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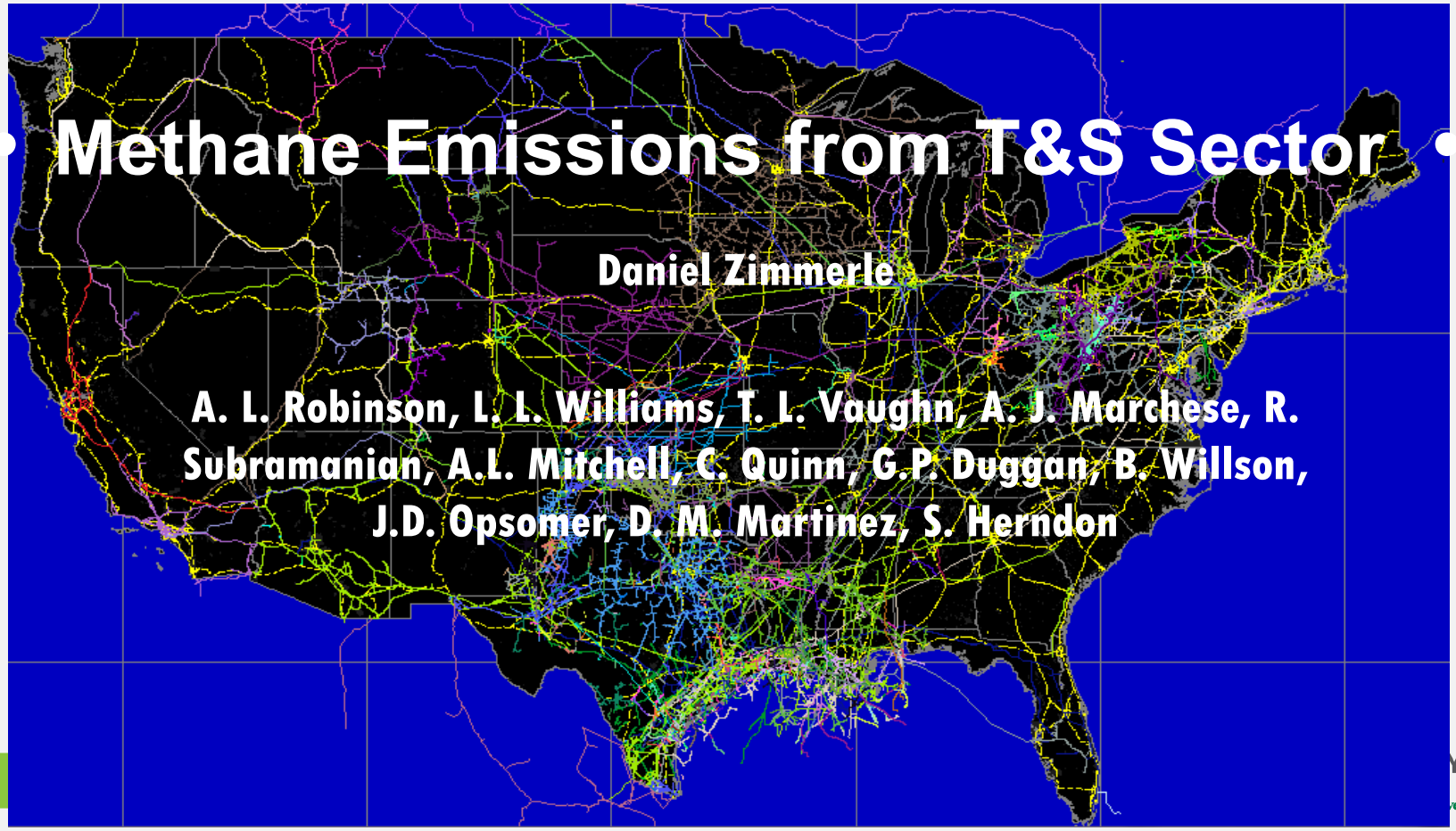

Methane Emissions from T&S Sector

Daniel Zimmerle

A. L. Robinson, L. L. Williams, T. L. Vaughn, A. J. Marchese, R. Subramanian, A.L. Mitchell, C. Quinn, G.P. Duggan, B. Willson, J.D. Opsomer, D. M. Martinez, S. Herndon

Acknowledgements

Study Team

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Colorado State University

Carnegie Mellon University

Aerodyne Research

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EDF ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

Dominion

Columbia Pipeline Group

DOW

ENABLE MIDSTREAM PARTNERS

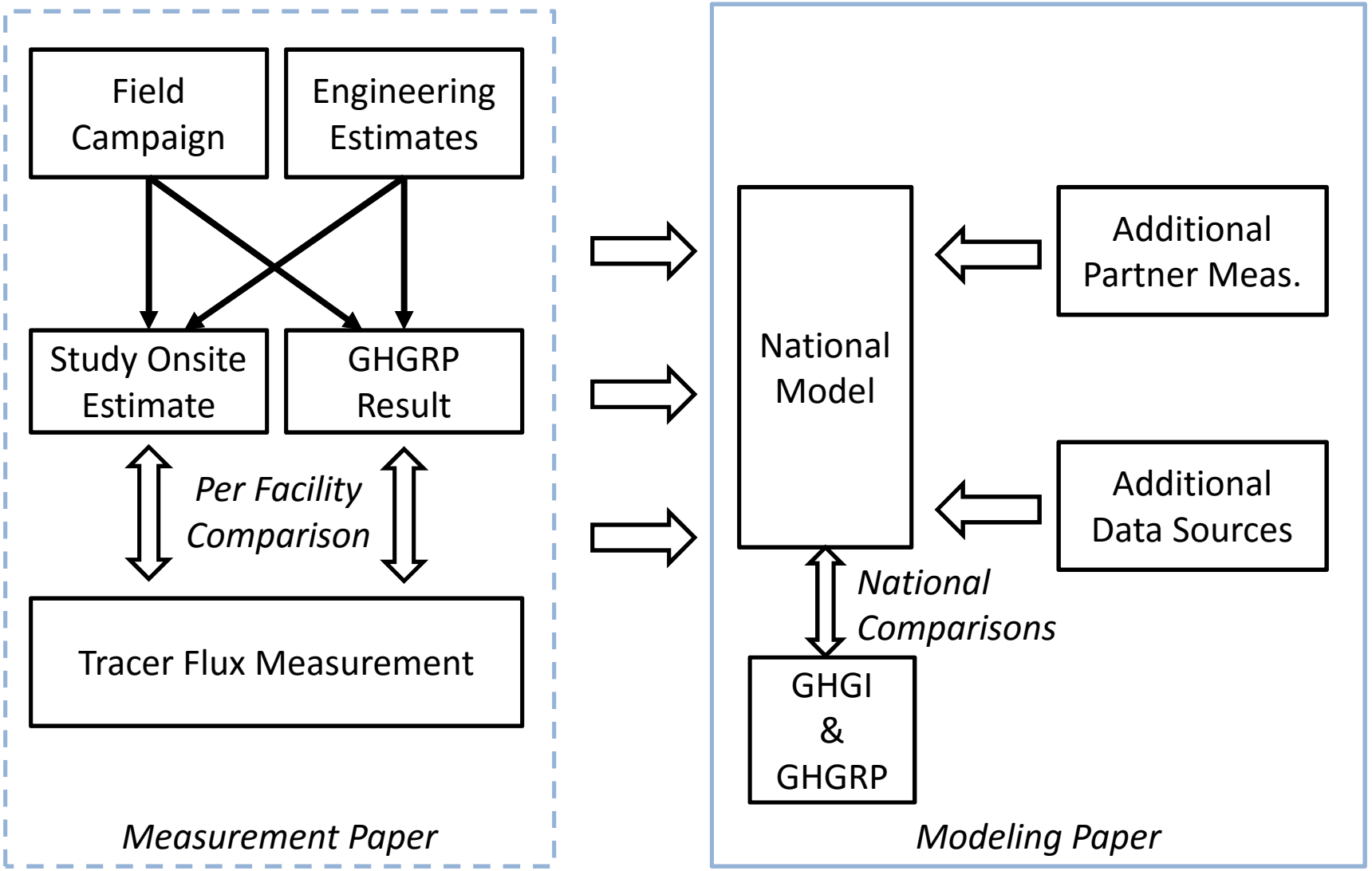
KINDER MORGAN

Williams

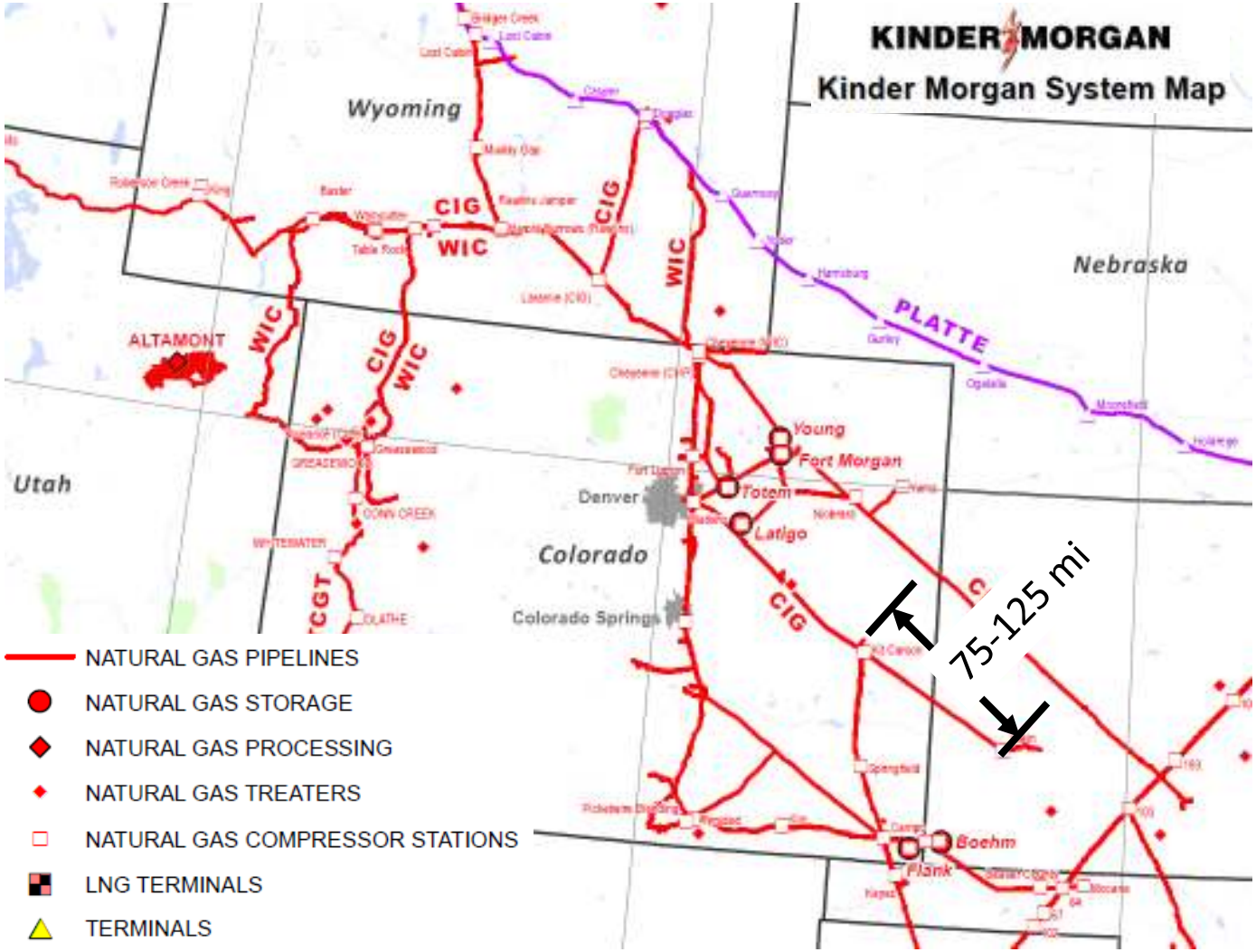
TransCanada
In business to deliver

INGAA

Study Design



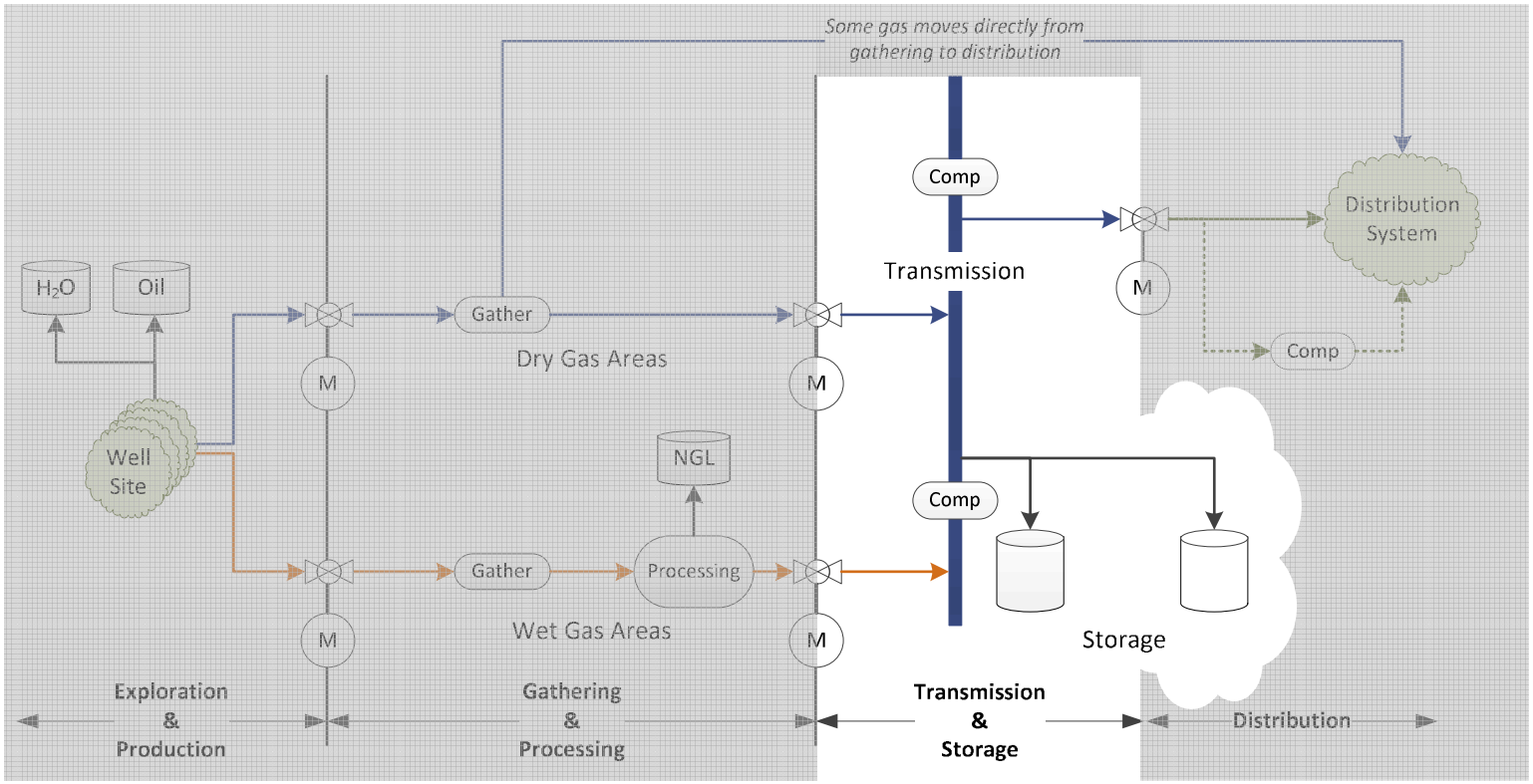
Sample of System Layout



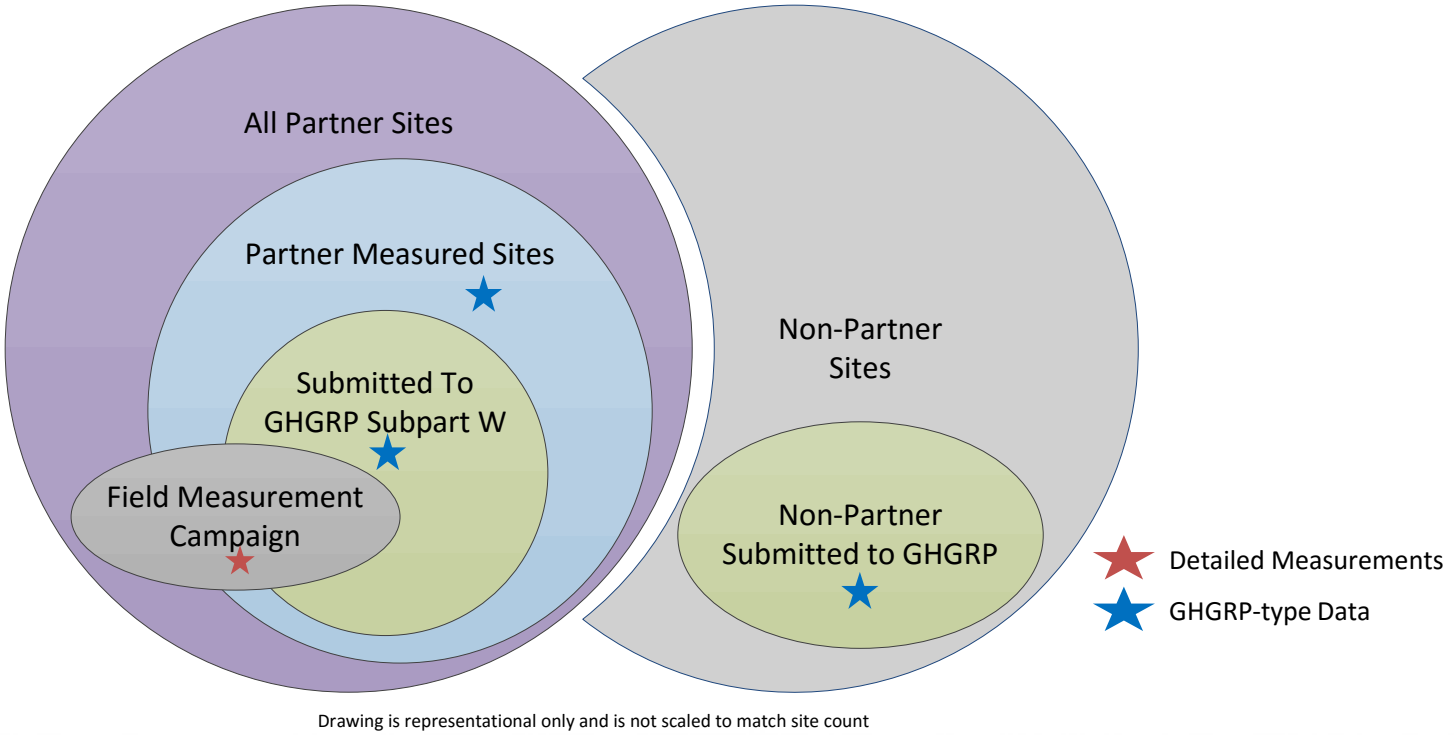
Extracted from Kinder Morgan system map, www.kindermorgan.com

MODELING NATIONAL EMISSIONS

Operational System Boundaries



Model Inputs



Drawing is representational only and is not scaled to match site count

922 *known* facilities – 823 transmission & 99 underground storage

1,279 measurements from field campaign
1,013 measurements from other measurements
EIA data → underground storage facility count
FERC Form 2 data → 2nd transmission facility count

Activity (Census) Data for Model

- Partner site details provided by partners
- Non-partner sites:
  - Site configuration from GHGRP data
  - EIA data for underground storage facility count
  - FERC Form 2 data for transmission facility count
- Omitted:
  - Pipelines
  - LNG
  - M&R
  - Add'l small categories

Emissions Data for Model

- Field Data (1,279 measurements)
- Additional measurement data (1,013 measurements)
  - Measurements from three partner companies
  - Measurements used same protocol as field campaign
  - All or nothing from each partner in each emission category
- Blowdown data from partners
- Methane in combustion exhaust:
  - Emissions measurements underlying AP-42
  - Additional exhaust measurements from partners

Facility-Specific Emissions Data

(in addition to field & partner measurements)

- Reported GHGRP data for 498 facilities
  - Partners provided data underlying submitted reports (262 facilities)
- Facilities which were measured by partners, but not required to report to GHGRP (179 facilities)

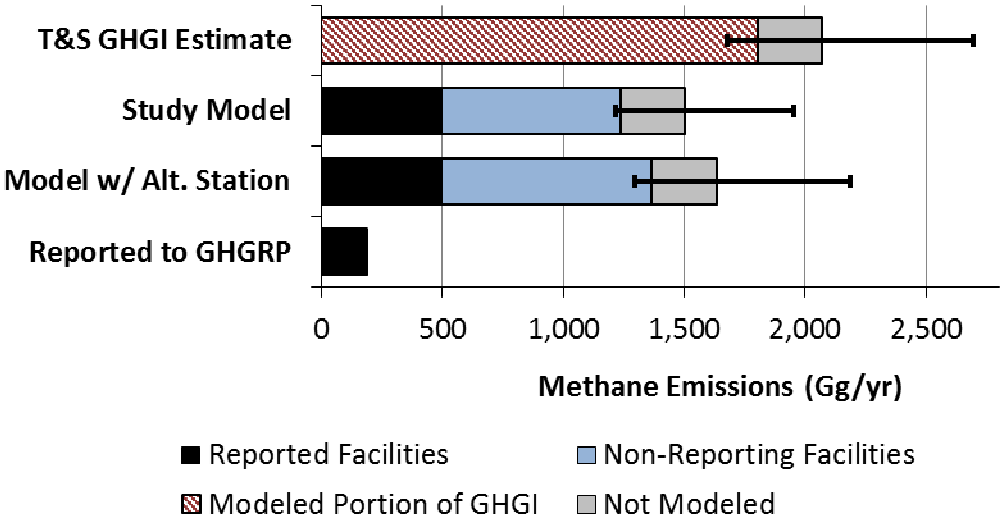
KEY FINDINGS

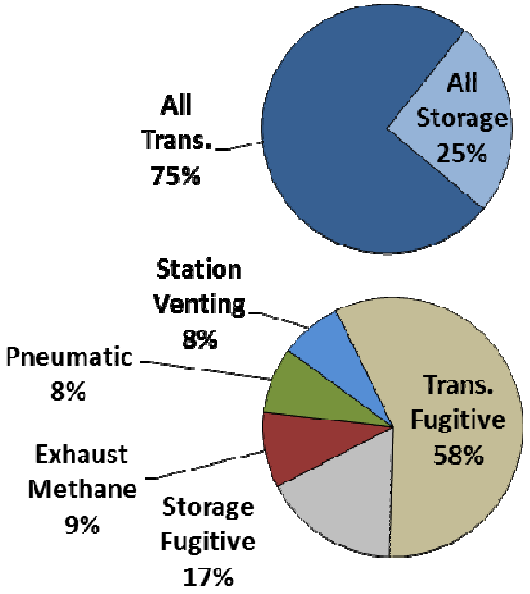
http://energyinstitute.colostate.edu/p/transmission-and-storage.html

Key Findings

- Statistically similar to GHGI → Due to significant offsetting factors in emission & activity categories
- "Activity" estimates have big impact on emissions estimates → Facility counts & equipment mix
- Super-emitters → Big impact but high uncertainty
- GHGRP under-reports significantly due to reporting requirements & some emissions factors

Overall Study Results

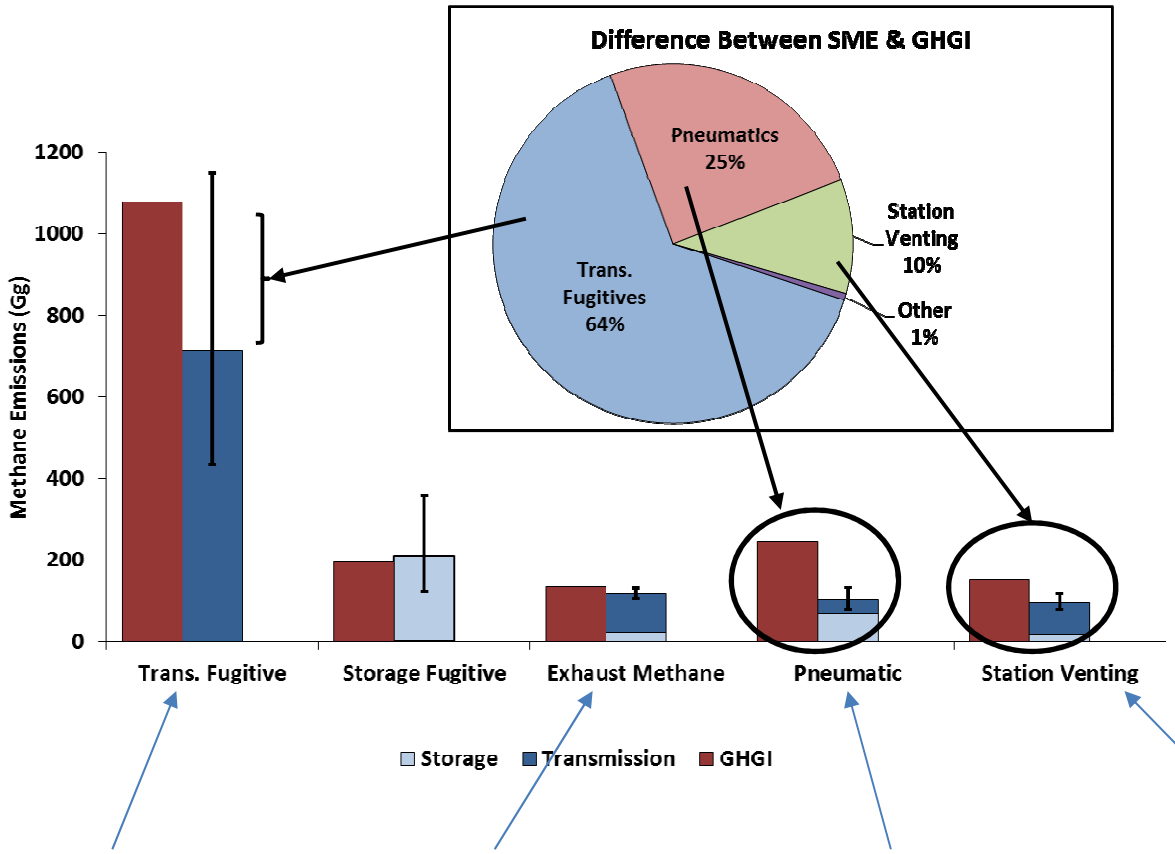




Notes:

- T&S GHGI → GHGI estimate net of "voluntary reductions"
- Model w/ Alt Station → Model with alternative method of estimating transmission station count
- Reported to GHGRP → ≈498 facilities in T&S that report to GHGRP

Results Compared to GHGI



Why?
(major reasons)

Emissions, Facility Count, Comp. Diff.

Offsetting Usage + Emissions Factors
(esp transmission)

Usage Difference
(esp transmission)

More Data Available
(transmission GHGRP)

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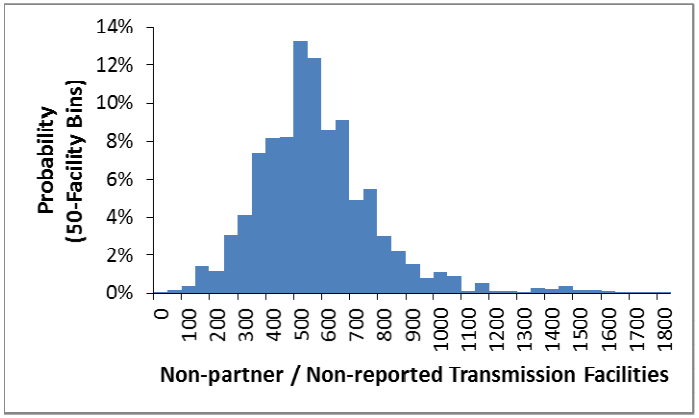
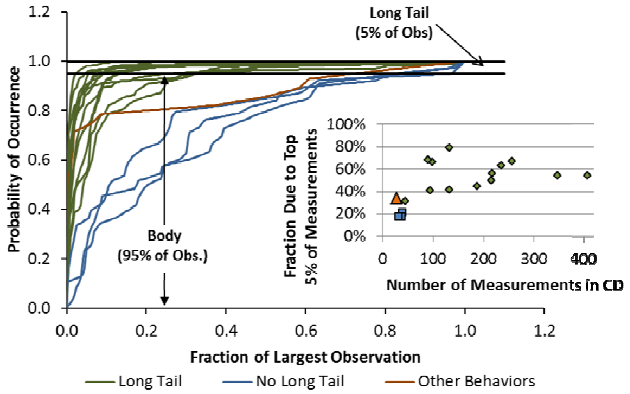
Challenge of Activity Estimates

- Facility Types:
  - ✓ GHGRP reported
  - ✓ Partner facilities
  - ✗ Non-Partner / Non-GHGRP
- Study estimates:
  - Fewer transmission stations than GHGI — 1,375 [+32%/-22%] vs 1799
  - ≈equal compressor power to GHGI — 20.3 GW [+25%/-18%] vs ≈19.5 GW
  - Slightly more underground storage stations — 382 [+9%/-9%] vs 344



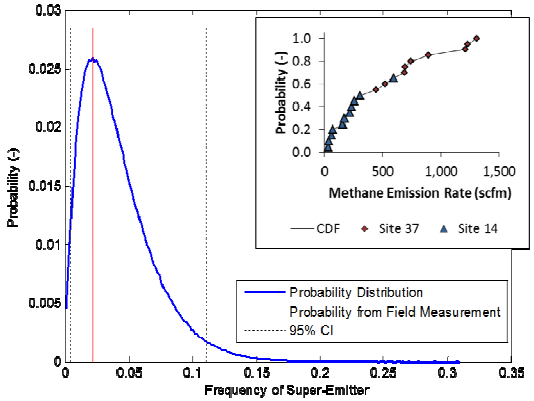
Two Types of Skewed Emissions Models

At device level



- "Long tail" present in most emissions distributions
- Included in emission model for each emission category

At facility level

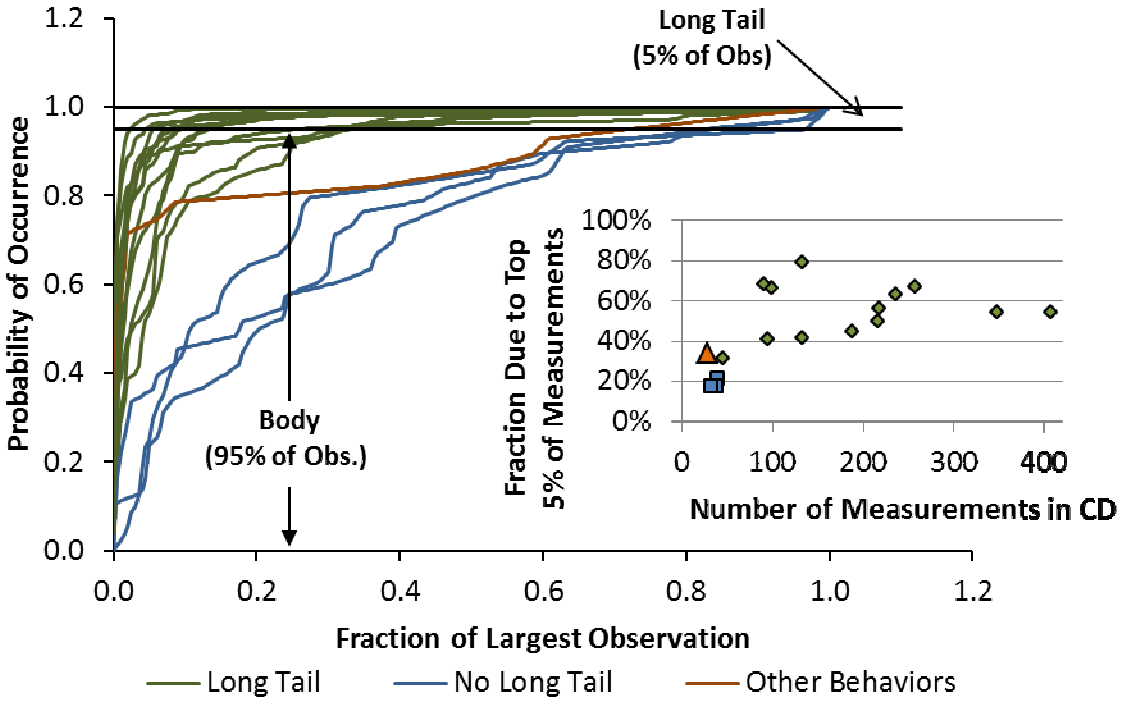


- "Super-emitters"- Exceptional emissions measured by tracer but not captured by on-site measurements
- Included for each *facility* as extra emission category

Skewed Emissions Distributions

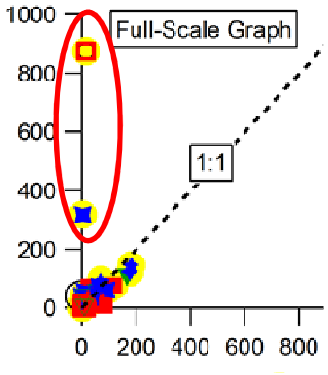
17 core emissions models from study

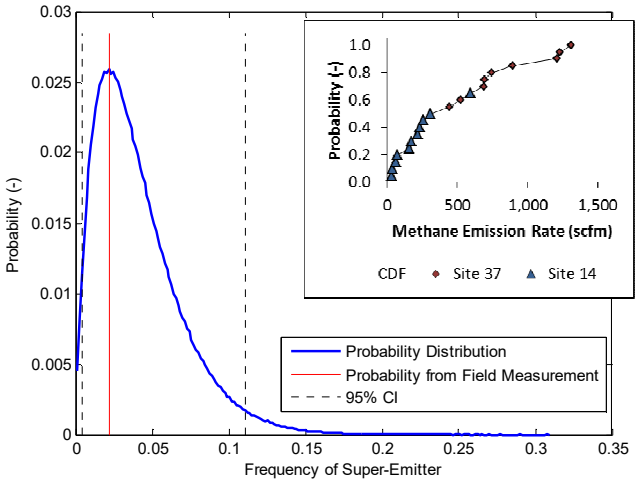
(excludes combustion methane & super-emitter models)

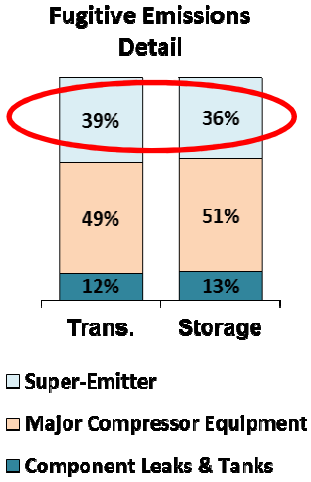


- "Skewed" defined as: ≥30% of emission from 5% of measurements
- All distributions > 90 measurements *skewed*
- All distributions < 40 measurements *not skewed*

Modeling Super-Emitters







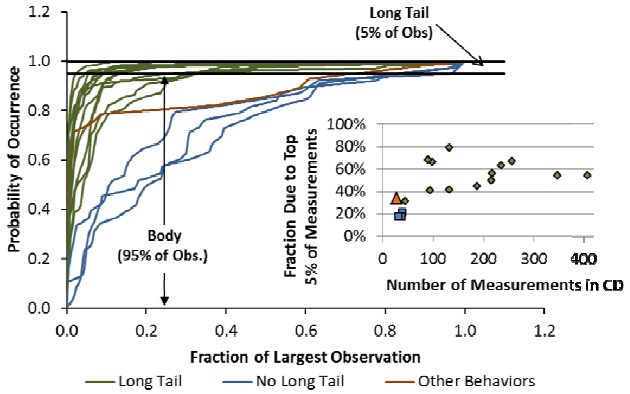
Field observation:
2 of 45 facilities
> 300 SCFM
2 operating modes

Model uncertainty of finding large emitters
Mean ≈ 4% of facilities for each operating mode

Big impact but high uncertainty:
+103%/-63% transmission
+153%/-83% storage

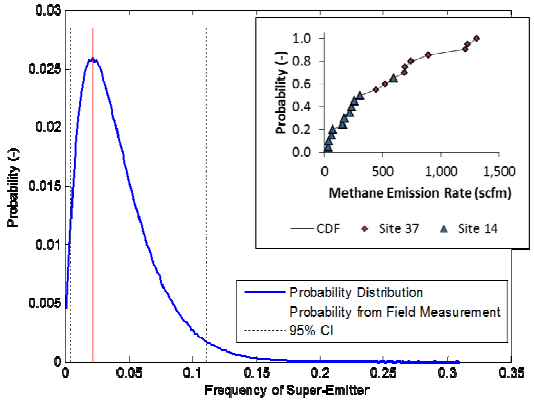
Impact of Skewed Emissions Models

- At device level



- "Long tail" present in most emissions distributions

- At facility level



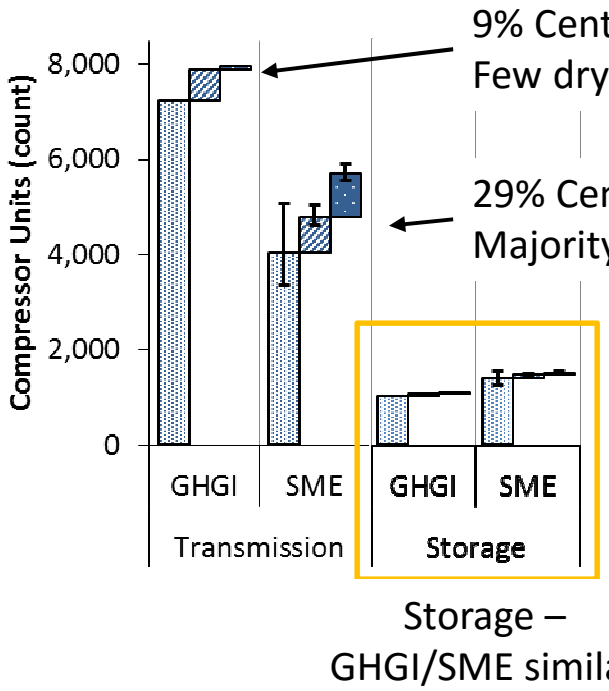
- "Super-emitters"- Exceptional emissions measured by tracer but not captured by on-site measurements

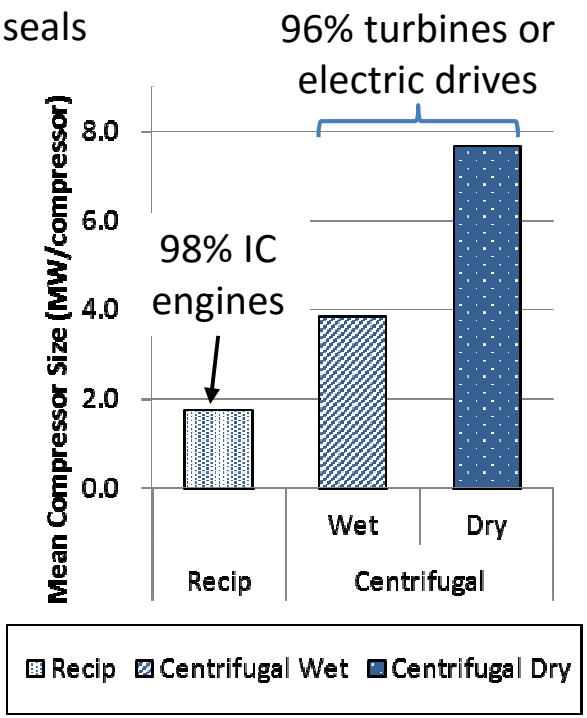
Long tail in 11 emission categories:
≈14-15% of total emissions

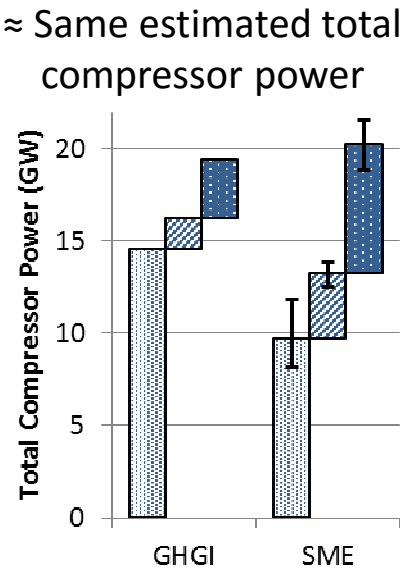
36-39% of fugitive emissions
23% of total emissions

40% of total emissions

Compressor Types: One Large Driver of Facility Emissions



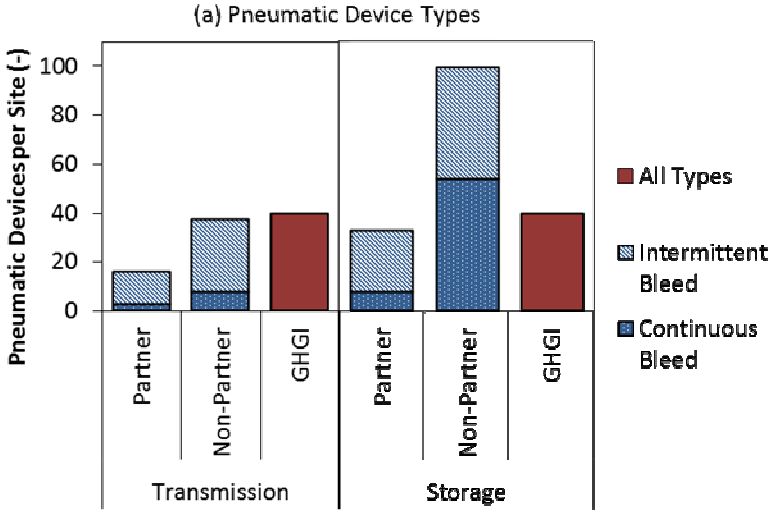




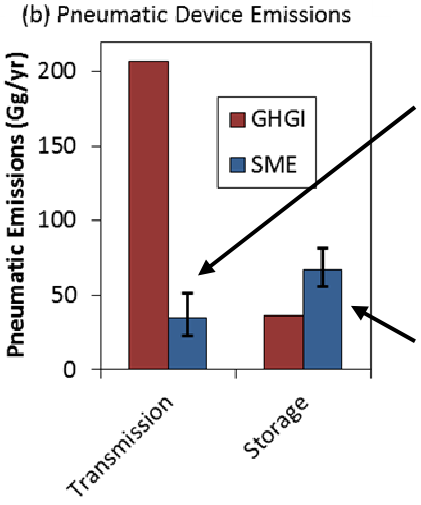
Notes:

- Based on activity data from partner & non-partner facilities
- Uses baseline transmission facility count estimate

Pneumatics



From GHGRP Data



17% of GHGI
Combo of device mix, station count & usage changes

239% of GHGI
Lower emission factor more than offset by increase in device usage

- Mix of intermittent and continuous drives emission factor
- May be seeing a shift from gas-driven to compressed air devices

Facility Type	Emission Rate (Mg/device/yr)	
	GHGI	Study
Transmission	2.9	1.0
Storage	2.7	2.1

Seals

- Study data shows smaller difference between wet and dry seals for centrifugal compressors
  - GHGI: Factor of 8 difference
  - Study: Factor of 3 difference
- Impact on centrifugal compressor fugitives
  - GHGI: Wet = 1.6 X dry
  - Study: Wet = 1.7 X dry … but for dry seal compressors much larger portion is due to dry seal vents (22%) than estimated in GHGI (8%)

Station Venting

- Transmission:
  - GHGRP blowdowns (>50 scf)
  - From 617 facilities
- Storage:
  - No GHGRP data
  - Transmission data weighted by compressor count

Station Type	Venting (Mg/station/yr)	
	GHGI	Study
Transmission Stations	72	57
Storage Stations	72	43

- Significantly more data than used for the GHGI

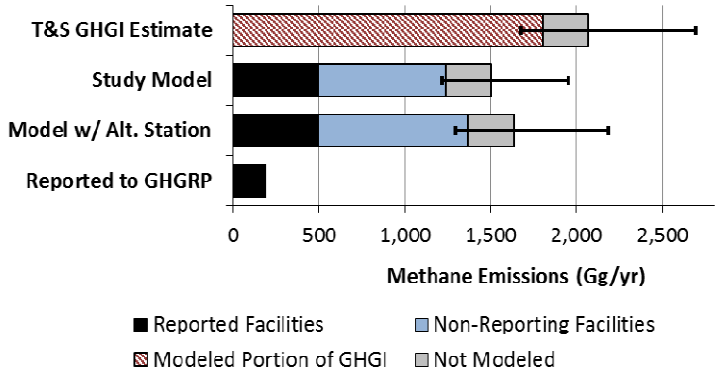
Engine Exhaust

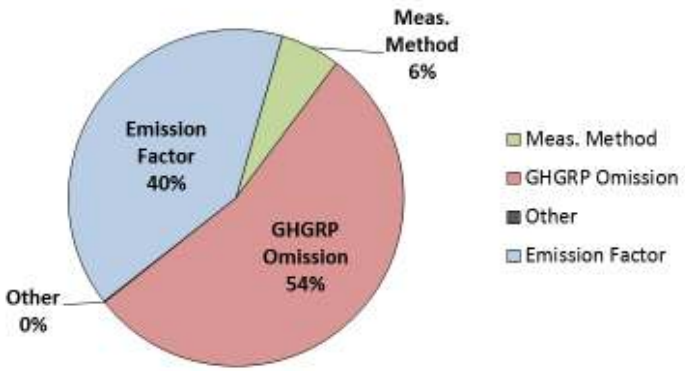
	Emissions Factor	Voluntary Reductions	Net Emissions Factor
GHGI	4.6 g/hp-hr	124 Gg	2.4 g/hp-hr
GHGRP			0.09 g/hp-hr
Study			3.7 g/hp-hr

- Emission model developed from AP-42 data + partner data → Not measured in study
- Study:
  - 3.7 g/hr-hr based upon AP-42 + new data
  - 1.6X higher than GHGI
  - Study >550X higher than GHGRP for lean-burn engines

Comparison to GHGRP

- Study:
  - 260% [215% to 330%] of reported emissions
- Why?
  - Omitted emission sources (including super-emitters)
  - Combustion exhaust & other emission factors
  - Measurement methods





Additional Observations

- Survey teams had a hard time distinguishing between “compressor component” and “non-compressor component” categories
- Hi/low bleed pneumatic categories are ambiguous at best – we use “continuous bleed”
- We saw a difference in *reported* emissions between partner & non-partner facilities

Conclusions

- Statistical similarity to GHGI hides significant offsetting differences embedded in:
  - Emissions factors
  - Facility & equipment utilization
- Super-emitters must be modeled carefully → More data on large emitters needed
- Significant challenges estimating "easy to get" data →counts of facilities & major equipment
- GHGRP under-reports significantly due to reporting requirements & some emissions factors

References

- Modeling paper

  Zimmerle, D.J., et. al., *Methane emissions from the natural gas transmission and storage system in the United States*, Environmental Science and Technology, 2015, DOI: 10.1021/acs.est.5b01669.

  http://pubs.acs.org/doi/abs/10.1021/acs.est.5b01669

- Web site

  http://energyinstitute.colostate.edu/p/transmission-and-storage.html

- Prior Papers:

Field study:

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. 2015, 49 (5), 3252–3261.*

Tracer methods paper:

Roscioli, J. R., et. al, *Measurements of methane emissions from natural gas gathering facilities and processing plants: measurement methods*, Atmos. Meas. Tech. Discuss., 7, 12357-12406, 2014.

Thank You

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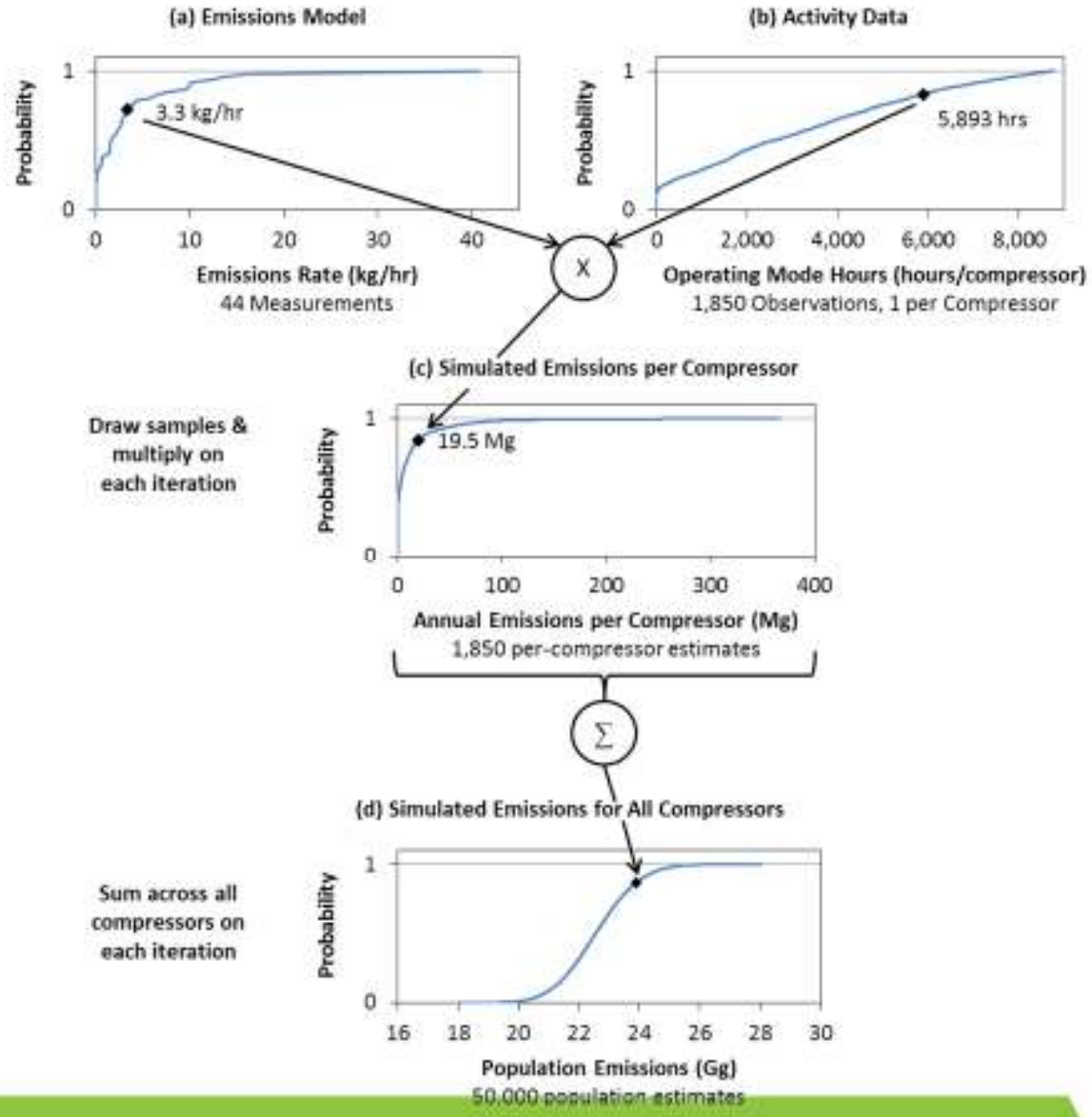
http://energyinstitute.colostate.edu/p/transmission-and-storage.html

Monte Carlo Model Example



GHGRP Details

Comparison of Study Model Estimate to GHGRP for Sites With Measured Emissions (Lane 1 Reported & Lane 2)									
Emission Source		GHGRP (Mg)	SME (Mg)	SME Confidence Interval	Category Ratio	Difference (SME - MRR) (Mg)	Fraction of Total Difference	Primary Origin of Difference in Emissions	Notes
Component Leaks, All GHGRP Categories		17,780	43,961	[+81%/-31%]	2.5	26,181	8.6%	Emission Factor	
Pneumatics	High & Low Continuous Bleed	7,387	13,152	[+7%/-7%]	1.8	5,765	1.9%	Emission Factor	
	Intermittent Bleed	4,312	4,312	[+0%/0%]	1.0	0	0.0%	Not modeled	1
Wellhead Components		762	762	[+0%/0%]	1.0	0	0.0%	Not modeled	1
Transmission Tanks	Flares	0	0	[+0%/0%]	1.0	0	0.0%	Not modeled	3
	Vent stack or dump valve	4,062	5,832	[+18%/-18%]	1.4	1,770	0.6%	Meas. Method	
Reciprocating Compressor Venting	Blowdown vent - NOP	11,730	18,281	[+12%/-10%]	1.6	6,551	2.2%	Meas. Method	
	Blowdown vent - OP	9,480	17,077	[+15%/-13%]	1.8	7,597	2.5%	Meas. Method	
	Isolation Valve - NOD	16,105	28,284	[+22%/-19%]	1.8	12,179	4.0%	Meas. Method	
	Rod Packing - NOP	0	44,407	[+7%/-7%]	-	44,407	14.6%	GHGRP Omission	
	Rod Packing - OP	42,994	35,701	[+9%/-9%]	0.8	-7,293	-2.4%	Other	
Centrifugal Compressor Venting	Blowdown vent - NOP	0	1,385	[+74%/-45%]	-	1,385	0.5%	Meas. Method	
	Blowdown vent - OP	3,393	6,131	[+25%/-19%]	1.8	2,738	0.9%	Meas. Method	
	Dry Seal Vent - OP	0	4,814	[+13%/-12%]	-	4,814	1.6%	GHGRP Omission	
	Isolation Valve - NOD	16,055	20,602	[+7%/-7%]	1.3	4,547	1.5%	Meas. Method	
	Wet Seal Vent - OP	4,580	11,651	[+20%/-18%]	2.5	7,071	2.3%	Other	
Combustion Methane	Lean 2 Stroke	115	64,137	[+4%/-4%]	558	64,022	21.1%	Emission Factor	
	Lean 4 Stroke	29	16,499	[+13%/-12%]	577	16,470	5.4%	Emission Factor	
	Rich 4 Stroke	6	535	[+19%/-17%]	91	529	0.2%	Emission Factor	
	Combustion Turbine	221	889	[+23%/-20%]	4.0	667	0.2%	Emission Factor	
Station Venting (Blowdowns)		51,250	55,744	[+9%/-5%]	1.1	4,494	1.5%	GHGRP Omission	2
Super-Emitter		0	100,074	[+128%/-80%]	-	100,074	32.9%	GHGRP Omission	
Total for Available Emissions Data		**190,524**	**494,539**	**[+26%/-17%]**	**2.60**	**303,970**	**100.0%**		

Notes	
1	Intermittent bleed pneumatics and wellhead components were modeled using GHGRP emission factors.
2	SME estimate for blowdowns reflects a pass through of transmission blowdowns and a per-facility estimate of storage blowdowns. The storage blowdowns are an omission from the GHGRP requirements.
3	Tank flare emissions (both GHGRP and SME) are smaller than the precision of the model and display as zero