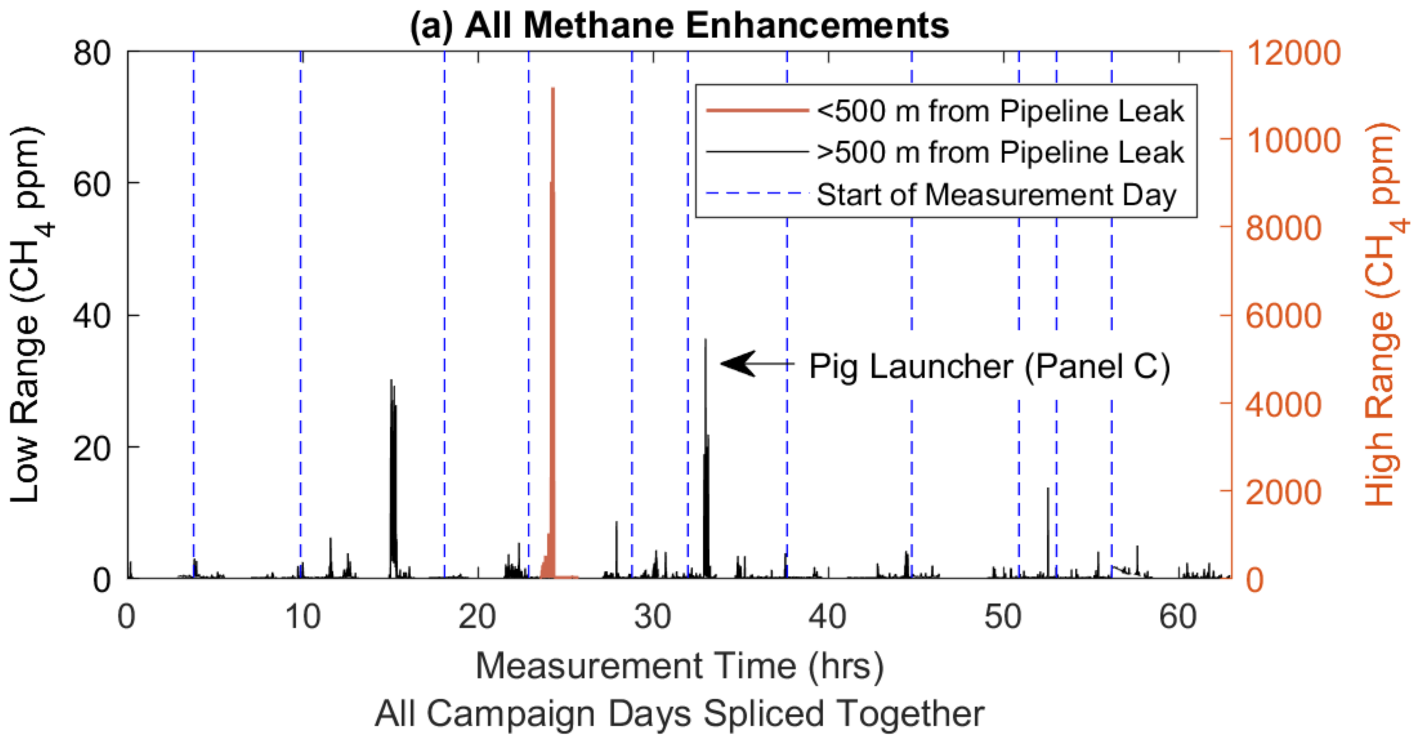
- Sampled 96 km of gathering pipeline
  - 4680 km in study area
- Measurements by GHD (Tom Ferraro / Brian Lamb)
- Vehicle-based leak detection
- Measure detected leaks

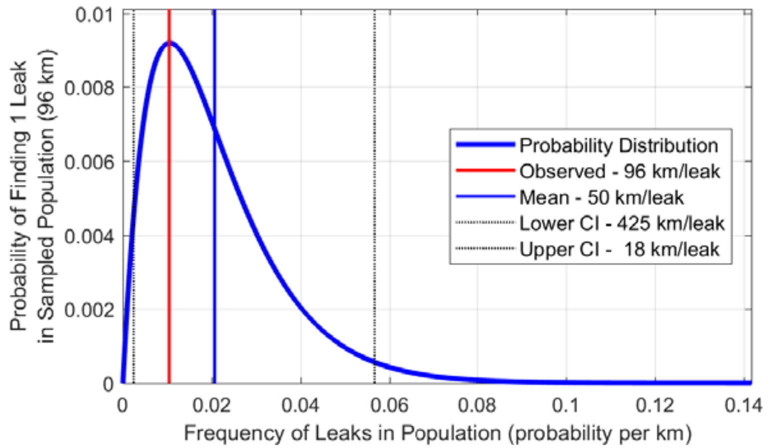


Category	Measured Methane Emissions Rates (kg CH_4/hr)	
	Mean	95% CI
Pigging Facility Equip.	0.014	-52% / +65%
Block Valves	0.002	-56% / +74%
Underground Leak	4.0	NA[2]

Results

- Above Ground
  - Found numerous small leaks …
- Below ground
  - Found 1 larger leak

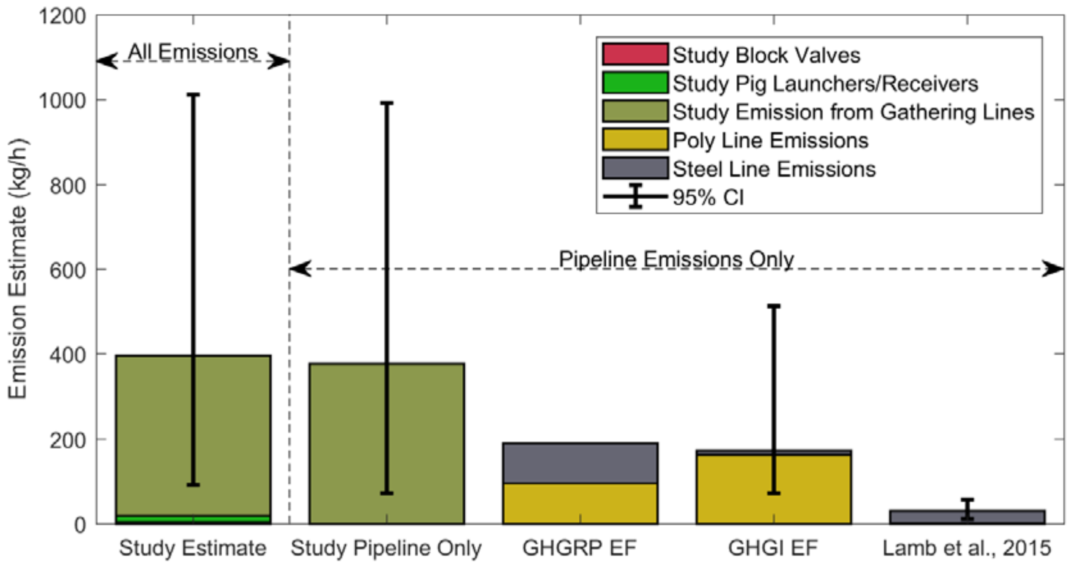




Modeled uncertainty of leak count: 50 km/leak [18 to 425]

Observations (Not Conclusions!)

- Too little / too restricted data to develop new emission factors
- Observations:
  - Above ground equipment very small relative to *highly uncertain* underground leak estimate
  - For this basin … switching from current emission factors to recent distribution measurements would not be advised.



Point 4: How to Plan Pipeline Emissions Campaigns

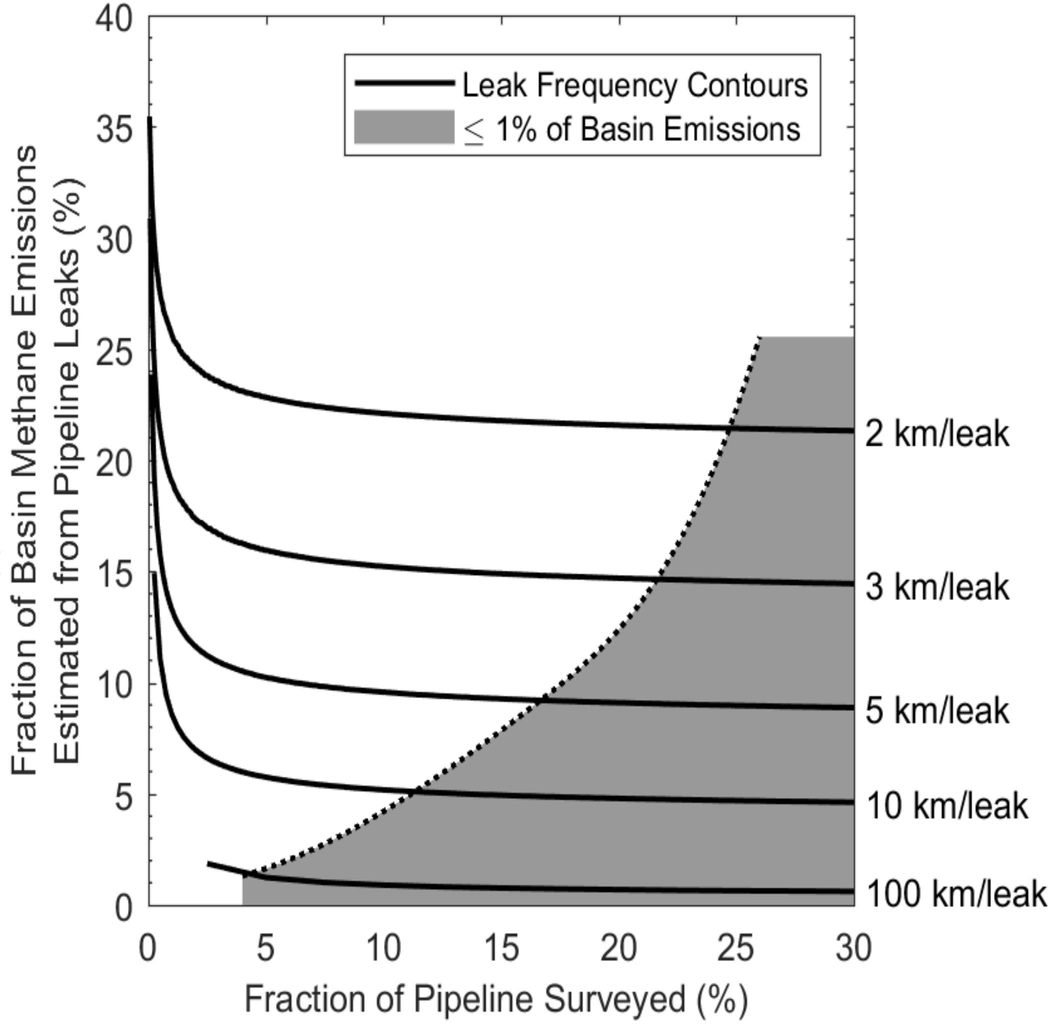
Assuming measurement seen here are representative …

1. Concentrate on underground leaks

and …

2. Use available leak frequency estimates to size the field campaign

→ Recommend to take steps to collect leak frequency data



Conclusions

1. Include "extra emissions" found only in downwind studies
2. Exhaust measurements are necessary for facility-level comparisons
   - Likely correct
   - AP-42 not specific enough for small populations
3. Properly developed on-site emissions likely represent true emissions
   - Tracer *may slightly* underestimate emissions from facilities dominated by lofted, hot, emissions
4. Start collecting pipeline *leak frequency* data to guide basin-level emissions studies for leak quantities

The Plug

Visit & Use METEC

METEC ready for Round 1 testing

Pad 1

Pad 2

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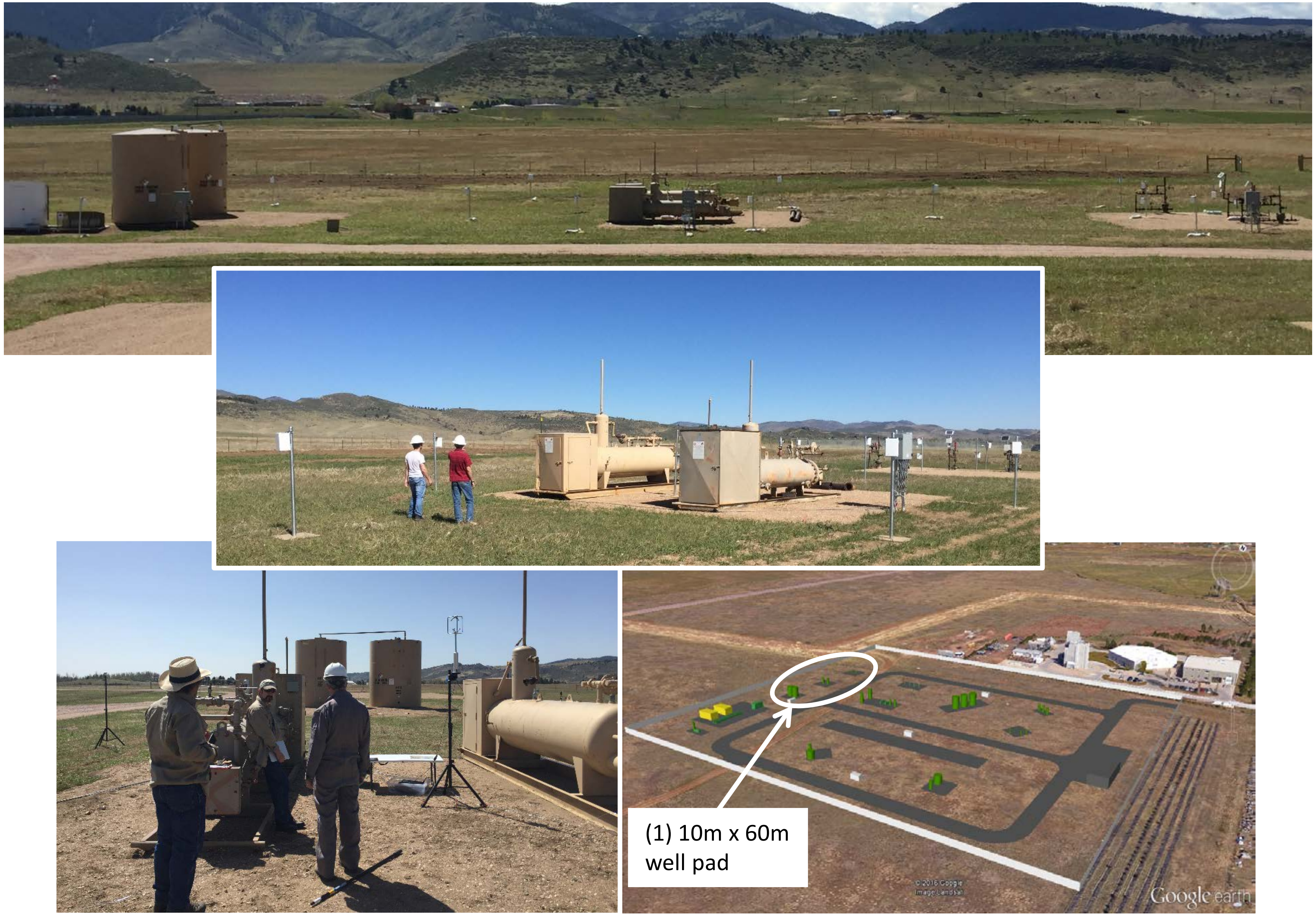
Pad 3



Yes … non-MONITOR technologies can test at METEC