April 2018

Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016: Revisions to Create Year-Specific Emissions and Activity Factors

1 Background

This memorandum documents the revisions considered and ultimately implemented in EPA's final 2018 *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI) to create year-specific emissions factors (EFs) and activity factors (AFs) using GHGRP subpart W data for several sources:

- Liquids unloading (Section 2);
- Gas well completions and workovers (Section 3); and
- Well testing not associated with completions (Section 4).

During the stakeholder process for developing the 2018 GHGI, stakeholders specifically suggested that liquids unloading and gas well completions and workover operations are not conducted uniformly across the U.S. and might exhibit changing trends year-to-year. EPA considered stakeholder input to develop the final 2018 GHGI methodologies for these sources (and well testing, as a similar source) and continues to seek feedback on further improvements.

This memo contains references to two companion memos also released during April 2018 that document revisions considered and implemented in the final 2018 GHGI[1]:

- *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016: Revisions to CO_2 Emissions Estimation Methodologies* ("2018 CO_2 Revisions memo")
- *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016: Additional Revisions Considered* ("2018 Additional Revisions memo")

2 Liquids Unloading

During the stakeholder process for developing the 2018 GHGI, stakeholders suggested that liquids unloading operations are not conducted uniformly across the U.S. and might exhibit changing trends year-to-year. In response to stakeholder comments, EPA evaluated basin-level GHGRP subpart W data covering reporting years (RYs) 2011 through 2016 and implemented methodological revisions in the 2018 GHGI, as described below.

2.1 Previous GHGI Methodology

EPA had updated the liquids unloading methodology in the 2017 GHGI, to incorporate the most up-to-date data available from GHGRP subpart W. The 2017 GHGI methodology used CH_4 emission factors (EFs) for liquids unloading with and without plunger lifts calculated by summing the emissions reported under GHGRP subpart W in each category for RY2011-RY2015 and dividing by the total number of wells in each category over those years. These EFs (2.86 MT CH4/plunger lift well, and 3.09 MT CH4/non-plunger lift well) were used for all years in the GHGI time series. CO_2 EFs were calculated by applying an assumed ratio of CO_2-to-CH_4 gas content to the CH_4 EFs; refer to the April 2018 *CO_2 Revisions* memo for additional discussion regarding the background for the previous CO_2 EF methodology and considerations toward implementing revisions for various sources.

The previous GHGI methodology used activity data derived from both subpart W data and a 2012 report published by the American Petroleum Institute (API) and America's Natural Gas Alliance (ANGA). The EPA used data from the API/ANGA report to develop the national average fraction of gas wells requiring liquids unloading (56%) (which may or may not result in venting dependent on the technology used), and applied this fraction throughout the time series. The EPA used subpart W data to calculate an activity factor (AF) representing the

[1] https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2016-ghg

percent of gas wells that vent during liquids unloading in recent years (16.6% in RY2015, applied to years 2011-2015, and 14.4% in RY2016). The EPA also calculated the year-specific fraction of wells with liquids unloading and venting that use plunger lifts (varies from 53-63%) and wells that vent without plunger lifts (varies from 37-47%) for 2011-2016. The EPA assumed that in 1990, all wells conducting liquids unloading (calculated as 56% of all gas wells) vent without plunger lifts (and that no wells vent with plunger lifts or use non-emitting technologies). Finally, the EPA applied linear interpolation from the 1990 data points to the 2011 data points to develop activity data over the time series.

Additional details on the 2017 GHGI liquids unloading methodology can be found in the 2017 Production memo.[2]

2.2 2018 GHGI Revisions for Liquids Unloading

EPA calculated national total liquids unloading CH_4 and CO_2 emissions using year-specific subpart W data to calculate national-level AFs (e.g., fraction of wells venting from liquids unloading) and EFs (e.g., CH_4 emissions per venting well). This approach is identical to the 2017 GHGI methodology for calculating AFs; the approach is similar to the 2017 GHGI methodology for calculating EFs, but calculations are performed on a year-specific basis, rather than combined years' data. EPA calculated EFs for liquids unloading with and without plunger lifts by summing the emissions reported under subpart W in each category in a given year and dividing by the total number of wells in each category. Table 1 below shows AFs, EFs, and national total emissions for this approach, for years 2011 through 2016. The 2011 AFs and EFs are applied to all prior years of the time series.

Table 1. 2018 GHGI AFs, EFs, and National Total CH_4 Emissions for Liquids Unloading, Years 2011 to 2016

Year	% Wells Venting for Liquid Unloading [% PL/% non-PL]	Plunger Lift CH_4 EF (MT CH_4/well)	Non-Plunger Lift CH_4 EF (MT CH_4/well)	National Total CH_4 Emissions (MT)
2011	17% [62% PL / 38% non-PL]	4.7	3.4	304,223
2012	17% [57% PL / 43% non-PL]	3.8	3.1	250,403
2013	17% [53% PL / 47% non-PL]	3.1	3.1	220,990
2014	17% [54% PL / 46% non-PL]	2.0	3.8	202,745
2015	17% [59% PL / 41% non-PL]	1.4	3.3	153,975
2016	14% [63% PL / 37% non-PL]	1.6	3.3	132,871

2.3 Other Approaches Considered

In response to stakeholder feedback, EPA also considered a basin-level approach to calculating AFs and EFs. For the basin-level evaluation, EPA calculated basin-specific AFs (e.g., fraction of wells venting from liquids unloading) and EFs (e.g., CH_4 emissions per well) for any basin contributing at least 10 percent of total annual emissions (on a CO_2e basis) in any year from 2011 through 2016; data for all other basins were combined. EPA identified five basins that contribute at least 10 percent of total annual emissions (on a CO_2e basis) in any year from 2011 through 2016: 160A - Appalachian Basin (Eastern Overthrust Area); 220 - Gulf Coast Basin; 345 - Arkoma Basin; 360 - Anadarko Basin; and 580 - San Juan Basin. For each basin and the group of all other basins, EPA calculated year-specific EFs for liquids unloading with and without plunger lifts by summing the emissions reported under subpart W in each category in a given year and dividing by the total number of wells in each category. Table 2 and

[2] https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2015-ghg.

Table 3 below show AFs, EFs, and scale-up data for these basins and the group of all other basins—for years 2015 and 2016, respectively.

Table 2. Calculated Basin-Level AFs, EFs, and National Estimates for Liquids Unloading, Year 2015

Basin ID	% Wells Venting for Liq UL [% PL/% non-PL]	Plunger Lift CH_4 EF (MT CH_4/well)	Non-Plunger Lift CH_4 EF (MT CH_4/well)	Subpart W Coverage (%)[a]	Total CH_4 Emissions (MT)
160A	14% [33% PL / 67% non-PL]	1.3	3.3	58%	37,184
220	13% [6% PL / 94% non-PL]	1.3	2.1	~100%	4,903
345	50% [16% PL / 84% non-PL]	4.4	4.4	66%	38,354
360	7% [71% PL / 29% non-PL]	1.4	5.1	75%	7,089
580	26% [91% PL / 9% non-PL]	4.0	1.0	94%	21,917
All other	16% [74% PL / 26% non-PL]	0.7	2.8	74%	46,022
National Total	-	-	-	-	**155,470**

a – Number of gas wellheads reported in the Equipment Leaks table (40 CFR 98.233(r)) divided by the total number of active non-associated gas wells in the given year based on current GHGI methodology (i.e., derived from DrillingInfo data).

Table 3. Calculated Basin-Level AFs, EFs, and National Estimates for Liquids Unloading, Year 2016

Basin ID	% Wells Venting for Liq UL [% PL/% non-PL]	Plunger Lift CH_4 EF (MT CH_4/well)	Non-Plunger Lift CH_4 EF (MT CH_4/well)	Subpart W Coverage (%)[a]	Total CH_4 Emissions (MT)
160A	16% [63% PL / 37% non-PL]	1.1	5.9	51%	46,789
220	9% [10% PL / 90% non-PL]	1.0	1.3	~100%	1,785
345	32% [31% PL / 69% non-PL]	6.5	5.0	66%	29,534
360	5% [78% PL / 22% non-PL]	0.7	3.3	80%	2,571
580	27% [84% PL / 16% non-PL]	3.8	1.0	90%	20,257
All other	14% [66% PL / 34% non-PL]	0.7	2.2	69%	36,346
National Total	-	-	-	-	**137,282**

a – Number of gas wellheads reported in the Equipment Leaks table (40 CFR 98.233(r)) divided by the total number of active non-associated gas wells in the given year based on current GHGI methodology (i.e., derived from DrillingInfo data).

Table 4 compares national total CH_4 emissions in years 2015 and 2016 calculated from the previous GHGI approach (used for the 2018 GHGI PR Draft estimates), basin-level approach (considered for 2018 GHGI) and national-level approach (implemented in 2018 GHGI).

Table 4. Liquids Unloading CH_4 Emissions Estimates for Years 2015 and 2016

Year	National Total CH_4 Emissions (MT)		
	2018 GHGI PR Draft	Basin-Level Approach	National-Level Approach
2015	208,565	155,470	153,975
2016	177,218	137,282	132,871

Based on the subpart W data as summarized in Tables 1, 2, and 3 above, there appear to be year-to-year differences in AFs and EFs for liquids unloading categories, which drive differences in national total emissions. The national total emissions using the previous GHGI methodology, wherein an average EF is calculated, results in significantly higher estimates for 2015 and 2016 compared to the year-specific EF approaches. Therefore, EPA calculated CH_4 and CO_2 emissions based on year-specific subpart W data for the final 2018 GHGI. EPA applied year-specific factors for years 2011 through 2016.

Based on comparing national total emissions estimates for years 2015 and 2016 in Table 4 by the basin-level and national-level approaches, it does not appear that the approaches lead to significant differences in estimates; the percent difference in total CH_4 emissions is only 1% for year 2015 and approximately 3% for year 2016. Therefore, EPA calculated emissions by the national-level approach in the 2018 GHGI, but will conduct periodic reviews and continue to engage with stakeholders to identify whether there are certain years when using a basin-level approach would increase the accuracy of estimates.

Note: EPA details another revision under consideration related to liquids unloading, specifically, estimates in early time series years (e.g., early 1990's), in a separate memo. Refer to the April 2018 *Additional Revisions* memo for more information including requests for stakeholder feedback on this topic. The emissions and activity data methodology implemented in the current GHGI rely exclusively on recently collected data (i.e., both subpart W and the API/ANGA report use data from 2011 or later). The EPA is continuing to evaluate the liquids unloading data collected for the 1996 GRI/EPA study to determine if it better represents early time series years.

3 Gas Well Completions and Workovers

During the stakeholder process for developing the 2018 GHGI, stakeholders specifically suggested that per-event emissions from hydraulically fractured (HF) gas well completions and workovers might exhibit changing trends year-to-year; the 2017 GHGI methodology used EFs developed from several combined years of GHGRP subpart W reporting data, so did not take this dynamic into account. In response to stakeholder comments, EPA evaluated year-specific GHGRP subpart W data covering RYs 2011 through 2016 and implemented methodological revisions in the 2018 GHGI for both HF and non-HF gas well completions and workovers, as described below.

Note: The methodology for oil well completions and workovers was not revised in the 2018 GHGI. Section 3 of the April 2018 *Additional Revisions* memo provides further detail on existing methodology and new data that might be evaluated to revise activity and EFs for these sources. EPA continues to consider revisions to improve the current estimates for these sources over the time series and seeks stakeholder feedback with specific questions in the April 2018 *Additional Revisions* memo.

3.1 Previous GHGI Methodology

The 2017 GHGI CH_4 EFs for non-HF gas well completions and workovers were both derived from the 1996 GRI/EPA study[3]; the completions EF is defined as covering both completions and well flow testing, and is based on the assumption that all gas is flared, whereas the workovers EF is based on the assumption that all gas is vented. The 2017 GHGI CH_4 EFs for HF gas well completions and workovers were based on combined GHGRP subpart W data from RYs 2011–2013 (which does not include well testing emissions); this CH_4 EF methodology is documented in

[3] *Methane Emissions from the Natural Gas Industry*. Prepared by Harrison, M., T. Shires, J. Wessels, and R. Cowgill, eds., Radian International LLC for National Risk Management Research Laboratory, Air Pollution Prevention and Control Division, Research Triangle Park, NC. EPA-600/R-96-080a.

two memos.[4,5] CO_2 EFs were calculated by applying an assumed ratio of CO_2-to-CH_4 gas content to the CH_4 EFs; refer to the April 2018 *CO_2 Revisions* memo for additional discussion regarding the background for the previous CO_2 EF methodology and considerations toward implementing revisions for various sources.

The activity data methodology for event counts in the 2017 GHGI had not been recently revised (nor was it revised in the 2018 GHGI) and is generally based on the 1996/EPA study for non-HF completions and workovers, and DrillingInfo and subpart W data for HF completions and workovers. Note: Section 5 of the 2018 *Additional Revisions* memo provides further detail on activity data for several well-related emission sources, including gas well completions and workovers. As the activity data methodology for these sources was not revised in the 2018 GHGI, EPA continues to consider revisions to improve the current activity estimates for these sources over the time series and seeks stakeholder feedback with specific questions in the 2018 *Additional Revisions* memo.

3.2 2018 GHGI Revisions for Gas Well Completions and Workovers

In the 2018 GHGI, EPA implemented several revisions to create year-specific EFs (and AFs, as necessary to parallel EF subcategories) from GHGRP subpart W data. When applying revised methodologies to calculate CH_4 EFs from subpart W data, EPA applied parallel methodology to calculate CO_2 EFs, for consistency.

For HF gas well completions and workovers, EPA calculated year-specific CH_4 and CO_2 EFs from subpart W data (2011–2016); year 2011 EFs are applied for all earlier years. Table 5 below shows the new subpart W EFs compared to values used in the 2017 GHGI. In both the previous and revised methodologies, data for completions and workovers are combined to calculate EFs. These revised EFs are used in conjunction with activity data based on existing methodology.

Table 5. Previous and Revised CH_4 EFs for HF Gas Well Completions and Workovers

REC Category	Control Category	2017 GHGI CH_4 EF (mt/event)[a]	2018 GHGI: CH_4 EFs (MT/event)					
			2011	2012	2013	2014	2015	2016
Non-REC	Vent	36.8	44.6	25.0	48.5	13.3	8.8	7.8
Non-REC	Flare	4.9	5.7	3.7	2.3	2.5	2.4	0.4
REC	Vent	3.2	4.0	4.9	3.4	1.8	4.9	7.5
REC	Flare	4.9	3.0	2.3	2.4	0.6	4.9	5.4

a – calculated from combined RY2011–2013 GHGRP subpart W data.

For non-HF gas well completions and workovers EFs, EPA used subpart W data to calculate new year-specific CH_4 and CO_2 EFs (2011–2016) and established new control categories (vented versus flared); year 2011 EFs are applied for all earlier years. Table 6 below summarizes the new EFs compared to values used in the 2017 GHGI.

Table 6. Previous and Revised CH_4 EFs for Non-HF Gas Well Completions and Workovers

Event Type	Control Category	2017 GHGI CH_4 EF (mt/event)	2018 GHGI: CH_4 EFs (MT/event)					
			2011	2012	2013	2014	2015	2016
Completion	Vent	0.01[a]	16.1	14.3	7.7	1.8	22.4	34.2
	Flare		1.9	0.1	1.9	1.9	0.2	0.2

[4] "Overview of Update to Methodology for Hydraulically Fractured Gas Well Completions and Workovers in the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012 (2014 Inventory)," available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-updates-1990-2012-inventory-published.

[5] "Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2013: Revision to Hydraulically Fractured Gas Well Completions and Workovers Estimate," available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-updates-1990-2013-inventory-published.

Event Type	Control Category	2017 GHGI CH_4 EF (mt/event)	2018 GHGI: CH_4 EFs (MT/event)					
			2011	2012	2013	2014	2015	2016
Workover	Vent	0.05[b]	0.1	0.2	0.1	0.1	0.1	0.1
	Flare		0.5	0.001	0.1	0.002	0.1	0.003

a – Used to represent all non-HF gas well completions, derived from a single data point, flared event.
b – Used to represent all non-HF gas well workovers, derived from data at two sites, vented events.

For non-HF gas well completions and workovers activity data, the methodology for total event counts is unchanged in the 2018 GHGI (as noted above in Section 3.1; refer to the 2018 *Additional Revisions* memo for ongoing considerations), but EPA developed new AFs to split event counts into control categories (vented versus flared) using subpart W data for recent years and applying assumptions for earlier years; previously, as shown in Table 6, control categories were not represented in the GHGI. Table 7 below summarizes the new non-HF gas well completions and workovers AFs.

For non-HF gas well completions, EPA assumed that flaring control was used to some extent throughout the 1990–2016 time series based on available data; the previous EF developed for base year 1992 represented flaring control (refer to footnote "a" of Table 6), and recent GHGRP data show a range of 3% flared events in 2011, to 69% flared events in year 2016. EPA therefore applied the year 2011 subpart W control fractions to all prior time series years, and used subpart W year-specific AFs from 2011 forward.

For non-HF gas well workovers, EPA assumed that flaring control was introduced over the 1990–2016 time series based on available data; the previous EF developed for base year 1992 represented only vented events (refer to footnote "a" of Table 6), and recent GHGRP data show a range of 1% flared events in 2011, to 9% flared events in year 2014, to 4% flared events in year 2016. EPA therefore assumed 0% flared events in base year 1992, applied subpart W year-specific AFs from 2011 forward, and used interpolation to calculate control fractions in intermediate years.

Table 7. 2018 GHGI Activity Factors for Non-HF Gas Well Completions and Workovers

Event Type	Control Category	Activity Factor (Fraction of Given Event Type within Control Category)							
		1992 Base Year	Intermediate years	2011	2012	2013	2014	2015	2016
Completion	Vent	0.97	0.97	0.97	0.96	0.97	0.99	0.78	0.31
	Flare	0.03	0.03	0.03	0.04	0.03	0.01	0.22	0.69
Workover	Vent	1.00	Interpolation	0.99	0.99	0.99	0.91	0.96	0.96
	Flare	0.00	Interpolation	0.01	0.01	0.01	0.09	0.04	0.04

4 Non-Completion Well Testing

For consistency with revisions to related sources (i.e., well completions, as discussed in Section 3) and for conformity to the IPCC guidelines[6] (which specifies an exploration category to include emissions from well drilling, testing, and completions), EPA developed new emissions estimates to represent well testing that is not conducted as part of a completion event. EPA evaluated year-specific GHGRP subpart W data covering RYs 2011 through 2016 to develop emissions estimation methodology for this new source that appears within both natural gas and petroleum production segments, as described below.

[6] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_4_Ch4_Fugitive_Emissions.pdf

4.1 2018 GHGI Methodology for Non-Completion Well Testing

In the 2018 GHGI, EPA used subpart W data to calculate year-specific CH_4 and CO_2 EFs and activity factors by well type (gas versus oil) and control category (vented versus flared) for years 2015 and 2016; year 2015 AFs and EFs are applied for all earlier years. Table 8Table 5 below summarizes the AFs and EFs used in the 2018 GHGI.

Table 8. 2018 GHGI Activity and Emissions Factors for Well Testing

Well Type	Control Category	Activity Factor (events/thousand wells)		CH_4 Emission Factor (MT/event)		CO_2 Emission Factor (MT/event)	
		2015	2016	2015	2016	2015	2016
Gas	Vent	0.9	0.9	5.26	1.56	0.17	0.10
	Flare	0.06	0.02	1.09	0.23	157.58	31.41
Oil	Vent	35.4	33.0	0.41	0.15	0.02	0.03
	Flare	2.9	1.9	0.60	0.15	150.70	31.88