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Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2013: Potential Revisions to Liquids Unloading Emissions Estimate

Overview of Methodology in 2013 and 2014 Inventories

Data from a 2012 report published by the American Petroleum Institute (API) and America's Natural Gas Alliance (ANGA)[1] were used beginning with EPA's 1990-2011 Inventory released in 2013 ("2013 Inventory") to develop regional activity data and regional emission factors for gas well liquids unloading activities in natural gas systems. For more information, see memo *Overview of Updates to the Natural Gas Sector Emissions Calculations for the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011*, available at http://epa.gov/climatechange/Downloads/ghgemissions/fact-sheet-oil-and-gas-estimates-in-2013-inventory.pdf.

Potential Revisions to Liquids Unloading Estimates

Several recent studies and upcoming data from GHGRP provide new information on liquids unloading. Below is a brief overview of the data and potential uses of the data to update the GHG Inventory estimates.

Allen et al. 2014

Allen et al. 2014 presented results of a study focused on emissions from liquids unloading.[2] The Allen et al. study measured unloading emissions from 107 natural gas wells owned by 10 study participant companies. The 107 wells were selected from 4 regions of the country, in proportion to the population of wells that were venting for liquids unloading in each region according to GHGRP data. The wells were selected to represent the three most common categories of unloading methods: automatic plunger-lift, manual plunger-lift and manual non-plunger. Using data from the emission measurements, Allen et al. developed five emission factors for various unloading methods and well types (termed "unloading categories" in this memorandum), in units of emissions per event. The 10 study participants were also surveyed to determine the frequency of events per year, for each of the five unloading categories, in each of four regions of interest. This information was combined with the 2012 GHGRP count of wells performing unloading operations (assumed to represent all national activity) to estimate national emissions from well unloading operations. The study estimated national methane emissions from unloading operations of 270 kilotons per year (kt/y) with a 95% confidence interval of 190 – 400 kt/y, for the year 2012. In contrast, the GHG Inventory estimated 2012 methane emissions of 273 kt/y from unloading activities. As shown in Table 1 below, the totals are in very close agreement, though the apportionment of emissions between non-plunger lift and plunger lift emissions differs between the two analyses.

Table 1. Comparison of 2012 National Methane Emissions from Liquids Unloading as Reported in the 2015 GHG Inventory and the Allen et. al Study

Lift Type	2015 GHG Inventory (kt)	Allen et al. (kt)
Non-plunger	152	80
Plunger	115	190

[1] "Characterizing Pivotal Sources of Methane Emissions from Natural Gas Production" (September 2012). Available online: http://www.api.org/~/media/Files/News/2012/12-October/API-ANGA-Survey-Report.pdf

[2] Allen, D.T., Sullivan, D., Zavala-Araiza, D., Pacsi, A., Harrison, M., Keen, K., Fraser, M., Hill, A.D., Lamb, B.K., Sawyer, R.F., and Seinfeld, J.H. Methane Emissions from Process Equipment at Natural Gas Production Sites in the United States: Liquid Unloadings, Environmental Science & Technology, 10.1021/es504016r. Available online: http://pubs.acs.org/doi/abs/10.1021/es504016r

Total	**267**	**270**

Summary of Allen et al. Approach

Allen et al. observed wide variability in measured emissions data from well unloading events. Allen et al. conducted statistical analyses to identify well and unloading event characteristics that could explain the variability observed and found that the variable that best explained the variability in the observed annual well emissions was unloading frequency. Allen et al. also found a positive correlation of event frequencies with well age (with older wells having more unloading events per year) and a negative correlation of annual emissions with well depth (with deeper wells having lower annual emissions).

Allen et al. study results indicated consistency in per-event emissions for five unloading categories that vary by wells with or without plunger lift and by event frequency:

- Wells without plunger lifts ≤ 10 events per year;
- Wells without plunger lifts 10 < events ≤ 50 per year;
- Wells without plunger lifts 50 < events per year;
- Wells with plunger lifts ≤ 100 events per year; and
- Wells with plunger lifts > 100 events per year.

To calculate national emissions, the Allen et al. study used national per-event emission factors for the five unloading categories above in conjunction with region-specific activity data comprising two components:

1. Regional total counts of wells in the five unloading categories. Allen et al. relied on 2012 GHGRP data for counts of wells on a regional level that perform liquids unloading with and without plunger lifts. The Allen et al. study then applied results from a survey of study participants to apportion the wells into the five unloading categories (e.g., 79% of non-plunger wells in the Appalachian region have ≤ 10 unloading events per year).
2. Regional average annual number of events that are performed on wells in each of the five unloading categories. Allen et al. applied results from the survey of study participants to determine the region-specific average annual number of unloading events in each unloading category (e.g., non-plunger wells with ≤ 10 unloading events per year in the Appalachian region perform 3.13 events/year on average).

The study found that the distribution of high event frequency wells (≥ 100 events/year) is not uniform within the Rocky Mountain region. In particular, AAPG Basin 580 (San Juan Basin) had a much higher fraction of high frequency plunger lift unloading than the rest of the region. Therefore, the total number of events in the two plunger lift unloading categories was calculated for two sub-basins of the Rocky Mountain region to avoid skewing a regional estimate with the activity observed in Basin 580.

Comparison of Allen et al. with EPA data

Currently, EPA is considering ways to better reflect regional-level emissions for liquids unloading in the GHG Inventory. Although regional emissions were not the focus of the Allen et al. study, regional data from the study were used to compile regional emissions. Since the Allen et al. study combines the Southwest region with Mid-Continent and combines the West Coast region with Rocky Mountain, these same combinations were made in order to compare the Allen et al. study results to the GHG Inventory and the GHGRP emissions on a regional basis as shown in Table 2 below.

Table 2. Regional and National Comparison of 2012 Liquids Unloading Methane Emissions

NEMS Region	2012 Liquids Unloading Emissions (MMT CO_2e)

	Allen et al.	2015 GHG Inventory	GHGRP
Appalachian	1.13	2.10	0.60
Gulf Coast	0.27	0.35	0.58
Mid-Continent/Southwest	1.85	2.50	1.20
Rocky Mountain/West Coast	3.78	1.78	3.54
Total	**7.03**	**6.73**	**5.92**

The Allen et al. study and GHG Inventory compare very closely at the national level, but not at the regional level. At the regional level, the Allen et al. study results compare more closely with the GHGRP (which is expected to some degree because the Allen et al. study estimates are based on regional GHGRP well count activity data).

Potential Applicability of Allen et al. to Revising the GHG Inventory Emission Factors

The GHG Inventory applies region-specific annual emission factors to wells unloading with and without plunger lifts. For wells without plunger lifts, the GHG Inventory regional emission factors range from 100 thousand to 2.6 million scf CH_4/well/year; for wells with plunger lifts, the regional emission factors range from 3.5 thousand to 1.4 million scf CH_4/well/year.

Table 3 below presents regional emission factors developed from the Allen et al. study. The basis for these factors is combining: (1) national average per-event emissions data (scf CH_4/event) in each unloading category that were obtained from study measurements; with (2) event frequency data (events/well/year) in each unloading category that were obtained from the survey of study participants. The factors labeled "Regional Average" in Table 3 take into accout the relative prevalence of wells in each unloading category in each region based on the study participant survey.

Table 3. Regional Methane Emission Factors (scf CH_4/well/year) Developed from Allen et al. Study

Unloading Category	Appalachian	Gulf Coast	Mid-Continent/ Southwest	Rocky Mountain/ West Coast
Wells without plunger lifts				
≤ 10 events per year	67,237	62,778	63,483	60,659
10 ≤ events ≤ 50 per year	514,707	470,360	510,892	431,633
50 ≤ events < 200 per year	2,352,151	3,177,691	2,611,834	2,657,585
Events ≥ 200 per year	-	12,105,491	14,478,647	-
Regional Average	**197,954**	**131,489**	**203,466**	**107,402**
Wells with plunger lifts				
< 100 events per year	69,357	50,985	49,790	91,114
≥ 100 events per year	326,206	162,000	2,139,423	1,447,558
Regional Average	**75,336**	**51,726**	**430,730**	**472,937**

Table 4 below compares regional emission factors developed from the Allen et al. study to the regional factors currently used in the GHG Inventory.

Table 4. Regional Methane Emission Factors (scf CH_4/well/year) Developed from Allen et al. Study Compared to Current GHG Inventory Factors[a]

Data Source	Appalachian	Gulf Coast	Mid-Continent/ Southwest	Rocky Mountain/ West Coast
Wells without plunger lifts				
GHG Inventory	166,000	301,000	230,000/ 97,000	2,579,000/ 304,000

Allen et al.	198,000	131,000	203,000	107,000
Wells with plunger lifts				
GHG Inventory	315,000	70,000	1,380,000/ 4,000	154,000/ 345,000
Allen et al.	75,000	52,000	431,000	473,000

a – Rounded to the nearest thousand.

In order to incorporate the Allen et al. factors into the GHG Inventory using the regional structure of the production segment calculations, the emission factors could be assigned to the Southwest region as the Mid-Continent region, and to the West Coast region as the Rocky Mountain region, since the Allen et al. study did not differentiate regions to the same granularity as the current Inventory methodology.

Potential Applicability of Allen et al. to Revising the GHG Inventory Activity Data

The Allen et al. study used GHGRP data to estimate national emissions. Note that the GHGRP data do not cover 100 percent of national activity due to the reporting threshold. Table 5 below shows activity data from the 2015 GHG Inventory compared to GHGRP data, for year 2012.

Table 5. Regional Activity Data from Current GHG Inventory Compared to GHGRP for Year 2012

Well Type/ Data Source	NEMS Region						
	North East	Gulf Coast	Mid-Continent	Southwest	Rocky Mountain	West Coast	National Total
Wells without plunger lifts							
GHG Inventory	18,181	2,627	5,383	10,527	1,199	179	38,096
GHGRP	7,562	4,649	3,569	3,980	6,720	33	26,513
Wells with plunger lifts							
GHG Inventory	7,030	860	3,031	1,797	10,162	200	23,080
GHGRP	11,118	1,613	1,903	2,596	15,412	0	32,642
Total wells with liquids unloading							
GHG Inventory	25,211	3,487	8,414	12,324	11,361	379	61,176
GHGRP	18,680	6,262	5,472	6,576	22,132	33	59,155

The results of a revision to the activity data methodology to use GHGRP data would better align the GHG Inventory with both the Allen et al. and the GHGRP results—both on a regional level and also regarding the overall apportionment between non-plunger lifts and plunger lifts.

Potential Impacts of Allen et al. on GHG Inventory Estimates

Table 6 below shows 2012 methane emissions from liquids unloading for five calculation approaches:

1. Allen et al. study estimates, which apply regional emission estimates based on unloading volumes and frequencies observed during the study to available GHGRP activity data (note that since Allen et al. publication, updated 2012 GHGRP data have been published);
2. Current GHG Inventory estimates, which are based on emissions estimates and event counts from a 2012 API-ANGA study[3];
3. Current GHGRP emissions data;

[3]American Petroleum Institute and America's Natural Gas Alliance (API/ANGA) Characterizing Pivotal Sources of Methane Emissions from Natural Gas Production: Summary and Analyses of API and ANGA Survey Responses, Final Report, updated September, 2012. Available online: http://www.api.org/news-and-media/news/newsitems/2012/oct- 2012/~/media/Files/News/2012/12-October/API-ANGA-Survey-Report.pdf

4. Emission factors developed from Allen et al. study data as shown in Table 4 applied to current GHG Inventory activity data; and
5. Emission factors developed from Allen et al. study data as shown in Table 4 applied to most up-to-date GHGRP activity data (i.e., updated activity data compared to approach 1).

Table 6. Regional and National Comparison of 2012 Liquids Unloading Methane Emissions

NEMS Region	2012 Liquids Unloading Methane Emissions (MMT CO_2e)				
	Allen et al. Study	Current GHG Inventory	GHGRP	EFs from Allen et al. Study & Inventory Activity Data	EFs from Allen et al. Study & GHGRP Activity Data
Appalachian	1.13	2.14	0.60	1.95	1.10
Gulf Coast	0.27	0.69	0.58	0.24	0.33
Mid-Continent/Southwest	1.85	2.04	1.20	2.51	1.64
Rocky Mountain/West Coast	3.78	1.81	3.54	2.39	3.79
Total	**7.03**	**6.67**	**5.92**	**7.09**	**6.86**

API/ANGA 2012 – Analysis of National versus Regional Factors

EPA compared liquids unloading emissions data for 2011 and 2012 from the 2014 Inventory to data reported to GHGRP as of August 18, 2014. As shown in Table 7, there were significant regional differences between the Inventory emissions estimates and the data reported to the GHGRP for the same year. For example, liquids unloading emissions reported to GHGRP in the Rocky Mountain and South West NEMS regions are over twice as high as emissions for these regions in the Inventory. In contrast, Inventory emissions for the North East and Mid-Continent regions are more than five times as high as GHGRP emissions for these regions. EPA is considering options to address the differences between the Inventory and GHGRP.

As discussed in the "Planned Improvements" section of the 2014 Inventory, EPA investigated the impact of using national-average data from the API/ANGA report as opposed to the regional data. Table 8 compares four sets of data on liquids unloading. The first column presents the data from year 2012 in the 2014 Inventory and is based on regional activity and emission factors developed from the API/ANGA study. The second column of data is the information reported under the GHGRP for year 2012 (as of August 18, 2014). The third column is the result of replacing regional emission factors for year 2012 in the Inventory with national-average emission factors for liquids unloading with and without plunger lifts that were developed from the API/ANGA study. The fourth column replaces the regional proportions of wells venting during liquids unloading with the national-average proportions that were reported in the API/ANGA study in addition to using national-average emission factors. For the national average proportions of wells venting during liquids unloading, the wells vented with plunger lifts were tracked separately from the wells vented without plunger lifts.

Table 7. Comparison of 2014 Inventory and GHGRP Emissions from Liquids Unloading

NEMS Region	Methane Emissions (MT CO_2e)*				
	GHGRP 2011 Emissions[a]	Inventory 2011 Emissions	GHGRP 2012 Emissions	Inventory 2012 Emissions	GHGRP 2013 Emissions[a]

North East	748,219	2,077,962	603,649	2,115,336	452,579
Mid-Continent	1,186,729	1,798,774	957,430	1,790,352	717,823
Rocky Mountain	4,351,672	1,857,979	3,510,845	1,837,101	2,632,219
South West	296,087	304,100	238,877	304,888	179,096
West Coast	33,275	44,541	26,845	43,392	20,127
Gulf Coast	716,507	747,532	578,064	748,132	433,397
TOTAL	**7,332,042**	**6,830,887**	**5,915,710**	**6,839,201**	**4,435,241**

*Methane GWP=25

a – EPA has not yet calculated emissions on a regional basis from GHGRP year 2011 and 2013 data. The regional allocations shown in Table 7 for GHGRP year 2011 and 2013 are estimated using total emissions for these years and applying the regional fraction of emissions observed in GHGRP year 2012 data.

Table 8. National Emissions Estimates for Liquids Unloading

NEMS Region	Methane Emissions (MT CO_2e)*			
	2012 Emissions (In 2014 Inventory)	GHGRP 2012 Emissions	Inventory 2012 Emissions Using National Average EFs	Inventory 2012 Emissions Using National Average EFs and Activity Assumptions
North East	2,115,336	603,649	2,967,625	2,669,870
Mid-Continent	1,790,352	957,430	843,800	1,814,631
Rocky Mountain	1,837,101	3,510,845	1,552,525	1,401,015
South West	304,888	238,877	1,110,200	696,792
West Coast	43,392	26,845	37,175	35,208
Gulf Coast	748,132	578,064	860,250	1,291,289
TOTAL	**6,839,201**	**5,915,710**	**7,371,575**	**7,908,807**

*Methane GWP=25

Moving from regional-level to national-level emission factors and activity factors did not improve regional consistency with the GHGRP emissions.

Greenhouse Gas Reporting Program

EPA's Greenhouse Gas Reporting Program (GHGRP) has collected 3 years of emissions data on liquids unloading. EPA anticipates that for future Inventories, it may be possible to calculate updated emission factors and/or activity data using GHGRP data that will be reported starting in 2015. Data currently available through GHGRP include total methane emissions from liquids unloading at the sub-basin level for each reporter. Data that would allow EPA to develop an updated approach for liquids unloading using GHGRP data include data on the number of wells venting for liquids unloading, each reporter's total number of wells, and the number of those wells with and without plunger lifts.

Table 9. Comparison of GHGRP and GHG Inventory Liquids Unloading CH_4 (kt)

Year	GHGRP	GHG Inventory (2015 PR draft)
2011	293	268
2012	237	267
2013	177	255

Requests for Stakeholder Feedback

- EPA seeks feedback on the utility and transparency of using event-based EFs (scf CH_4/event/year) versus well-based EFs (scf CH_4/well/year) to develop national estimates in the Inventory.
- EPA seeks feedback on estimating emissions using emissions data from Allen et al. The Allen et al. study apportioned wells into five unloading categories (e.g., 79% of non-plunger wells in the Appalachian region have ≤ 10 unloading events per year). To apply emissions data in this structure, annual data (or a method to approximate annual data) would be needed on the number of wells in each category. Reflecting changes to this distribution across the time series from 1990 through 2013 would require data on distribution of unloading events over time. EPA seeks comment on data availability on distribution of unloading events and approaches to ensure that the Inventory reflects changes in practices over time.
- EPA seeks feedback on an approach that uses the Allen et al. data to develop regional emission factors for plunger and non-plunger wells (similar to the current Inventory structure). Average emission factors that incorporate the Allen et al. study data have a built-in assumption regarding the distribution of unloading frequency. If these factors are applied across the time series, then the implied assumption is that distribution of unloading frequency categories has not changed over time. EPA seeks feedback on approaches that may be applied to ensure accuracy across the time series.
- Allen et al. observed that older wells had more frequent unloading events than newer wells. EPA seeks stakeholder feedback on an approach to calculating annual national emissions that incorporates data on well age to reflect this variability.
- EPA seeks feedback on options for activity data for wells performing liquids unloading with and without plunger lifts, across the time series. The two right-most columns of Table 6 above show the impacts of moving from the current Inventory activity data to GHGRP activity data (while applying the same regional EFs developed from the Allen et al. study).
- EPA seeks feedback on the sampling and measurement methods used in the Allen et al. study and the appropriateness of the data set for calculating national emissions estimates.
- EPA seeks feedback on approaches for developing updated uncertainty estimates for this source. The Allen et al. study utilized a bootstrapping method to calculate uncertainty because the distributions of event emissions were not normally distributed about a mean. In the bootstrapping procedure, the original data set of each type of well was recreated by making random event selections, with replacement, from the data set.
- The API/ANGA study estimated nationally 1.1 million unloadings without plunger lifts and 11.6 million with plunger lifts per year. The Allen et al. study data estimated much lower national event counts—approximately 0.2 million unloadings without plunger lift and 6.8 with plunger lifts per year. According to the Allen et al. analysis, the API/ANGA data set also show a much higher fraction of wells that experience very frequent unloadings (> 50 events/year) compared to the Allen et al. study findings. EPA seeks comment on the different findings of these studies.