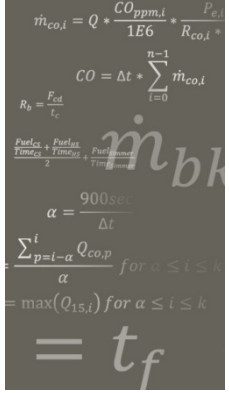
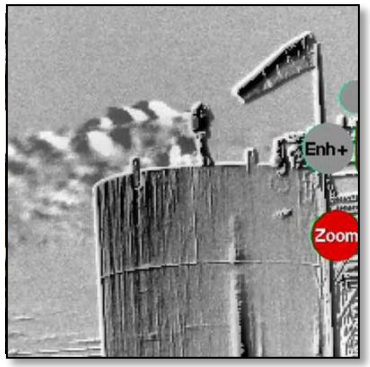
Stakeholder Workshop on EPA GHG Data: Petroleum and Natural Gas Systems
November 19, 2015





Methane Emissions from U.S. Natural Gas Gathering Facilities and Processing Plants: EPA GHGI Implications

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EDF ENVIRONMENTAL DEFENSE FUND™

Methane Emissions from U.S Gathering and Processing
Study Team

Partners

Environmental Defense Fund, Anadarko Petroleum, Access Midstream, Williams, SWN, Hess, DCP Midstream*

Total Partner Facility Inventory

738 gathering facilities

28 processing plants

Study Team

Colorado State University (Anthony Marchese, Dan Zimmerle)

Carnegie Mellon University (Allen Robinson)

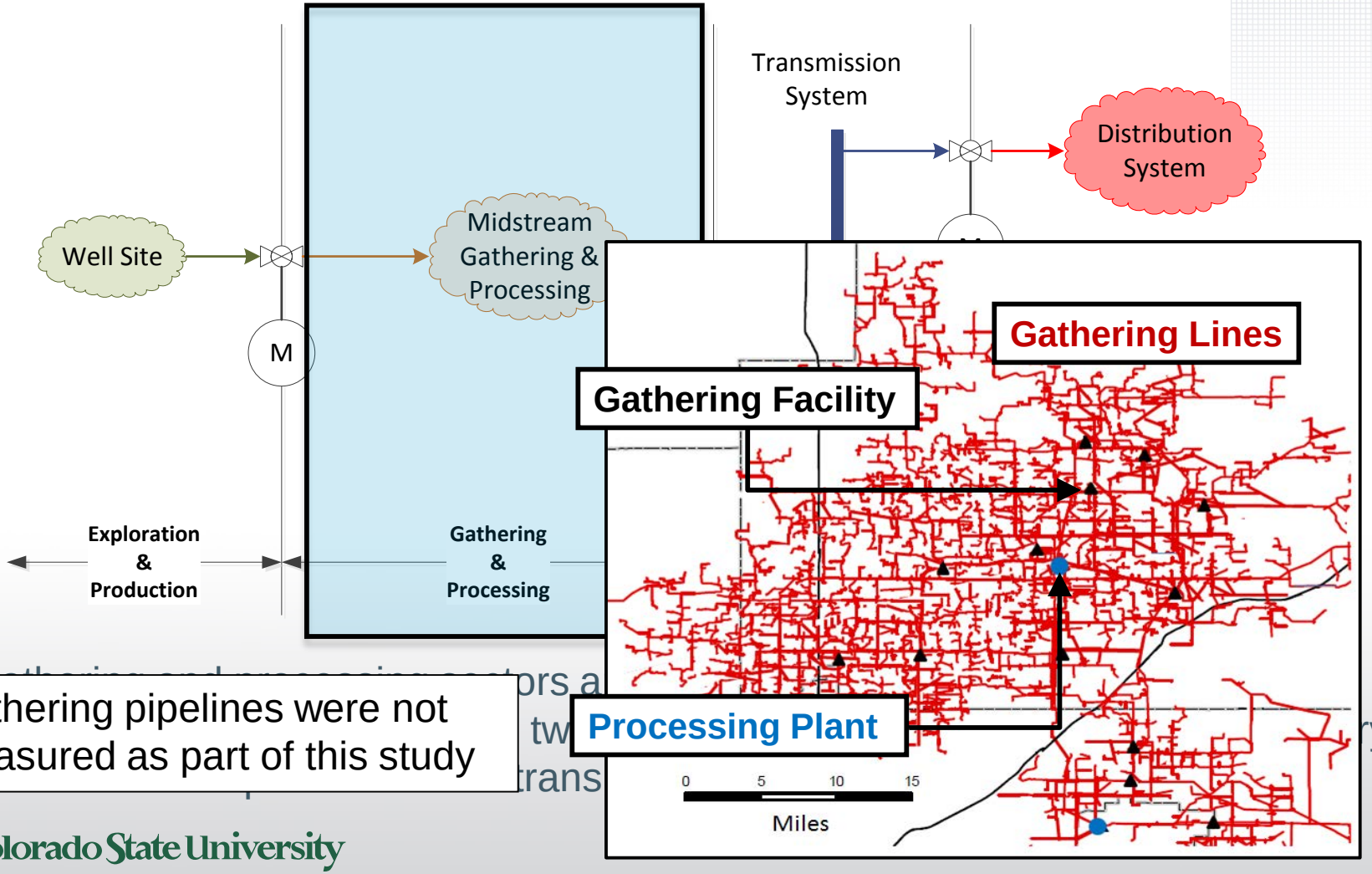
Aerodyne Research (Scott Herndon)

*DCP provided access to one randomly chosen processing plant but did not provide funding.

Methane Emissions from Gathering and Processing

Sector Definition

Gathering and Processing Systems = gathering pipelines, gathering compressor/booster stations and processing plants

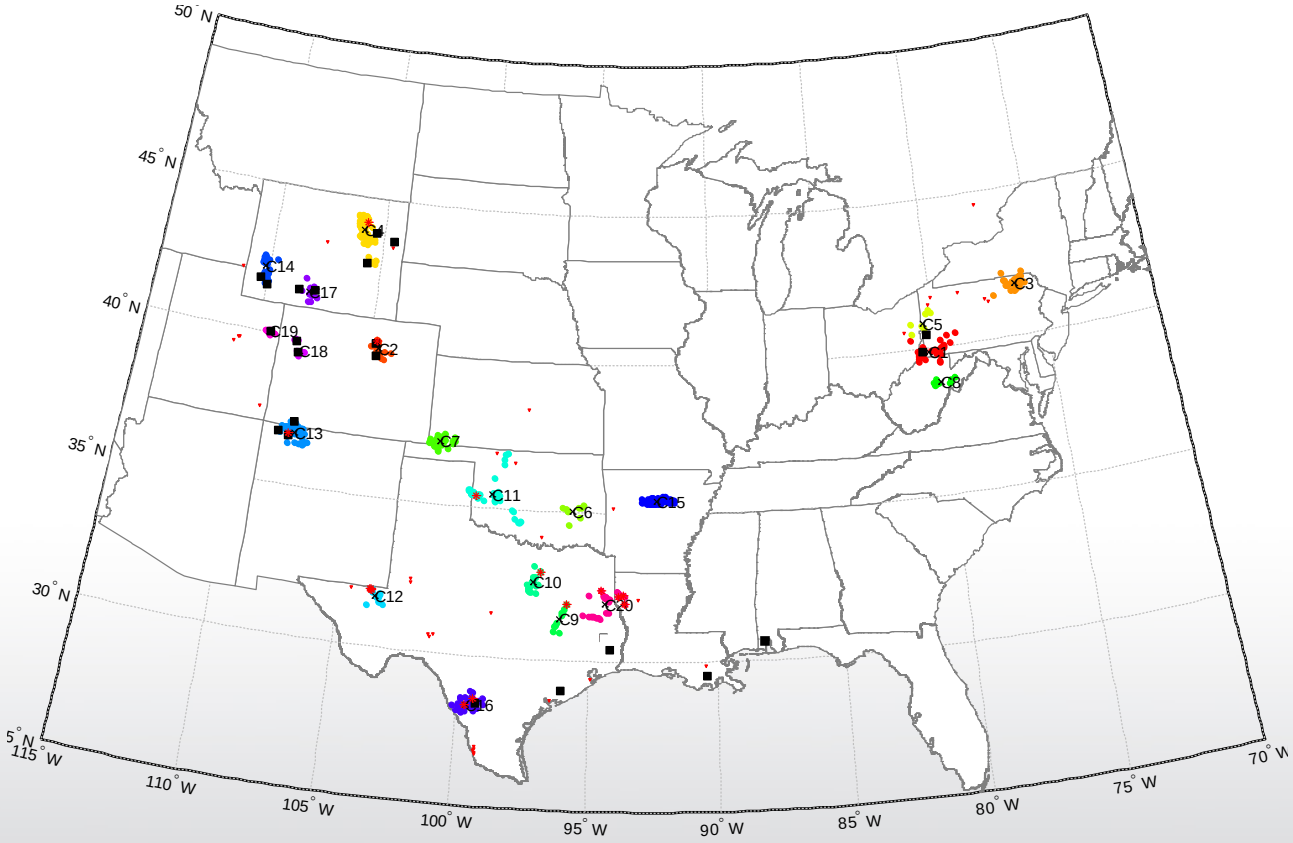


Gathering pipelines were not measured as part of this study

Field Campaign

Study Partner Assets

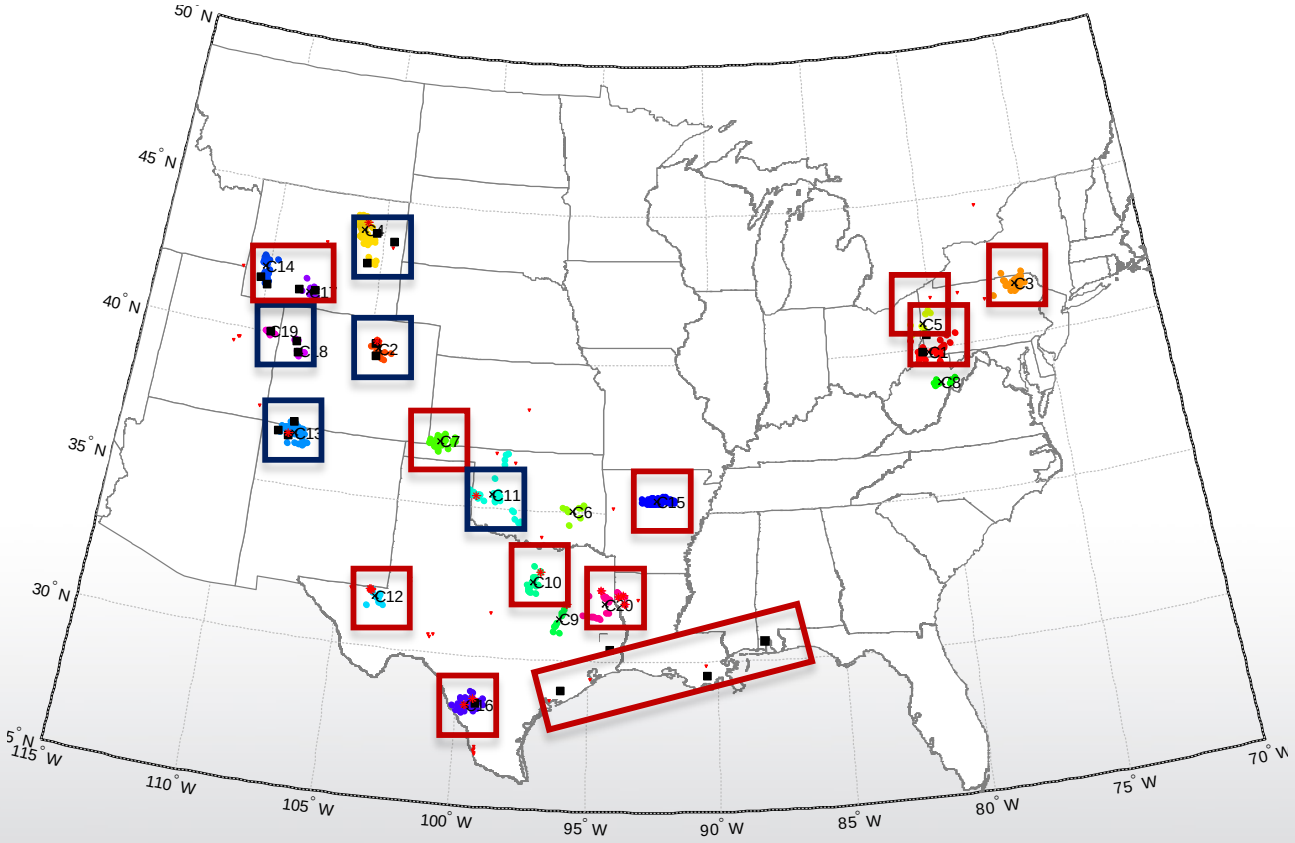
Study partner assets included 738 gathering facilities and 28 Subpart KKK processing plants located in 13 U.S. states.



Methane Emissions from U.S Gathering and Processing
Field Campaign

Comprehensive Measurements

Facility-level CH_4 emissions were acquired from **16 processing plants** and **114 gathering facilities** in 13 U.S. states in 20 weeks.



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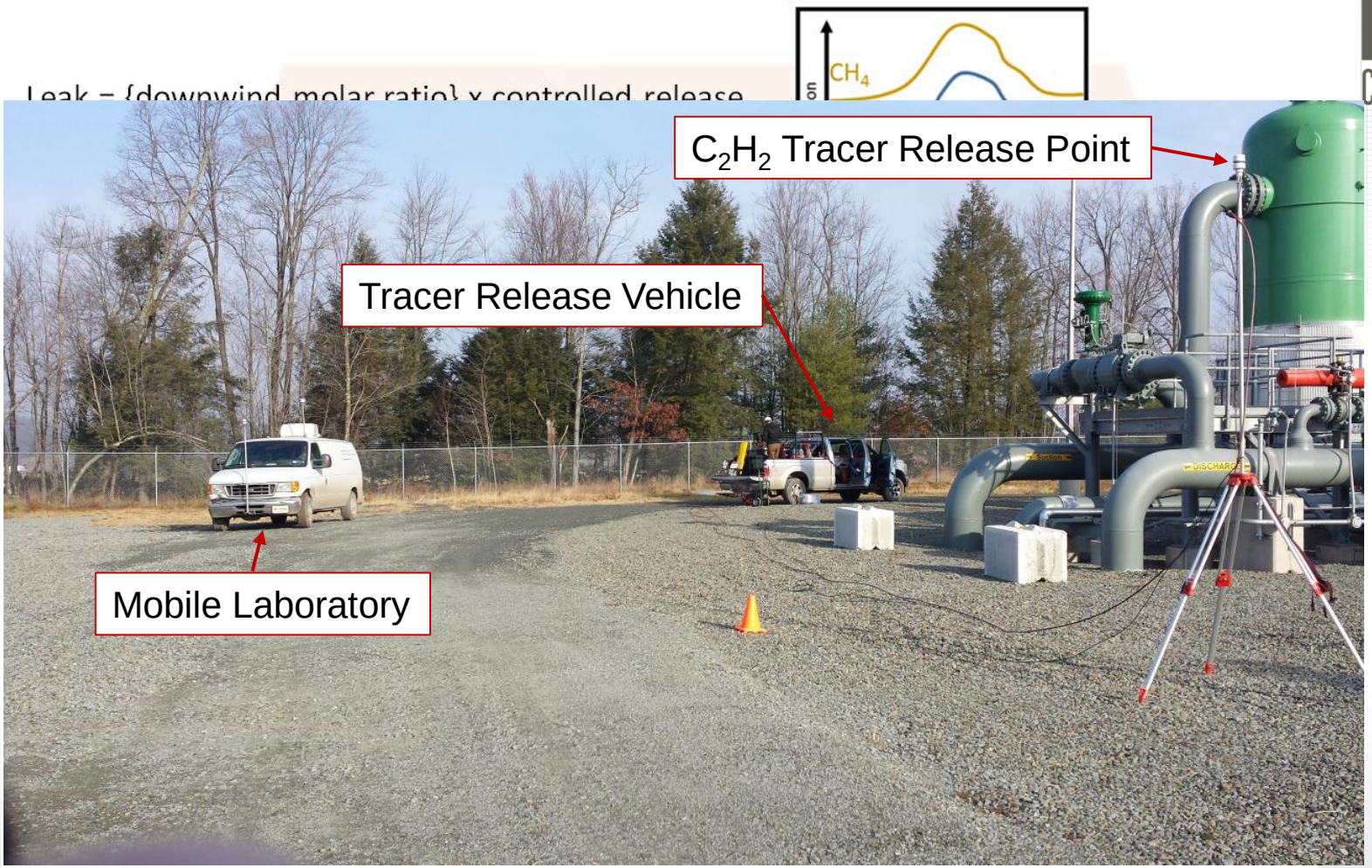
Methane Emissions from the G&P Sectors

Dual Tracer Gas Method



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

Methane Emissions from the G&P Sectors
Facility-Level CH_4 Emission Rates

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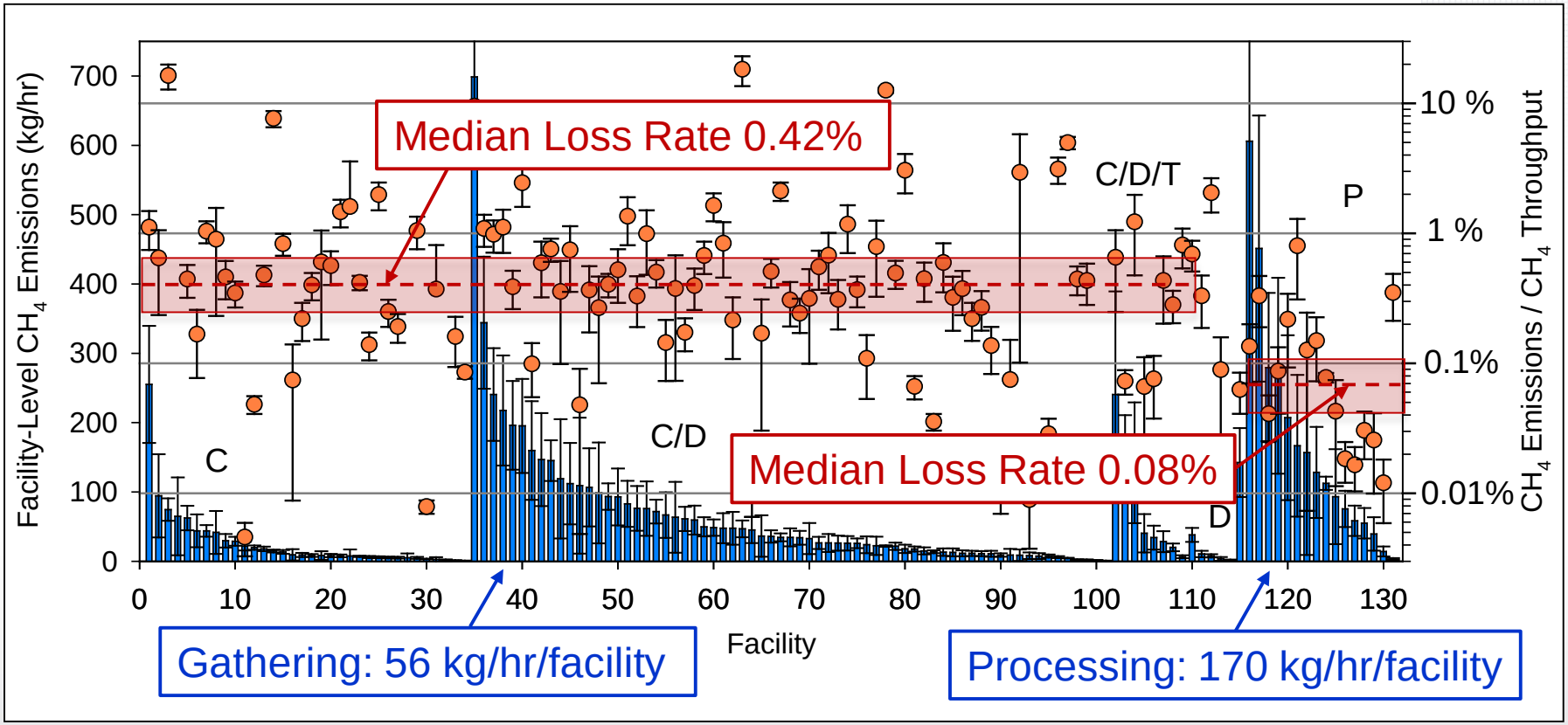
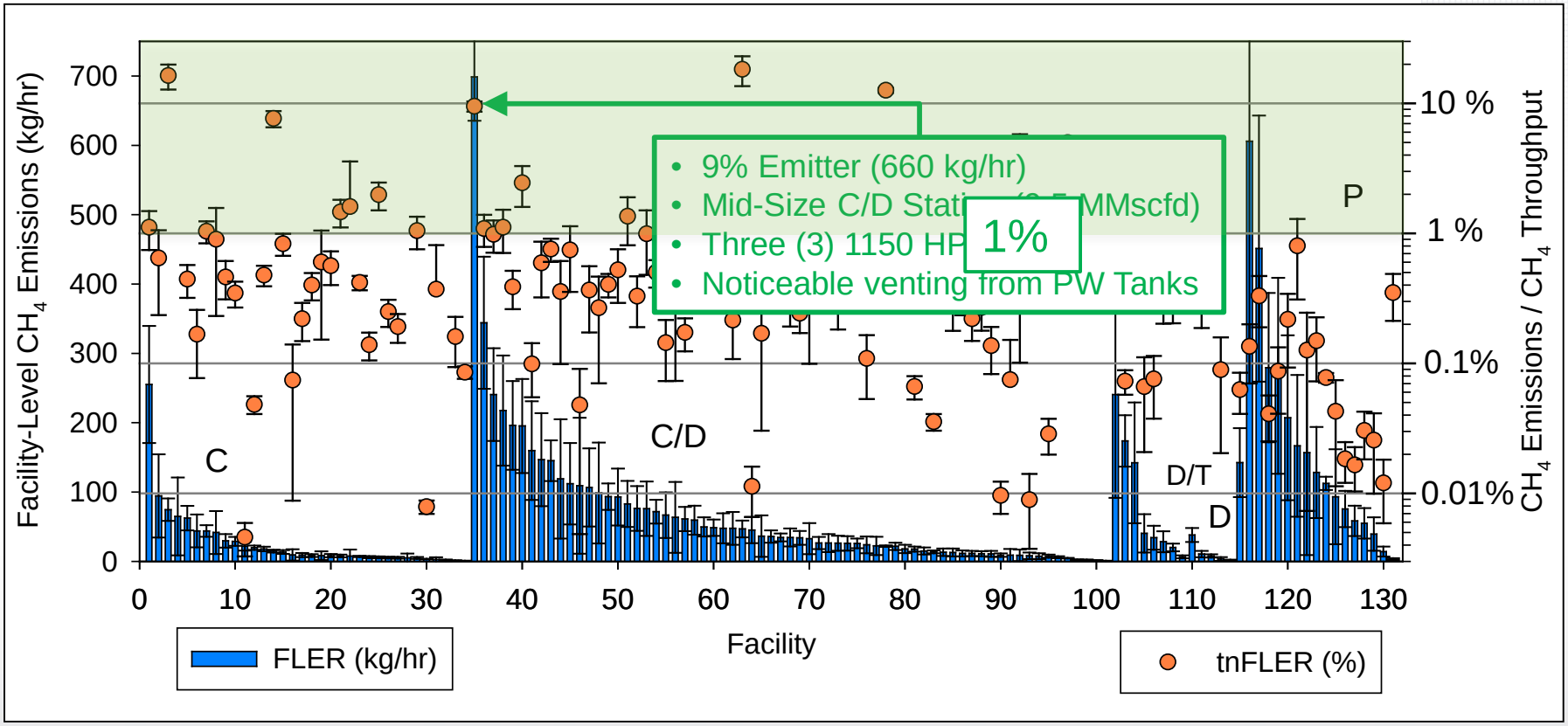
Facility-Level Methane Emissions (kg/hr) and Loss Rate(%)



Mitchell, A.L., Zimmerle, D., Marchese, A.J., Robinson, A.L. et al. Measurements of Methane Emissions from Natural Gas Gathering Facilities and Processing Plants: Measurement Results. *Environ. Sci. Technol.*, **49** (5) 3219-3227.

Methane Emissions from the G&P Sectors
Facility-Level CH_4 Emission Rates

High Emitters: 25 facilities had methane loss rates > 1%



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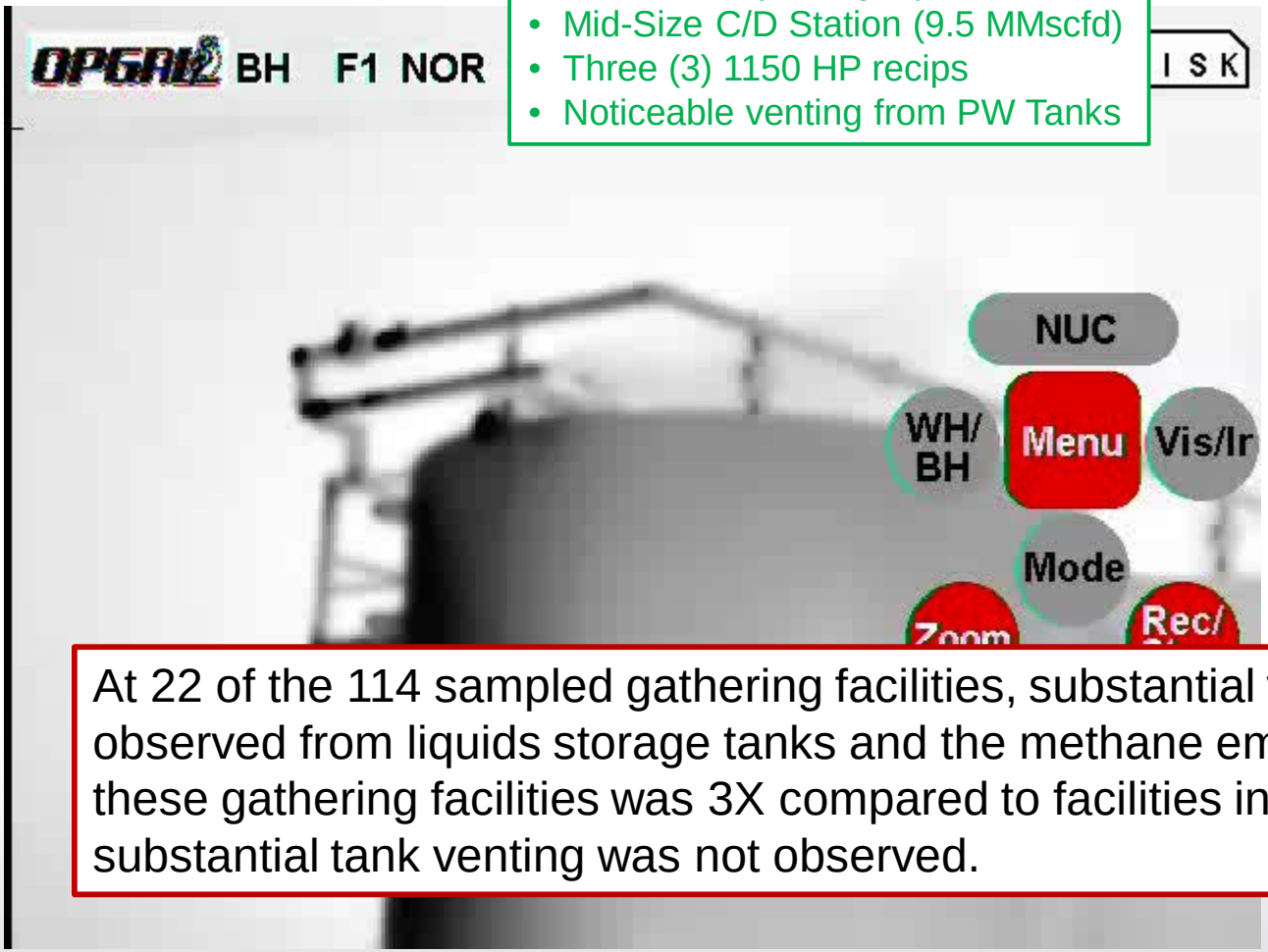
Methane Emissions from the G&P Sectors
Facility-Level CH_4 Emission Rates

- 9% Emitter (660 kg/hr)
- Mid-Size C/D Station (9.5 MMscfd)
- Three (3) 1150 HP recips
- Noticeable venting from PW Tanks



At 22 of the 114 sampled gathering facilities, substantial venting was observed from liquids storage tanks and the methane emissions from these gathering facilities was 3X compared to facilities in which substantial tank venting was not observed.

Methane Emissions from the G&P Sectors

"Back of the Envelope" Estimates

Median loss rates (%) and facility-level emission factors (kg/hr/facility) can provide order of magnitude estimates of how the emissions might scale nationally.

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Gathering Facilities

- (0.42% CH_4 loss rate) x (421 Tg CH_4 gathered in 2012) ≈ 1770 Gg
- (≈ 4500 facilities) x (56 kg/hr/facility) ≈ 2200 Gg

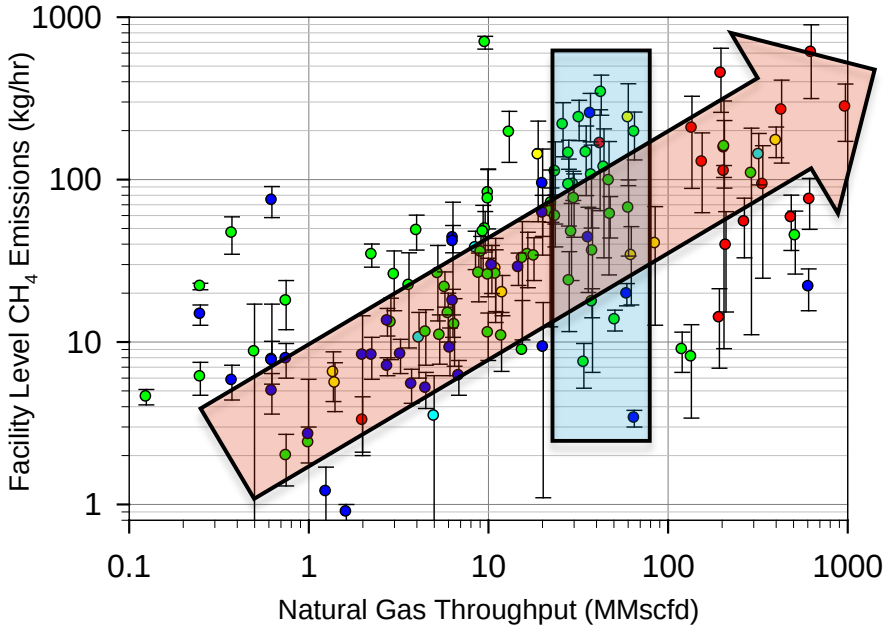
Subpart KKK Processing Plants

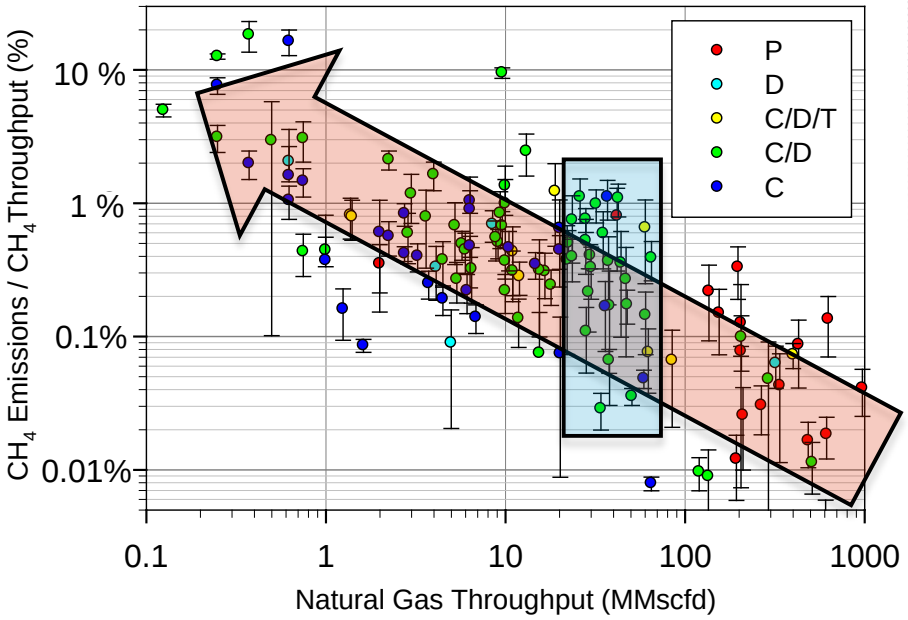
- (0.08% CH_4 loss rate) x (287 Tg CH_4 processed in 2012) ≈ 230 Gg
- (≈ 600 facilities) x (170 kg/hr/facility) ≈ 890 Gg

Even without a sophisticated model, the experimental results indicate that methane emissions from gathering facilities are substantial (≈ 30% of entire NG supply chain methane emissions).

Methane Emissions from the G&P Sectors
Development of National Estimate

Scale Up of CH_4 Measurements to National Estimate





Issues for Scale Up:

- Facility size varies over several orders of magnitude (0.1 to 1000 MMscfd)
- Emissions vary with throughput
- Large variation in emissions for a given throughput range

Scale up to a national estimate requires:

- Accurate facility count of all gathering facilities and processing plants
- Average natural gas throughput (MMscfd) or proxy such as installed compressor engine power for each facility
- Natural gas can flow through multiple gathering/boosting stations during transit from the production site to transmission.

Methane Emissions from the G&P Sector
Development of National Estimate

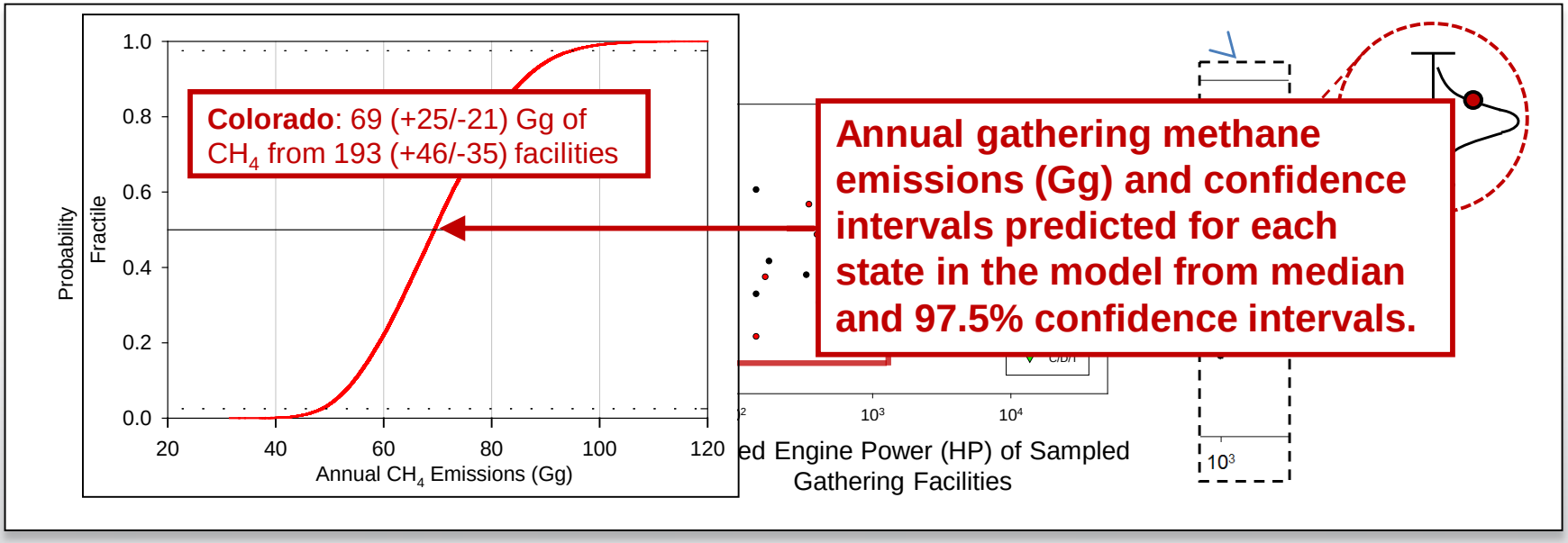
Gathering Facility Counts

State	Data Source	Identified Gathering Facilities	Known Partner Gathering Facilities	Identified Partner Gathering Facilities	Extrapolated Gathering Facilities
AR	Arkansas Department of Environmental Quality	211	63	62	214
CO	Colorado Oil and Gas Conservation Commission	169	40	35	193
LA	Louisiana Department of Environmental Quality	312	7	6	364
NM		253	67	60	283
OK	Oklahoma Department of Environmental Quality	711	45	29	1103
PA	Pennsylvania Department of Environmental Protection - Bureau of Air Quality	204	58	48	246
TX	Texas Commision on Environmental Quality	351	156	30	1012*
WY	Wyoming Department of Environmental Quality	298	150	117	382

Methane Emissions from the G&P Sectors
Development of National Estimate

Monte Carlo Simulation Scheme (Gathering)

- Installed compressor engine power is used as a proxy for facility natural gas throughput.
- For each facility in a state database, an emissions value is randomly drawn from among the 10 sampled facilities with closest HP.
- Experimental uncertainty and uncertainty in facility count included.
- Process is repeated for 50,000 iterations.



Methane Emissions from the G&P Sectors
Development of National Estimate

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Monte Carlo Simulation: Gathering Results

Total annual emission of methane (Gg) from all gathering facilities in the states of AR, CO, LA, OK, PA, TX and WY, and extrapolated U.S. results.

State	Number of Gathering Facilities	Annual Emission of CH_4 from Gathering Facilities (Gg)	2012 CH_4 Gathered (Gg)	Modeled CH_4 Loss Rate (%)
AR	214 (+43/-38)	53 (+20/-25)	19,723	0.27% (+0.10%/-0.08%)
CO	193 (+46/-35)	69 (+25/-21)	28,261	0.25% (+0.09%/-0.07%)
LA	364 (+62/-124)	104 (+42/-36)	50,207	0.21% (+0.08%/-0.07%)
NM	282 (+82/-82)	96 (+40/-33)	20,215	0.47% (+0.20%/-0.16%)
OK	1103 (+132/-132)	322 (+56/-52)	34,263	0.94% (+0.16%/-0.15%)
PA	247 (+22/-7)	70 (+16/-14)	37,676	0.19% (+0.04%/-0.04%)
TX	1012 (+304/-101)	616 (+124/-118)	126,552	0.49% (+0.10%/-0.09%)
WY	382 (+77/-66)	86 (+25/-22)	34,414	0.25% (+0.07%/-0.06%)
Total States in Model	3,797 (+768/-587)	1,417 (+158/-154)	351,310	0.40% (+0.05%/-0.04%)
Total U.S.	4,549 (+921/-703)	**1,697 (+189/-185)**	420,906	0.40% (+0.05%/-0.04%)

Colorado State University

Methane Emissions from the G&P Sectors

Comparison to EPA GHGI

Processing

2014 EPA Inventory of CH_4 emissions (Gg) f
operation is **851 Gg**, which is higher than ou

Majority of CH_4

Observations from the field campaign suggest differences in reciprocating and centrifugal compressor activity data:

- **3890 reciprocating**
- **1473 centrifugal**

Activity	Activity Data	Activity Units	Emissio Factor (Potentia					culated CH4 ns (Mg)	% Total Net Emissions
Normal Fugitives									
Plants	606	plants	7906	Scfd/ plant	33,680.5	(5,068.2)		28,612.3	3.21%
Reciprocating Comp.	5,624	compressors	11,196	Scfd/ comp	442,633.5	(66,606.5)		376,027.0	42.17%
Centrifugal Comp. (wet seals)	658	compressors	51,370	Scfd/ comp	237,724.1	(35,772.2)		201,951.9	22.65%
Centrifugal Comp. (dry seals)	248	compressors	25,189	Scfd/ comp	43,936.6	(6,611.5)		37,325.1	4.19%
Vented and Combusted									
Normal Operation									
Compressor Exhaust									
Gas Engines	40,403	MMHPhr/year	0.24	scf/HPhr	186,750.5	**(6,100.0)**		180,650.5	20.26%
Gas Turbines	47,907	MMHPhr/year	0.01	scf/HPhr	5,259.3	(791.4)		4,467.9	0.50%
AGR Vents	307	AGR units	6,083	scfd/AGR	13,134.2	(1,976.4)		11,157.8	1.25%
Kimray Pumps	1,463,675	MMscf/yr	178	scf/MMscf	5,010.8	(754.0)		4,256.8	0.48%
Dehydrator Vents	13,186,262	MMscf/yr	122	scf/MMscf	30,869.7	**(9,300.0)**	**(16,300.0)**	5,269.7	0.59%
Pneumatic Devices	606	plants	164,721	scfy/plant	1,922.6	(289.3)		1,633.3	0.18%
Routine Maintenance									
Blowdowns/Venting	606	plants	4,060	Mscfy/plant	47,386.5	(7,130.6)		40,255.9	4.51%
Regulatory Reductions (Gg)							**(16.3)**		
Voluntary Reductions (Gg)						**(140.4)**			
Total Reductions (Gg)									
Total Potential Emissions (Gg)					**1,048.3**				
Total Net Methane Emissions from Processing (Gg)								**891.6**	100%
Total Net Emission from Processing less Routine Maintenance (Gg)								**851.4**	

Methane Emissions from the G&P Sector

Comparison to EPA GHGI

Gathering. The 2014 EPA Greenhouse Gas Inventory (GHGI) embeds gathering systems (pipelines and facilities) within its natural gas production inventory.

Activity	Activity Data	Activity Units	Total Potential CH_4 Emissions (Mg)	2012 Voluntary Reductions (Mg)	2012 Regulatory Reductions (Mg)	2012 Net CH4 Emissions (Mg)	% Total Net Emissions
Field Separation Equipment							
Heaters	112,786	heaters	33,300	(12,437)		20,863	1.46%
Separators	276,938	separators	106,700	(39,850)		66,850	4.67%
Dehydrators	65,653	dehydrators	32,800	(12,250)		20,550	1.44%
Meters/Piping	398,662	meters	106,200	(39,663)		66,537	4.65%
Gathering Compressors							
Small Reciprocating Compressors	35,930	compressors	70,900	(26,480)		44,420	3.10%
Large Reciprocating Compressors	136	compressors	15,400	(5,752)		9,648	0.67%
Large Reciprocating Stations	17	stations	1,000	(373)		627	0.04%
Gathering Pipelines							
Pipeline Leaks	445,135	miles	175,500	-		175,500	12.26%
Pipeline Blowdowns	445,135	miles	2,800	(1,046)		1,754	0.12%
Mishaps	111,284	miles	1,500	(560)		940	0.07%
Normal Operation							
Pneumatic Device Vents	477,606	controllers	207,500	**(873.100)**		334,400	23.37%
Chemical Injection Pumps	44,637	active pumps	67,300	**(2,800)**		64,500	4.51%
Kimray Pumps	16,392,515	MMscf/year	388,400	(145,059)		243,341	17.00%
Dehydrator Vents	21,567,356	MMscf/year	121,100		**(38,900)**	82,200	5.74%
Compressor Exhaust							
Gas Engines	54,971	MMHPhr/year	265,700	**(139,900)**		125,800	8.79%
Condensate Tank Vents							
Without Control Devices	88	MMbbl/yr	187,700		**(60,300)**	127,400	8.90%
With Control Devices	88	MMbbl/yr	37,500			37,500	2.62%
Blowdowns							
Vessel Blowdowns	455,376	vessels	700	(261.43)		439	0.03%
Compressor Blowdowns	35,930	compressors	2,700	(1,008.39)		1,692	0.12%
Compressor Starts	35,930	compressors	6,100	**(500.0)**		5,600	0.39%
Upsets							
Pressure Relief Valves	1,050,977	PRV	700	(261.43)		439	0.03%
Regulatory Reductions (Gg)					**(99.2)**		
Voluntary Reductions (Gg)				**(1,301.3)**			
Total Potential Emissions from Shared Gathering and Production Categories (Gg)			**2,831.5**				
Total Net Emissions from Shared Gathering and Production Categories(Gg)						**1,431.0**	

A total of 1,431 Gg of

The model results for gathering facilities alone (1,697 Gg) are greater than all of the source categories common to both gathering and production in the EPA GHGI (1,431 Gg).

Methane Emissions from the G&P Sector

Comparison to EPA GHGI

Gathering. The 2014 EPA Greenhouse Gas Inventory (GHGI) embeds gathering systems (pipelines and facilities) within its natural gas production inventory.

Activity	Activity Data	Activity Units	Mass Emission Factor (Net)	Mass Emission Factor Units	2012 Net CH4 Emissions (Mg)	% Total Net Emissions for Gathering Sector	% Total Net Emissions for Gathering Facilities
Field Separation Equipment							
Heaters	***4,549***	heaters	0.1850	Mg/heater	841	0.21%	0.37%
Separators	***6,784***	separators	0.2414	Mg/sep	1,637	0.41%	0.73%
Dehydrators	***5,187***	dehydrators	0.3130	Mg/dehy	1,624	0.40%	0.72%
Meters/Piping	***13,886***	meters	0.1669	Mg/meter	2,318	0.57%	1.03%
Gathering Compressors							
Small Reciprocating Compressors	***25,575***	compressors	1.2363	Mg/comp	31,619	7.83%	14.00%
Large Reciprocating Compressors	136	compressors	70.9445	Mg/comp	9,648	2.39%	4.27%
Large Reciprocating Stations	17	stations	36.8543	Mg/station	627	0.16%	0.28%
Gathering Pipelines							
Pipeline Leaks	445,135	miles	0.3943	Mg/mile	175,500	43.44%	
Pipeline Blowdowns	445,135	miles	0.0039	Mg/mile	1,754	0.43%	
Mishaps	111,284	miles	0.0084	Mg/mile	940	0.23%	
Normal Operation							
Pneumatic Device Vents	***54,588***	controllers	0.7082	Mg/cont	38,220	9.46%	16.93%
Chemical Injection Pumps	***9,098***	active pumps	1.4450	Mg/pump	13,147	3.25%	5.82%
Kimray Pumps	***1,295,226***	MMscf/year	0.0148	Mg/MMscf	19,227	4.76%	8.52%
Dehydrator Vents	***1,704,107***	MMscf/year	0.0038	Mg/MMscf	6,495	1.61%	2.88%
Compressor Exhaust							
Gas Engines	***39,128***	MMHPhr/year	2.2885	Mg/MMHPhr	89,545	22.17%	39.66%
Condensate Tank Vents							
Without Control Devices	***3***	MMbbl/yr	1447.7273	Mg/MMbbl	4,343	1.08%	1.92%
With Control Devices	***3***	MMbbl/yr	426.1364	Mg/MMbbl	1,278	0.32%	0.57%
Blowdowns							
Vessel Blowdowns	***4,549***	vessels	0.0010	Mg/vessel	4	0.00%	0.00%
Compressor Blowdowns	***25,575***	compressors	0.0471	Mg/comp	1,204	0.30%	0.53%
Compressor Starts	***25,575***	compressors	0.1559	Mg/comp	3,986	0.99%	1.77%
Upsets							
Pressure Relief Valves	***13,647***	PRV	0.0004	Mg/PRV	6	0.00%	0.00%
Total Net Emissions from Gathering (Gg)					**404.0**		
Total Net Emissions from Gathering Facilities (Gg)					**225.8**		

The relatively small fraction of activity data assigned to "gathering" is consistent with Allen et al (2015) observations that suggest a high volume of equipment at production sites:

- **124,000 heaters**
- **495,000 separators**
- **36,000 dehydrators**
- **12,000 compressors**
- **1,608,000 pneumatic controllers**
- **247,000 liquid tanks**

Methane Emissions from the G&P Sectors
Comparison to EPA Programs

Comparison of national estimate of CH_4 emissions from U.S. natural gas gathering systems and processing plants with 2014 EPA Greenhouse Gas Inventory and 2013 EPA Greenhouse Gas Reporting Program.