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Gathering Compressor Stations

Recent Results

Daniel Zimmerle

The MeTeC$_{H_4}$ Facility

Project Team & Partners

Project Team

- Daniel Zimmerle (CSU, PI)
- Tim Vaughn (CSU, field team lead)
- Ben Luck (CSU)
- Kristine Bennett (CSU, project manager)
- Matt Harrison (AECOM, co-PI)
- Terri Lauderdale (AECOM)
- Kindal Keen (AECOM)
- Laurie Williams (Fort Lewis State)
- David Allen (UTA, consultant)
- & numerous field staff

Cost share & site access:

- Anadarko Petroleum Corporation
- DCP Midstream
- Kinder Morgan Natural Gas Pipelines
- Mark West Energy Partners
- Pioneer Natural Resources
- Southwestern Energy
- Equinor (formerly Statoil Gulf Services)
- Williams
- XTO Energy, Inc., a subsidiary of ExxonMobil

Funding:

- DOE, Office of Fossil Energy contract DE-FE0029068
- ONE Future

Agenda

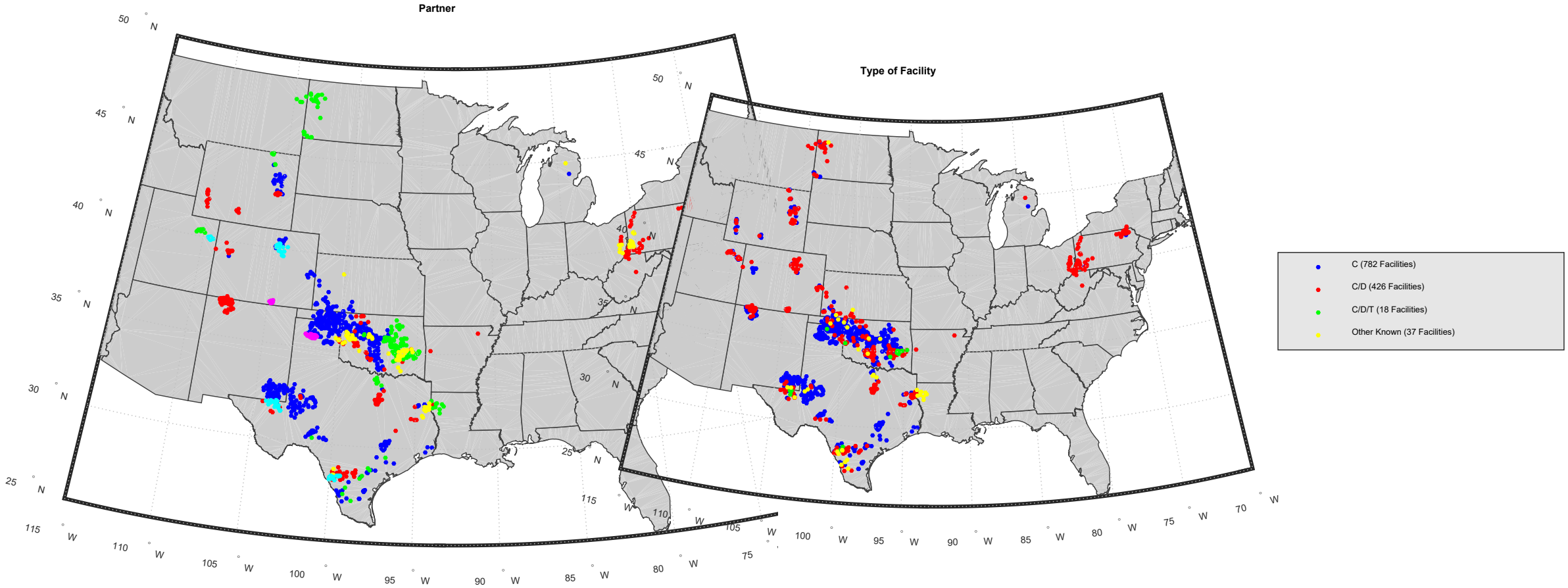
- Study design
- Compressor Station Results
- Pneumatics Long-duration Recordings
- Some notes about testing the Bacharach™ High Flow Sampler

Publications & Reports

- Full report & data at https://mountainscholar.org/handle/10217/195489
  - Final Report http://dx.doi.org/10.25675/10217/194544
  - Volume 1: Pneumatic measurements
    http://dx.doi.org/10.25675/10217/194543
    Luck, B., Zimmerle, D., Vaughn, T., Lauderdale, T., Keen, K., Harrison, M., Marchese, A., Williams, L., Allen, D., 2019. Multiday Measurements of Pneumatic Controller Emissions Reveal the Frequency of Abnormal Emissions Behavior at Natural Gas Gathering Stations. Environ. Sci. Technol. Lett. https://doi.org/10.1021/acs.estlett.9b00158
  - Volume 2: Engine exhaust measurements
    http://dx.doi.org/10.25675/10217/194542
    Paper in preparation; will be methods focused.
  - Volume 3: Emission factors & national model
    http://dx.doi.org/10.25675/10217/194541
    Paper in internal review, likely out early 2020

Study Design

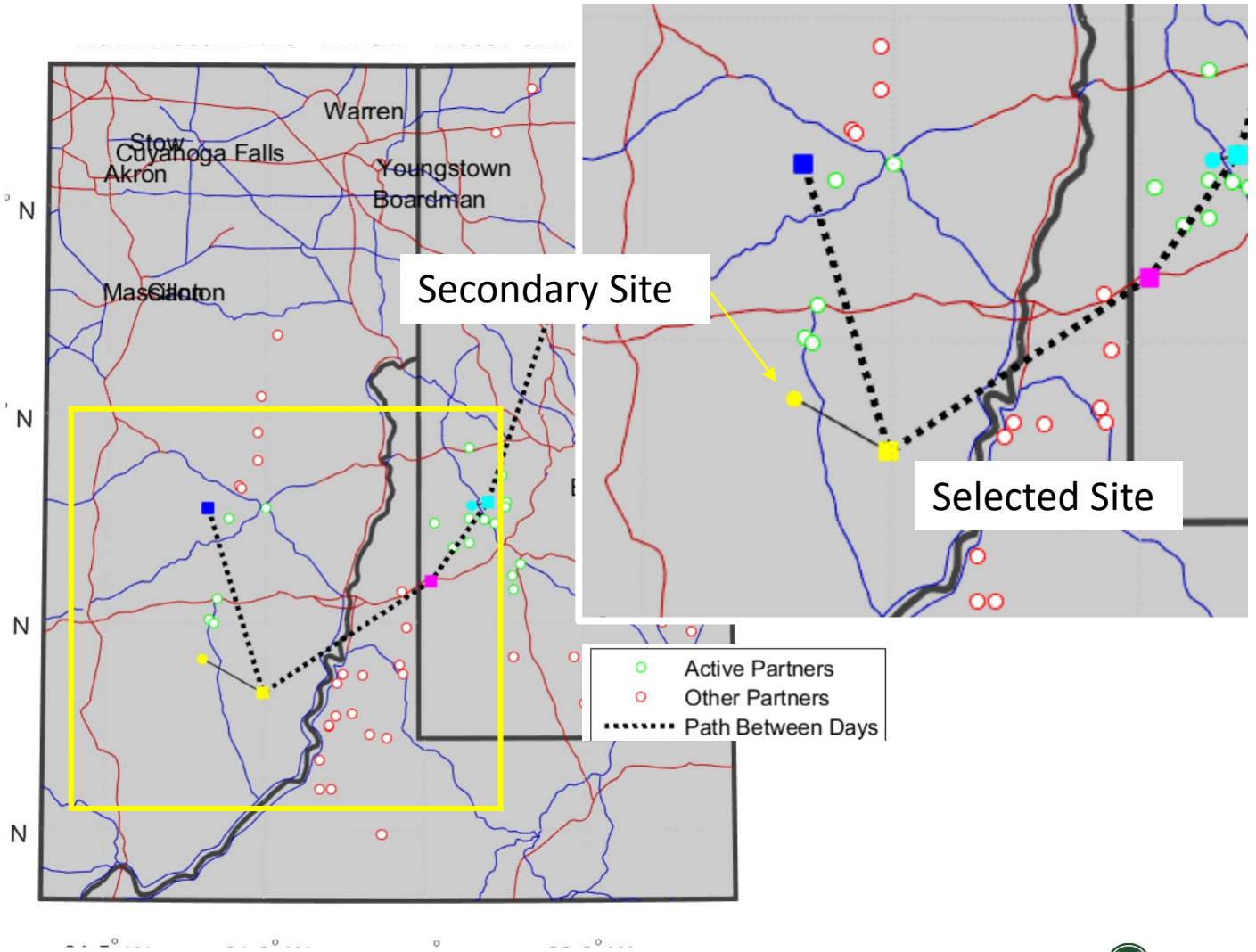
Sampling: Collected Data from Partners



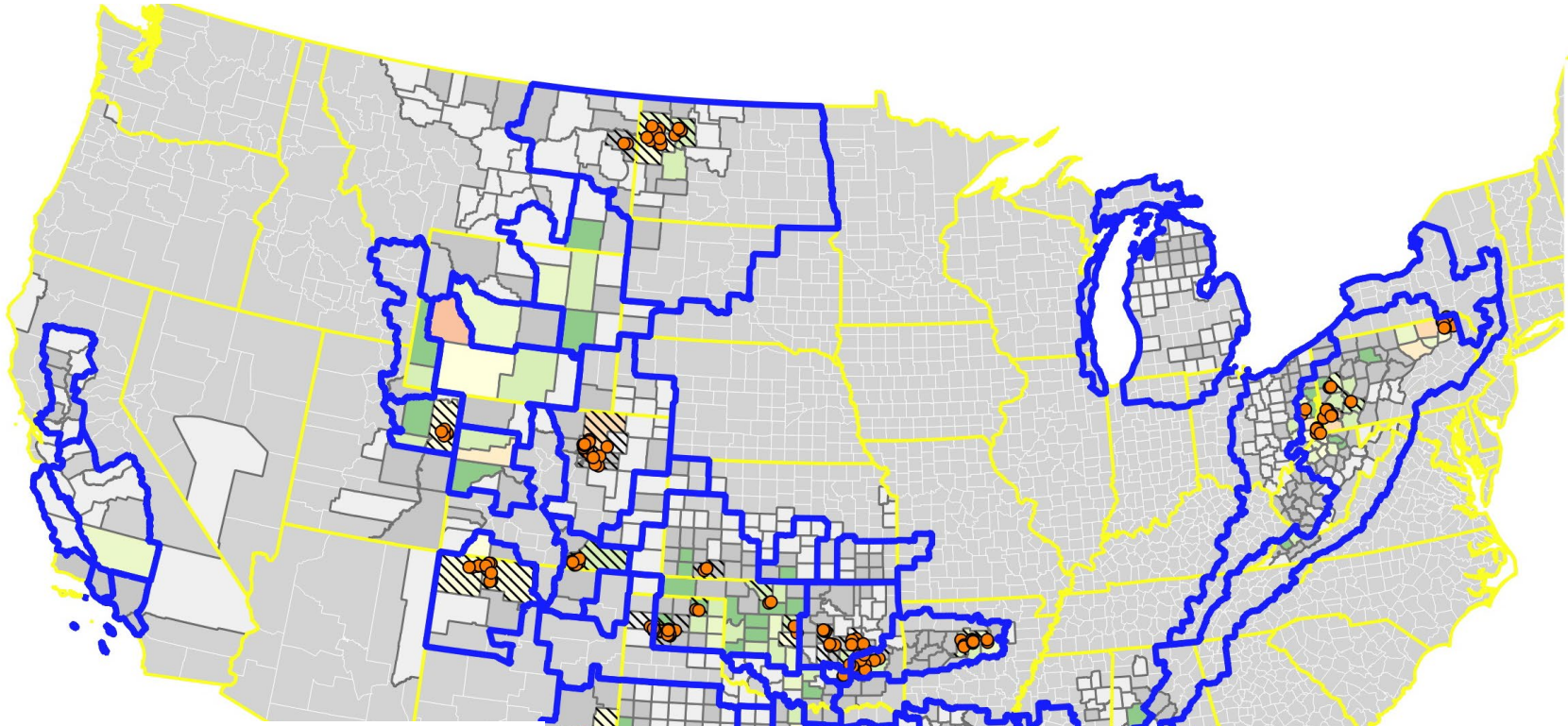
Early planning maps shown with data from 6 Partners

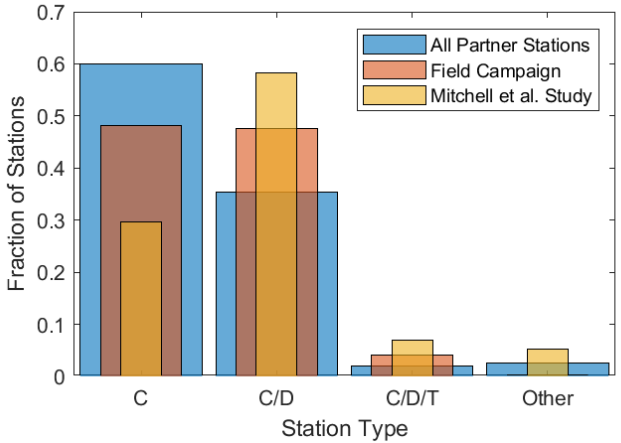
Geographically Clustered Sampling

- Select 1-2 partners for each week
- Randomly select 5 starting sites for each day
- Order geographically
- Identify sites nearby selected sites for each day



National





Legend

- Basins with GHGRP Facilities
- Field Measurement Locations
- Counties Sampled in Field Campaign
- State Boundaries

2016 County Gas Production (BCF)

- 0 - 1
- 1 - 25
- 25 - 50
- 50 - 100
- 100 - 200
- 200 - 400
- 400 - 600
- 600 - 800
- 800 - 1000
- 1000 - 1200
- 1200 - 1213
- No Gas Production

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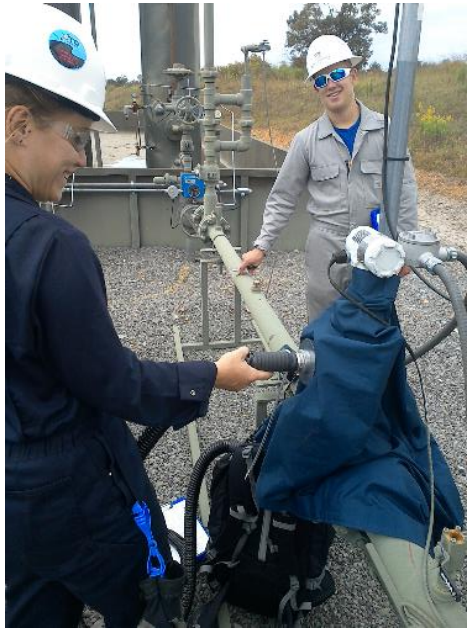
Methods

OGI Detection + Direct component measurements

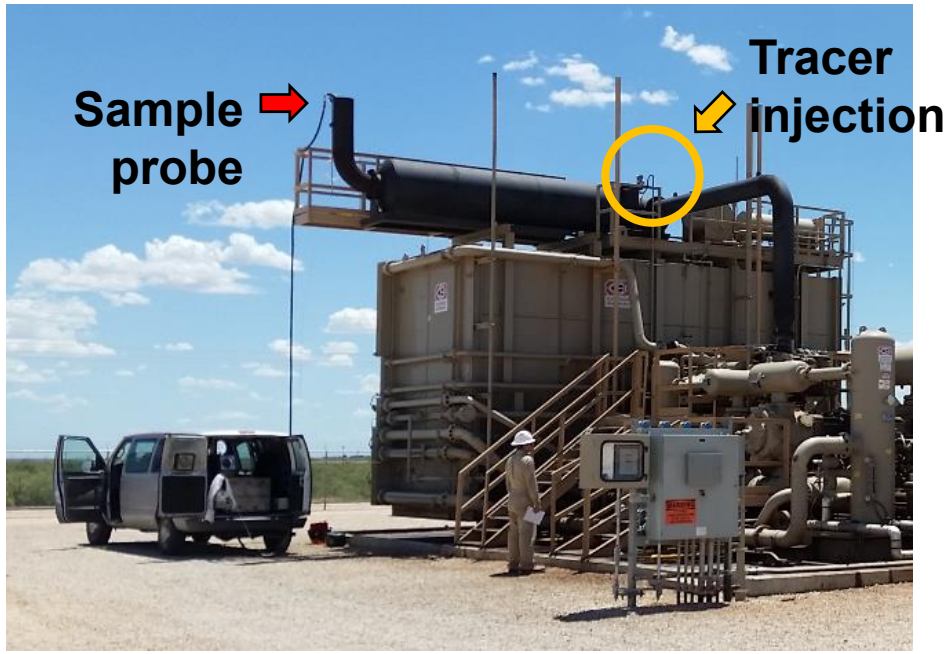


All teams

Long duration measurements of pneumatic controllers

Team 1
Extended field campaign

In-stack tracer measurements of exhaust emissions



Team 1

G&B Compressor Stations

Methods & Definitions

- A ‘station’ is all equipment on a G&B compressor station
  - Does not include co-located well pad equipment
- All major equipment units were recorded on every station visited
  - Yard piping was broken into several sub-sections at most stations
- All counting, screening and measurement was done on ‘units of major equipment’
  - A ‘measured unit’ was fully screened and fully measured
  - A ‘counted unit’ was fully counted
  - Not all measured units were counted and vice versa

Post Campaign Analysis

- Classification of all unmeasurable emissions

Measured 2 types – BHFS or bag	**Not measured but similar in observed size** 5 types	**Not measured & unusual size** 2 types – large emitter & incomplete capture	**Measured but no emission was detected** 1 type

- Correction for gas composition (see high flow discussion)
- Combined data from longitudinal study done by GSI Environmental
- Model for station and national emissions

QC Checks

Measurements when no emissions were detected

Table S3-8: Measurements where no Emissions were Detected with OGI

Measurement Location	Count of OGI Detections: No Emissions Measured	Count of OGI Detections: Non-Zero Emissions Measured)	Fraction Non-Zero
Blowdown Vent	68	0	0%
Common Multi-Unit Vent	2	0	0%
Common Single-Unit Vent	39	0	0%
Common Station Vent	1	0	0%
Connector Threaded	1	0	0%
OEL	1	0	0%
PRV	199	0	0%
Pocket Vent	1	0	0%
Rod Packing Vent	56	1	1.8%
Starter Vent	32	0	0%
Thief Hatch	25	0	0%
Valve	3	0	0%
Total	428	1	0.23%

Zero measurements when emissions were detected

Table S3-9: OGI Detections with Zero Measurements

Measurement Location	Total Measurements	Number of Zero Measurements	Zero Fraction
Compressor Blowdown Vent	29	2	6.9%
Compressor Common Multi-Unit Vent	**13**	**2**	**15%**
Compressor Common Single-Unit Vent	23	0	0%
Compressor Connector Flanged	39	2	5.1%
Compressor Connector Threaded	98	9	9.2%
Non-compressor Pump	11	0	0%
Non-compressor Regulator	37	3	8.1%
Non-compressor Valve	**86**	**22**	**26%**
Tank Common Multi-Unit Vent	14	0	0%
Tank Common Single-Unit Vent	**42**	**5**	**12%**
Tank Thief Hatch	65	2	3.1%
Total	1133	88	7.8%

Leaker Emission Factors

Table S3-23: Component Leaker Factor Comparison

Component[1]	Emission Factor (scfh whole gas)	GHGRP[2] Emission Factor	Ratio Study to GHGRP	Transmission[3] Emission Factor	Ratio Study to Transmission
All OEL	5.58 [+67%/-51%]	2.8	1.99	143 [+1093%/-100%]	0.044 [0.016 to 0.1]
All Other	24 [+67%/-49%]			22.6 [+1218%/-97%]	1.1 [0.43 to 2.5]
Comp Blowdown Vent	21.3 [+150%/-70%]			76.4 [+546%/-100%]	0.15 [0.066 to 0.28]
Comp Conn. Flange	12.2 [+57%/-40%]	4.1	2.98	21.2 [+465%/-100%]	0.77 [0.21 to 2]
NC Conn. Flange	7.88 [+42%/-36%]	4.1	1.92	9.87 [+491%/-99%]	0.84 [0.47 to 1.4]
Comp Conn. Thread	14.5 [+52%/-38%]	1.3	11.2	21.2 [+465%/-100%]	0.64 [0.19 to 1.5]
NC Conn. Thread	5.77 [+31%/-28%]	1.3	4.44	12 [+368%/-100%]	0.5 [0.29 to 0.78]
Comp PRV	21.2 [+82%/-57%]	4.5	4.71	22.6 [+1218%/-97%]	0.8 [0.29 to 1.8]
NC PRV	10.8 [+123%/-80%]	4.5	2.41	22.6 [+1218%/-97%]	0.53 [0.092 to 1.4]
Comp Reg.	13.9 [+38%/-32%]	4.5	3.09		
NC Reg.	8.01 [+33%/-30%]	4.5	1.78		
Comp Rod Packing Vent	28.2 [+37%/-24%]			219 [+728%/-100%]	0.12 [0.059 to 0.23]
Comp Valve	41.1 [+109%/-64%]	4.9	8.39	12.2 [+613%/-95%]	3.3 [0.91 to 8.2]
NC Valve	7.89 [+46%/-37%]	4.9	1.61	12 [+368%/-100%]	0.68 [0.38 to 1.1]

[1] Abbreviations: "Comp" = Compressor service; "NC" = non-compressor service; "Conn." = connector; "Reg." = regulator.

Does not include estimates for detected 'large emitters'

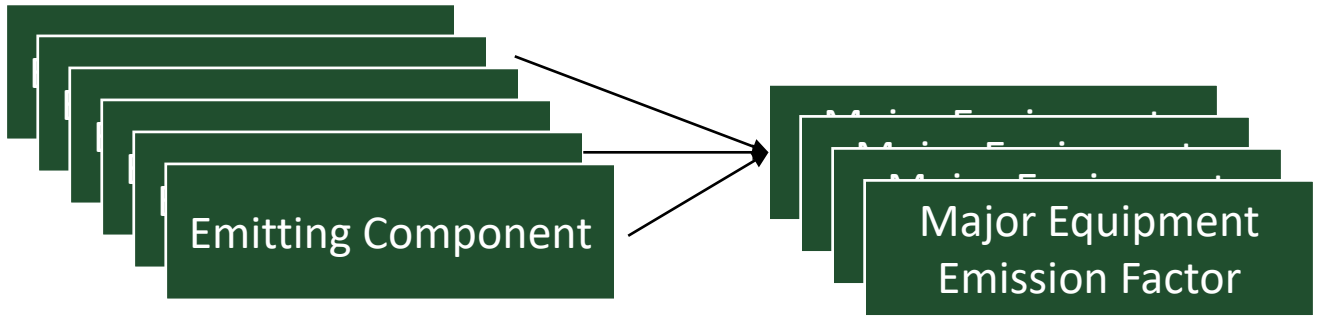
Average (Population) Emission Factors

Table S3-28: Comparison of Whole Gas Average Emission Factors to GHGRP Factors

Category	Emission Factor (scfh)	Eastern Region		Western Region	
		GHGRP EF (scfh)	Ratio of Study to GHGRP EF	GHGRP EF (scfh)	Ratio of Study to GHGRP EF
Compressor Connector Flanged	0.0186 [+25%/-14%]	0.003	6.28 [4.65 to 8.53]	0.017	1.1 [0.902 to 1.4]
Non-compressor Connector Flanged	0.0213 [+17%/-14%]	0.003	7.2 [5.41 to 9.47]	0.017	1.26 [1.04 to 1.5]
Compressor Connector Threaded	0.0308 [+31%/-20%]	0.003	10.4 [7.45 to 14.7]	0.017	1.82 [1.42 to 2.43]
Non-compressor Connector Threaded	0.0127 [+12%/-11%]	0.003	4.3 [3.28 to 5.54]	0.017	0.75 [0.639 to 0.878]
Compressor PRV	0.54 [+44%/-25%]	0.04	17.4 [5.21 to 42.8]	0.193	2.93 [1.63 to 4.95]
Non-compressor PRV	0.279 [+50%/-22%]	0.04	9.01 [2.82 to 22.5]	0.193	1.52 [0.871 to 2.64]
Compressor Valve	0.169 [+38%/-18%]	0.027	6.46 [4.27 to 9.78]	0.121	1.4 [1.1 to 1.95]
Non-compressor Valve	0.091 [+28%/-23%]	0.027	3.48 [2.21 to 5.16]	0.121	0.755 [0.564 to 0.991]
Compressor Rod Packing Vent	27.7 [+25%/-11%]	1.3	21.8 [15.2 to 30.8]	1.3	21.9 [15.3 to 31.2]
All OEL	0.294 [+30%/-21%]	0.061	5.32 [2.6 to 9.76]	0.031	9.92 [6.03 to 15.6]
Compressor Rod Packing Vent (OP)	25.2 [+25%/-11%]	1.3	19.8 [13.9 to 28.3]	1.3	19.8 [13.9 to 28.1]
Compressor Rod Packing Vent (NOP)	1.14 [+39%/-28%]	1.3	0.895 [0.556 to 1.37]	1.3	0.895 [0.558 to 1.4]
Compressor Rod Packing Vent (NOD)	0.15 [+18%/-20%]	1.3	0.119 [0.0814 to 0.165]	1.3	0.118 [0.0807 to 0.167]

Does not include estimates for detected ‘large emitters’

Major Equipment Emission Factors



- For all detected emissions:

Measured 2 types – BHFS or bag	**Not measured but similar in observed size** 5 types	**Not measured & unusual size** 2 types – large emitter & incomplete capture	**Measured but no emission was detected** 1 type
Use Measurement	*Draw from leaker distribution for component type*	*Simulate emissions (see report)*	*Draw from LDL estimate for high flow sampler*

Includes all detected emissions

Major Equipment Emission Factors

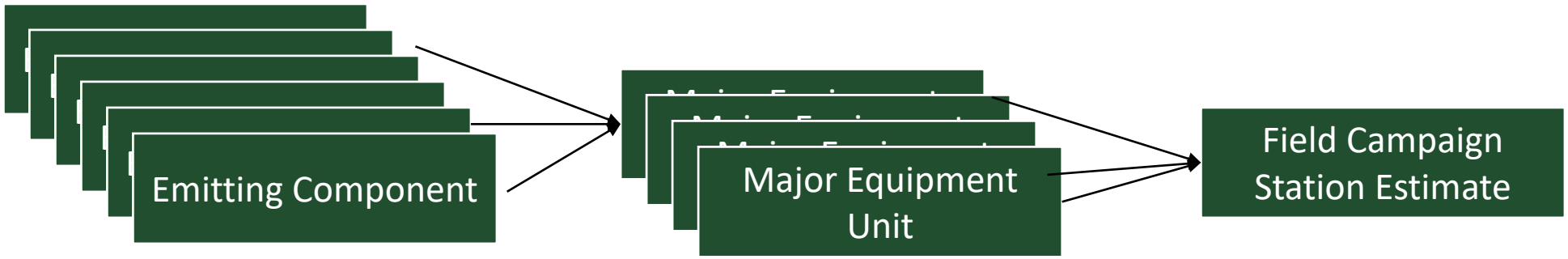
Table S3-40: Major Equipment Factor Comparison

Component[1]	Emission Factor (scfh whole gas)	GHGI[2] Emission Factor	Ratio Study to GHGI	GHGRP East[3] Emission Factor	Mean Ratio Study to GHGRP East	GHGRP West[3] Emission Factor	Mean Ratio Study to GHGRP West
AGRU	4.04 [+451%/-95%]						
Compressor	110 [+542%/-100%]	14.5	7.58	0.5	220	12.7	8.63
Dehydrator	3.41 [+894%/-94%]	3.41	1	1.11	3.07	4.87	0.7
Separator	0.647 [+1188%/-68%]	2.84	0.228	0.05	12.9	6.49	0.0998
Tank	39.3 [+560%/-99%]						
YardPiping	86.3 [+190%/-100%]	1.5	57.5	0.46	188	2.78	31

[1] Abbreviations: "Comp" = Compressor; "AGRU" = Acid gas removal unit;

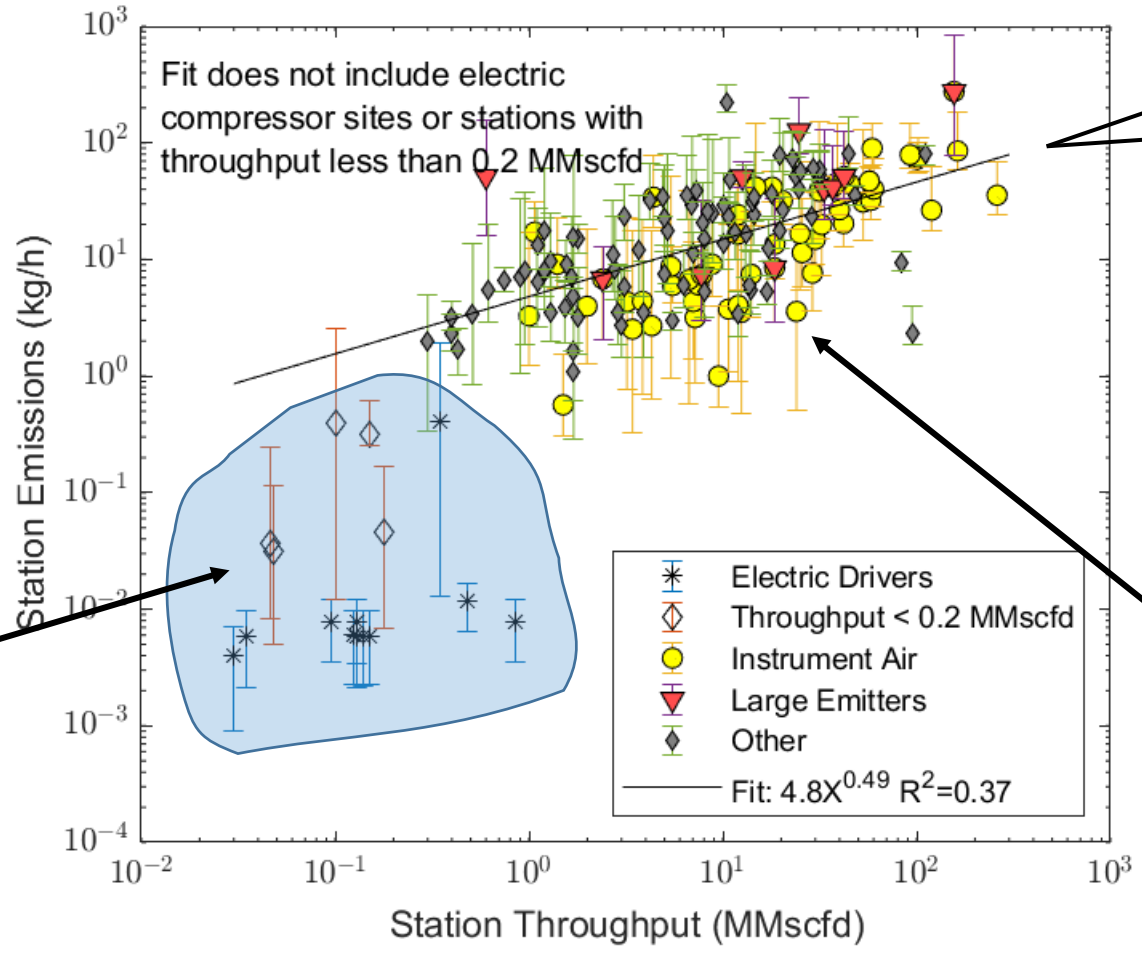
- Includes estimates for detected 'large emitters'
- Definition of 'yard piping' includes all equipment not in other equipment categories

Station Estimates



- If unit was screened & measured, use:
  - Measurements + simulated emissions for all ‘detected but unmeasured’
- If unit was not screened and/or measured:
  - Draw from major equipment emission factors

Station Measurements



$\sqrt{2}$ factor seen in other studies

Both throughput & emissions correlate to number of engines running

Small / Low Emissions
Not seen in prior G&P study

Instrument air lowers emissions … but effect is not statistically significant when mixed with other emissions sources

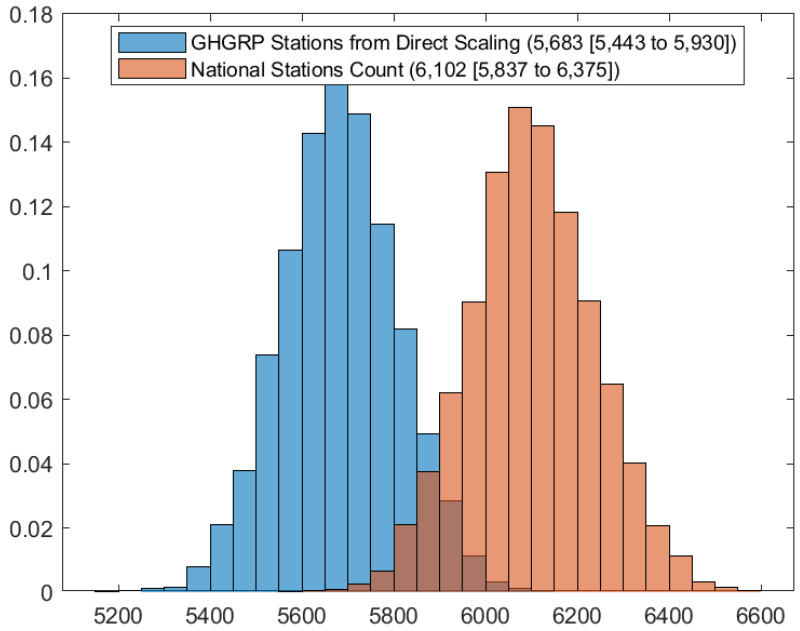
National Emissions

GHGRP Equipment Counts × Major Equipment Emission Factors

+

Estimated Station & Separator Counts × Yard Piping & Separator EFs

× Scaling for non-reporting operations = National Estimate



Simplified, see report

National Estimate

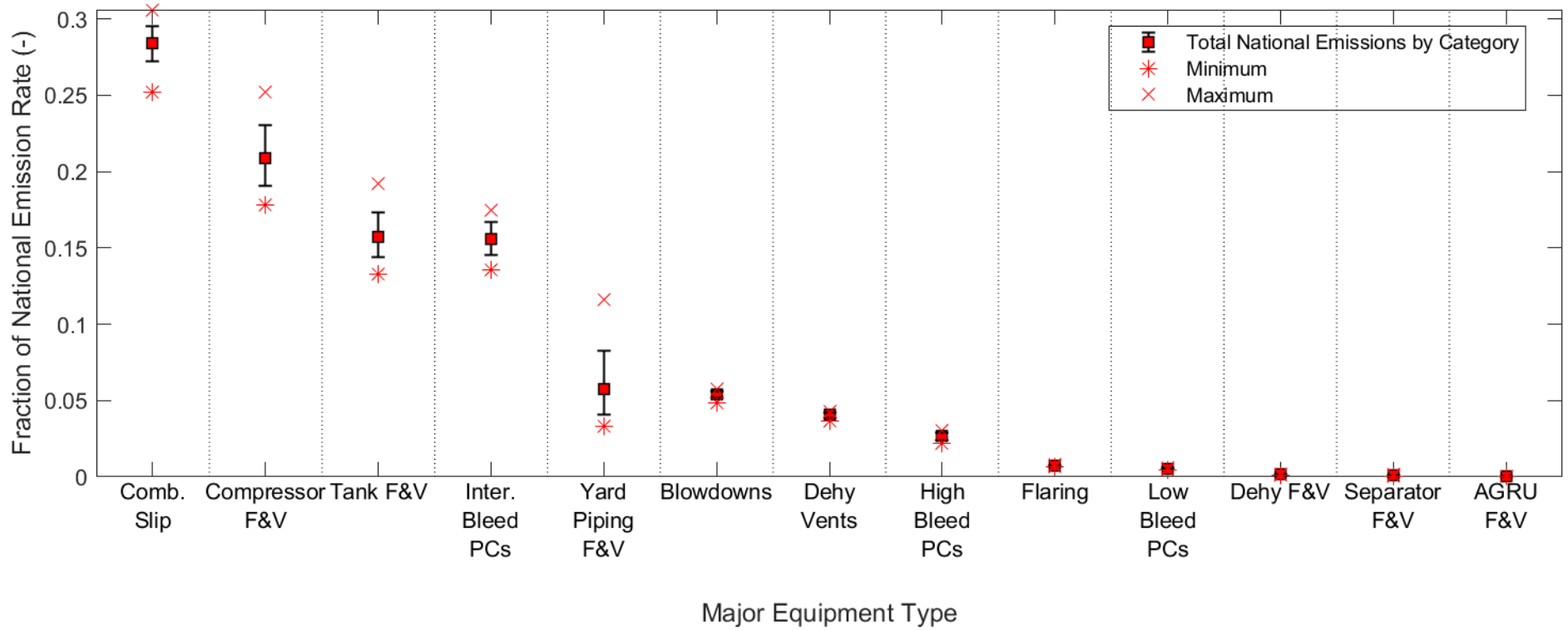
Table 10: National and Station Summary of Emissions

Estimate	Total Methane Emissions ($Gg \cdot y^{-1} CH_4$)	Activity Factor (Stations)	Emission Factor ($kg \cdot h^{-1} station^{-1} CH_4$)
National Estimate & Comparison			
Marchese et. al [4]	1697 [1,512 to 1,886]	4,459 [3,756 to 5,380]	42.6 [34.6 to 52.6]
EPA GHGI[9]	1,955.1	5,241	42.6*
This Study	1,286 [1,241 to 1,338]	6,102 [5,837 to 6,375]	24.1 [22.8 to 25.5]
Study Field Campaign Comparison+			
Mitchell et. al [3]		115	55.4 [40.9 to 72.7]
Study Field Campaign		180	24.3 [18.5 to 31.8]

* Current GHGI estimate for G&B uses the Marchese et al. emission factor.

+ Comparison of field campaign results does not include episodic emissions, which were not measured in either field campaign.

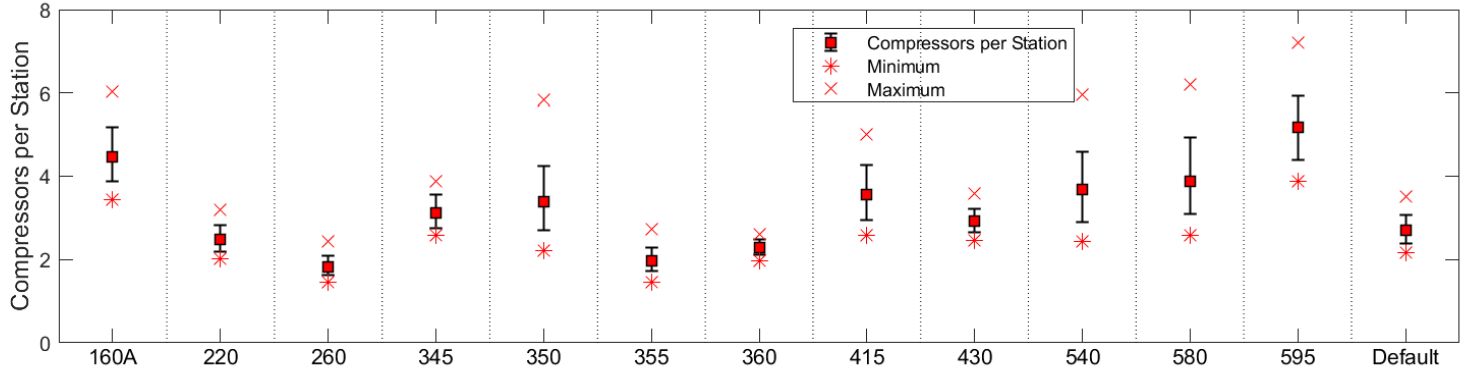
Fraction of Emissions by Category



Factors Behind Change

- Estimate more, smaller, facilities
  - Based upon partner data from >1700 facilities
  - Estimates vary substantially between AAPG basins
- Mix of compressor drivers different *by basin* differs from prior studies
- Been lots of attention on NG emissions over last five years

More analysis in forthcoming paper



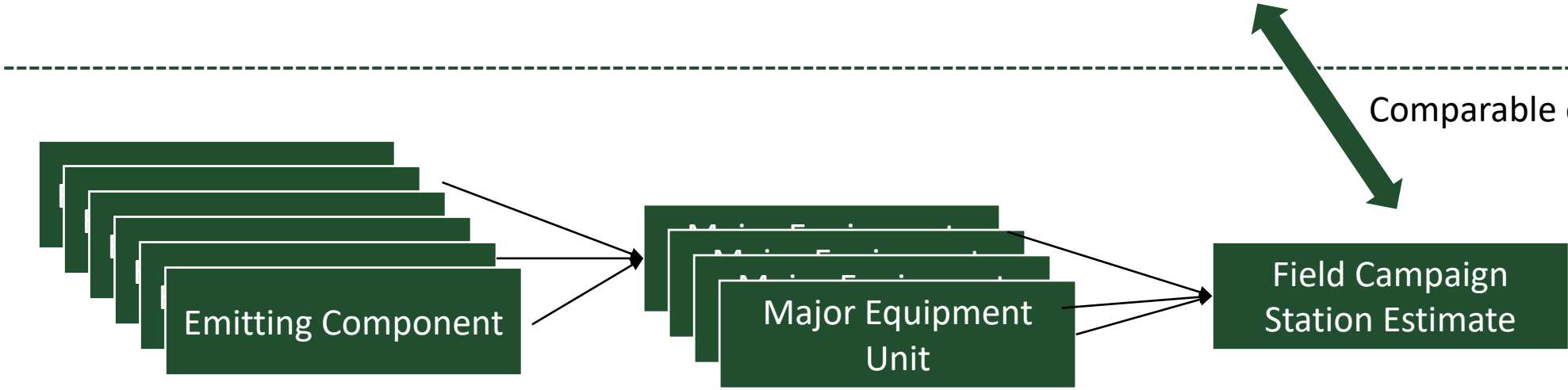
AAPG Province ID

	160A	220	260	345	350	355	360	415	430	540	580	595	Default
Compressors	482	418	273	458	140	201	1,002	145	581	119	217	101	487
Stations	108	169	151	145	42	101	439	41	200	33	57	20	181

Two Estimates of Station Emissions

GHGRP Equipment Counts × Major Equipment Emission Factors × Scaling for non-reporting operations = National Estimate

National Estimate ÷ Estimated National Station Count = Per Station Emissions



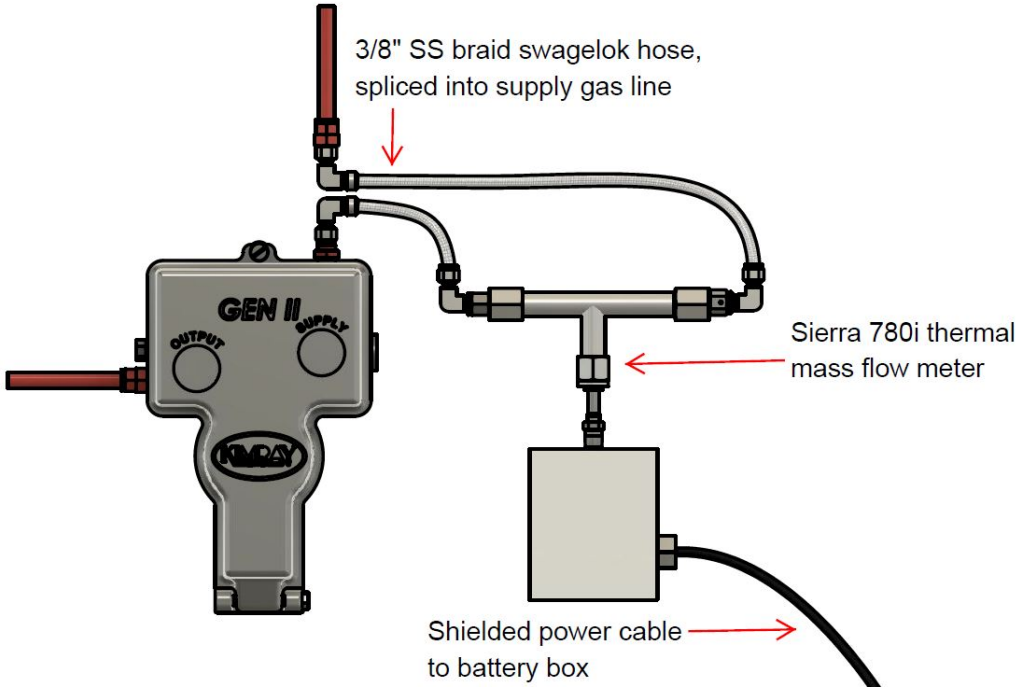
National Estimate: What's Missing?

- Some estimates for Alaska
- Engine crankcase vents
- Direct measurements for blowdowns, flares and certain vents

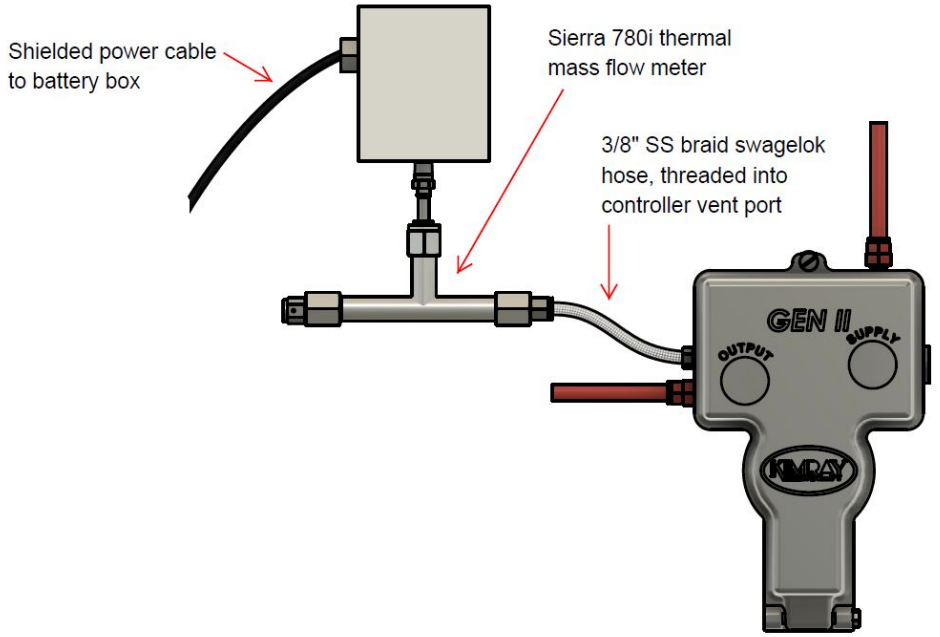
Pneumatic Results

Luck, B., Zimmerle, D., Vaughn, T., Lauderdale, T., Keen, K., Harrison, M., Marchese, A., Williams, L., Allen, D., 2019. Multiday Measurements of Pneumatic Controller Emissions Reveal the Frequency of Abnormal Emissions Behavior at Natural Gas Gathering Stations. Environ. Sci. Technol. Lett. https://doi.org/10.1021/acs.estlett.9b00158

Pneumatic Monitoring Installs

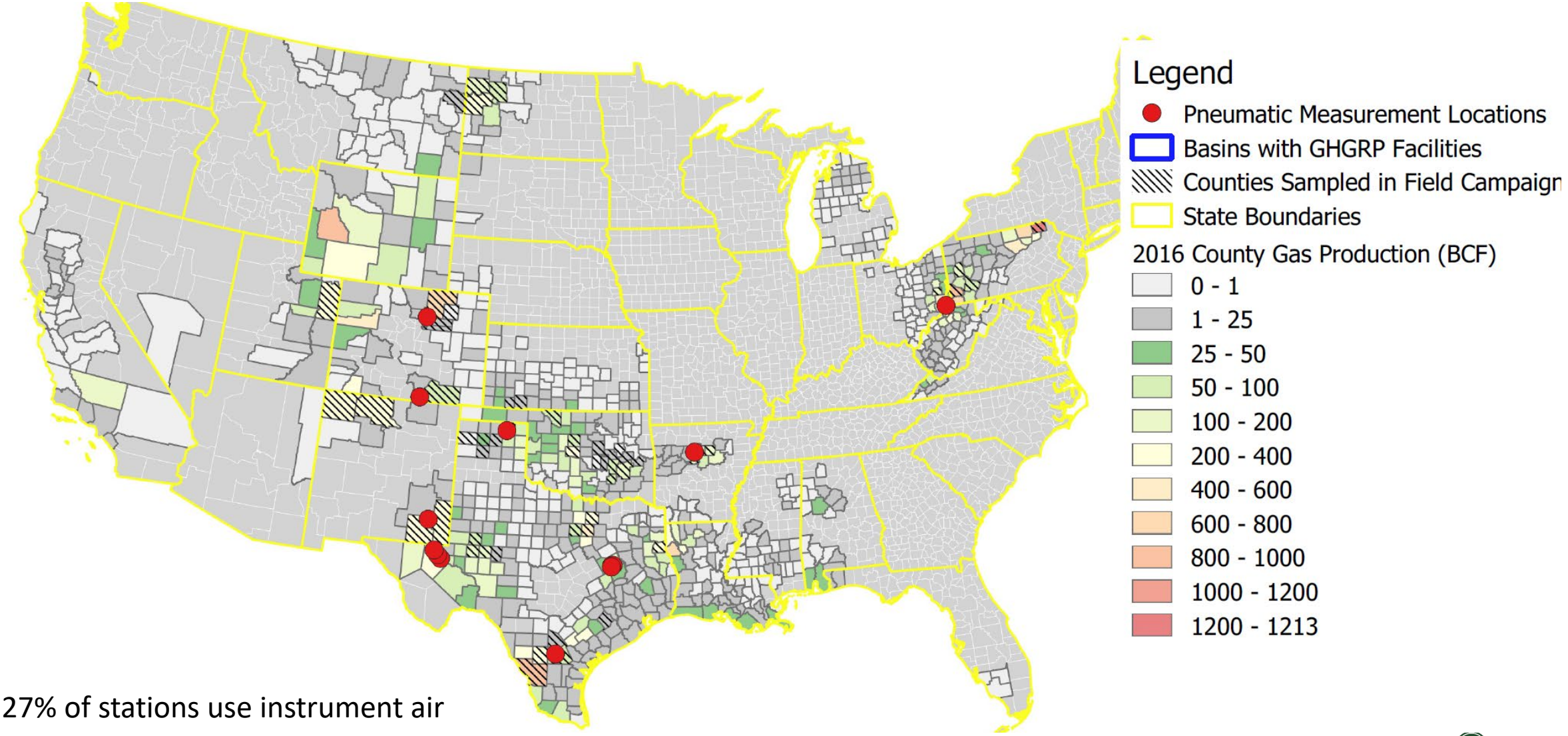


Inline



On exhaust port

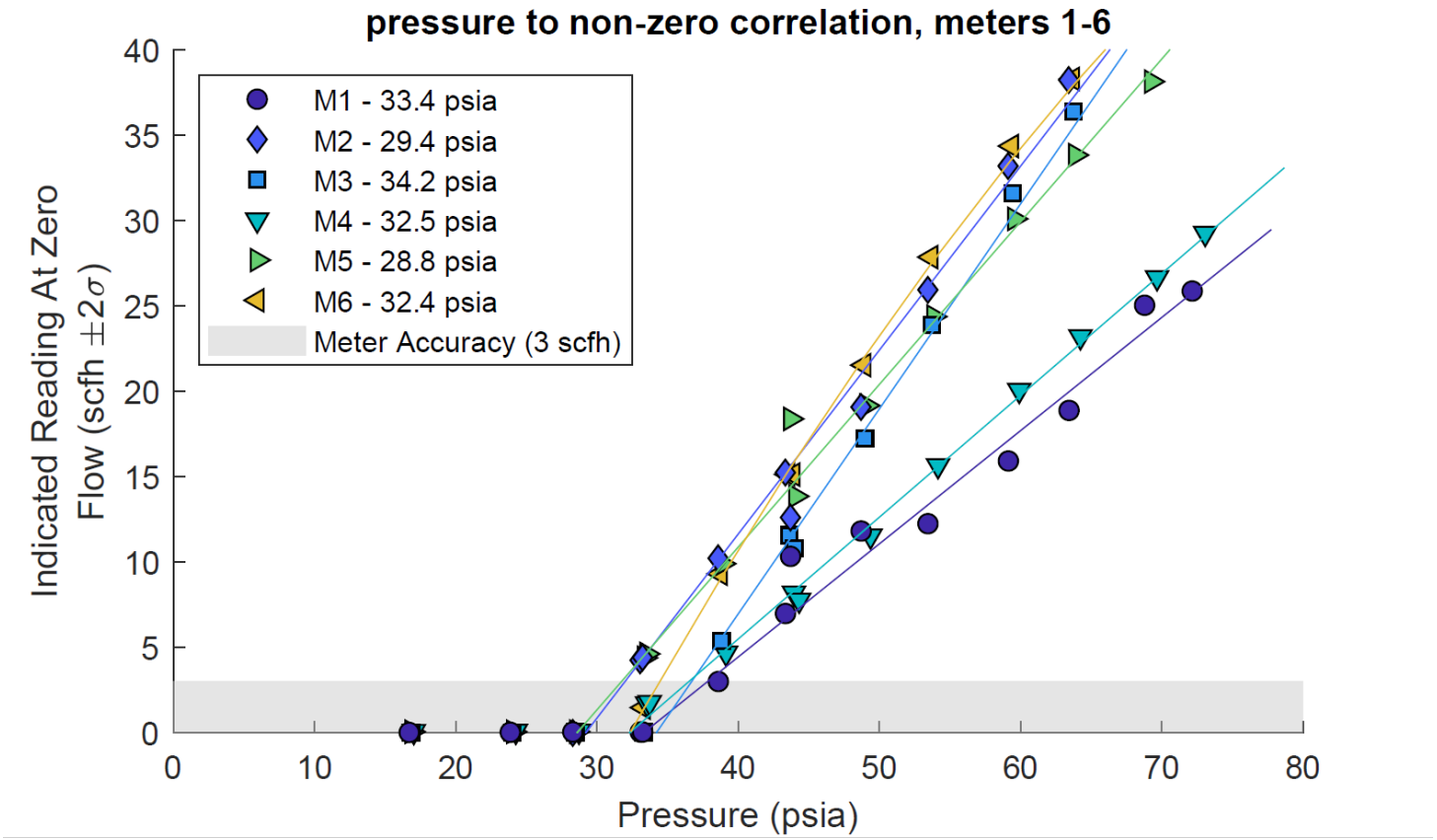
Where Pneumatic Measurements were Taken



27% of stations use instrument air

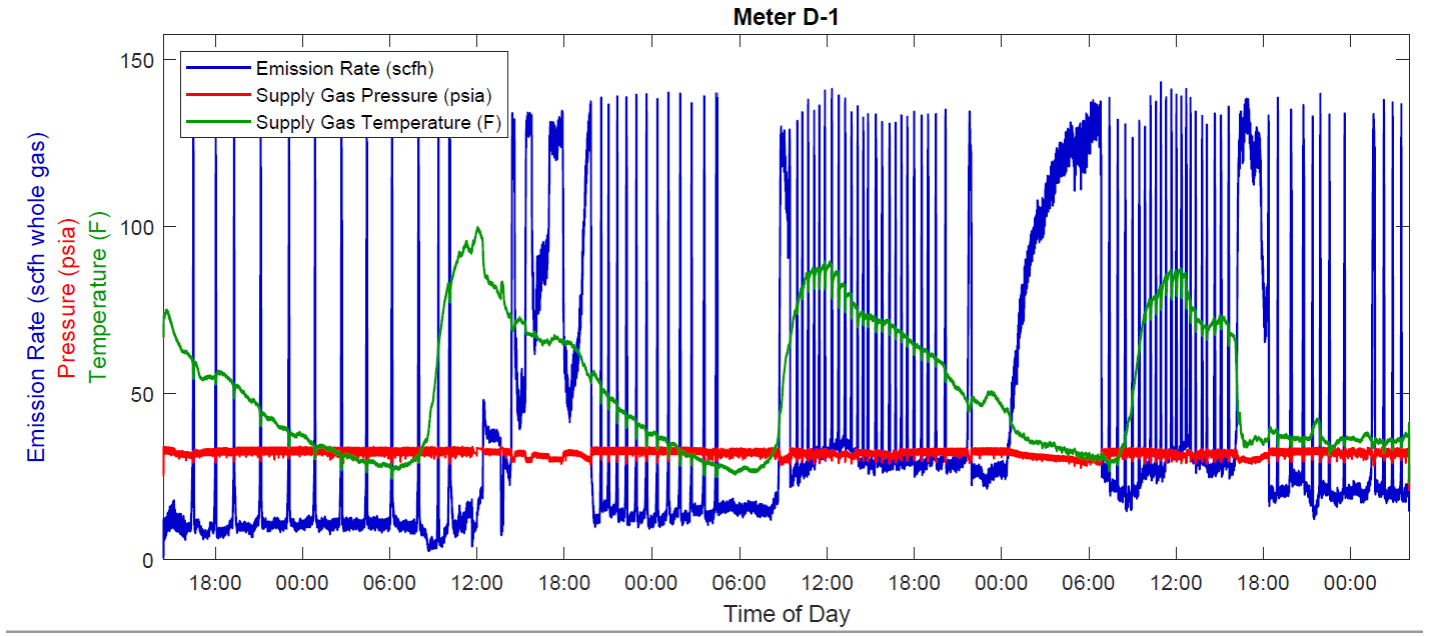
Calibration Problems

- Meters indicated flow when none was present
- Problem only above 30 psia supply pressure
- Makes difficult to distinguish small flows from meter errors



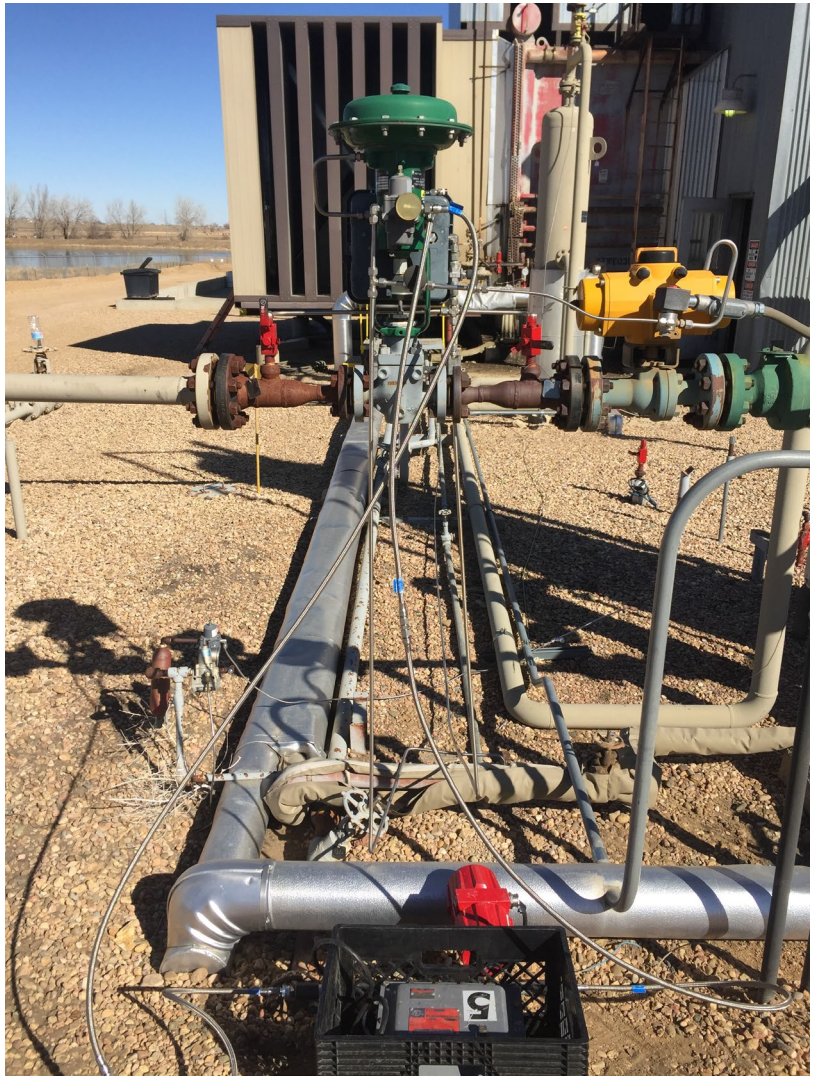
Data Collected

- 72 successful measurements
  - 40 intermittent
  - 24 low bleed
  - 8 high bleed
- Average duration of 76 hours

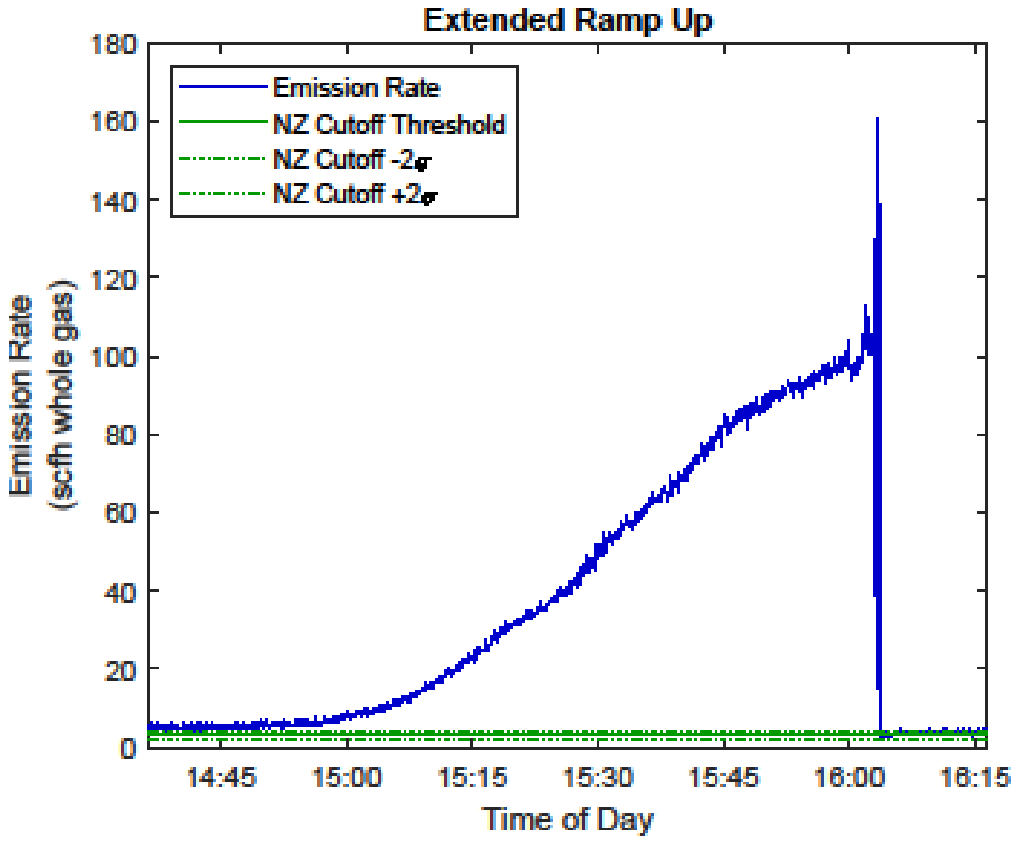


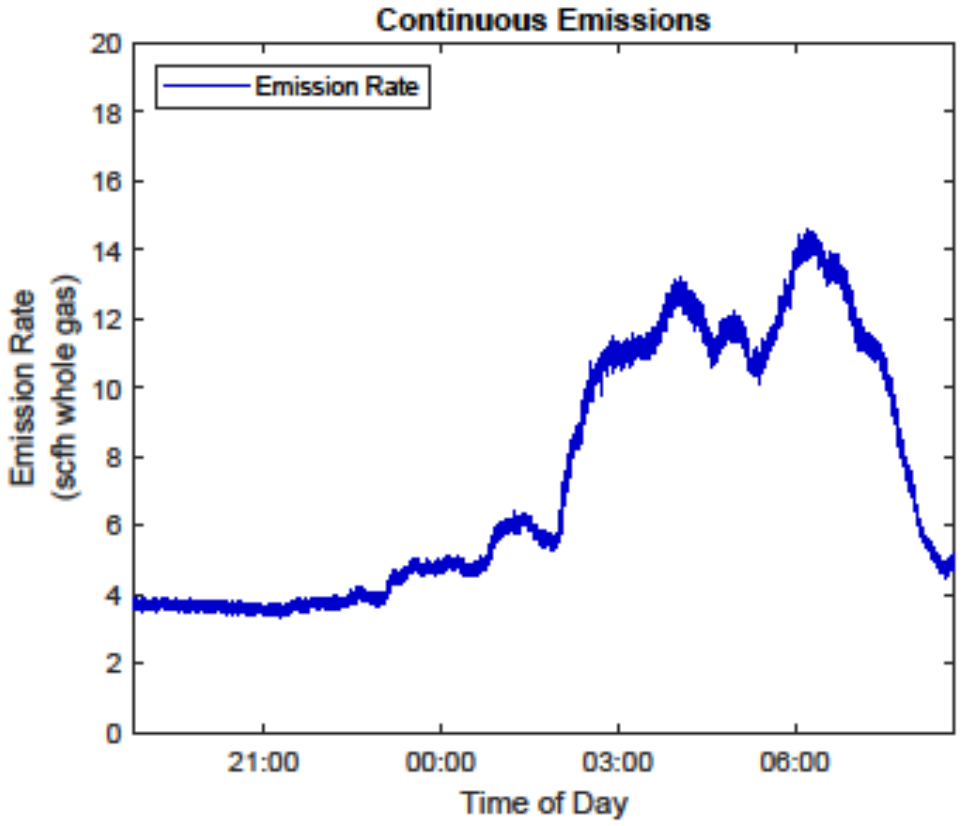
Fault Observations

- Definitions:
  - Low bleed: Normally operating if their average emission rates were ≤ 6 scfh.
  - High bleed: normally operating if average emission rates consistent with their published steady state gas consumption values
  - Intermittent: identified four failure behaviors
- Refers to emissions behavior only
- Determined by expert panel from API, industry members, study team

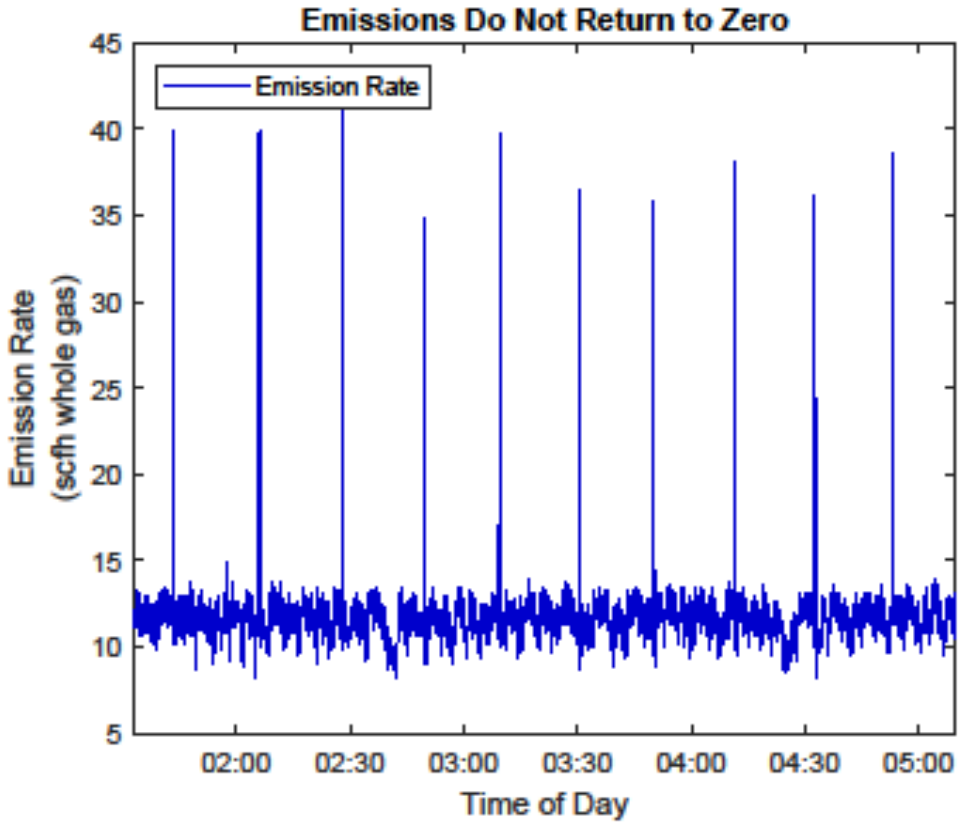


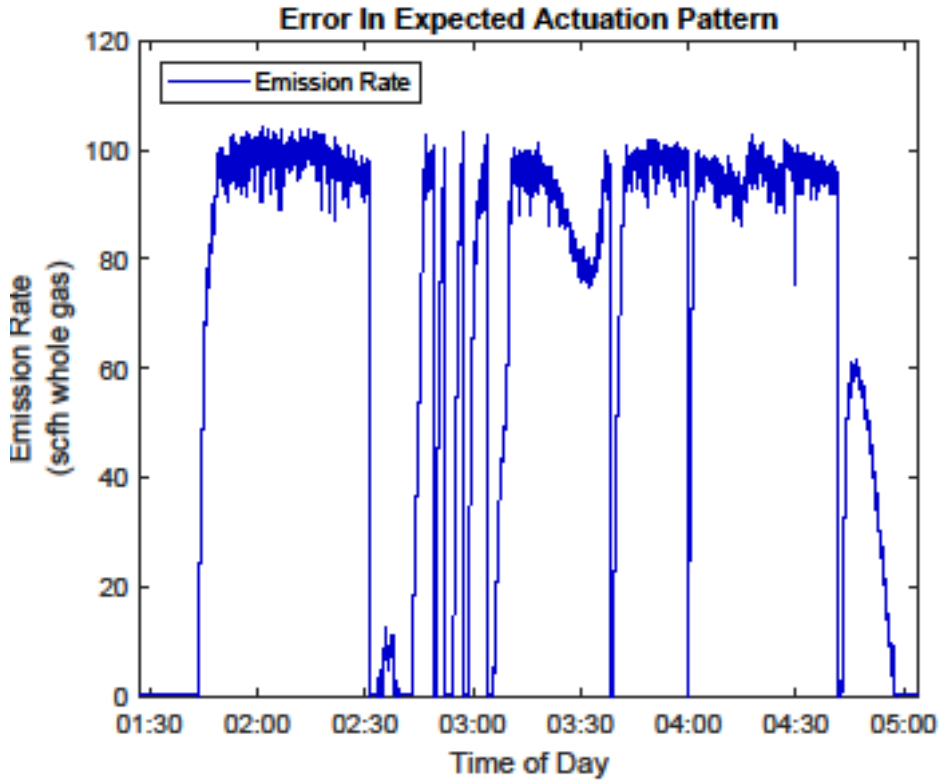
Intermittent PC Abnormal Op. Modes





Intermittent PC Abnormal Op. Modes





Results

Individual Controllers could have multiple error types

Table S1-2: Classification of abnormally operations for intermittent PCs

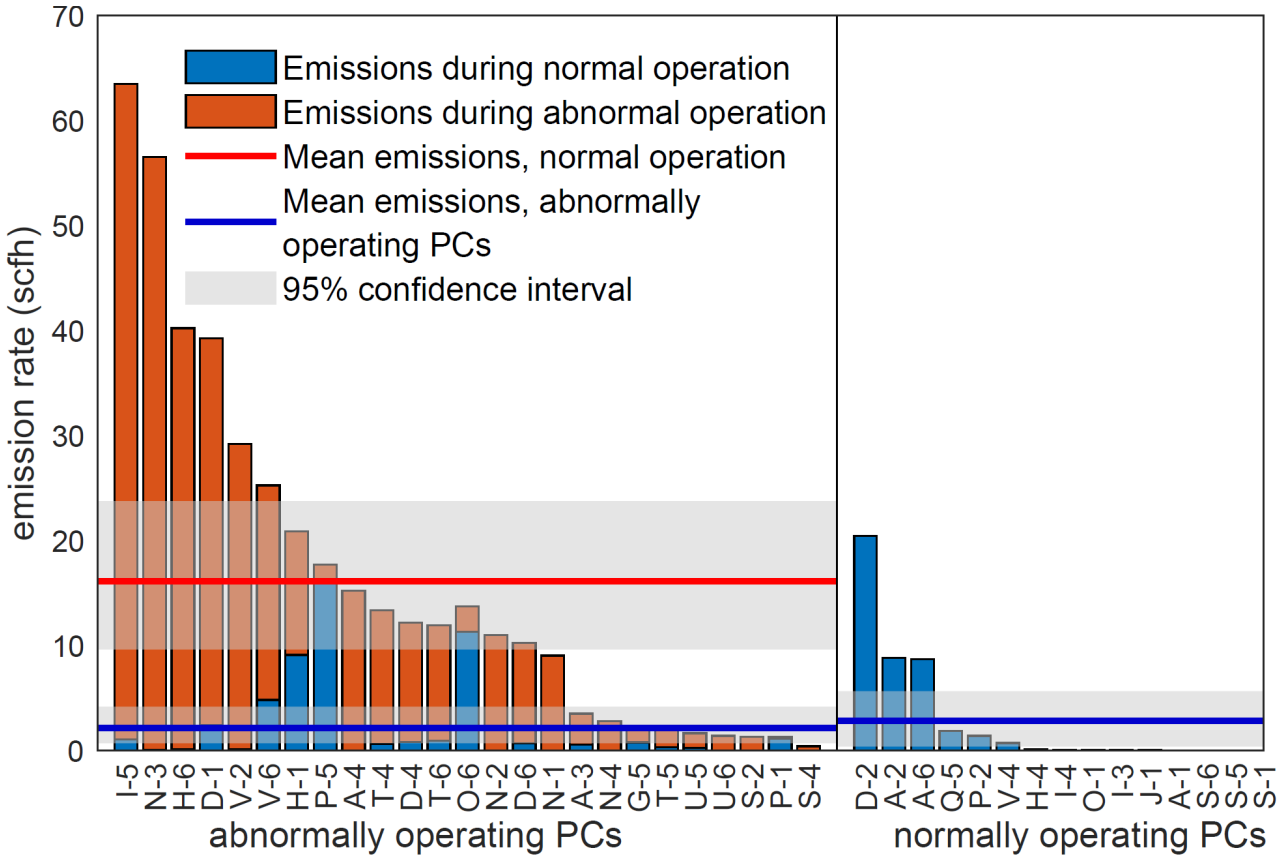
Recording ID	Continuous Emissions	Extended Ramp	Does Not Return to Zero Between Actuations	Irregular Behavior	Total AO Classifications
A-3			✓		1
A-4	✓				1
D-1	✓	✓	✓	✓	4
D-4	✓		✓	✓	3
D-6			✓	✓	2
T-5		✓			1
T-6		✓		✓	2
U-5		✓			1
U-6		✓			1
V-2	✓			✓	2
V-6	✓	✓	✓		3
Fraction Impacted	48%	40%	24%	58%	

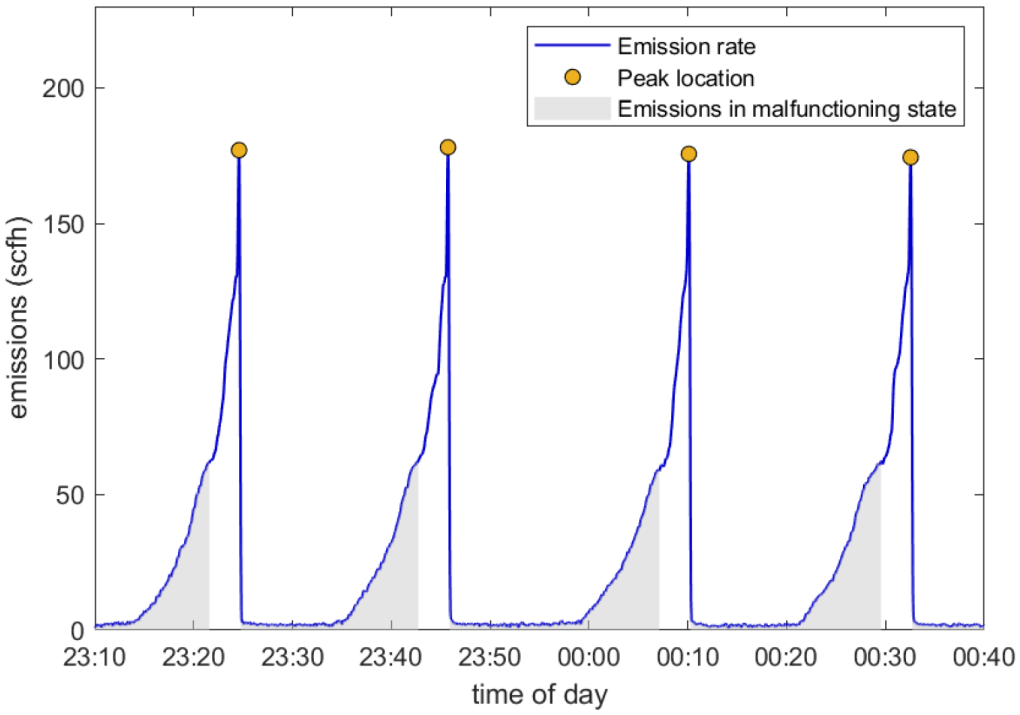
Table 1. Average Emission Rates for Normally and Abnormally Operating PCs

	no. of samples		average emissions (scfh whole gas)	
pneumatic controller type	total	exhibiting abnormal behavior[a]	normally operating	behaving abnormally[a]
intermittent	40	25	2.82 [+3.23/−2.41]	16.11 [+7.88/−6.35]
low-bleed	24	5	0.68 [+0.50/−0.42]	34 [+20.81/−19.78]
high-bleed	8	0	19.25 [+13.55/−10.26]	–[b]
total	72	30	4.98 [+3.49/−2.95]	19.09 [+7.61/−6.80]

[a]An expert panel identified abnormal emissions behavior from the pneumatic controller. [b]No high-bleed PCs were assigned as malfunctioning.

Intermittent PCs Emission Rates

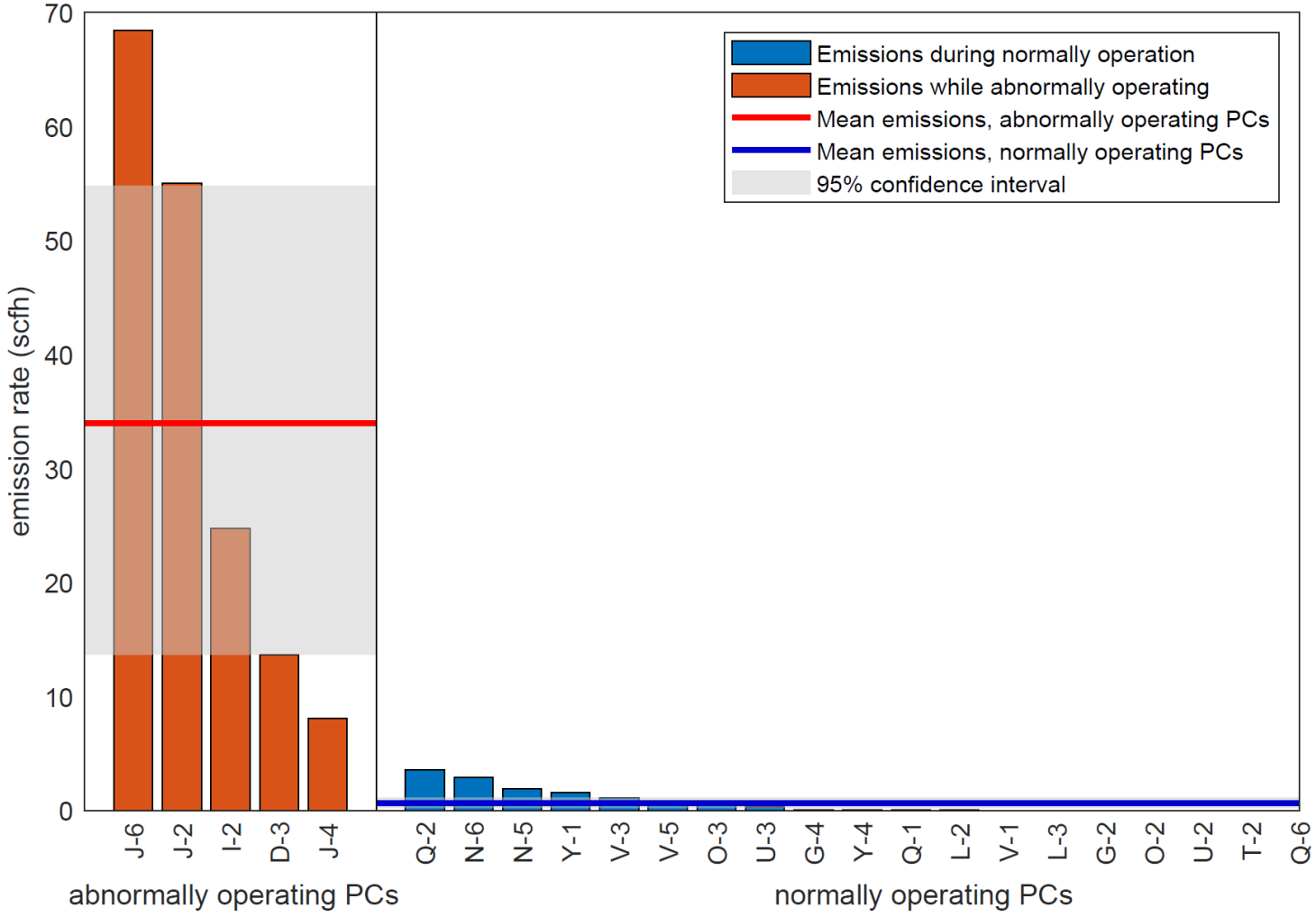




Example of classified emissions

Low Bleed PC Emission Rates

- Abnormal = average emissions > 6 scfh



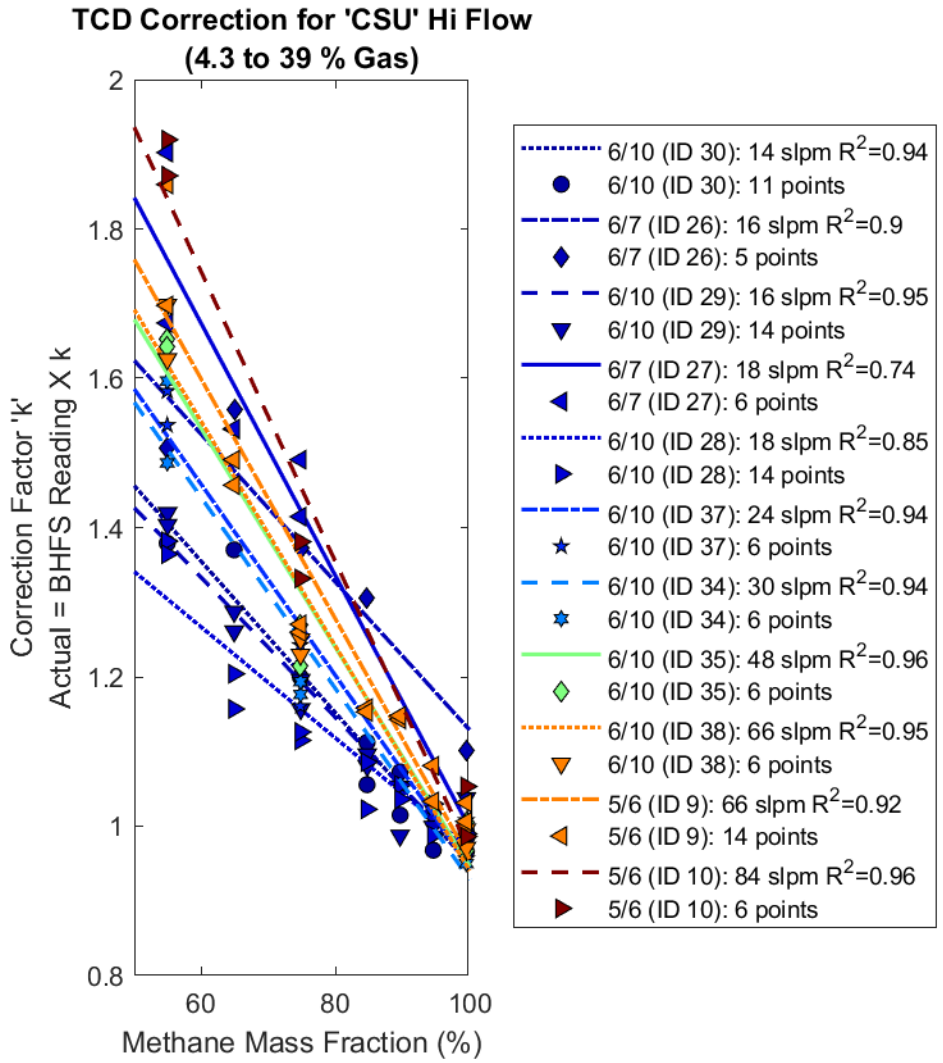
Notes from High Flow Testing

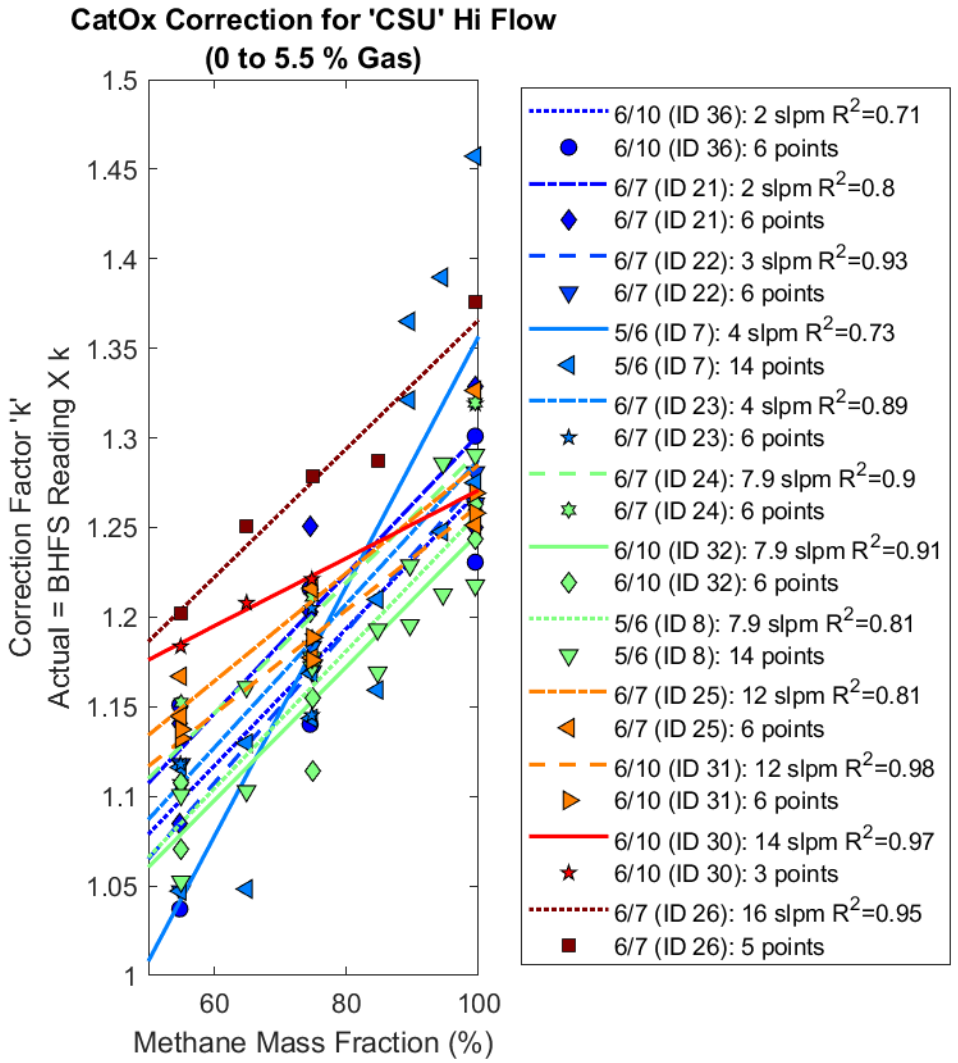
Testing @ METEC

- Post campaign
- 3 high flow units used in field (out of six)
- Using knowledge from Connelly et al. testing (tested only sensor & software)
- Full-function test
  - Metered emission rate 50-100% methane
  - Fed through entire instrument, as in field
  - Assure 100% capture

Connolly, J.I., Robinson, R.A., Gardiner, T.D., 2019. Assessment of the Bacharach Hi Flow® Sampler characteristics and potential failure modes when measuring methane emissions. Measurement 145, 226–233. https://doi.org/10.1016/j.measurement.2019.05.055

Sample measurement data:





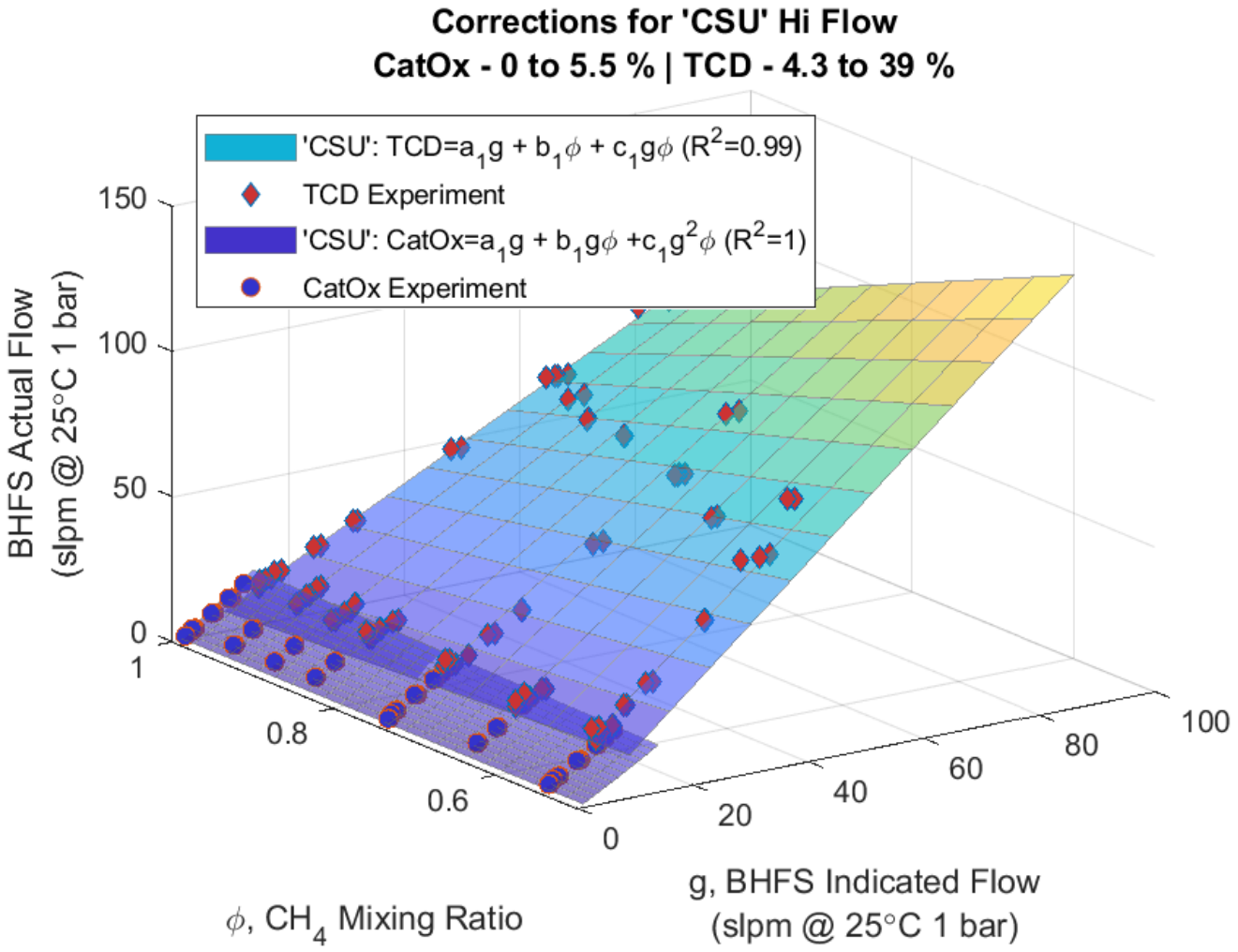
Observations

- Testing performed in sets – each set should form one curve at same flow rate with varying methane concentration
- Gas mix taken from gas compositions in study

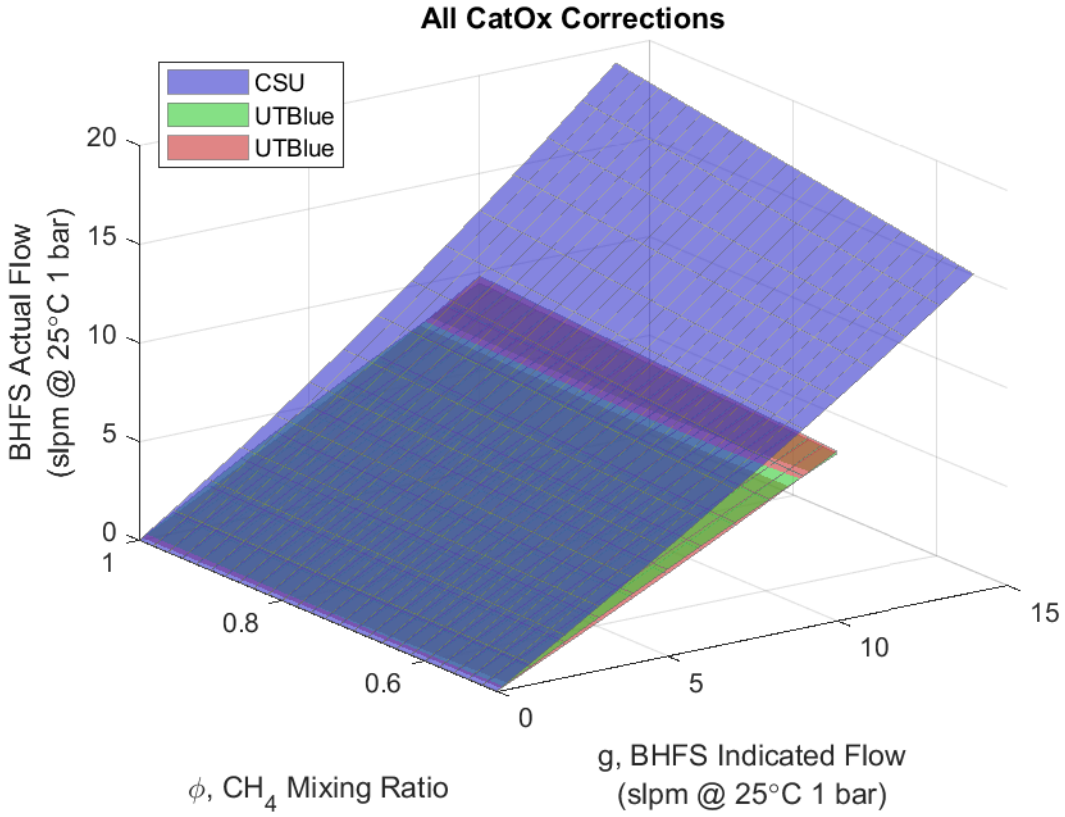
- Switch over point between CatOx and TCD varies substantially
- Repeatability is not great (cal'd every day)
- Correction from reading to actual depends on reading
  - i.e. correction curve is a *correction surface*

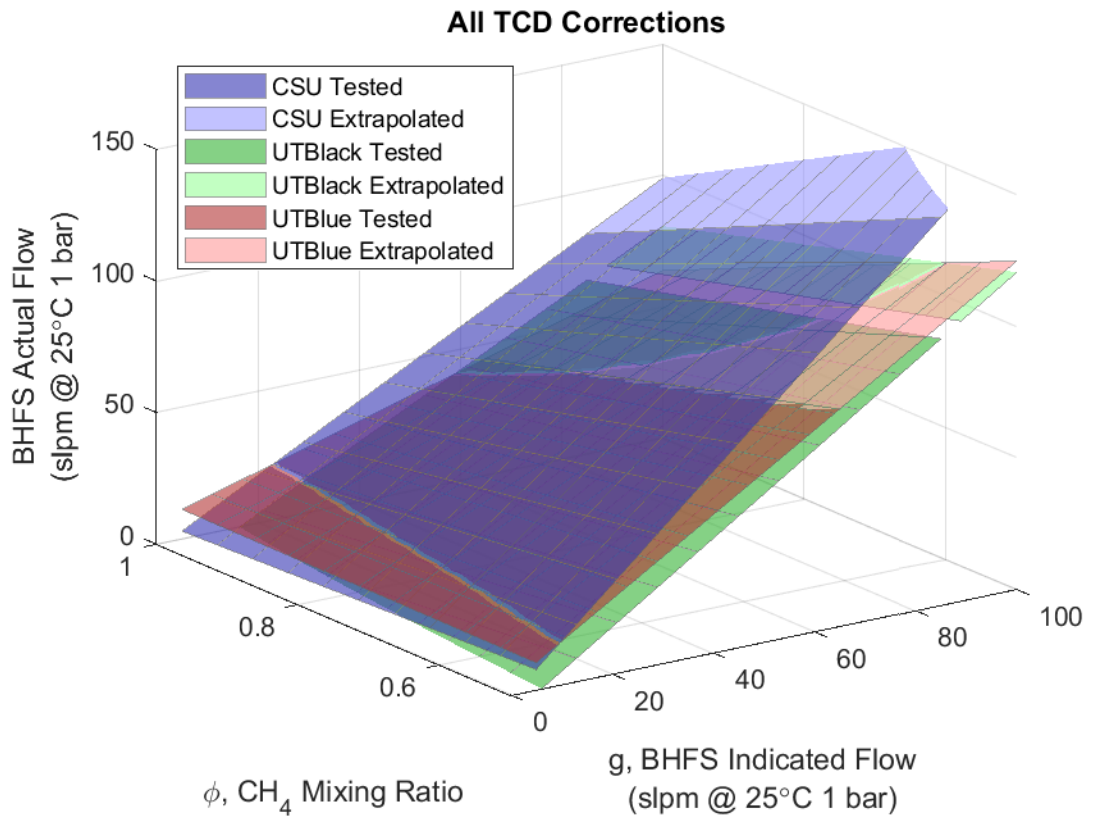
Correction Surface

- Two surfaces … one for each sensor mode
  - Surfaces ‘twist’ in opposite directions
- Transition between surfaces is visible on the display … but varies in gas composition



Substantial Variation Between Instruments





Closing Observations

- Testing shows that the high flow *method* works
- Uncertainty in measurements may be higher than previously thought
- Testing the sensor / software system independent of the full flow illuminates only some behaviors
- Corrections likely need to be unit-specific
- Calibration process appears to contribute to some day-to-day variation

Thank You

Contact

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