Supporting Information

Measurements of methane emissions from natural gas gathering facilities and processing plants: measurement results

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A – Facility selection process

This section provides additional details on the facility selection process, including some discussion of potential biases. The facility selection was performed by the study team, using data and other information provided by the partner companies. The partner companies were only involved at discrete times during the process and were not involved in final facility selection.

The study team was provided a list of all five partner companies' G&P assets (>700 facilities) in August 2013. Their G&P assets were organized into 20 geographic clusters, which ranged in size from eight to 76 facilities. The number of sampling weeks per cluster was then defined to maximize coverage of geography and of gas types while considering logistics and the proportion of facilities owned by each partner company. To avoid oversampling of one company, the study team regularly examined the balance of sampled facilities and adjustments were made as needed to maintain this balance.

Approximately three weeks prior to conducting measurements in a particular geographic cluster, the study team performed an initial desktop screening of all G&P facilities in the target cluster. The screening process involved using aerial imagery (Google Earth) to remove facilities with limited road access on their periphery (0.5-2 km) or facilities that were located very near obvious potential sources of methane interference. The list of the remaining facilities, generally 1/3 to 1/2 of the original list for each cluster, was shared with partner companies. At times in this process, the study team sought feedback from the partner companies about potential issues with road access or potential sources of interference (e.g., non-partner natural gas facilities). The partner companies notified the study team of facilities that could not be sampled because of issues such as commissioning, decommissioning, transactions (sale of asset), construction or litigation. The output from this process was a prescreened list of facilities deemed suitable for tracer flux measurements in each cluster. Over the course of the field campaign the partner companies requested on fewer than 10 occasions that a facility not be sampled.

Final selection of most gathering facilities was made by the study team from the prescreened list the evening before or the day of sampling, considering road access, wind forecasts, and logistics. Selecting facilities "on the fly" greatly enhanced the success rate of the tracer teams (valid tracer flux data were obtained at 130 of the 136 facilities visited by the study team). The fact that most gathering facilities were selected "on the fly" also addresses questions about whether the study partners' operations personnel could have prepared their facilities for sampling. As discussed in the main text (and summarized in SI E, Table S5), adjustments were made on some facilities by company personnel as part of normal operations. Sampling at processing plants was scheduled in advance to align with operator and operations schedules. Processing plants were staffed 24/7, and some of the higher throughput gathering facilities had daytime operators.

There are a number of potential biases within the facility selection process. One potential source of bias is that study facilities were not chosen randomly. Random selection was not possible because many of the facilities lacked suitable roads on their periphery for the mobile lab. Gathering facilities deemed most suitable for tracer flux measurement based on downwind road access and meteorological conditions were selected in all cases. If the prospects for successful tracer flux measurement were the same at two facilities (in terms of interference and road access relative to wind), the study team also considered logistical factors (e.g., proximity to hotel). Any factors unrelated to the success of tracer flux measurement or the safety of the tracer teams were not considered the selection process.

This study would not have been possible without the facility access provided by the partner companies. This access allowed tracer gases to be release onsite, which reduces the uncertainty of the measured emission rates. The study partners also provided facility data such as methane throughput, gas composition, equipment census and other facility information used to analyze the results. However, it is important emphasize that the facility selection process was conducted by the study team, not the partner companies. Final decisions on facility selection were made by the study team.

In assessing the representativeness of the G&P facilities included in this study, an obvious consideration is the companies that participated in this study. The sum of gas gathered by the four partner companies with gathering facilities (about 5.9 trillion cubic feet) represents around a quarter of the marketed U.S. gas production in 2013 (26.7 trillion cubic feet).[1] Simple extrapolation (from the 738 gathering facilities owned by partner companies) suggests there are around 3,000 gas gathering facilities in the US. According to the Energy Information Administration 757 survey, there were 517 active processing plants in the lower-48 U.S. states in 2012.[2] The Oil & Gas Journal survey counted 606 processing plants in 2013.[3] While we cannot demonstrate that these five companies operate their facilities and control methane emissions in a manner that is representative of their peers, these companies do own a diverse set of G&P assets and operational practices appeared more closely related to geography (producing basin) than company. Differences among partner companies were examined by including a dummy variable for each company as an independent variable in the multiple linear least-squares regressions of ln-WAFLER (SI L). Statistically significant differences in ln-WAFLER were not found between any of the companies.

Another potential source of bias is due to the presence of collocated non-partner equipment (SI D). Other potential biases may exist at the cluster level. Weather conditions impacted company operations and the efficiency of the tracer teams. Unusually cold temperatures, brought on by repeated polar vortexes, occurred while sampling in some clusters. Cold weather protections were common in regions accustomed to freezing temperatures, these were much less common in others, potentially making certain equipment issues (e.g., frozen valves) more likely. Precipitation (rain, snow, and ice) and unfavorable wind conditions hampered tracer flux measurements in some clusters more than others, making facilities or downwind roads inaccessible at times.

B – Facility information collected by onsite observer

Table S1. Facility #, sampling date, state, year built, facility type, gas type, and gas composition for 130 G&P facilities reported in this study. Inlet gas composition is from the most recent gas chromatography analysis performed by study partners and is reported in mole fractions (mol/mol). Analysis dates ranged from a couple of days to a couple of years before the sampling date. Average mole fraction is reported for facilities with multiple inlets. NR indicates not recorded, usually because the value was unknown. (CBM = coal bed methane)

Facility #	Sampling date	State	Year Built	Facility Type	Gas Type	% CH_4	% C_2H_6	% C_3H_8	% C_4+	% CO_2	% N_2	% H_2S
1	2/6/2014	TX	2012	C	Shale	77.1	12.9	5.3	3.3	1.0	0.2	0.22
2	4/8/2014	UT	2004	C	Shale	90.7	5.1	1.8	1.4	0.9	0.1	-
3	2/13/2014	TX	2010	C	Tight Sands	91.2	4.1	1.0	1.0	1.5	1.2	-
4	2/13/2014	TX	NR	C	Conventional / Shale	96.3	1.9	0.4	0.4	0.8	0.3	<0.01
5	4/9/2014	UT	2012	C	Shale	87.1	5.8	1.9	1.5	1.0	2.8	-
6	4/9/2014	UT	NR	C	Shale	90.7	5.1	1.8	1.4	0.9	0.1	-
7	11/6/2013	WY	NR	C	Conventional	82.7	10.8	3.3	1.6	0.8	0.8	-
8	4/7/2014	UT	2004	C	Shale	90.7	5.1	1.8	1.4	0.9	0.1	-
9	1/29/2014	TX	2011	C	Shale	76.3	14.0	5.5	2.9	1.2	0.0	-
10	2/6/2014	TX	2011	C	Shale	70.3	14.8	7.3	4.9	2.0	0.4	0.40
11	12/4/2013	PA	2012	C	Shale	97.7	1.9	0.1	0.0	-	0.3	-
12	3/25/2014	NM	1990	C	Conventional	86.7	6.4	2.7	2.0	1.8	0.4	-
13	1/28/2014	TX	2011	C	Shale	73.5	14.3	6.0	4.5	1.0	0.7	-
14	2/12/2014	TX	2005	C	Tight Sands	96.9	0.3	0.0	0.0	2.2	0.6	-
15	2/19/2014	KS	1996	C	Conventional	73.8	6.8	4.3	2.9	0.1	11.7	-
16	4/14/2014	CO	1990	C	Shale	77.3	11.5	4.5	3.7	2.5	0.4	<0.01
17	3/17/2014	OK	1998	C	Conventional	85.3	7.7	3.5	2.8	0.3	0.4	<0.01
18	2/18/2014	KS	1997	C	Conventional	80.7	5.4	3.0	2.8	0.2	7.6	-
19	3/25/2014	NM	1990	C	Conventional	86.1	6.6	2.9	2.3	1.5	0.5	-
20	4/1/2014	WY	2009	C	CBM	81.8	0.4	-	-	16.9	0.9	<0.01
21	3/24/2014	OK	NR	C	Conventional	90.1	4.4	1.9	1.5	0.1	1.9	<0.01
22	2/14/2014	TX	NR	C	Conventional / Shale	95.8	0.5	0.0	-	3.3	0.4	<0.01
23	2/18/2014	KS	1997	C	Conventional	77.2	5.1	2.8	2.6	0.2	11.7	-
24	11/6/2013	WY	NR	C	Conventional	81.1	11.8	4.3	2.1	0.6	-	-
25	2/10/2014	TX	2008	C	Tight Sands	97.5	0.5	0.1	0.3	1.4	0.2	-
26	2/19/2014	KS	1996	C	Conventional	73.4	6.7	4.3	2.9	0.2	12.2	-
27	2/19/2014	KS	1996	C	Conventional	75.4	6.4	3.7	2.5	0.1	11.6	-
28	2/13/2014	TX	NR	C	Conventional / Shale	95.6	2.6	0.5	0.5	0.5	0.3	-
29	2/11/2014	TX	2008	C	Tight Sands	95.4	1.7	0.8	0.8	1.0	0.4	-
30	11/6/2013	WY	NR	C	Conventional	82.7†	10.8	3.5	1.8	0.7	0.5	-
31	3/18/2014	OK	1983	C	Conventional	90.8	3.8	2.0	2.1	0.3	1.1	<0.01
32	3/24/2014	OK	NR	C	Conventional	77.7	10.3	6.0	4.8	0.4	0.8	<0.01
33	2/19/2014	KS	1996	C	Conventional	74.7	6.5	3.8	2.5	0.1	12.0	<0.01
34	2/18/2014	KS	1997	C	Conventional	81.0	5.1	2.5	2.4	0.2	8.6	-
35	10/25/2013	TX	2008	C/D	Conventional	95.7	0.9	0.0	0.0	2.7	0.7	<0.01
36	3/27/2014	NM	1990	C/D	Shale	92.7	0.6	0.1	0.1	6.3	0.2	-
37	2/26/2014	AR	2007	C/D	CBM / Conventional	95.2	1.0	0.0	0.0	3.4	0.3	<0.01
38	2/6/2014	AR	2010	C/D	Shale	93.5	1.1	0.0	-	5.1	0.2	<0.01
39	2/24/2014	AR	NR	C/D	Shale	96.8	1.1	0.0	-	1.7	0.4	<0.01
40	2/11/2014	TX	2012	C/D	Shale	76.0	11.9	6.9	4.1	0.2	0.8	-
41	12/2/2013	NY	2010	C/D	Shale	97.7	1.9	0.1	0.0	0.0	0.3	-
42	3/26/2014	OK	2012	C/D	Shale	88.2	5.5	2.4	2.3	0.2	1.4	-
43	3/26/2014	OK	2013	C/D	Shale	85.3	6.9	3.1	2.8	0.2	1.7	-

Facility #	Sampling date	State	Year Built	Facility Type	Gas Type	% CH_4	% C_2H_6	% C_3H_8	% C_4+	% CO_2	% N_2	% H_2S
44	2/26/2014	AR	2010	C/D	Shale	94.7	1.1	0.0	0.0	3.9	0.3	<0.01
45	4/3/2014	NM	1992	C/D	Shale	79.5	1.2	0.3	0.1	18.9	0.1	-
46	12/3/2013	PA	2012	C/D	CBM	97.5	2.1	0.1	0.0	0.0	0.2	-
47	2/5/2014	AR	2009	C/D	Shale	96.7	1.3	0.0	-	1.6	0.3	<0.01
48	2/25/2014	AR	2009	C/D	Shale	97.7	1.4	0.0	-	0.7	0.2	<0.01
49	2/5/2014	AR	2010	C/D	Shale	97.0	1.3	0.0	-	1.5	0.2	<0.01
50	3/20/2014	TX	2005	C/D	Shale	78.8	10.5	5.2	4.0	0.5	0.9	<0.01
51	2/11/2014	TX	NR	C/D	Conventional	76.6	11.1	7.0	4.3	0.3	0.8	-
52	2/24/2014	AR	2009	C/D	Shale	96.3	1.3	0.0	-	2.0	0.3	<0.01
53	12/13/2013	PA	NR	C/D	Shale	95.8	2.5	0.3	0.3	0.2	0.8	-
54	3/28/2014	NM	1993	C/D	Conventional / Shale	79.3	0.9	0.2	0.1	19.6	0.1	-
55	10/24/2013	TX	2003	C/D	CBM	95.5	1.5	0.1	0.0	1.9	1.0	<0.01
56	10/23/2013	TX	2003	C/D	Shale	95.6	1.6	0.1	0.1	1.6	1.1	-
57	3/31/2014	NM	1990	C/D	Shale	92.5	1.7	0.4	0.3	5.0	0.1	-
58	2/3/2014	TX	2010	C/D	CBM / Conventional	79.3	11.7	5.1	2.8	0.9	0.1	-
59	10/25/2013	TX	2008	C/D	Shale	95.7	0.9	0.0	0.0	2.7	0.7	<0.01
60	4/2/2014	WY	2000	C/D	Shale	92.9	0.0	-	-	4.6	2.4	<0.01
61	2/5/2014	TX	2011	C/D	CBM	75.9	13.3	5.5	3.8	1.4	0.1	-
62	2/3/2014	AR	2006	C/D	Shale	95.1	1.3	0.0	-	3.4	0.2	<0.01
63	3/25/2014	OK	NR	C/D	Shale	85.3	7.9	3.4	2.1	0.9	0.4	<0.01
64	12/5/2013	PA	NR	C/D	Conventional	97.2	2.4	0.1	0.0	0.0	0.3	-
65	4/16/2014	CO	2009	C/D	Shale	70.2	14.7	7.2	4.5	2.6	0.6	-
66	12/12/2013	PA	NR	C/D	Shale	96.4	2.4	0.2	0.2	0.2	0.5	-
67	3/27/2014	OK	2008	C/D	Conventional	90.5	4.5	1.9	2.0	0.3	0.8	-
68	3/27/2014	NM	1990	C/D	Shale	84.5	0.6	0.1	0.1	14.7	0.1	-
69	2/25/2014	AR	2010	C/D	CBM / Conventional	97.0	1.4	0.0	-	1.4	0.2	<0.01
70	3/20/2014	OK	1983	C/D	Shale	83.8	8.9	3.4	2.6	0.5	0.8	-
71	4/17/2014	CO	2013	C/D	Conventional	67.7	14.0	9.1	5.2	2.5	1.3	-
72	3/27/2014	OK	2010	C/D	Shale	92.8	4.0	1.5	1.5	0.2	-	-
73	2/27/2014	AR	2008	C/D	Shale	96.1	1.1	0.0	-	2.5	0.2	<0.01
74	4/1/2014	WY	NR	C/D	Shale	92.3	0.1	-	-	4.4	3.2	-
75	10/29/2013	WY	1992	C/D	CBM	88.1	6.1	2.7	2.0	0.6	0.5	-
76	2/7/2014	AR	2011	C/D	Conventional	96.6	1.2	0.0	-	1.7	0.4	<0.01
77	2/12/2014	TX	2008	C/D	Shale	97.5	0.2	0.0	0.1	1.7	0.5	-
78	3/19/2014	OK	1986	C/D	Tight Sands	87.3	5.4	2.2	2.4	0.8	1.8	<0.01
79	3/18/2014	OK	2006	C/D	Conventional	95.5	2.4	0.6	0.4	0.7	0.4	<0.01
80	2/14/2014	TX	2004	C/D	Tight Sands	97.7	0.4	0.0	0.1	1.4	0.4	-
81	11/7/2013	WY	1958	C/D	Conventional	88.1	6.3	2.6	1.7	0.6	0.7	-
82	4/2/2014	WY	2011	C/D	Conventional	70.0	13.3	7.9	6.6	1.5	0.6	<0.01
83	10/22/2013	TX	2008	C/D	Shale	94.9	2.6	0.2	0.3	1.5	0.7	-
84	2/14/2014	TX	1996	C/D	Tight Sands	96.5	1.1	0.2	0.4	1.5	0.3	-
85	3/28/2014	NM	1990	C/D	CBM	76.7	1.7	0.6	0.4	20.6	0.1	-
86	3/19/2014	OK	2005	C/D	Conventional	85.3	7.4	3.2	2.4	0.8	0.9	<0.01
87	1/27/2014	TX	2011	C/D	Shale	64.7	18.4	10.0	5.8	1.1	0.1	-
88	12/11/2013	PA	NR	C/D	Conventional	95.2	3.2	0.5	0.3	0.1	0.6	-
89	3/24/2014	NM	1994	C/D	CBM	83.9	0.6	0.1	0.0	15.4	0.1	-
90	12/11/2013	PA	NR	C/D	Shale	97.0	2.2	0.1	-	0.4	0.2	-
91	10/22/2013	TX	2007	C/D	Shale	95.9	1.9	0.1	0.1	1.5	0.6	-
92	12/16/2013	WV	2010	C/D	Shale	74.0	16.3	5.8	3.4	0.2	0.4	-
93	11/5/2013	WY	NR	C/D	Conventional	83.8	7.6	3.3	2.2	3.0	0.2	-
94	2/3/2014	TX	2011	C/D	Shale	75.9	13.2	5.7	3.7	1.3	0.2	-
95	2/26/2014	AR	2009	C/D	Shale	95.8	1.0	0.0	-	2.7	0.5	<0.01
96	2/10/2014	TX	2007	C/D	Tight Sands	97.9	0.4	0.0	0.1	1.5	0.2	-
97	12/9/2013	PA	NR	C/D	Conventional	92.5	3.5	0.5	0.3	0.1	3.2	-
98	4/16/2014	CO	2011	C/D	Shale	67.5	13.9	8.1	6.9	2.5	1.0	-
99	12/17/2013	WV	2010	C/D	Shale	77.0	15.1	4.9	2.4	0.1	0.5	-

Facility #	Sampling date	State	Year Built	Facility Type	Gas Type	% CH_4	% C_2H_6	% C_3H_8	% C_4+	% CO_2	% N_2	% H_2S
100	3/17/2014	OK	2007	C/D	Conventional	84.3	4.9	3.2	2.7	0.1	4.9	<0.01
101	3/21/2014	OK	1983	C/D	Shale	93.4	3.3	1.1	0.8	1.0	0.3	<0.01
102	2/4/2014	TX	2011	C/D/T	Shale	76.5	13.2	5.7	3.2	1.1	0.2	0.06
103	1/27/2014	TX	2010	C/D/T	Shale	74.2	14.4	6.3	4.1	1.0	0.1	<0.01
104	2/12/2014	TX	2013	C/D/T	Shale	76.3†	11.5	7.0	4.2	0.2	0.8	-
105	4/7/2014	UT	2012	C/D/T	Shale	89.8†	5.3	1.8	1.4	0.9	0.8	-
106	4/9/2014	UT	NR	C/D/T	Shale	89.8†	5.3	1.8	1.4	0.9	0.8	-
107	1/28/2014	TX	2011	C/D/T	Conventional	74.2†	14.4	6.3	4.1	1.0	0.1	-
108	1/28/2014	TX	2012	C/D/T	Shale	74.2	14.4	6.3	4.1	1.0	0.1	-
109	1/31/2014	TX	2009	C/D/T	Shale	72.7	14.9	6.8	3.3	1.8	0.6	NR
110	11/5/2013	WY	NR	D	Conventional	80.7	8.7	4.3	3.4	2.8	0.2	-
111	12/6/2013	PA	NR	D	Shale	97.3	2.3	0.1	0.0	0.0	0.3	-
112	12/17/2013	WV	2010	D	Shale	76.1	15.9	5.1	2.0	0.0	0.5	-
113	12/10/2013	PA	2011	D	Shale	97.9	1.4	0.1	-	0.4	0.2	-
114	12/4/2013	PA	NR	D	Shale	97.4	2.2	0.1	0.0	0.0	0.3	-
115	3/26/2014	NM	1990	D/T	CBM	88.4	0.9	0.2	0.1	9.4	0.9	-
116	4/11/2014	CO	NR	P	Shale	89.3	5.1	1.3	1.0	3.1	0.1	-
117	2/20/2014	LA	1997	P	Offshore	86.5	6.3	4.0	2.8	0.7	0.3	-
118	11/8/2013	WY	1958	P	Conventional	87.5	7.4	2.4	1.4	0.8	0.6	-
119	4/1/2014	CO	1954	P	CBM / Conventional	89.5	3.6	1.5	1.1	4.1	0.2	-
120	4/2/2014	NM	1948	P	Conventional	87.1	6.7	2.5	1.7	1.6	0.3	-
121	3/31/2014	WY	1950	P	Conventional	61.9	15.0	10.9	9.4	1.5	1.3	<0.01
122	4/15/2014	CO	1974	P	Shale	75.5	13.3	5.7	2.6	2.5	0.4	-
123	3/20/2014	CO	2009	P	Shale	69.0	14.4	6.1	-	2.6	0.2	-
124	10/30/2013	WY	1986	P	Conventional	88.1†	6.1	2.7	2.0	0.6	0.5	-
125	12/18/2013	WV	2013	P	Shale	80.6	13.0	3.9	2.0	0.2	0.4	-
126	11/4/2013	WY	1993	P	Conventional	83.2	7.9	3.4	2.2	3.0	0.2	-
127	4/10/2014	CO	NR	P	Shale	90.8	5.5	1.4	1.2	1.0	0.1	-
128	2/17/2014	TX	2001	P	Offshore / Shale	84.5	8.5	3.5	2.2	0.9	0.2	-
129	2/21/2014	AL	1999	P	Offshore / Shale	91.1	4.3	2.0	1.5	0.9	0.2	-
130	1/30/2014	TX	2013	P	Shale	75.7	13.3	5.8	4.1	1.1	0.1	-
131	4/3/2014	WY	1982	P	Conventional	58.9	12.1	13.9	12.6	1.0	1.4	<0.01

†Gas composition data were unavailable. Mol% values were estimated from one or more proximal study G&P facilities.

Table S2. Facility throughput (2012 and 2013 average, and day of sampling), facility capacity, inlet and outlet pressures, number of dehydration units (of any type), and total number of gas pneumatics (sum of all low, high, and continuous bleed counted). Air indicates compressed air used by pneumatic devices. Natural gas capacity data were, in some cases, approximated by company representative and may not be accurate. NR indicates not recorded, usually because the value was unknown. (t/hr = tonnes per hour[1])

Facility #	Facility Type	Facility natural gas throughput (t/hr, 2012 average)	Facility natural gas throughput (t/hr, 2013 average)	Facility natural gas throughput (t/hr, day of sampling)	Facility natural gas capacity (t/hr)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	# Dehydration Units	# Gas pneumatics
1	C	24.1	19.0	29.7	48.2	390	7,160	1	70
2	C	19.7	17.3	16.1	24.1	460	2,520	-	Air
3	C	0.2	0.2	0.5	NR	570	4,100	-	8
4	C	5.6	7.1	-	NR	470	6,130	-	13
5	C	23.9	NR	16.1	24.1	460	2,940	-	8
6	C	23.4	24.9	28.9	32.1	490	2,810	-	Air
7	C	NR	4.9	5.1	NR	1,230	4,510	-	4
8	C	17.1	NR	5.1	22.5	460	2,470	-	Air
9	C	8.9	13.1	8.4	NR	280	6,580	-	38
10	C	9.6	8.0	11.8	18.5	590	3,340	-	40
11	C	350.8	436.4	487.1	601.9	6,590	9,500	-	Air
12	C	51.0	48.3	47.3	NR	1,430	2,790	-	1
13	C	9.2	NR	5.1	14.4	290	6,680	-	22
14	C	4.0	3.3	0.2	NR	300	5,720	1	18
15	C	2.6	2.5	2.2	5.6	60	440	-	1
16	C	15.0	8.3	16.2	20.1	460	1,520	-	Air
17	C	2.8	2.4	4.9	4.8	310	3,070	-	2
18	C	2.6	2.4	2.6	4.8	110	1,540	-	7
19	C	2.1	1.8	1.6	NR	370	1,680	-	7
20	C	2.8	2.6	1.8	NR	110	570	-	1
21	C	0.4	0.3	0.6	0.8	280	3,350	-	6
22	C	1.2	1.4	0.5	NR	770	3,390	-	8
23	C	2.8	2.6	2.2	6.4	180	1,650	-	3
24	C	NR	4.8	5.5	NR	1,260	4,580	-	4
25	C	0.3	0.2	0.3	NR	690	6,990	-	4
26	C	3.2	3.1	3.0	4.0	60	590	-	-
27	C	4.2	4.1	3.6	6.4	50	390	-	-
28	C	0.8	1.0	-	NR	580	-	-	8
29	C	0.6	0.5	0.5	NR	810	5,630	-	10
30	C	NR	53.0	52.1	NR	880	2,500	-	Air
31	C	0.8	0.7	0.8	NR	240	590	-	15
32	C	0.2	0.2	-	0.8	230	230	-	5
33	C	1.0	1.0	1.0	2.0	60	460	-	-
34	C	1.2	1.3	1.3	2.0	30	370	-	1
35	C/D	12.0	10.8	7.7	8.0	680	4,980	1	-
36	C/D	10.3	10.1	34.1	57.8	720	6,300	5	-
37	C/D	12.8	10.4	25.7	32.1	350	7,680	2	-
38	C/D	25.7	23.3	20.9	27.3	300	6,560	2	38
39	C/D	55.9	50.9	52.2	57.8	350	8,030	3	-
40	C/D	6.9	10.7	10.5	NR	320	6,930	1	13
41	C/D	NR	NR	165.3	184.6	6,990	6,520	3	Air
42	C/D	16.1	20.1	28.1	NR	300	7,540	1	29
43	C/D	9.6	8.0	22.5	NR	230	7,130	1	29
44	C/D	32.1	26.5	35.3	38.5	350	7,680	2	-
45	C/D	7.0	6.4	18.9	NR	1,490	6,690	1	-

Facility #	Facility Type	Facility natural gas throughput (t/hr, 2012 average)	Facility natural gas throughput (t/hr, 2013 average)	Facility natural gas throughput (t/hr, day of sampling)	Facility natural gas capacity (t/hr)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	# Dehydration Units	# Gas pneumatics
46	C/D	120.4	135.6	233.9	296.1	7,360	7,400	3	3
47	C/D	34.8	32.5	30.1	32.1	420	8,010	1	38
48	C/D	23.8	17.7	37.7	44.9	330	7,750	2	-
49	C/D	51.4	44.1	23.8	32.1	320	7,580	3	43
50	C/D	13.6	12.4	22.5	24.1	500	3,200	1	33
51	C/D	11.4	9.2	8.0	28.1	290	6,990	2	14
52	C/D	25.7	24.1	24.1	24.1	410	8,370	1	-
53	C/D	8.5	8.4	8.0	NR	280	5,610	1	19
54	C/D	4.1	3.4	18.0	24.1	740	6,400	2	23
55	C/D	52.2	50.6	48.4	NR	770	5,960	1	49
56	C/D	20.1	20.9	17.7	NR	540	6,230	2	10
57	C/D	33.7	38.9	38.2	40.1	1,470	1,800	2	-
58	C/D	9.6	9.6	18.9	26.5	3,060	7,120	2	26
59	C/D	12.0	10.8	7.7	8.0	680	4,980	1	-
60	C/D	5.0	3.8	3.2	NR	480	7,680	1	5
61	C/D	7.2	7.2	7.5	14.0	660	6,820	1	33
62	C/D	22.0	21.2	23.3	24.1	450	6,850	1	24
63	C/D	0.4	0.3	0.3	0.8	920	6,520	1	10
64	C/D	240.8	256.8	410.1	505.6	6,570	7,600	5	Air
65	C/D	10.1	23.0	30.5	32.1	1,060	7,690	1	Air
66	C/D	5.0	8.0	7.3	NR	280	5,050	1	25
67	C/D	3.2	1.8	1.8	NR	230	6,820	1	18
68	C/D	6.1	5.3	13.3	19.3	680	6,300	4	-
69	C/D	19.3	13.6	14.4	19.3	330	6,990	1	-
70	C/D	9.6	11.2	12.4	16.1	540	2,990	1	15
71	C/D	NR	1.0	7.1	16.1	390	7,320	1	Air
72	C/D	8.8	7.2	4.2	NR	360	7,150	1	25
73	C/D	9.1	10.8	8.8	8.8	430	7,160	1	21
74	C/D	4.6	4.6	2.4	12.8	460	8,720	1	5
75	C/D	10.0	9.1	8.0	10.4	290	7,270	1	32
76	C/D	32.1	22.3	22.6	27.3	340	6,620	1	28
77	C/D	2.0	1.8	2.9	NR	1,610	4,420	1	18
78	C/D	0.4	0.3	0.2	0.8	300	7,340	1	15
79	C/D	4.0	4.0	4.6	5.6	570	3,780	1	26
80	C/D	0.9	0.8	0.6	1.6	410	6,160	1	7
81	C/D	NR	89.9	30.3	NR	450	4,430	1	Air
82	C/D	3.5	8.1	4.8	5.6	110	3,540	1	11
83	C/D	44.1	41.7	40.6	NR	1,080	6,310	2	Air
84	C/D	2.2	2.0	2.3	3.0	630	6,650	1	21
85	C/D	5.6	5.4	5.2	10.4	640	2,380	2	-
86	C/D	1.2	4.1	3.6	5.6	1,130	6,650	1	31
87	C/D	1.6	4.4	8.0	10.4	370	6,600	2	21
88	C/D	7.2	4.5	4.3	NR	330	5,960	1	15
89	C/D	12.5	11.5	9.5	16.9	910	6,270	4	43
90	C/D	48.8	78.6	96.3	NR	1,130	6,300	2	Air
91	C/D	12.0	12.4	12.4	NR	1,100	5,960	1	9
92	C/D	NR	8.7	0.4	4.0	6,660	6,660	1	3
93	C/D	101.1	101.1	108.3	NR	1,820	6,650	1	-
94	C/D	0.1	0.1	0.014	0.5	540	7,680	1	17
95	C/D	25.7	21.7	27.3	25.7	460	7,680	2	-
96	C/D	0.3	0.2	0.2	NR	370	3,200	1	8
97	C/D	0.2	0.1	0.1	NR	510	2,850	1	-
98	C/D	1.1	1.0	0.8	2.8	190	1,270	1	Air
99	C/D	NR	1.4	0.6	4.0	6,270	6,270	1	8

Facility #	Facility Type	Facility natural gas throughput (t/hr, 2012 average)	Facility natural gas throughput (t/hr, 2013 average)	Facility natural gas throughput (t/hr, day of sampling)	Facility natural gas capacity (t/hr)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	# Dehydration Units	# Gas pneumatics
100	C/D	0.1	0.1	-	0.0	2,990	-	1	2
101	C/D	0.2	0.2	-	NR	200	-	1	15
102	C/D/T	16.1	12.8	48.2	NR	5,020	6,990	1	Air
103	C/D/T	95.3	NR	321.0	NR	4,920	6,990	5	Air
104	C/D/T	NR	4.8	15.2	20.1	640	7,560	1	5
105	C/D/T	65.1	66.7	68.0	80.3	1,250	6,710	2	Air
106	C/D/T	54.5	51.6	50.1	184.6	1,200	6,570	2	Air
107	C/D/T	9.7	17.1	8.8	NR	300	7,210	1	14
108	C/D/T	9.7	17.1	9.6	12.0	330	6,990	1	27
109	C/D/T	1.6	1.2	1.1	1.6	440	2,160	1	1
110	D	4.5	4.3	6.8	NR	2,580	2,580	1	6
111	D	80.3	85.9	3.3	168.5	7,720	7,720	3	16
112	D	NR	2.6	0.5	4.0	6,300	6,300	1	2
113	D	9.6	5.6	4.0	8.0	4,370	4,370	1	19
114	D	NR	6.8	NR	NR	5,610	5,610	2	21
115	D/T	382.0	325.8	256.8	521.6	6,300	6,160	5	Air
116	P	599.5	521.6	503.2	722.3	5,250	8,450	5	Air
117	P	227.9	186.2	158.1	481.5	5,140	5,460	1	Air
118	P	NR	1020.0	780.4	1,163.6	2,030	5,010	1	Air
119	P	363.5	341.9	344.3	NR	2,320	5,540	2	-
120	P	127.1	119.1	109.1	172.5	3,960	3,220	1	Air
121	P	22.1	25.9	33.6	40.1	120	7,080	1	Air
122	P	60.6	70.6	164.5	353.1	3,340	5,440	1	8
123	P	128.4	NR	124.4	128.4	750	5,540	1	Air
124	P	120.6	99.3	164.5	164.5	2,160	5,960	1	Air
125	P	190.2	172.5	270.4	417.3	6,780	6,360	9	Air
126	P	468.7	435.0	492.7	573.8	700	4,690	-	Air
127	P	368.3	370.8	389.2	361.1	7,560	8,340	-	Air
128	P	NR	NR	213.5	401.3	6,320	4,510	1	Air
129	P	256.8	212.7	168.8	481.5	6,870	6,650	1	7
130	P	NR	NR	154.9	160.5	6,820	7,030	2	Air
131	P	1.4	1.3	1.6	2.4	110	2,580	1	-

[1] based on 19.26 grams per standard cubic foot CH_4 at 15.6°C and 1 atmosphere[4]

Table S3. Total and operating horsepower of gas powered reciprocating engines and turbines; census of operating (OP), non-operating pressurized (NOP), and non-operating depressurized (NOD) compressors. Notes on primary driver(s) include engine characteristics (lean and rich burn, two stroke (2-S), and four stroke (4-S)), turbine type, and electric motor. The number of each driver type and operating status are given in parenthesis when noted by onsite observer. NR indicates not recorded, usually because the value or information was unknown.

Facility #	Facility Type	Engine HP (total)	Engine HP (OP)	Turbine HP (total)	Turbine HP (OP)	# Recip compressors (OP - NOP - NOD)	# Cent compressors (OP - NOP - NOD)	Notes on primary driver(s)
1	C	13,800	6,900	-	-	5 - 2 - 3	0 - 0 - 0	4-S ultra lean burn
2	C	4,305	3,040	-	-	2 - 1 - 0	0 - 0 - 0	4-S lean burn
3	C	145	145	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
4	C	3,600	2,400	-	-	2 - 0 - 1	0 - 0 - 0	4-S lean burn
5	C	5,060	3,795	-	-	3 - 0 - 1	0 - 0 - 0	4-S lean burn
6	C	6,195	6,195	-	-	4 - 0 - 0	0 - 0 - 0	4-S lean burn
7	C	1,480	1,480	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
8	C	3,795	3,795	-	-	3 - 0 - 0	0 - 0 - 0	4-S lean burn
9	C	4,800	3,600	-	-	3 - 0 - 1	0 - 0 - 0	4-S lean burn
10	C	4,110	4,110	-	-	3 - 0 - 0	0 - 0 - 0	4-S lean burn
11	C	4,155	-	15,400	15,400	0 - 3 - 0	2 - 0 - 0	4-S lean burn (3); Solar Taurus (2)
12	C	-	-	5,840	4,500	0 - 0 - 0	2 - 0 - 1	Solar turbines
13	C	4,800	2,400	-	-	2 - 0 - 2	0 - 0 - 0	4-S lean burn
14	C	1,875	1,875	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
15	C	2,400	2,400	-	-	2 - 0 - 0	0 - 0 - 0	4-S rich burn
16	C	2,400	2,400	-	-	2 - 0 - 0	0 - 0 - 0	4-S lean burn
17	C	1,350	1,350	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
18	C	1,200	1,200	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
19	C	716	716	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
20	C	1,637	1,000	-	-	1 - 0 - 1	0 - 0 - 0	4-S lean burn
21	C	NR	NR	-	-	1 - 0 - 0	0 - 0 - 0	2-S engine
22	C	180	90	-	-	1 - 1 - 0	0 - 0 - 0	4-S lean burn
23	C	1,900	1,900	-	-	2 - 0 - 0	0 - 0 - 0	4-S rich burn
24	C	1,480	1,480	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
25	C	80	80	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
26	C	1,500	1,500	-	-	2 - 0 - 0	0 - 0 - 0	4-S rich burn
27	C	2,250	1,500	-	-	2 - 0 - 1	0 - 0 - 0	4-S rich burn
28	C	90	-	-	-	0 - 1 - 0	0 - 0 - 0	4-S lean burn
29	C	335	335	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
30	C	-	-	7,700	7,700	0 - 0 - 0	1 - 0 - 0	Solar Taurus 60
31	C	145	145	-	-	1 - 0 - 0	0 - 0 - 0	4-S rich burn
32	C	NR	-	-	-	0 - 1 - 0	0 - 0 - 0	4-S rich burn
33	C	650	650	-	-	1 - 0 - 0	0 - 0 - 0	4-S rich burn
34	C	1,000	1,000	-	-	1 - 0 - 0	0 - 0 - 0	4-S rich burn
35	C/D	3,450	2,300	-	-	2 - 1 - 0	0 - 0 - 0	4-S rich burn
36	C/D	14,927	8,142	-	-	6 - 0 - 5	0 - 0 - 0	4-S lean burn
37	C/D	8,875	7,100	-	-	4 - 1 - 0	0 - 0 - 0	4-S lean burn
38	C/D	10,650	8,875	-	-	5 - 1 - 0	0 - 0 - 0	4-S lean burn
39	C/D	15,540	15,540	-	-	9 - 0 - 0	0 - 0 - 0	4-S lean burn
40	C/D	4,800	3,600	-	-	3 - 0 - 1	0 - 0 - 0	4-S lean burn
41	C/D	10,060	5,325	-	-	3 - 1 - 0	0 - 0 - 0	4-S lean burn
42	C/D	8,875	8,875	-	-	5 - 0 - 0	0 - 0 - 0	4-S lean burn
43	C/D	5,520	4,140	-	-	3 - 1 - 0	0 - 0 - 0	4-S ultra lean burn
44	C/D	10,650	10,650	-	-	6 - 0 - 0	0 - 0 - 0	4-S lean burn
45	C/D	6,000	4,000	-	-	4 - 0 - 2	0 - 0 - 0	4-S lean burn
46	C/D	10,650	7,100	-	-	2 - 1 - 0	0 - 0 - 0	4-S lean burn
47	C/D	9,780	9,780	-	-	6 - 0 - 0	0 - 0 - 0	4-S lean burn

Facility #	Facility Type	Engine HP (total)	Engine HP (OP)	Turbine HP (total)	Turbine HP (OP)	# Recip compressors (OP - NOP - NOD)	# Cent compressors (OP - NOP - NOD)	Notes on primary driver(s)
48	C/D	11,990	11,990	-	-	7 - 0 - 0	0 - 0 - 0	4-S lean burn
49	C/D	14,200	10,650	-	-	6 - 2 - 0	0 - 0 - 0	4-S lean burn
50	C/D	4,050	4,050	-	-	3 - 0 - 0	0 - 0 - 0	4-S lean burn
51	C/D	8,400	2,400	-	-	2 - 0 - 5	0 - 0 - 0	4-S lean burn
52	C/D	7,100	7,100	-	-	4 - 0 - 0	0 - 0 - 0	4-S lean burn
53	C/D	4,340	3,000	-	-	1 - 0 - 1	0 - 0 - 0	4-S lean burn (1); Electric (1)
54	C/D	6,785	5,428	-	-	4 - 0 - 1	0 - 0 - 0	4-S lean burn
55	C/D	13,210	13,210	-	-	9 - 0 - 0	0 - 0 - 0	4-S lean burn (6); 4-S rich burn (3)
56	C/D	6,100	4,600	-	-	3 - 1 - 0	0 - 0 - 0	4-S rich burn
57	C/D	2,714	2,714	-	-	2 - 0 - 0	0 - 0 - 0	4-S lean burn
58	C/D	4,800	3,600	-	-	3 - 0 - 1	0 - 0 - 0	4-S lean burn
59	C/D	3,450	2,300	-	-	2 - 1 - 0	0 - 0 - 0	4-S rich burn
60	C/D	3,260	1,680	-	-	1 - 0 - 1	0 - 0 - 0	4-S rich burn
61	C/D	4,060	2,720	-	-	2 - 0 - 1	0 - 0 - 0	4-S lean burn
62	C/D	6,230	6,230	-	-	4 - 0 - 0	0 - 0 - 0	4-S lean burn
63	C/D	350	350	-	-	1 - 0 - 0	0 - 0 - 0	2-S engine
64	C/D	17,750	14,200	-	-	4 - 1 - 0	0 - 0 - 0	4-S lean burn
65	C/D	7,050	7,050	-	-	3 - 0 - 0	0 - 0 - 0	4-S lean burn
66	C/D	4,180	2,840	-	-	2 - 0 - 1	0 - 0 - 0	4-S lean burn (2); Electric (1 OP)
67	C/D	2,600	1,300	-	-	1 - 1 - 0	0 - 0 - 0	4-S lean burn
68	C/D	6,785	4,071	-	-	3 - 0 - 2	0 - 0 - 0	4-S lean burn
69	C/D	5,325	5,325	-	-	3 - 0 - 0	0 - 0 - 0	4-S lean burn
70	C/D	4,050	1,350	-	-	1 - 0 - 2	0 - 0 - 0	4-S lean burn
71	C/D	3,550	3,550	-	-	2 - 0 - 0	0 - 0 - 0	4-S lean burn
72	C/D	5,200	2,600	-	-	2 - 2 - 0	0 - 0 - 0	4-S lean burn
73	C/D	2,680	2,680	-	-	2 - 0 - 0	0 - 0 - 0	4-S lean burn
74	C/D	3,110	1,430	-	-	1 - 0 - 1	0 - 0 - 0	4-S lean burn
75	C/D	3,000	3,000	-	-	3 - 0 - 0	0 - 0 - 0	4-S rich burn
76	C/D	7,100	7,100	-	-	4 - 0 - 0	0 - 0 - 0	4-S lean burn
77	C/D	1,340	1,340	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
78	C/D	1,340	1,340	-	-	1 - 0 - 0	0 - 0 - 0	4-S rich burn
79	C/D	1,380	1,380	-	-	1 - 0 - 0	0 - 0 - 0	4-S rich burn
80	C/D	400	400	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
81	C/D	-	-	15,530	15,530	0 - 0 - 0	3 - 0 - 0	Solar Centaur
82	C/D	3,059	3,059	-	-	3 - 0 - 0	0 - 0 - 0	4-S rich burn
83	C/D	7,200	6,090	-	-	5 - 1 - 0	0 - 0 - 0	4-S rich burn (4); 4-S lean burn (2)
84	C/D	635	635	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
85	C/D	1,357	1,357	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
86	C/D	1,350	1,350	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
87	C/D	3,030	2,400	-	-	2 - 0 - 1	0 - 0 - 0	4-S lean burn
88	C/D	2,750	1,375	-	-	1 - 1 - 0	0 - 0 - 0	4-S lean burn
89	C/D	5,000	2,000	-	-	2 - 0 - 3	0 - 0 - 0	4-S lean burn
90	C/D	8,280	-	15,000	15,000	0 - 0 - 6	1 - 0 - 0	4-S lean burn (6); Solar turbine (1)
91	C/D	2,600	2,600	-	-	2 - 0 - 0	0 - 0 - 0	4-S lean burn
92	C/D	90	-	-	-	0 - 0 - 1	0 - 0 - 0	4-S rich burn
93	C/D	-	-	15,000	15,000	0 - 0 - 0	1 - 0 - 0	Solar Mars
94	C/D	90	90	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
95	C/D	7,100	7,100	-	-	4 - 0 - 0	0 - 0 - 0	4-S lean burn
96	C/D	68	68	-	-	1 - 0 - 0	0 - 0 - 0	4-S lean burn
97	C/D	169	169	-	-	1 - 0 - 0	0 - 0 - 0	4-S rich burn
98	C/D	1,350	750	-	-	1 - 1 - 0	0 - 0 - 0	4-S lean burn
99	C/D	415	-	-	-	0 - 0 - 1	0 - 0 - 0	4-S rich burn
100	C/D	95	-	-	-	0 - 1 - 0	0 - 0 - 0	4-S rich burn
101	C/D	145	-	-	-	0 - 1 - 0	0 - 0 - 0	2-S lean burn
102	C/D/T	4,095	4,095	-	-	3 - 0 - 0	0 - 0 - 0	4-S lean burn
103	C/D/T	1,500	-	10,000	10,000	0 - 0 - 1	2 - 0 - 0	4-S lean burn; Turbines (2)

Facility #	Facility Type	Engine HP (total)	Engine HP (OP)	Turbine HP (total)	Turbine HP (OP)	# Recip compressors (OP - NOP - NOD)	# Cent compressors (OP - NOP - NOD)	Notes on primary driver(s)
104	C/D/T	4,800	4,800	-	-	4 - 0 - 0	0 - 0 - 0	4-S lean burn
105	C/D/T	5,060	5,060	-	-	6 - 0 - 0	0 - 0 - 0	4-S lean burn (4); Electric (2)
106	C/D/T	13,780	13,780	-	-	5 - 0 - 0	0 - 0 - 0	4-S lean burn (2); Electric (3)
107	C/D/T	4,800	3,600	-	-	3 - 0 - 1	0 - 0 - 0	4-S lean burn
108	C/D/T	4,800	4,800	-	-	4 - 0 - 0	0 - 0 - 0	4-S lean burn
109	C/D/T	670	-	-	-	0 - 1 - 0	0 - 0 - 0	4-S lean burn
110	D	-	-	-	-	0 - 0 - 0	0 - 0 - 0	None
111	D	-	-	-	-	0 - 0 - 0	0 - 0 - 0	None
112	D	-	-	-	-	0 - 0 - 0	0 - 0 - 0	None
113	D	-	-	-	-	0 - 0 - 0	0 - 0 - 0	None
114	D	-	-	-	-	0 - 0 - 0	0 - 0 - 0	None
115	D/T	-	-	-	-	0 - 0 - 0	0 - 0 - 0	Turbines (2), not for compression
116	P	45,065	43,800	-	-	11 - 9 - 0	0 - 0 - 0	4-S lean burn (8 OP, 1 NOP or NOD); 2-S lean burn (8 NOP or NOD); Electric (3 OP)
117	P	14,677	4,773	48,000	16,000	3 - 7 - 0	1 - 2 - 0	4-S lean burn; Solar turbines
118	P	-	-	126,310	85,665	1 - 1 - 0	8 - 3 - 0	NR
119	P	50,000	35,714	10,000	6,667	5 - 0 - 2	2 - 0 - 1	NR
120	P	-	-	25,623	21,931	0 - 0 - 0	8 - 0 - 1	Turbines (9)
121	P	13,938	12,258	-	-	8 - 0 - 1	0 - 0 - 0	4-S lean burn (12 OP); 2-S engines (2 OP); Generators (6) not included in horsepower
122	P	9,828	9,828	-	-	10 - 0 - 0	0 - 0 - 0	4-S lean burn (5); Electric
123	P	22,400	19,200	-	-	8 - 1 - 0	0 - 0 - 0	4-S lean burn; Electric (2)
124	P	11,436	11,436	-	-	6 - 0 - 0	0 - 0 - 0	4-S rich burn (3); 4-S lean burn (5)
125	P	9,900	NR	-	-	0 - 0 - 0	0 - 0 - 0	4-S lean burn (3); Electric (6)
126	P	11,364	11,364	71,300	71,300	7 - 0 - 0	7 - 0 - 0	4-S lean burn; Solar turbines
127	P	-	-	44,916	44,916	0 - 0 - 0	3 - 0 - 0	Solar Titan
128	P	2,120	2,120	27,000	24,000	2 - 0 - 0	2 - 2 - 0	4-S lean burn; Solar turbines
129	P	-	-	45,000	15,000	0 - 0 - 0	1 - 2 - 0	Solar Mars
130	P	24,000	19,200	-	-	4 - 1 - 0	0 - 0 - 0	Electric
131	P	1,570	1,170	-	-	2 - 0 - 1	0 - 0 - 0	4-S rich burn

C – Summary figures of onsite information

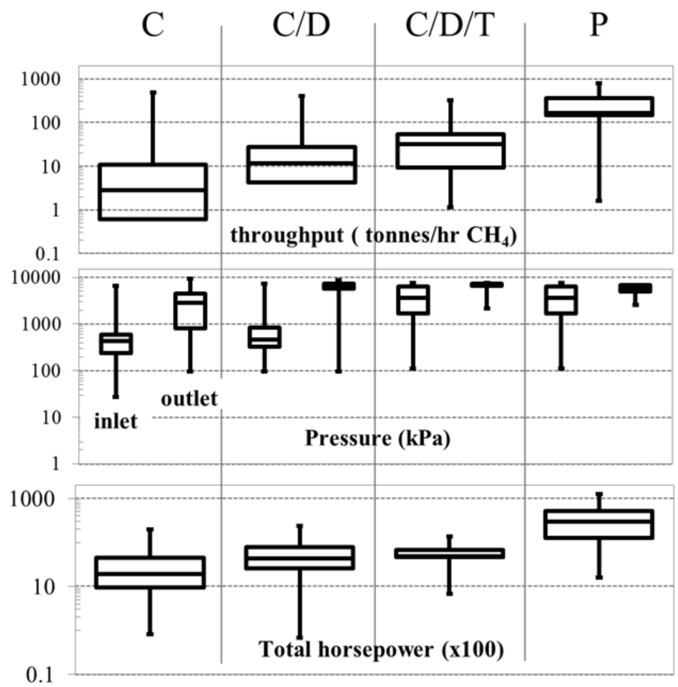

Figure S1. Information obtained from C, C/D, C/D/T, and P facilities sampled in this study. The boxes represent the 25th, 50th, and 75th percentiles of throughput (tonnes/hr CH_4), inlet and outlet pressure (kPa), and total horsepower (motor + engine + turbine); whiskers represent the min and max. The minimum throughput at three C and two C/D facilities was zero.

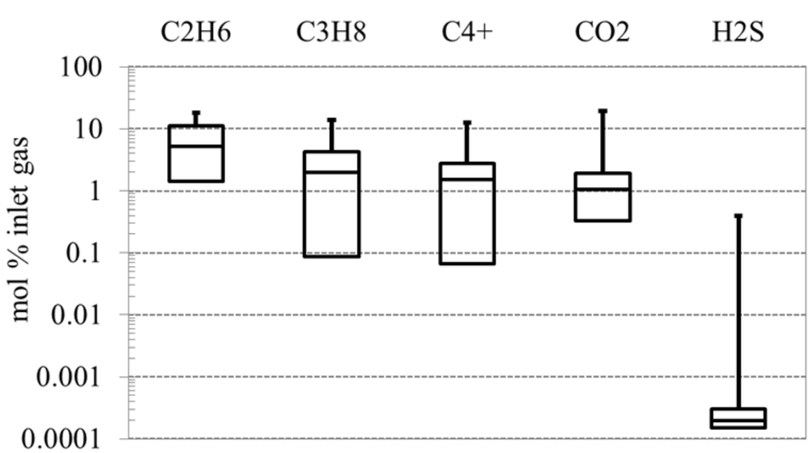

Figure S2. Non-methane species (mol/mol) in inlet gas at all 130 facilities. Box represents 25th, 50th, and 75th percentiles; top whisker is the maximum. Minimum mol % for all species was near zero. Data were obtained from company-provided gas chromatography analyses (Table S1). H_2S was only reported by 40 facilities.

D – Non-partner equipment collocated with study facilities

Table S4. Description of non-partner equipment collocated with study G&P facilities. Types of non-partner equipment were not specified in all cases, hence the use of the generic term natural gas "facility" to describe any non-specific observations of a non-partner equipment collocated or nearby a study facility.

Facility #	Facility type	Description of non-partner equipment collocated with a study facility
3	C	Wellhead and ~4 oil storage tanks; assessed and leaking order of magnitude less than target facility
9	C	Next to another natural gas "facility."
10	C	One proximal wellhead, two other wells nearby.
13	C	Next to another natural gas "facility."
14	C	Wellhead and production tank.
17	C	Wellhead; no leaks observed.
19	C	Wellhead, separator, and a condensate tank; separator and condensate tank are venting.
22	C	Wellhead; no emissions were observed.
23	C	Meter run and tank battery.
25	C	Wellhead; observed negligible emissions. Nearby well pad; emissions ~50% relative to target facility.
29	C	Single-well producing on pad; observed negligible emissions in mobile lab.
37	C/D	Valve nest and pigging facilities, with piping/valves and a condensate tank that are used when pigging (once every two weeks); small amount of venting from the condensate tank.
46	C/D	Inlet filter separator, pigging facilities, metering, piping, produced water tank; produced water tank appears to be venting steadily.
51	C/D	Wellhead and water tanks; described as "capped and probably not leaking much."
55	C/D	Between two natural gas "facilities;" venting from a produced water tank.
56	C/D	Three sales points, one of them owned the final system of valves and odorized at the outlet; valve was leaking.
57	C/D	Next to another natural gas "facility."
58	C/D	Wellhead approximately 100 meters from target facility.
59	C/D	Next to another natural gas "facility;" no observed leaks/venting and the flare appeared to be in stand-by.
62	C/D	Nearby another natural gas "facility."
64	C/D	Wellhead and two water tanks; no leaks observed from well and tanks not observed
69	C/D	Valve nest and pigging facilities), with piping/valves and a condensate tank that are used when pigging (once every two weeks); small amount of venting from the condensate tank.
77	C/D	Wellhead, separation equipment, and produced water tank; observed negligible emissions
79	C/D	Wellhead and water tanks; described as "nearly empty" and no leaks observed
85	C/D	Wellhead approximately 100 meters from target facility.
87	C/D	Nearby another natural gas "facility."
92	C/D	Wellhead, dehydration unit, and flare; assessed and observed to be small relative to uncertainty but flare operated intermittently
99	C/D	Wellhead.
100	C/D	Dehydration unit, oil well (shut in), and tanks; observed no emissions from tanks.
102	C/D/T	Adjacent C/D facility.
110	D	Dehydration unit.
112	D	Wellhead.
113	D	Production well pad.
114	D	Three-well production pad.
120	P	Three other natural gas facilities on the periphery.
125	P	Multiple production wellheads.

E – Documented changes to equipment and/or facility state(s)

Table S5. Brief descriptions of operational changes to G&P facilities, including adjustments to equipment, attempted corrective actions, and other events noted by the onsite observer. Observations of increased or reduced emission are also noted.

Facility #	Facility type	Changes, adjustments, and other notable events during measurements
1	C	Multiple compressor blowdowns
2	C	Adjusting compressor; shut down and restarted multiple times
4	C	Stopped flowing to sales
12	C	Loaded condensate which resulted in higher venting from two condensate tanks
37	C/D	Attempted corrective actions to address substantial venting from liquids storage tanks
38	C/D	Adjusted suction side valves, potentially increasing venting from liquids storage
39	C/D	Fixed two "leaky" valves on inlet separator; closed stuck vent valve on liquids storage tanks after completion of measurements
41	C/D	Vented section of sales pipe (10 minutes)
44	C/D	Turned off second-stage compression process before measurements and restarted afterward
46	C/D	One compressor started, another went NOP
48	C/D	Compressor shut down for maintenance and restarted (1 hour)
55	C/D	Produced water tank emptied (1 hour)
61	C/D	Restarted combustor resulting in reduced venting from produced water tank
64	C/D	Single compressor restarted multiple times, 2-3 minute vent during troubleshooting
76	C/D	Vented gas to produced water tanks due to frozen inlet separation valve (> 1 hour)
80	C/D	Reset diaphragm of liquid level controller, stopping previously observed emissions
85	C/D	Produced water dump lines opened and blown (1 minute)
87	C/D	Attempted corrective actions to seal on blowdown stack
88	C/D	Compressor started resulting in lower observed emissions from meter tubing
104	C/D/T	Multiple restarts of a single compressor during measurements
105	C/D/T	Produced water or condensate tank emptied (40 minutes)
109	C/D/T	Multiple restarts and two blowdowns of a single compressor during measurements
121	P	Compressor went NOP without releasing gas
124	P	Counted seven trucks loading liquids during measurements; single compressor started
126	P	Blowdown of pig receiver and barrel
128	P	Reciprocating engines started

F – Observations from infrared camera surveys at gathering facilities

Table S6. Summary of infrared camera survey performed at 108 gathering facilities. Flags indicate documented observations of venting and leaking associated with equipment (liquids storage tanks, pneumatics) and processes (dehydration, compression). Other includes observed leaks at piping, inlet separation/filtration, meters, etc. These data represent only what was observed given time constraints and wind conditions (smaller magnitude emissions are difficult to observe in high winds). Another consideration is that the infrared camera may not be used to distinguish between non-methane hydrocarbons. N/A indicates no observations reported, which is the case when an infrared survey was not performed.

Facility #	Facility type	Infrared survey performed?	Infrared video recorded?	Liquids storage (Substantial)	Liquids storage (Any)	Dehydration	Compression	Pneumatics	Other
1	C	Yes	Yes	1	1	-	1	-	1
2	C	Yes	No	-	-	-	-	-	-
3	C	Yes	Yes	1	1	-	-	1	-
4	C	Yes	Yes	1	1	-	-	-	-
5	C	Yes	No	-	-	-	1	1	-
6	C	Yes	No	-	-	-	-	-	-
7	C	Yes	Yes	-	-	-	1	-	1
8	C	Yes	No	1	-	-	-	-	-
9	C	Yes	No	-	-	-	-	1	-
10	C	Yes	No	-	-	-	-	-	-
11	C	Yes	Yes	-	1	-	-	-	1
12	C	Yes	No	-	-	-	1	1	1
13	C	Yes	Yes	-	-	-	1	-	-
14	C	Yes	Yes	-	-	-	-	1	-
15	C	Yes	Yes	-	-	-	1	-	-
16	C	Yes	No	-	-	-	-	-	-
17	C	Yes	No	-	-	-	-	-	-
18	C	Yes	Yes	-	1	-	-	-	-
19	C	Yes	No	-	1	-	-	-	1
20	C	No	No	N/A	N/A	N/A	N/A	N/A	N/A
21	C	Yes	No	-	-	-	-	1	-
22	C	Yes	No	-	1	-	-	-	-
23	C	Yes	Yes	-	1	-	1	1	-
24	C	Yes	Yes	-	1	-	1	-	1
25	C	Yes	Yes	-	-	-	-	1	-
26	C	Yes	Yes	-	-	-	-	-	-
27	C	Yes	Yes	-	-	-	-	-	-
28	C	Yes	Yes	-	1	-	1	-	-
29	C	Yes	Yes	-	-	-	1	-	-
30	C	Yes	Yes	-	-	-	1	-	-
31	C	Yes	Yes	-	-	-	-	-	-

Facility #	Facility type	Infrared survey performed?	Infrared video recorded?	Liquids storage (Substantial)	Liquids storage (Any)	Dehydration	Compression	Pneumatics	Other
32	C	Yes	Yes	-	-	-	1	-	-
33	C	Yes	Yes	-	-	-	1	-	-
34	C	Yes	Yes	-	-	-	-	-	-
35	C/D	Yes	Yes	1	1	-	-	-	-
36	C/D	Yes	No	1	1	1	1	-	-
37	C/D	Yes	Yes	1	1	-	-	1	-
38	C/D	Yes	Yes	1	1	-	-	-	-
39	C/D	Yes	Yes	1	1	-	-	1	-
40	C/D	Yes	Yes	-	-	-	1	-	-
41	C/D	Yes	Yes	1	1	-	-	-	-
42	C/D	Yes	Yes	1	1	-	-	-	-
43	C/D	Yes	Yes	1	1	-	-	-	-
44	C/D	Yes	Yes	1	1	-	-	1	-
45	C/D	Yes	No	1	1	-	1	-	-
46	C/D	Yes	Yes	-	-	1	1	-	-
47	C/D	Yes	No	-	-	-	-	-	-
48	C/D	Yes	Yes	-	-	-	-	1	-
49	C/D	Yes	Yes	1	1	-	-	-	-
50	C/D	Yes	No	-	1	-	-	-	-
51	C/D	Yes	Yes	-	1	-	1	-	-
52	C/D	Yes	No	-	-	-	-	-	-
53	C/D	Yes	No	-	-	-	-	-	1
54	C/D	Yes	No	-	1	-	1	1	1
55	C/D	Yes	Yes	-	1	-	1	-	-
56	C/D	Yes	Yes	-	-	-	1	1	-
57	C/D	Yes	No	-	1	-	1	-	-
58	C/D	Yes	Yes	1	1	-	-	-	-
59	C/D	Yes	Yes	-	1	-	-	-	-
60	C/D	No	No	N/A	N/A	N/A	N/A	N/A	N/A
61	C/D	Yes	Yes	1	1	-	1	-	-
62	C/D	Yes	No	-	-	-	-	-	-
63	C/D	Yes	Yes	1	1	-	1	1	-
64	C/D	No	No	N/A	N/A	N/A	N/A	N/A	N/A
65	C/D	Yes	Yes	-	1	-	1	-	-
66	C/D	Yes	No	-	-	-	-	-	-
67	C/D	Yes	Yes	1	1	-	-	1	-
68	C/D	Yes	No	-	1	-	1	-	-
69	C/D	Yes	Yes	-	-	-	-	1	-
70	C/D	Yes	No	-	-	-	-	-	-
71	C/D	Yes	No	-	-	-	-	-	-
72	C/D	Yes	No	-	-	-	-	1	-
73	C/D	Yes	Yes	-	1	-	-	1	-
74	C/D	No	No	N/A	N/A	N/A	N/A	N/A	N/A
75	C/D	Yes	No	-	-	-	1	1	1
76	C/D	Yes	Yes	-	-	-	-	-	-
77	C/D	Yes	Yes	-	-	-	1	1	-
78	C/D	Yes	No	-	-	-	-	-	-
79	C/D	Yes	Yes	-	-	-	-	-	-
80	C/D	Yes	Yes	1	1	-	-	1	-
81	C/D	Yes	Yes	-	-	-	1	-	-

Facility #	Facility type	Infrared survey performed?	Infrared video recorded?	Liquids storage (Substantial)	Liquids storage (Any)	Dehydration	Compression	Pneumatics	Other
82	C/D	No	No	N/A	N/A	N/A	N/A	N/A	N/A
83	C/D	Yes	Yes	-	-	-	-	-	-
84	C/D	Yes	Yes	-	-	-	-	1	-
85	C/D	Yes	No	-	1	1	1	-	1
86	C/D	Yes	No	-	-	-	-	-	-
87	C/D	Yes	Yes	-	-	-	-	-	1
88	C/D	Yes	Yes	-	-	-	-	-	1
89	C/D	Yes	No	-	-	1	1	1	-
90	C/D	Yes	No	-	-	-	-	-	-
91	C/D	Yes	Yes	-	-	-	-	-	-
92	C/D	Yes	Yes	-	-	1	-	-	-
93	C/D	Yes	No	-	1	-	1	-	1
94	C/D	Yes	Yes	-	1	-	1	-	-
95	C/D	Yes	Yes	-	1	-	-	-	-
96	C/D	Yes	Yes	-	-	1	-	1	-
97	C/D	Yes	Yes	-	-	-	-	-	1
98	C/D	Yes	Yes	-	1	1	1	-	-
99	C/D	Yes	Yes	-	-	-	-	-	-
100	C/D	Yes	No	-	-	-	-	-	-
101	C/D	Yes	No	-	-	-	-	-	1
102	C/D/T	Yes	No	1	-	-	-	-	1
103	C/D/T	Yes	Yes	1	1	-	-	-	-
104	C/D/T	Yes	Yes	1	-	1	1	-	-
105	C/D/T	Yes	No	-	-	-	-	-	-
106	C/D/T	Yes	No	-	-	-	-	-	-
107	C/D/T	Yes	Yes	-	-	-	-	-	-
108	C/D/T	Yes	No	-	-	-	1	-	1
109	C/D/T	Yes	Yes	-	1	-	-	-	-
110	D	Yes	Yes	-	-	1	-	1	1
111	D	Yes	Yes	-	-	-	-	1	1
112	D	Yes	Yes	-	-	1	-	-	-
113	D	Yes	Yes	-	-	-	-	-	1
114	D	Yes	Yes	-	-	-	-	-	1
115	D/T	No	No	N/A	N/A	N/A	N/A	N/A	N/A
116	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
117	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
118	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
119	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
120	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
121	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
122	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
123	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
124	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
125	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
126	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
127	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
128	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
129	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
130	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A
131	P	No	No	N/A	N/A	N/A	N/A	N/A	N/A

G – Brief description of tracer flux methodology

Roscoli et al.[5] describes in detail the tracer flux methodology used by this study. Briefly, it involved releasing two tracer gases, nitrous oxide (N_2O) and acetylene (C_2H_2), at a known emission rate from the target facility. The concentrations of these tracers, as well as ethane, carbon monoxide, carbon dioxide, and the target analyte (methane) were then measured downwind of the facility using high time resolved instrumentation deployed on a mobile sampling laboratory. The measurements were made by driving the mobile laboratory at a constant speed on a downwind road that is perpendicular to the wind direction to develop a plume profile, as illustrated in Figure S3. This was done repeatedly obtain multiple plume profiles. The measured concentration ratio of these species in combination with the tracer release rates were used to estimate the facility-level methane emission rate from individual plumes. The ethane-to-methane mixing ratio measured in the plume was also used to attribute the measured methane to the target facility. Roscoli et al.[5] details the methods for analyzing the plume profiles to obtain facility-level emissions over a period of a couple minutes (the typical duration of a plume transect). Importantly, interpreting these data does not require modeling pollutant dispersion - that complexity is captured by the tracers.

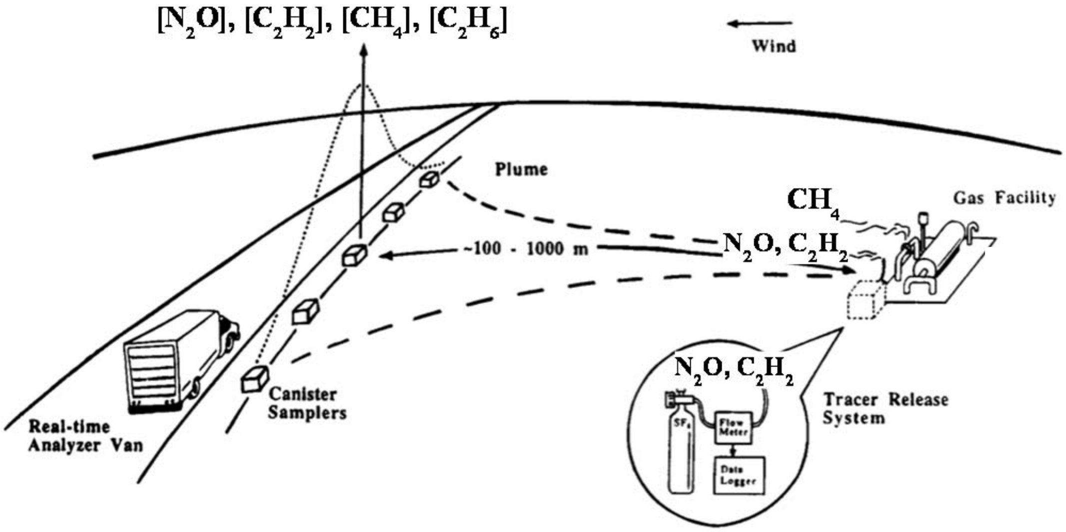

Figure S3. Schematic of the tracer flux measurement method showing the tracer release at the source of interest, and the use of a mobile lab to locate and sample the methane/tracer plumes. Reproduced and modified from Lamb et al.[6]. Canisters were not used in this study.

H –Tracer flux measurements results

Out of the 136 facilities visited by the Carnegie Mellon University and Aerodyne Research tracer teams, emissions data are reported for 130 facilities (131 WAFLER estimates), which are presented in Table S7. Two WAFLER estimates are given for one facility (facility #'s 35 and 59), which was initially venting substantial amounts of methane. For two facilities (#41 and 46) a leak on one of the mobile lab's inlet sampling line caused minor dilution of the sampled plumes. WAFLER estimates from these two facilities were not impacted because all instruments pulled from a common sampling line, which would result in equal dilution of measured species. No methane emissions data are reported for six facilities. Poor wind conditions and instrument malfunction hampered data collection at four facilities, while significant from methane interference impacted measurements at two. The interference at one facility was from a nearby natural gas facility, which was determined to be emitting significantly more methane than the target facility. At the other, which was in West Virginia, the interference was caused by methane venting from an operating mine. The presence of methane emissions from mine vents in this region has been noted elsewhere.[7]

Table S7. Summary tracer flux measurements for 130 G&P facilities reported in this study, including average downwind distance from facility to mobile lab, average wind speed measured from a height of 2m at the facility, the approximate ambient temperature at the start of measurements, and the total number of accepted downwind plumes. The results given are the weighted average facility-level emission rates (WAFLER) of CH_4, the unbiased weighted standard deviation of WAFLER, and the throughput-normalized WAFLER (tnWAFLER) as a percentage of facility CH_4 throughput. tnWAFLER could not be calculated for six facilities (indicated by N/A). Ambient temperature was not recorded at a few facilities (indicated by NR).

Facility #	Facility Type	Avg. downwind distance[1] (km)	Avg. wind speed[2] (m/s, @ 2m)	Approximate ambient temperature (C)	# Accepted plumes	WAFLER (kg/hr CH_4)	Unbiased weighted standard deviation WAFLER (kg/hr)	tnWAFLER (as a % of CH_4 throughput)
1	C	2.9	3.3	4.7	6	255.1	84.4	1.11%
2	C	0.5	1.3	8.9	4	94.3	60.0	0.65%
3	C	0.5	3.0	5.8	27	74.5	16.2	17.52%
4	C	2.1	4.4	11.7	9	64.8	56.1	N/A
5	C	0.8	1.7	8.9	7	62.4	17.7	0.45%
6	C	0.9	1.9	7.2	12	43.9	23.7	0.17%
7	C	1.8	6.4	1.1	4	43.8	8.4	1.03%
8	C	0.4	3.7	12.5	7	41.6	30.9	0.90%
9	C	0.5	2.4	10.0	10	29.6	9.7	0.46%
10	C	2.0	4.0	3.3	5	28.8	6.5	0.35%
11	C	1.0	2.5	1.7	7	21.9	6.3	<0.01%
12	C	0.6	2.5	15.6	3	19.8	3.1	0.05%
13	C	0.8	3.4	5.3	10	17.9	3.2	0.48%
14	C	0.9	2.6	5.8	13	14.8	2.1	8.45%
15	C	1.2	9.1	11.1	17	13.5	2.6	0.81%
16	C	0.7	2.3	1.1	8	9.3	8.2	0.07%
17	C	1.6	3.8	4.4	16	9.2	3.0	0.22%
18	C	1.9	5.7	23.9	5	8.4	2.0	0.39%
19	C	1.0	2.1	15.6	2	8.3	6.2	0.60%
20	C	0.6	4.2	7.2	13	8.3	2.4	0.58%
21	C	1.1	4.2	1.7	42	7.9	1.9	1.58%
22	C	1.0	4.2	20.0	16	7.7	9.4	1.66%
23	C	0.2	4.5	21.4	4	7.1	0.9	0.41%
24	C	0.6	5.9	4.4	7	6.2	1.5	0.14%
25	C	1.1	4.7	5.6	6	5.8	1.4	2.25%
26	C	0.6	5.7	17.2	9	5.5	1.3	0.24%
27	C	0.5	5.1	4.4	8	5.2	1.3	0.19%
28	C	0.7	1.5	24.7	8	5.0	6.3	N/A
29	C	0.8	4.3	1.1	36	5.0	1.4	0.97%
30	C	0.3	8.4	3.3	2	3.4	0.4	<0.01%
31	C	1.0	6.3	21.7	11	2.7	3.2	0.38%
32	C	0.2	5.3	15.6	13	1.6	1.0	N/A
33	C	1.0	6.4	10.8	5	1.2	0.5	0.17%
34	C	0.3	7.0	13.9	3	0.9	0.1	0.08%
35	C/D	1.0	2.4	NR	2	698.6	63.2	9.54%
36	C/D	0.5	5.1	3.9	5	344.1	95.2	1.09%
37	C/D	1.1	3.5	-1.7	8	240.5	66.9	0.98%
38	C/D	1.5	1.7	-8.9	5	217.6	79.4	1.12%
39	C/D	0.7	4.1	0.3	18	196.1	64.0	0.39%

Facility #	Facility Type	Avg. downwind distance[1] (km)	Avg. wind speed[2] (m/s, @ 2m)	Approximate ambient temperature (C)	# Accepted plumes	WAFLER (kg/hr CH_4)	Unbiased weighted standard deviation WAFLER (kg/hr)	tnWAFLER (as a % of CH_4 throughput)
40	C/D	0.5	2.1	-0.8	17	195.3	67.8	2.44%
41	C/D	0.8	0.6	5.6	8	159.8	71.2	0.10%
42	C/D	1.8	10.2	7.8	16	146.7	67.0	0.59%
43	C/D	2.0	8.5	5.6	23	145.2	29.4	0.76%
44	C/D	0.8	2.3	0.6	15	119.0	86.0	0.36%
45	C/D	0.5	3.3	2.8	31	112.0	58.7	0.75%
46	C/D	1.9	1.2	1.1	6	109.1	98.0	0.05%
47	C/D	0.8	2.9	-2.5	13	106.6	56.3	0.37%
48	C/D	1.0	3.8	1.7	11	98.6	72.7	0.27%
49	C/D	0.7	4.3	-1.1	22	93.4	19.1	0.41%
50	C/D	0.7	7.4	5.0	26	92.8	41.0	0.52%
51	C/D	3.1	1.8	0.6	6	82.9	33.2	1.35%
52	C/D	0.5	4.3	0.0	12	76.3	32.2	0.33%
53	C/D	0.4	2.0	-1.1	12	76.0	39.2	0.99%
54	C/D	0.6	2.8	1.7	4	71.7	17.1	0.50%
55	C/D	0.6	2.1	NR	11	66.7	32.9	0.14%
56	C/D	0.6	2.7	15.6	8	63.5	51.1	0.38%
57	C/D	1.3	7.2	7.2	8	61.1	17.4	0.17%
58	C/D	0.6	3.3	4.4	7	59.4	20.9	0.40%
59	C/D	0.7	3.5	NR	8	49.7	13.9	0.68%
60	C/D	2.5	4.9	-3.9	18	48.6	11.8	1.63%
61	C/D	0.4	4.2	15.0	16	47.7	21.7	0.84%
62	C/D	1.0	2.6	-1.1	15	47.6	23.7	0.21%
63	C/D	1.0	2.5	-2.2	18	46.8	12.1	17.08%
64	C/D	1.2	2.4	0.0	9	45.1	18.9	0.01%
65	C/D	1.5	11.1	2.8	8	36.4	29.9	0.17%
66	C/D	0.6	5.3	-5.3	36	35.8	8.9	0.51%
67	C/D	1.4	9.1	14.4	16	34.5	5.6	2.16%
68	C/D	0.4	4.9	10.0	3	34.5	12.9	0.31%
69	C/D	0.7	2.8	8.6	8	33.9	10.0	0.24%
70	C/D	1.5	8.1	21.7	17	32.7	22.4	0.31%
71	C/D	0.9	1.8	13.1	13	26.5	8.8	0.55%
72	C/D	0.4	8.9	21.1	21	26.4	12.9	0.68%
73	C/D	0.7	2.7	-1.1	12	26.2	10.8	0.31%
74	C/D	1.7	2.7	7.2	12	26.0	10.4	1.17%
75	C/D	0.4	3.4	4.4	2	25.9	6.9	0.37%
76	C/D	1.1	4.1	-7.2	16	23.8	12.2	0.11%
77	C/D	1.7	4.6	6.1	6	22.3	13.1	0.79%
78	C/D	0.9	5.5	10.0	8	22.0	1.0	11.84%
79	C/D	1.1	5.9	7.2	26	21.7	5.3	0.49%
80	C/D	0.7	2.5	21.1	8	17.9	6.0	3.04%
81	C/D	0.2	3.4	5.0	2	17.7	3.6	0.07%
82	C/D	2.1	6.1	1.1	13	15.0	5.0	0.45%
83	C/D	0.2	2.2	21.1	3	13.7	2.0	0.04%
84	C/D	0.4	4.5	10.0	18	13.2	5.4	0.59%
85	C/D	0.2	5.4	7.2	3	12.8	5.7	0.32%
86	C/D	1.0	3.9	10.0	15	11.5	4.3	0.37%
87	C/D	0.2	4.6	21.1	7	11.4	3.7	0.22%
88	C/D	1.0	3.1	-1.7	10	11.0	3.7	0.27%
89	C/D	0.5	5.5	15.6	5	10.9	4.3	0.14%

Facility #	Facility Type	Avg. downwind distance[1] (km)	Avg. wind speed[2] (m/s, @ 2m)	Approximate ambient temperature (C)	# Accepted plumes	WAFLER (kg/hr CH_4)	Unbiased weighted standard deviation WAFLER (kg/hr)	tnWAFLER (as a % of CH_4 throughput)
90	C/D	1.0	1.6	0.0	6	9.0	2.5	<0.01%
91	C/D	0.2	0.7	10.0	9	8.9	9.1	0.07%
92	C/D	1.2	0.9	-5.6	4	8.7	8.4	2.92%
93	C/D	0.7	3.8	-3.3	5	8.1	4.7	<0.01%
94	C/D	1.6	2.2	5.8	4	7.5	4.2	69.60%
95	C/D	0.3	2.3	1.1	6	7.5	2.3	0.03%
96	C/D	1.3	1.5	5.6	18	6.1	1.4	2.52%
97	C/D	0.9	2.4	-1.1	12	4.6	0.5	4.17%
98	C/D	2.1	6.4	4.4	8	2.4	0.6	0.45%
99	C/D	0.6	2.3	-1.1	4	2.0	0.7	0.47%
100	C/D	1.0	2.2	4.4	3	1.4	0.5	N/A
101	C/D	0.5	3.0	21.7	8	0.7	0.2	N/A
102	C/D/T	0.9	2.5	14.7	15	240.5	148.8	0.65%
103	C/D/T	1.3	5.8	18.3	7	173.7	37.1	0.07%
104	C/D/T	0.8	4.0	6.9	21	142.1	87.1	1.16%
105	C/D/T	0.4	1.7	15.6	11	40.4	27.7	0.07%
106	C/D/T	0.6	2.9	23.3	7	34.1	17.2	0.08%
107	C/D/T	0.3	4.5	7.8	5	28.3	15.1	0.43%
108	C/D/T	0.2	3.9	4.4	5	20.1	5.6	0.28%
109	C/D/T	0.7	2.4	12.8	14	6.5	2.2	0.75%
110	D	0.8	5.1	-7.5	6	38.0	10.1	0.69%
111	D	1.6	1.2	NR	9	10.6	4.6	0.33%
112	D	1.9	2.7	1.1	6	7.8	2.3	2.07%
113	D	0.6	4.4	-3.6	12	3.5	2.7	0.09%
114	D	2.4	2.0	1.7	3	1.9	0.6	N/A
115	D/T	0.4	5.2	7.2	8	142.4	49.7	0.06%
116	P	2.1	3.0	8.3	14	606.0	290.7	0.132%
117	P	1.5	6.3	25.3	16	451.1	191.9	0.289%
118[†]	P	0.5	6.7	5.0	16	279.4	107.7	0.041%
119	P	1.6	5.5	7.2	10	267.7	141.3	0.081%
120	P	0.7	3.7	7.2	5	207.1	118.9	0.202%
121	P	2.1	5.5	-3.9	12	166.6	102.2	0.622%
122	P	0.8	4.8	7.2	22	156.8	147.7	0.126%
123	P	0.7	3.2	4.4	19	128.2	65.7	0.110%
124	P	2.8	4.1	NR	3	112.5	9.5	0.078%
125	P	0.4	6.2	-2.8	14	93.2	68.5	0.040%
126	P	0.8	3.4	-5.6	6	75.5	26.1	0.018%
127	P	0.3	4.3	8.3	8	58.4	21.8	0.016%
128	P	1.5	6.0	22.2	6	54.9	21.9	0.028%
129	P	0.4	4.0	14.7	7	39.4	24.1	0.024%
130	P	0.7	4.0	8.6	18	14.1	7.2	0.012%
131	P	0.6	8.5	0.3	29	3.3	1.3	0.350%

[1] The average distance between the mobile laboratory and tracer release points for accepted plumes.

[2] The average of all wind speed measured at the facility, usually an open area 2m from the ground, for all plumes. Wind speed recorded at the mobile laboratory are used for 11 facilities, and National Weather Service records were used for a single facility.

[†] Analysis performed using linear combination method [5] due to limited road access.

Table S8: Minimum, maximum, and quartiles (25th, 50th, 75th percentiles) of facility-level emission rates (FLER) of CH_4 for 130 G&P facilities reported in this study. Percentile values are not applicable to facilities with less than three (3) accepted plumes (indicated by N/A).

Facility #	Facility Type	# Accepted plumes	WAFLER (kg/hr CH_4)	Minimum FLER (kg/hr CH_4)	Maximum FLER (kg/hr CH_4)	25th %tile FLER (kg/hr CH_4)	50th %tile FLER (kg/hr CH_4)	75th %tile FLER (kg/hr CH_4)
1	C	6	255.1	157.8	356.4	232.1	304.2	343.8
2	C	4	94.3	58.4	188.8	63.7	108.3	160.5
3	C	27	74.5	50.1	131.3	61.0	71.8	81.7
4	C	9	64.8	12.2	226.9	47.1	54.3	63.4
5	C	7	62.4	28.3	84.5	55.4	59.9	76.5
6	C	12	43.9	11.9	100.5	26.9	48.3	55.1
7	C	4	43.8	30.8	49.9	33.2	40.1	47.1
8	C	7	41.6	8.2	90.4	14.5	21.9	57.7
9	C	10	29.6	21.6	52.1	24.4	29.2	35.2
10	C	5	28.8	21.8	39.4	25.8	26.2	33.7
11	C	7	21.9	13.3	30.7	18.4	18.8	26.7
12	C	3	19.8	16.8	22.9	N/A	N/A	N/A
13	C	10	17.9	13.4	21.5	14.8	18.5	20.0
14	C	13	14.8	11.8	17.7	13.4	13.7	16.1
15	C	17	13.5	9.5	21.9	11.4	12.7	15.3
16	C	8	9.3	4.8	30.5	5.3	7.6	9.0
17	C	16	9.2	4.8	18.5	7.5	8.2	9.0
18	C	5	8.4	5.6	10.5	8.1	9.4	9.8
19	C	2	8.3	5.1	13.9	N/A	N/A	N/A
20	C	13	8.3	3.7	12.8	6.2	8.7	10.0
21	C	42	7.9	3.1	12.5	7.2	8.0	8.7
22	C	16	7.7	3.5	47.0	3.7	5.3	7.6
23	C	4	7.1	6.5	8.1	6.5	6.7	7.2
24	C	7	6.2	3.5	8.1	5.1	6.7	7.2
25	C	6	5.8	4.1	7.9	4.8	5.3	5.7
26	C	9	5.5	3.7	6.8	4.9	5.1	6.3
27	C	8	5.2	3.6	8.1	4.7	5.1	5.4
28	C	8	5.0	0.8	19.6	1.7	2.3	5.5
29	C	36	5.0	2.6	11.0	4.2	4.7	5.4
30	C	2	3.4	3.1	3.7	N/A	N/A	N/A
31	C	11	2.7	0.2	8.0	0.7	1.1	4.0
32	C	13	1.6	0.7	4.0	1.2	1.2	1.5
33	C	5	1.2	0.6	1.9	0.9	1.2	1.7
34	C	3	0.9	0.9	1.0	N/A	N/A	N/A
35	C/D	2	698.6	653.9	743.3	N/A	N/A	N/A
36	C/D	5	344.1	190.5	431.0	320.5	374.1	404.6
37	C/D	8	240.5	155.3	365.7	206.5	240.8	264.8
38	C/D	5	217.6	143.8	308.3	149.0	199.4	275.7
39	C/D	18	196.1	66.3	332.0	158.0	185.6	224.8
40	C/D	17	195.3	131.3	349.0	155.0	168.1	254.5
41	C/D	8	159.8	85.2	305.2	109.4	146.0	178.9
42	C/D	16	146.7	66.4	342.1	117.3	128.5	151.4
43	C/D	23	145.2	106.7	292.0	131.7	143.5	159.8
44	C/D	15	119.0	30.0	369.6	73.3	108.4	123.0
45	C/D	31	112.0	43.3	252.1	61.8	80.4	132.6
46	C/D	6	109.1	30.1	276.7	48.1	61.0	151.8
47	C/D	13	106.6	30.8	201.2	77.0	85.0	154.8

Facility #	Facility Type	# Accepted plumes	WAFLER (kg/hr CH_4)	Minimum FLER (kg/hr CH_4)	Maximum FLER (kg/hr CH_4)	25th %tile FLER (kg/hr CH_4)	50th %tile FLER (kg/hr CH_4)	75th %tile FLER (kg/hr CH_4)
48	C/D	11	98.6	25.0	294.6	34.5	64.3	116.0
49	C/D	22	93.4	70.1	155.5	85.1	92.3	115.8
50	C/D	26	92.8	11.3	220.2	70.3	86.3	110.9
51	C/D	6	82.9	48.6	126.4	55.2	69.6	109.8
52	C/D	12	76.3	30.6	139.9	54.5	90.1	107.7
53	C/D	12	76.0	6.8	110.3	70.9	89.4	104.8
54	C/D	4	71.7	47.8	87.9	66.2	75.5	80.9
55	C/D	11	66.7	15.2	115.9	49.5	78.2	94.1
56	C/D	8	63.5	9.8	133.2	24.7	76.9	99.8
57	C/D	8	61.1	42.3	83.1	52.6	67.8	80.3
58	C/D	7	59.4	38.2	100.7	53.2	61.7	69.7
59	C/D	8	49.7	22.5	72.4	39.0	53.1	64.8
60	C/D	18	48.6	23.6	76.8	42.8	49.1	57.6
61	C/D	16	47.7	19.6	110.5	36.2	42.8	53.6
62	C/D	15	47.6	13.9	116.1	31.3	49.4	64.6
63	C/D	18	46.8	17.1	69.6	36.5	45.8	51.2
64	C/D	9	45.1	27.9	82.8	32.1	36.5	57.8
65	C/D	8	36.4	19.5	128.8	24.9	28.3	35.4
66	C/D	36	35.8	18.2	66.2	29.0	33.2	38.3
67	C/D	16	34.5	25.5	46.1	31.3	33.5	36.9
68	C/D	3	34.5	24.3	49.1	N/A	N/A	N/A
69	C/D	8	33.9	13.2	45.0	26.8	35.2	39.6
70	C/D	17	32.7	8.5	133.6	20.6	26.9	39.3
71	C/D	13	26.5	13.5	47.6	22.2	24.5	32.7
72	C/D	21	26.4	11.8	88.7	20.0	24.5	31.7
73	C/D	12	26.2	12.0	49.2	21.1	24.0	40.9
74	C/D	12	26.0	11.0	57.5	18.5	24.9	32.8
75	C/D	2	25.9	20.9	30.8	N/A	N/A	N/A
76	C/D	16	23.8	5.8	44.6	14.1	19.6	33.2
77	C/D	6	22.3	7.9	42.3	12.9	17.8	31.7
78	C/D	8	22.0	19.7	23.9	21.4	22.0	22.9
79	C/D	26	21.7	14.4	41.0	18.3	20.8	22.8
80	C/D	8	17.9	4.7	24.3	14.0	17.1	23.2
81	C/D	2	17.7	15.1	20.3	N/A	N/A	N/A
82	C/D	13	15.0	9.9	28.7	11.9	13.4	15.8
83	C/D	3	13.7	11.7	15.6	N/A	N/A	N/A
84	C/D	18	13.2	7.6	34.6	10.5	13.9	16.2
85	C/D	3	12.8	8.2	18.1	N/A	N/A	N/A
86	C/D	15	11.5	2.0	17.4	7.3	11.0	14.5
87	C/D	7	11.4	6.7	17.8	8.4	10.3	13.0
88	C/D	10	11.0	5.8	16.5	9.3	10.1	14.8
89	C/D	5	10.9	6.5	17.8	9.2	9.4	11.5
90	C/D	6	9.0	4.7	10.9	7.9	9.1	10.2
91	C/D	9	8.9	1.7	28.4	3.0	5.7	7.4
92	C/D	4	8.7	3.1	21.5	3.7	8.7	15.5
93	C/D	5	8.1	2.8	11.8	3.5	4.2	9.2
94	C/D	4	7.5	4.1	12.6	4.5	7.4	10.8
95	C/D	6	7.5	3.7	9.2	3.8	5.6	8.0
96	C/D	18	6.1	3.1	7.9	5.4	6.3	7.1
97	C/D	12	4.6	3.9	7.5	4.4	4.5	4.9
98	C/D	8	2.4	1.6	3.4	2.1	2.2	2.9

Facility #	Facility Type	# Accepted plumes	WAFLER (kg/hr CH_4)	Minimum FLER (kg/hr CH_4)	Maximum FLER (kg/hr CH_4)	25th %tile FLER (kg/hr CH_4)	50th %tile FLER (kg/hr CH_4)	75th %tile FLER (kg/hr CH_4)
99	C/D	4	2.0	1.5	2.7	1.5	2.1	2.7
100	C/D	3	1.4	1.1	2.0	N/A	N/A	N/A
101	C/D	8	0.7	0.5	1.0	0.6	0.7	0.8
102	C/D/T	15	240.5	52.5	570.4	113.1	234.4	348.4
103	C/D/T	7	173.7	114.5	248.5	156.1	186.6	195.1
104	C/D/T	21	142.1	40.2	352.9	75.9	120.8	203.8
105	C/D/T	11	40.4	8.5	104.2	24.7	38.3	49.7
106	C/D/T	7	34.1	15.6	56.6	43.5	49.4	52.9
107	C/D/T	5	28.3	18.7	53.8	19.6	24.4	26.2
108	C/D/T	5	20.1	11.3	25.8	16.0	18.6	25.3
109	C/D/T	14	6.5	3.4	11.9	5.9	6.5	7.6
110	D	6	38.0	21.8	50.5	36.4	39.1	41.0
111	D	9	10.6	6.7	20.3	7.8	8.1	13.4
112	D	6	7.8	5.3	12.2	7.0	7.4	7.6
113	D	12	3.5	0.6	7.4	1.2	2.2	6.5
114	D	3	1.9	1.4	2.5	N/A	N/A	N/A
115	D/T	8	142.4	45.2	203.6	103.4	143.4	174.7
116	P	14	606.0	116.6	1,688.1	488.4	639.2	742.7
117	P	16	451.1	269.7	1,093.1	335.6	410.5	500.2
118†	P	16	279.4	96.7	473.5	197.4	263.4	379.2
119	P	10	267.7	132.2	708.5	218.0	324.8	430.8
120	P	5	207.1	80.1	382.0	102.8	192.2	225.8
121	P	12	166.6	19.6	445.7	104.2	163.8	229.6
122	P	22	156.8	3.4	577.2	86.7	125.6	203.8
123	P	19	128.2	61.4	272.2	94.9	121.6	179.6
124	P	3	112.5	103.0	122.0	N/A	N/A	N/A
125	P	14	93.2	10.2	200.7	30.4	53.1	105.3
126	P	6	75.5	54.4	131.2	56.8	69.9	88.9
127	P	8	58.4	22.9	87.2	45.4	54.0	71.7
128	P	6	54.9	27.6	86.6	36.5	45.3	60.1
129	P	7	39.4	12.0	86.2	26.3	30.5	47.1
130	P	18	14.1	3.5	30.8	9.0	11.9	20.1
131	P	29	3.3	1.6	9.4	2.6	3.2	3.8

† Analysis performed using linear combination method [5] due to limited road access.

I – Measurements of intermittent methane release events

Table S9. Summary of observed intermittent methane release events, including description of event, number of accepted plumes sampled during an event, and the average methane emissions from all accepted plumes. Event duration was not estimated, but it was only a small fraction of the several hour period during which plumes were collected at each of these facilities.

Facility #	Facility type	Intermittent event description	Accepted plumes	Average emissions (kg/hr CH_4)
42	C/D	Compressor blowdown(s)	2	243
65	C/D	Compressor blowdown(s)	2	1,826
49	C/D	Compressor startup	1	744
3	C	Methane release onsite, origin unknown	1	1,460
109	C/D/T	Compressor blowdown(s)	4	55

J – Downwind recovery of exhaust stack methane

Uncombusted methane in engine or turbine exhaust ("exhaust stack methane") can be an important source of methane emissions from facilities equipped with compressors. This is especially true for engines, which emit more than 40-times as much methane per horsepower than turbines. [8] This exhaust is emitted from elevated stacks (up to 12 meters for engines, and 18 meters to turbines) at high temperature (up to 540°C) and high velocity (up to 45 m/s). The contribution of these elevated emissions can be difficult to fully characterize with ground based tracer flux measurements, especially if the measurements are made close to the facility before the plumes have become fully mixed. In theory the problem can be mitigated by making measuring further downwind, which increases the probability of dispersion of all emissions with the tracer gases. However, unfavorable winds and/or limited downwind road access hampered efforts to measure these emissions at some facilities. In addition, signal-to-noise becomes more of a problem further downwind. Figure S4 presents an example of tracer flux measurements conducted at a facility with limited downwind road access. The lack of any CO signal in the plume suggests that the measured methane in this plume were not associated with combustion exhaust.

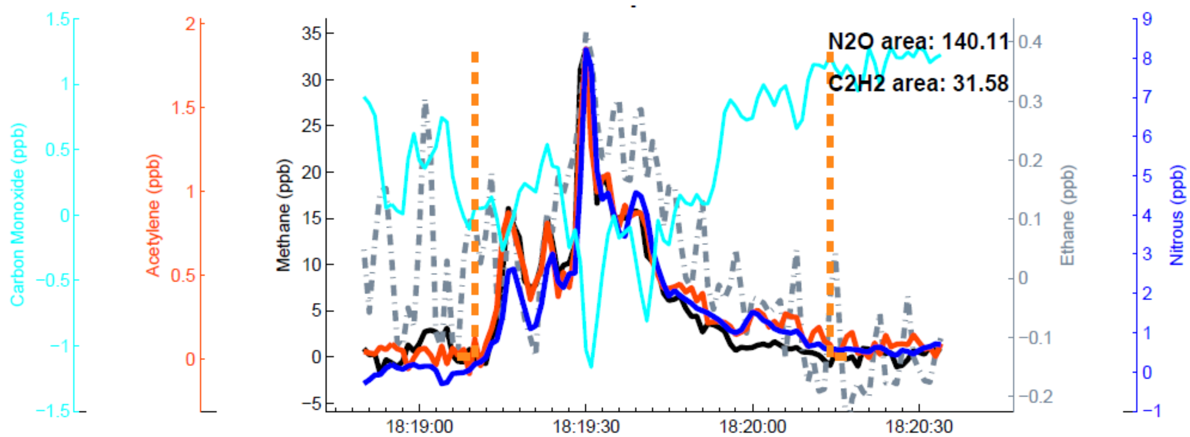

Figure S4. Time series of downwind plume at facility #95, including methane (black), ethane (dashed), nitrous (blue), acetylene (red), and carbon monoxide (turquoise). Carbon monoxide is in the noise despite strong signals from methane and tracer gases. Low recovery of exhaust stack methane in compressor engine exhaust is likely because measurements were conducted <250m downwind from this gathering facility

Each facility was analyzed to assess the potential bias in WAFLER from low recovery of uncombusted methane emissions in the exhaust of reciprocating engines and turbines. A database of ~1,900 compressor engines (>200HP) at O&G facilities in New Mexico[9] was analyzed to obtain the 75th and 90th percentiles of stack height, exhaust temperature, and exhaust flow rate. From these data, two lofted plume scenarios, WC1 and WC2 in Table S10, were generated. To reflect differences between large and small engines, the WC1 scenario was applied to each of the study facilities with an average reciprocating engine horsepower <1,000, and WC2 was applied to all study facilities with >1,000 horsepower, on average. All facilities with turbines had >1,000 horsepower, on average. These scenarios are designed to produce worst-case scenarios of plume rise.

Table S10. Summary of lofted plume scenarios, WC1 and WC2, used in dispersion modeling. Assuming a 20:1 fuel ratio, exhaust flow rate was estimated from the stack diameter and exhaust velocity reported for each engine in the New Mexico database.

Worst-case scenarios	Stack height (m)	Exhaust temperature (ºC)	Exhaust flow rate (cfm)	Applies to
WC1	7.6	527	7,715	< 1,000 HP
WC2	12.2	679	12,527	≥ 1,000 HP

Roscioli et al.[5] analyzed WC1 and WC2 using a Gaussian dispersion model with Briggs plume rise equations[10]. Table S11 provides the minimum downwind distances to recover 30%, 50%, and 80% of exhaust stack methane under both scenarios calculated for three atmospheric stability classes A, B, and C. For each facility, the average wind speed at 10m during measurements (assumed to be 50% greater than the facility wind speed, which was measured at a height of 2m) was used to determine which atmospheric stability class applied. Class A applied with average wind speed <3 m/s, B with average wind speed <5m/s, and C otherwise. Moderate solar insolation was assumed for all facilities.

Table S11. Minimum downwind distances (meters) for three levels of exhaust stack methane recovery, 80%, 50%, and 30%.

Class	A			B			C		
Recovery	80%	50%	30%	80%	50%	30%	80%	50%	30%
WC1	1,566	960	706	1,839	921	618	2,524	1,195	794
WC2	2,015	1,380	1,077	2,817	1,546	1,097	4,330	2,094	1,453

Worst-case recovery of exhaust stack methane recovery was then determined from the average downwind distance (between the tracer release points and mobile lab) of accepted plumes. For example, given average reciprocating engine horsepower >1,000 and average wind speed <3 m/s during measurement, a worst-case recovery of 50% would be applied to this facility if the average downwind distance of accepted plumes was 1,600 meters. A worst-case recovery of 10% of exhaust stack methane was assumed for all facilities with an average downwind distance less than the minimum for 30% recovery. Table S12 includes the worst-case recovery estimates for each facility. For a majority of facilities, less than 50% recovery of exhaust stack methane is the worst-case.

Using worst-case recovery, a worst-case WAFLER (WC-WAFLER) is calculated for each facility. WC-WAFLER is equal to WAFLER plus the product of unrecovered methane emissions (1 - Recovery) and an estimate of combustion-related emissions. The combustion-related emissions estimates are derived from AP-42 emissions factors, which account for the thermal efficiency of operating reciprocating engines and turbines. Thermal efficiency was estimated from horsepower data and engine characteristics (i.e., lean burn vs. rich burn, and two-stroke vs. four stroke), which are given in SI B, Table S3, as well as corresponding information gathered from manufacturers.

Potential bias in WAFLER is then assessed as the ratio of WAFLER to WC-WAFLER. Figure S5 presents a histogram of the ratios of WAFLER to WC-WAFLER. Though AP-42 emissions factors are uncertain, this analysis provides a conservative assessment of bias given the worst-case assumptions used to calculate recovery.

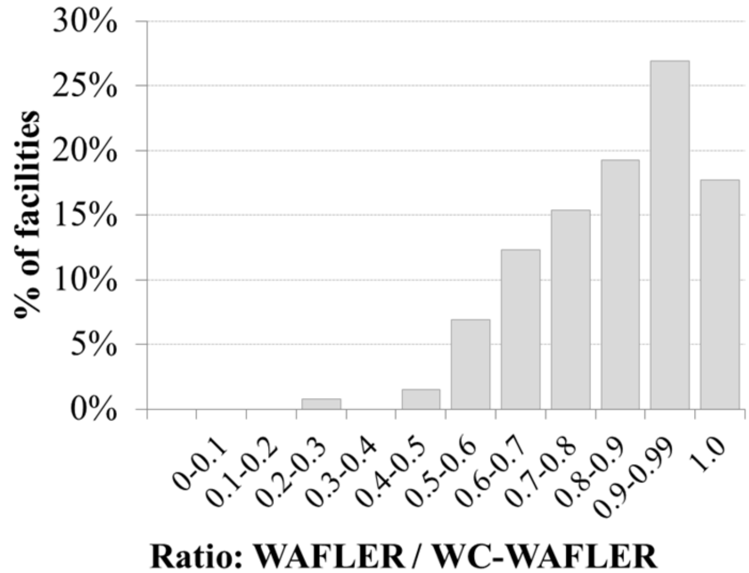

Figure S5. Histogram of the ratios of WAFLER to worst-case WAFLER (WC-WAFLER) assuming worst-case recovery of uncombusted methane emissions in the exhaust of natural-gas powered operating reciprocating engines and turbines. WAFLER is ≥70% of WC-WAFLER at 79% of facilities, and ≥90% at 45% of facilities. At 20 facilities with electric motors or no operating compressors, the uncombusted methane emissions are zero.

Figure S5 supports the conclusion that partial recovery of combustion-related methane emissions may create a modest bias in WAFLER (<30%) at 79% of facilities. Importantly, the magnitude of this bias is less than the standard deviation of methane WAFLER at most facilities. The actual levels of bias are likely lower because the tracers at many facilities were released upwind of compressors, increasing the time for tracer gases to lift and co-disperse with exhaust gases. The tracers were also released from elevated points (>2m) at some facilities, improving the co-dispersion of exhaust stack methane with the tracer(s). This analysis also shows that significant bias, due to the low recovery of combustion-related methane emissions, is likely for about 5-20% of facilities in this study, particularly those with limited downwind road access. The methane WAFLER estimates reported for these facilities are probably lower than actual methane emissions rates. The methane WAFLER for Facility #95 (Figure S4), may be only about 20% of actual emissions. For 27 facilities, methane WAFLER may be underestimated by as much as 30-50%. As reported in the main text, this bias has a small impact relative to the normalized methane emissions from all gathering facilities and processing plants. However, it needs to be considered how low recovery of exhaust stack methane could impact the distribution of emissions and subsequent extrapolation.

Table S12. Average downwind distance and wind speed, climate stability class, worst case recovery (%) of uncombusted methane emissions from reciprocating engine and turbine exhaust, estimated methane emissions using the AP-42 method, and the ratio of WAFLER to WC-WAFLER. Ratios of WAFLER to WC-WAFLER <0.7 are highlighted, indicating facilities with the highest likelihood of underestimated emissions due to low recovery of uncombusted methane emissions.

Facility #	Facility Type	Avg. downwind distance[1] (km)	Avg. wind speed[2] (m/s, @2m)	Climate stability class	% Recovery of uncombusted methane emissions (worst-case)	Estimated methane emissions: AP-42 method (kg/hr)	Ratio: WAFLER / WC-WAFLER
1	C	2.9	3.3	B	80%	28.2	0.98
2	C	0.5	1.3	A	10%	12.4	0.89
3	C	0.5	3.0	B	10%	0.6	0.99
4	C	2.1	4.4	C	50%	9.9	0.93
5	C	0.8	1.7	A	30%	15.6	0.85
6	C	0.9	1.9	A	10%	25.2	0.66
7	C	1.8	6.4	C	30%	6.0	0.91
8	C	0.4	3.7	C	10%	15.6	0.75
9	C	0.5	2.4	B	10%	14.8	0.69
10	C	2.0	4.0	C	30%	16.8	0.71
11	C	1.0	2.5	B	10%	0.5	0.98
12	C	0.6	2.5	B	10%	0.1	0.99
13	C	0.8	3.4	C	30%	9.9	0.72
14	C	0.9	2.6	B	10%	7.5	0.69
15	C	1.2	9.1	C	10%	2.0	0.88
16	C	0.7	2.3	B	10%	9.9	0.51
17	C	1.6	3.8	C	30%	5.5	0.70
18	C	1.9	5.7	C	30%	4.9	0.71
19	C	1.0	2.1	B	50%	3.0	0.85
20	C	0.6	4.2	C	10%	4.1	0.69
21	C	1.1	4.2	C	100%	-	1.00

Facility #	Facility Type	Avg. downwind distance[1] (km)	Avg. wind speed[2] (m/s, @2m)	Climate stability class	% Recovery of uncombusted methane emissions (worst-case)	Estimated methane emissions: AP-42 method (kg/hr)	Ratio: WAFLER / WC-WAFLER
22	C	1.0	4.2	C	30%	0.4	0.97
23	C	0.2	4.5	C	10%	1.6	0.83
24	C	0.6	5.9	C	10%	6.0	0.53
25	C	1.1	4.7	C	30%	0.3	0.96
26	C	0.6	5.7	C	10%	1.3	0.83
27	C	0.5	5.1	C	10%	1.3	0.82
28	C	0.7	1.5	A	100%	-	1.00
29	C	0.8	4.3	C	10%	1.4	0.80
30	C	0.3	8.4	C	10%	0.3	0.93
31	C	1.0	6.3	C	30%	0.1	0.96
32	C	0.2	5.3	C	100%	-	1.00
33	C	1.0	6.4	C	30%	0.6	0.76
34	C	0.3	7.0	C	10%	0.8	0.54
35	C/D	1.0	2.4	B	50%	1.9	1.00
36	C/D	0.5	5.1	C	10%	33.3	0.92
37	C/D	1.1	3.5	C	10%	28.7	0.90
38	C/D	1.5	1.7	A	50%	35.8	0.92
39	C/D	0.7	4.1	C	10%	62.9	0.78
40	C/D	0.5	2.1	B	10%	14.8	0.94
41	C/D	0.8	0.6	A	10%	21.5	0.89
42	C/D	1.8	10.2	C	30%	35.8	0.85
43	C/D	2.0	8.5	C	30%	16.9	0.92
44	C/D	0.8	2.3	B	10%	43.0	0.75
45	C/D	0.5	3.3	B	10%	16.5	0.88
46	C/D	1.9	1.2	A	50%	26.9	0.89
47	C/D	0.8	2.9	B	10%	39.7	0.75
48	C/D	1.0	3.8	C	10%	48.5	0.69
49	C/D	0.7	4.3	C	10%	43.0	0.71
50	C/D	0.7	7.4	C	10%	16.6	0.86
51	C/D	3.1	1.8	A	80%	9.9	0.98
52	C/D	0.5	4.3	C	10%	28.7	0.75
53	C/D	0.4	2.0	A	100%	-	1.00
54	C/D	0.6	2.8	B	10%	22.2	0.78
55	C/D	0.6	2.1	B	10%	42.1	0.64
56	C/D	0.6	2.7	B	10%	3.8	0.95
57	C/D	1.3	7.2	C	10%	11.1	0.86
58	C/D	0.6	3.3	B	10%	14.8	0.82
59	C/D	0.7	3.5	C	10%	1.9	0.97

Facility #	Facility Type	Avg. downwind distance[1] (km)	Avg. wind speed[2] (m/s, @2m)	Climate stability class	% Recovery of uncombusted methane emissions (worst-case)	Estimated methane emissions: AP-42 method (kg/hr)	Ratio: WAFLER / WC-WAFLER
60	C/D	2.5	4.9	C	50%	1.4	0.99
61	C/D	0.4	4.2	C	10%	11.1	0.83
62	C/D	1.0	2.6	B	10%	25.3	0.68
63	C/D	1.0	2.5	B	50%	1.8	0.98
64	C/D	1.2	2.4	B	30%	53.8	0.54
65	C/D	1.5	11.1	C	10%	27.9	0.59
66	C/D	0.6	5.3	C	10%	5.5	0.88
67	C/D	1.4	9.1	C	50%	5.3	0.93
68	C/D	0.4	4.9	C	10%	16.7	0.70
69	C/D	0.7	2.8	B	10%	21.5	0.64
70	C/D	1.5	8.1	C	50%	5.5	0.92
71	C/D	0.9	1.8	A	10%	14.3	0.67
72	C/D	0.4	8.9	C	10%	10.7	0.73
73	C/D	0.7	2.7	B	10%	11.0	0.73
74	C/D	1.7	2.7	B	50%	5.8	0.90
75	C/D	0.4	3.4	C	10%	2.5	0.92
76	C/D	1.1	4.1	C	10%	28.7	0.48
77	C/D	1.7	4.6	C	30%	5.5	0.85
78	C/D	0.9	5.5	C	10%	1.1	0.96
79	C/D	1.1	5.9	C	10%	1.2	0.95
80	C/D	0.7	2.5	B	30%	1.7	0.94
81	C/D	0.2	3.4	C	10%	0.6	0.97
82	C/D	2.1	6.1	C	30%	2.6	0.89
83	C/D	0.2	2.2	B	10%	14.1	0.52
84	C/D	0.4	4.5	C	10%	2.6	0.85
85	C/D	0.2	5.4	C	10%	5.6	0.72
86	C/D	1.0	3.9	C	10%	5.5	0.70
87	C/D	0.2	4.6	C	10%	9.9	0.56
88	C/D	1.0	3.1	B	50%	5.6	0.80
89	C/D	0.5	5.5	C	10%	8.3	0.59
90	C/D	1.0	1.6	A	10%	0.5	0.95
91	C/D	0.2	0.7	A	10%	10.7	0.48
92	C/D	1.2	0.9	A	100%	-	1.00
93	C/D	0.7	3.8	C	10%	0.5	0.94
94	C/D	1.6	2.2	B	50%	0.4	0.98
95	C/D	0.3	2.3	B	10%	28.7	0.22
96	C/D	1.3	1.5	A	50%	0.3	0.98
97	C/D	0.9	2.4	B	30%	0.2	0.98

Facility #	Facility Type	Avg. downwind distance[1] (km)	Avg. wind speed[2] (m/s, @2m)	Climate stability class	% Recovery of uncombusted methane emissions (worst-case)	Estimated methane emissions: AP-42 method (kg/hr)	Ratio: WAFLER / WC-WAFLER
98	C/D	2.1	6.4	C	50%	3.1	0.61
99	C/D	0.6	2.3	B	100%	-	1.00
100	C/D	1.0	2.2	B	100%	-	1.00
101	C/D	0.5	3.0	B	100%	-	1.00
102	C/D/T	0.9	2.5	B	10%	16.8	0.94
103	C/D/T	1.3	5.8	C	10%	0.4	1.00
104	C/D/T	0.8	4.0	C	10%	19.7	0.89
105	C/D/T	0.4	1.7	A	10%	20.8	0.68
106	C/D/T	0.6	2.9	B	10%	10.4	0.78
107	C/D/T	0.3	4.5	C	10%	14.8	0.68
108	C/D/T	0.2	3.9	C	10%	19.7	0.53
109	C/D/T	0.7	2.4	B	100%	-	1.00
110	D	0.8	5.1	C	100%	-	1.00
111	D	1.6	1.2	A	100%	-	1.00
112	D	1.9	2.7	B	100%	-	1.00
113	D	0.6	4.4	C	100%	-	1.00
114	D	2.4	2.0	B	100%	-	1.00
115	D/T	0.4	5.2	C	100%	-	1.00
116	P	2.1	3.0	B	50%	109.0	0.92
117	P	1.5	6.3	C	30%	20.0	0.97
118	P	0.5	6.7	C	10%	3.0	0.99
119	P	1.6	5.5	C	30%	134.4	0.74
120	P	0.7	3.7	C	10%	0.8	1.00
121	P	2.1	5.5	C	30%	53.4	0.82
122	P	0.8	4.8	C	30%	39.4	0.85
123	P	0.7	3.2	B	10%	73.6	0.66
124	P	2.8	4.1	C	50%	41.5	0.84
125	P	0.4	6.2	C	100%	-	1.00
126	P	0.8	3.4	C	10%	48.7	0.63
127	P	0.3	4.3	C	10%	1.4	0.98
128	P	1.5	6.0	C	30%	9.6	0.89
129	P	0.4	4.0	C	10%	0.5	0.99
130	P	0.7	4.0	C	100%	-	1.00
131	P	0.6	8.5	C	10%	1.0	0.78

[1] The average distance between the mobile laboratory and tracer release points for accepted plumes.

[2] The average of all wind speed measured at the facility, usually an open area 2m from the ground, for all plumes. Wind speed measurements recorded at the mobile laboratory are used for 11 facilities, and National Weather Service records are used for a single facility.

K – Comparison of facility level emissions at processing plants

Table S13. Summary of facility-level data reported by Shorter et al.[11], including facility-level methane emissions rate estimates for seven processing plants and two gathering facilities. Measurements were performed with tracer flux methods.

Area	Test#	Facility Type	Capacity (tonnes/hr)	Methane emissions (kg/hr)			Recip #	Dehy #
				Canister	Mobile lab	Final estimate		
West	1	Gas Plant	32	124	-	124	13	-
West	2	Gas Plant	32	98	44	45	13	-
West	6	Gas Plant	104	-	69	69	4	-
TX/LA	1	Production	20	161	123	142	4	2
TX/LA	12	Gas Plant	56	887	789	838	6	-
TX/LA	13	Gas Plant	80	162	141	152	7	-
TX/LA	14	Gas Plant	60	76	115	95	4	-
West	5	Gathering Compressor Station	-	-	86	86	2	-
West	6	Compressor Station	-	-	115	115	3	-

Table S14. Summary of data collected by National Gas Machinery Laboratory[12] and Picard et al.[13], including facility-level methane emissions rate estimates for nine processing plants (eight unique). Emissions rates are the sum of emissions estimated from component and process-level calculations and measurements.

Study	Plant #	Natural gas throughput (tonnes/hr)	Methane emissions rate (kg/hr)
National Gas Machinery Laboratory (NGML), 2006	1	401	217
	2	165	18
	3	104	94
	4	36	55
	5	70	339
Picard et al, 2002	1	43	139
	2	48	171
	3	169	513
	4	96	279

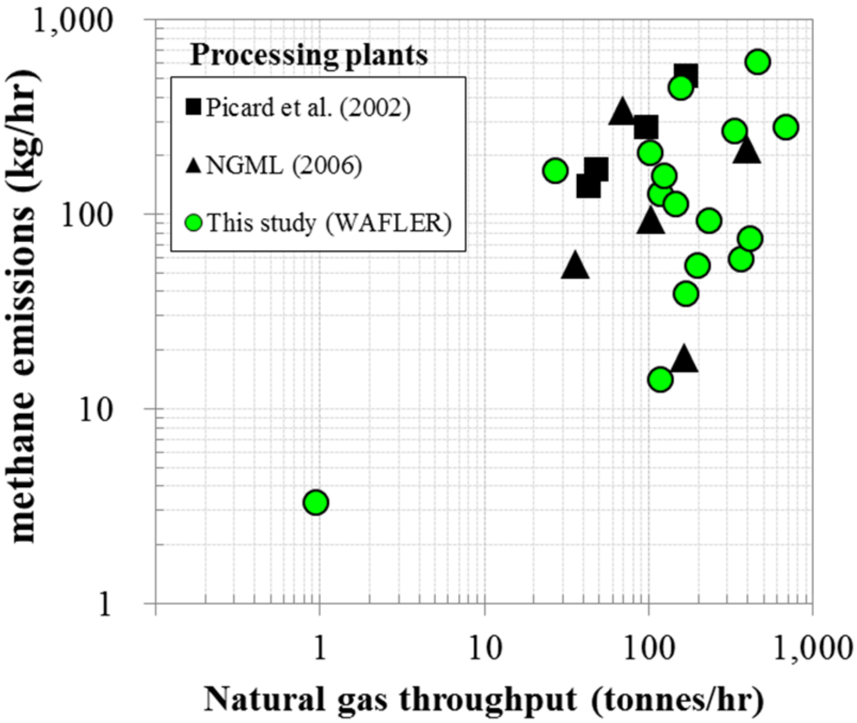

Figure S6. Previously reported methane emissions rates (kg/hr) for nine processing plants [12,13] and WAFLER estimates obtained for 16 processing plants in this study versus natural gas throughput (tonnes/hr).

L – Multiple linear least squares regression variables and results

Multiple linear least squares regressions were performed on gathering facilities to investigate the influence of different factors on WAFLER. The purpose was exploratory, to have a greater understanding of relevant factors and to incorporate qualitative observations made in the field. The independent variables considered were gas composition, engine and turbine horsepower (total and operating), total and CH_4 throughput, equipment counts (compressors, dehydration units, and pneumatics), pressure (inlet, outlet, delta, and ratio), AP-42 methane emissions estimates, and ambient temperature. Included were binary (dummy) variables for facility type (C, C/D, etc.), company, primary driver type (turbine), engine types (rich-burn and two-stroke), presence of collocated non-partner equipment, and onsite observations of leaking and/or venting. Two-way interactions (horsepower * inlet pressure and throughput/inlet pressure) were also included to describe the logical relationships between these variables.

All gathering facilities with positive throughput (108 out of 114) were used in the regression. (Facility #59 was not included because it is not a unique data point.) Numerous model variants were explored, controlling each step to avoid strongly correlated independent variables being introduced to the model (e.g., total and operating reciprocating engine horsepower). Models using WAFLER or tnWAFLER as the dependent variable resulted in coefficients that were highly sensitive to a few facilities. The final regression model, which is presented in the text, uses ln-WAFLER as the dependent variable. The significant parameters are ln-throughput, delta pressure, and dummy variables for turbines being the primary driver type and observation of substantial venting from liquids storage tanks. The model has an adjusted r-square of 0.66, and a Root Mean Square Error of 0.76. Figure S7 presents predicted WAFLER versus measured WAFLER.

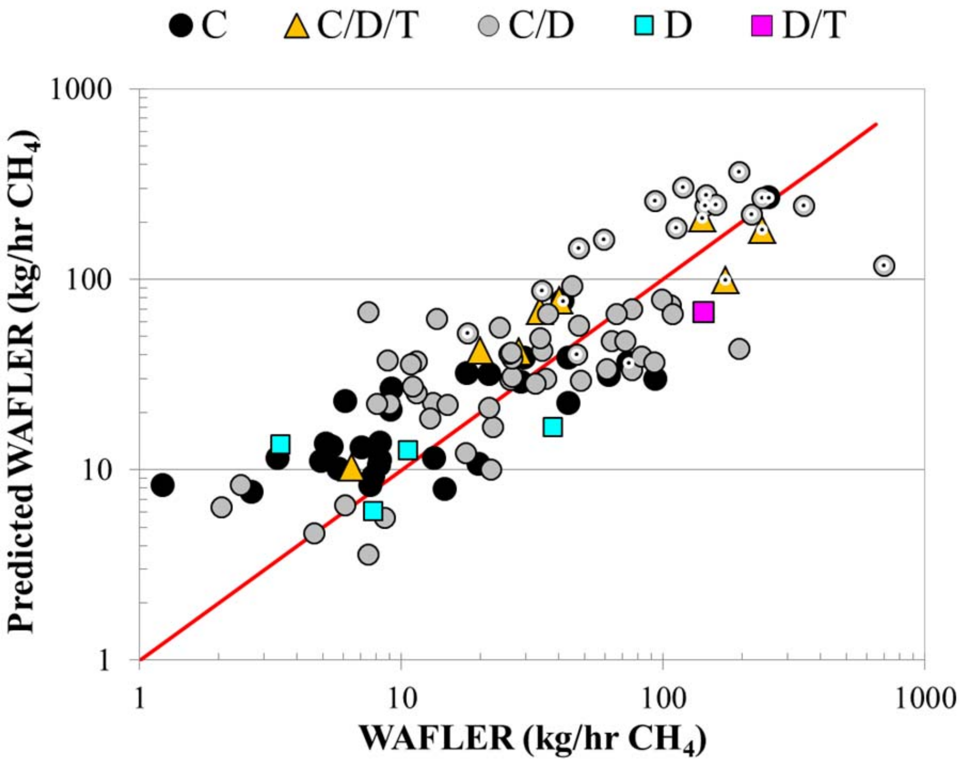

Figure S7. Predicted versus measured WAFLER (in log scale). Facility types are indicated by their respective shapes and colors. Facilities flagged with observation of substantial venting from liquids storage tanks are indicated by concentric black and white circles (22 total). Predicted WAFLER adjusted using standard error of the regression [$\hat{y} = \exp\left(\frac{\hat{\sigma}}{2}\right)\exp(ln\widehat{WAFLER})$] [14].

Coefficients of the model are provided in Table S15. The coefficient for the independent variable delta pressure describes a percentage change in ln-WAFLER. The coefficient of ln-throughput describes a percentage change in ln-WAFLER from a percentage change in ln-throughput. The coefficients of the dummy variables are interpreted differently, quantifying the relative (%) differences between the means of flagged and non-flagged facilities. The % difference in level scale is determined by using the exponential function [100*(exp(β_1) – 1)][15].

Table S15. Regression model results, including average and 95th percentile values for the coefficients, as well as their respective standard error (SE), t-stats, and p-values. All coefficients are significant at the 95% confidence level.

Model coefficients[1]	Description	Average	2.5%	97.5%	SE	t-stat	p-value
	Intercept	1.57					
β_1	Primary driver type (turbine)	(1.36)	(2.00)	(0.71)	0.32	-4.2	<0.0001
β_2	ln CH4 throughput	0.39	0.30	0.47	0.04	9.0	<0.0001
β_3	Delta pressure	8.1E-04	4.1E-04	1.2E-03	2.1E-04	4.0	0.0001
β_4	Substantial venting (tank)	1.40	1.02	1.77	0.19	7.4	<0.0001

[1]Equation form: $\ln\_WAFLER = 1.57 - 1.36 * turbine\_driven + 0.39 * \ln\_throughput + 8.1 * 10^{-4} * \Delta pressure + 1.4 * tank\_vent$

Multiple diagnostic plots for the regression model are provided. Figure S8 presents a histogram of regression residuals. Importantly, the residuals appear to be normally distributed with a mean near zero. Regression residuals versus predicted WAFLER are plotted in Figure S9. There are no apparent trends with the regression residuals and predicted WAFLER. Figure S10 is a plot of Cook's distance[16] versus observed minus predicted ln-WAFLER. Cook's distance indicates the most influential data points. While the Cook's distances for 11 facilities are greater than three times the average, these influential data points are well distributed, resulting in a regression model that is insensitive to any single data point. To verify, regression model coefficients were re-calculated after individually excluding facilities with the largest Cook's distance. As an example, Table S16 includes the regression model coefficients excluding facility #35, which was flagged for substantial venting, had the largest Cook's distance, and had the highest methane WAFLER of 700 kg/hr. The coefficient for major tank emissions decreases to 1.29 (from 1.40), which is a small change in relative terms. The other coefficients are essentially unchanged.

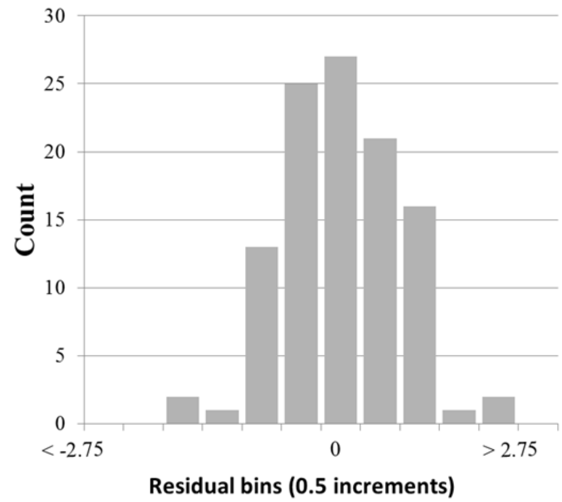

Figure S8. Histogram of regression residuals in bin increments of 0.5. The residuals are approximately normal and centered at zero.

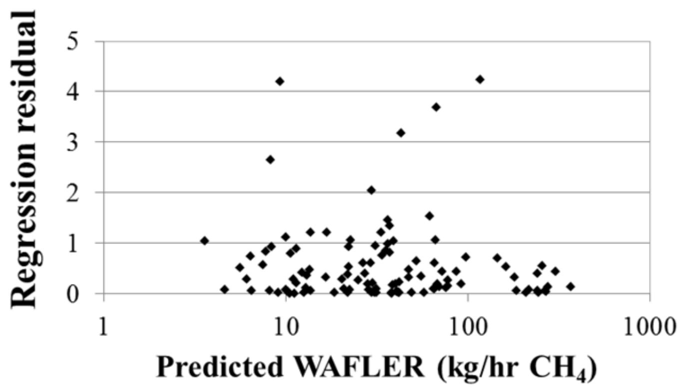

Figure S9. Regression residuals versus predicted WAFLER (log scale). There are no apparent trends with the regression residuals and predicted WAFLER.

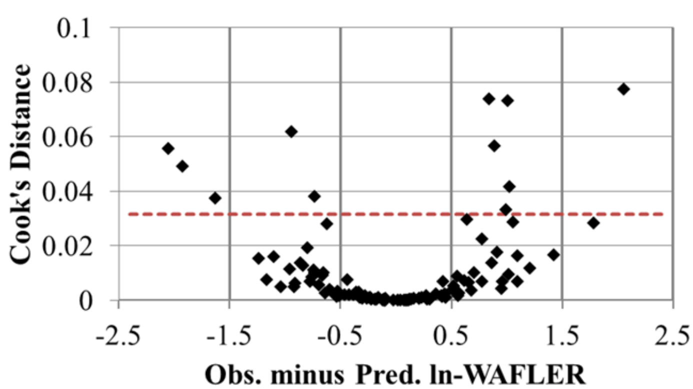

Figure S10. Cook's distance versus observed minus predicted ln-WAFLER. Dashed line indicates three times the average Cook's distance. 11 data points are above the dashed line, but are well distributed among the other 97 data points.

Table S16. Regression model results excluding facility #35, including average and 95th percentile values for the coefficients. Facility #35 was flagged for substantial venting, had the largest Cook's distance, and had the highest methane WAFLER of 700 kg/hr.

Model coefficients	Description	Average	2.5%	97.5%
	Intercept	1.55		
β_1	Primary driver type (turbine)	(1.35)	(1.97)	(0.73)
β_2	ln CH4 throughput	0.39	0.31	0.47
β_3	Delta pressure	8.4E-04	4.4E-04	1.2E-03
β_4	Substantial venting (tank)	1.29	0.92	1.66

M – Summary of high emitters

In the companion paper detailing the tracer flux methodology used in this study, Roscioli et al.[5] demonstrated that specific methane emissions sources may be targeted through strategic placement of tracer release points. Out of the 23 gathering facilities flagged for substantial methane emissions from liquids storage tanks, estimates for the magnitude of these emissions could be obtained for five, Table S17. At six other facilities, it appeared that *most* of the methane emissions were due to substantial tank venting, but the contribution of tank venting to WAFLER could not be isolated from other emissions sources.

Table S17. AP-42 emissions, natural gas throughput, tnWAFLER, and WAFLER of gathering facilities flagged for substantial tank venting (23 total). At five facilities the magnitudes of methane emissions due to tank venting have been estimated. At six other facilities most of the emissions appeared to be due to tank venting, but emissions from other sources could not be quantified separately. Issues reported by company personnel regarding causes of substantial methane emissions and other observed emissions sources are noted.

Facility #	Facility Type	AP-42 emissions (kg/hr)	Facility Natural Gas Throughput (tonnes/hr)	tnWAFLER (% of CH_4 throughput)	WAFLER (kg/hr CH_4)	Emissions due to substantial tank venting	Noted issue associated with substantial tank venting	Other observed emissions sources
1	C	28.2	29.7	1.11%	255.1	-	-	Compressor venting
3	C	0.6	0.5	17.52%	74.5	-	-	-
4	C	9.9	-		64.8	Most	-	-
8	C	15.6	5.1	0.90%	41.6	~10 kg/hr‡	-	-
35	C/D	1.9	7.7	9.54%	698.6	~650 kg/hr†	Stuck dump valve on first stage scrubber	-
36	C/D	33.3	34.1	1.09%	344.1	-	-	Compressor and dehydrator venting
37	C/D	28.7	25.7	0.98%	240.5	Most	Float dump valve stuck open	Compressor and dehydrator venting; pneumatics
38	C/D	35.8	20.9	1.12%	217.6	-	-	-
39	C/D	62.9	52.2	0.39%	196.1	Most	Stuck vent valve	Three leaky valves
41	C/D	21.5	165.3	0.10%	159.8	-	-	-
42	C/D	35.8	28.1	0.59%	146.7	-	-	-
43	C/D	16.9	22.5	0.76%	145.2	Most	Open thief hatch	-

Facility #	Facility Type	AP-42 emissions (kg/hr)	Facility Natural Gas Throughput (tonnes/hr)	tnWAFLER (% of CH_4 throughput)	WAFLER (kg/hr CH_4)	Emissions due to substantial tank venting	Noted issue associated with substantial tank venting	Other observed emissions sources
44	C/D	43.0	35.3	0.36%	119.0	-	-	Pneumatics
45	C/D	16.5	18.9	0.75%	112.0	~70 kg/hr‡	-	Compressor crank-case / rod packing vents
49	C/D	43.0	23.8	0.41%	93.4	-	-	-
58	C/D	14.8	18.9	0.40%	59.4	-	Pressure relief valve seated improperly	-
61	C/D	11.1	7.5	0.84%	47.7	~23 kg/hr‡	Combustor not operating	Leaking compressor pipe
63	C/D	1.8	0.3	17.08%	46.8	-	-	Pneumatics; engines
67	C/D	5.3	1.8	2.16%	34.5	Most	-	-
80	C/D	1.7	0.6	3.04%	17.9	-	-	Pneumatics
102	C/D/T	16.8	48.2	0.65%	240.5	~290 kg/hr†	-	Leak at pig launcher
103	C/D/T	0.4	321.0	0.07%	173.7	-	-	-
104	C/D/T	19.7	15.2	1.16%	142.1	Most	-	Compressor rod packing vent

† Estimated from average emissions before and after changes to emissions from tanks.
‡ Estimated using linear combination[5].

Table S18. Other potentially substantial emissions sources noted by onsite observer for gathering facilities (facilities in Table S17 are not included).

Facility #	Facility Type	AP-42 emissions (kg/hr)	Facility Natural Gas Throughput (tonnes/hr)	tnWAFLER (% of CH_4 throughput)	WAFLER (kg/hr CH_4)	Noted emissions sources
7	C	6.0	5.1	1.03%	43.8	Leaks from pressure relief valves
14	C	7.5	0.2	8.45%	14.8	Leaky valve; Compressor vents
40	C/D	14.8	10.5	2.44%	195.3	Leaky pipe near compressor
51	C/D	9.9	8.0	1.35%	82.9	Tank venting; four compressors venting from fuel line purge
56	C/D	3.8	17.7	0.38%	63.5	Pneumatic valve leaking; rod packing vents
92	C/D	-	0.4	2.92%	8.7	Dehydrator venting
94	C/D	0.4	0.014	69.60%	7.5	Leaky pipe union
96	C/D	0.3	0.25	2.52%	6.1	Dehydrator venting
97	C/D	0.2	0.12	4.17%	4.6	Leak from line heater
112	D	-	0.5	2.07%	7.8	Dehydrator venting

N – Cumulative distributions for C and C/D facilities

Figure S11 presents cumulative distributions of WAFLER and tnWAFLER for C and C/D gathering facilities, the two classes of facility with the largest sample sizes. The distributions are presented as a percentage of cumulative throughput. Facility-level tnWAFLER estimates are also shown.

(a)

(b)

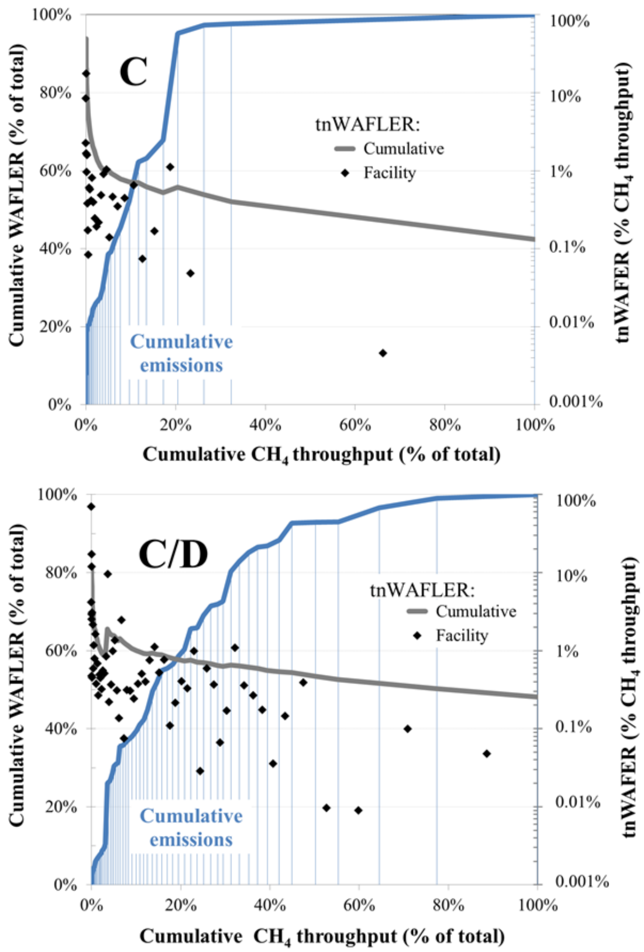

Figure S11. Cumulative methane emissions (solid curve) for (a) C and (b) C/D facilities ranked by throughput (low to high). Also plotted are the normalized methane emissions: tnWAFLER (symbols) and cumulative tnWAFLER (dashed line). (Included are three C facilities and two C/D facilities that had zero throughput but were still emitting methane.)

Figure S11 shows that the methane emissions from C and C/D facilities are highly skewed. For example, for the C facilities (Figure S11(a)), nearly 50% of the emissions came from 25 facilities that contributed less than 10% of the cumulative CH_4 throughput. However, facility #11, the highest throughput C gathering facility sampled, accounted for more than 60% of the aggregate throughput (487 tonnes/hr). This facility had a WAFLER of 22 ± 6.3 kg/hr (0.005% of CH_4 throughput). Without this facility, the cumulative normalized methane emissions across all C facilities was 0.40%, but with it falls to 0.13%. This highlights the sensitivity of normalized methane emission rates to highly-skewed emissions.

Figure S11(b) shows that C/D facilities' methane emissions are somewhat less skewed than for the C facilities, with 50% of the methane emissions coming from 20% of methane throughput. The cumulative tnWAFLER across all C/D facilities is 0.26%. The highest tnWAFLER estimates are, again, associated with the smallest throughput facilities.

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