Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2021: Updates to Incorporate Additional Geographically Disaggregated Data for the Production Segment

1 Introduction

This memo documents the updates implemented in EPA's 2023 *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI) to develop national emission estimates for certain emissions sources by quantifying emissions for those sources at the basin level and aggregating those estimates to the national level. EPA developed basin-level methodologies for certain onshore production segment emission sources for the 2023 GHGI: pneumatic controllers (section 2), storage tanks (section 3), equipment leaks and chemical injection pumps (section 4), and liquids unloading (section 5). Additional considerations for disaggregating data to more granular levels were previously discussed in memos released in October 2022 (Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2021: Updates Under Consideration for Incorporating Additional Geographically Disaggregated Data [October 2022 Disaggregation memo]) and February 2023 (Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2021: Updates Under Consideration for Incorporating Additional Geographically Disaggregated Data for the Production Segment [February 2023 Production Disaggregation memo]).[1,2]

In recent years, EPA has developed additional GHG Inventory products that break out emissions from the national-level into gridded and state-level estimates.

- Gridded Inventory.[3] In an effort to improve the ability to compare the national-level Inventory with measurement results that may be at other spatial and temporal scales, a team at Harvard University along with EPA and other coauthors developed a gridded inventory of U.S. anthropogenic methane emissions with 0.1 degree x 0.1 degree spatial resolution, monthly temporal resolution, and detailed scale-dependent error characterization. The gridded methane inventory is designed to be consistent with the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014* estimates for the year 2012, which presents national totals. An updated version of the gridded inventory is being developed and will improve efforts to compare results of the GHG Inventory with atmospheric studies.

- State Inventory.[4] In 2022, EPA released its first annual publication of state greenhouse gas (GHG) data consistent with the GHGI, meaning state GHG totals when summed, will equal national totals in the GHGI. For Petroleum and Natural Gas Systems, the methods used to develop state-level estimates generally rely on relative differences in basic activity levels (e.g., petroleum production), and do not reflect differences between states due to differences in practices, technologies, or formation types.

Both the gridded and the state versions of the GHGI generally rely on national-level average activity and emission factors, along with location-specific information on activity drivers such as well counts or production. The updates discussed in this memo seek to improve the ability of the gridded and state inventories to reflect variation due to differences in formation types, technologies and practices, regulations, or voluntary initiatives, and not only the differences in key activity levels that are reflected in the current gridded and state inventories.

[1] Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2021: Updates Under Consideration for Incorporating Additional Geographically Disaggregated Data. https://www.epa.gov/system/files/documents/2022-10/ghgi-webinar2022_memo.pdf.
[2] Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2021: Updates Under Consideration for Incorporating Additional Geographically Disaggregated Data for the Production Segment. https://www.epa.gov/system/files/documents/2023-02/2023%20GHGI_Update%20on%20Disaggregated%20Production%20Data.pdf.
[3] U.S. EPA. Gridded 2012 Methane Emissions. https://www.epa.gov/ghgemissions/gridded-2012-methane-emissions.
[4] U.S. EPA. State GHG Emissions and Removals. https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals.

This memo discusses developing emissions estimates for the national GHGI using basin-specific data that are currently aggregated and averaged to develop national-level estimates. Specifically, EPA incorporated additional basin-level data from GHGRP subpart W in the GHGI. GHGRP subpart W data are used in the GHGI to calculate numerous emission factors (EFs) and activity factors (AFs) for emission sources across the industry segments in Natural Gas and Petroleum Systems.

The incorporation of basin-specific data will improve future versions of both the gridded and state-level inventories. This will allow EPA to use the gridded inventory for improved comparisons of the GHGI with various atmospheric observation studies (since regions will better reflect the local differences in emissions rates as reported to GHGRP) and will allow the state-level inventory to reflect differences in state-level programs, formation type mixes, and varying technologies and practices.

For the updates, EPA focused on the onshore oil and gas production segment, where data are available from the GHGRP that reflects distinctions in emissions levels by region, and which impact (to varying extents) total emissions in the GHGI. Specifically, EPA assessed the four highest emitting sources within the onshore production segment for basin-level approaches. EPA analyzed subpart W basin-level data for pneumatic controllers, storage tanks, well pad equipment (including equipment leaks and chemical injection pumps), and liquids unloading.

Key considerations for use of the GHGRP subpart W data for onshore production to develop subnational estimates are the variability of emissions and activity levels between basins and GHGRP coverage of total activity for each basin. EPA presented variability and coverage considerations in the October 2022 Disaggregation memo and in webinar slides.[5]

Subpart W of the EPA's GHGRP collects annual activity and emissions data on numerous sources from Natural Gas and Petroleum Systems that meet a reporting threshold of 25,000 metric tons of CO_2 equivalent (CO_2e) emissions. Reporting requirements under subpart W began in reporting year (RY) 2011 for onshore production. Onshore production facilities in subpart W are defined as a unique combination of operator and basin of operation (i.e., all operator sites within a basin). The GHGRP subpart W data used in the analyses discussed in this memo were reported to the EPA as of August 12, 2022. Coverage of onshore production activities varies by basin.

EPA considered a variety of approaches to take coverage into consideration when evaluating basin-specific calculations, such as: including basin-specific data for all basins regardless of coverage (all basins approach), selecting a coverage threshold and aggregating basin data from basins with lower coverage and developing a combined AF/EF for those basins (threshold basins approach), combining data from neighboring basins, retaining the national level approach, or developing another approach to rely on a larger (combined) dataset for emissions in those areas. EPA used basin-specific data for all basins that reported under subpart W for the updates incorporated into the final version of the 2023 GHGI. In the February 2023 Production Disaggregation memo, EPA presented results for a threshold basins approach that used 50 percent as a coverage threshold for basin-specific calculations. This coverage threshold was selected only for demonstration purposes. EPA continues to seek stakeholder feedback on approaches for incorporating additional basin-level data including the use of a coverage threshold, and in case of its use, an appropriate coverage threshold level. Other approaches to address coverage could also be considered, such as a threshold based on the number of reported wells or number of reporters in each basin. Coverage data are also needed to determine how to scale emissions and/or activity from reported totals to basin totals.

[5] Memos and webinar slides supporting the updates for the 2023 GHGI are available here: https://www.epa.gov/ghgemissions/stakeholder-process-natural-gas-and-petroleum-systems-1990-2021-inventory

GHGRP has proposed revisions to subpart W, some of which could impact sources discussed in this memo. The general analyses and approaches discussed in this memo would likely be applicable to both current and future GHGRP data.

2 Pneumatic Controllers

2.1 2022 (Previous) GHGI Methodology

In the 2022 GHGI, EPA estimated pneumatic controller emissions using AFs and EFs that are specific to low-bleed, intermittent-bleed, and high-bleed controllers. EPA calculated year-specific, national-level AFs using subpart W data for recent years. The AFs were updated annually, and EPA calculated two types of AFs: (1) the average number of controllers per well and (2) the fraction of controllers that are low-bleed, intermittent-bleed, and high-bleed controllers. For the average number of controllers per well AF, EPA calculated year-specific values for 2015 forward and applied the RY2015 AF to 2011 through 2014. For the fraction of each controller type, EPA calculated year-specific AFs for 2011 forward. EPA also calculated the AFs separately for pneumatic controllers at gas wells and oil wells.

For pneumatic controllers at gas wells, the average number of controllers per well was presented by NEMS region for 1990 through 1992 (based on the 1996 GRI/EPA study); the values were linearly interpolated between 1992 and the subpart W-based AF for 2011. EPA applied the fraction of each controller type developed from the 1996 GRI/EPA study for 1990 through 1992. EPA then linearly interpolated from the 1992 to the 2011 fraction of each controller type value.

For pneumatic controllers at oil wells, EPA estimated the total number of controllers for 1990 through 1993 based on the consensus of an Industry Review Panel. Then EPA linearly interpolated the total number of controllers from 1993 through 2011. For the fraction of each controller type from 1990 through 1993, EPA applied values based on the consensus of an Industry Review Panel and then linearly interpolated from 1993 through 2011.

EPA calculated EFs for the three different types of controllers using RY2014 subpart W data from controllers at oil and gas wells combined. The same EFs were applied to all years.

2.2 Update Implemented in the 2023 GHGI for Basin-Level EFs and AFs

For the 2023 GHGI update, EPA calculated year-specific AFs for each controller type (high-bleed, intermittent-bleed, and low-bleed) at the basin-level using subpart W data. The AFs were calculated separately for gas wells and oil wells. Subpart W data includes basin-level well counts, pneumatic controller counts by type of controller, and emissions. Using these data, EPA estimated basin-level AFs (average number of controllers/well and fraction of controllers, by type) for 2011 through 2021 for gas wells and for oil wells. For basins without subpart W data, EPA applied national-level average AFs. Table 1 shows the average number of pneumatic controllers per well for select basins calculated using subpart W RY2021 data and compares to the 2022 GHGI estimate. Similarly, Table 2 compares the pneumatic controller type fractions for select basins using subpart W RY2021 data to the 2022 GHGI estimate. The basins shown in Tables 1 and 2 are the highest emitting basins and collectively contributed 52% of national emissions in 2021 from oil and gas wells.

Table 1. Average Pneumatic Controllers Per Well for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Controllers/Well (Gas)	Controllers/Well (Oil)
2022 GHGI[a]		*1.9*	*1.4*
Anadarko	360	1.3	2.8
Appalachian	160	0.4	5.0
Appalachian (Eastern Overthrust)	160A	1.1	2.0
Gulf Coast	220	1.7	2.8
Permian	430	1.2	1.1

a. The 2022 GHGI equals the average of all subpart W data for RY2020.

Table 2. Pneumatic Controller Type Fractions for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Bleed Type Fractions (Gas)			Bleed Type Fractions (Oil)		
		Low	Intermittent	High	Low	Intermittent	High
2022 GHGI[a]		*0.26*	*0.73*	*0.01*	*0.29*	*0.70*	*0.01*
Anadarko	360	0.21	0.70	0.09	0.27	0.68	0.05
Appalachian	160	0.08	0.92	0	0.09	0.91	0
Appalachian (Eastern Overthrust)	160A	0.16	0.83	0.001	0.26	0.74	0
Gulf Coast	220	0.31	0.69	0.01	0.21	0.79	0.002
Permian	430	0.17	0.81	0.02	0.48	0.51	0.01

a. The 2022 GHGI equals the average of all subpart W data for RY2020.

Note: The bleed type fractions don't add up to 1, in some instances, due to rounding.

As part of this update, EPA also calculated year-specific basin-level CH_4 EFs (scfd/controller) using subpart W data for RY2011 through RY2021. The basin-level EFs were calculated separately for gas wells and oil wells. For basins without subpart W data, EPA applied national average EFs. The CH_4 EFs for select basins are shown in Table 3. The basins shown in Table 3 match those in Tables 1 and 2 and are the highest emitting basins in 2021 for pneumatic controller emissions from oil and gas wells.

Table 3. Pneumatic Controller EFs for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Gas Well CH_4 EF (scfd/controller)			Oil Well CH_4 EF (scfd/controller)		
		Low	Intermittent	High	Low	Intermittent	High
2022 GHGI[a]		*25.2*	*187.8*	*689.7*	*21.1*	*177.3*	*628.6*
Anadarko	360	22.6	213.1	569.5	23.6	221.2	688.1
Appalachian	160	26.8	252.3	NA	27.2	259.3	NA
Appalachian (Eastern Overthrust)	160A	27.8	170.6	536.4	27.0	218.1	NA
Gulf Coast	220	20.6	191.3	645.9	22.4	197.2	623.3
Permian	430	20.9	201.8	599.2	22.9	221.4	578.3

a. The 2022 GHGI equals the average of all subpart W data for RY2020.

2.3 Time Series Considerations

In the 2023 GHGI update, EPA retained the 2022 GHGI AFs for 1990 through 1992 (for gas wells) and the 2022 GHGI assumptions regarding activity data for 1990 through 1993 (for oil wells) for all basins (i.e., the same AFs and assumptions were applied to all basins) and applied linear interpolation between the 1992 (or 1993) and

2011 AFs at the basin level. EPA applied emission factors developed using subpart W data for RY2011 for the time series years without subpart W data (i.e., 1990-2010).

2.4 National Emissions for Pneumatic Controllers in the 2023 GHGI

EPA calculated national time series estimates by applying the basin-level AF and EF methodologies presented in sections 2.2 and 2.3. Tables 4 and 5 present a summary of national CH_4 estimates from pneumatic controllers for select time series years for gas wells and for oil wells. Details on the emissions, EFs, AFs, activity data, data sources, and methodologies for each year from 1990 to 2021 are available in spreadsheet file annexes.[6]

Table 4. National CH_4 Estimates for Gas Well Pneumatic Controllers (Metric Tons)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI	*510,354*	*1,041,503*	*1,104,896*	*1,072,874*	*1,024,678*	*950,718*	*N/A*
2023 GHGI Update							
Low-Bleed Controllers	0	22,745	32,360	33,805	31,475	27,364	25,609
Intermittent-Bleed Controllers	230,504	569,592	873,015	835,249	874,372	744,622	692,097
High-Bleed Controllers	350,535	483,375	108,533	87,071	53,233	42,332	42,828
Total	**581,039**	**1,075,712**	**1,013,908**	**956,125**	**959,080**	**814,318**	**760,534**

Table 5. National CH_4 Estimates for Oil Well Pneumatic Controllers (Metric Tons)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI	*736,447*	*708,680*	*835,129*	*727,365*	*732,092*	*853,562*	*N/A*
2023 GHGI Update							
Low-Bleed Controllers	51,170	63,773	20,104	31,779	50,456	36,752	46,360
Intermittent-Bleed Controllers	0	276,145	1,252,028	1,155,041	762,647	1,006,263	920,518
High-Bleed Controllers	708,800	493,011	89,472	73,438	73,278	87,884	48,202
Total	**759,970**	**832,929**	**1,361,605**	**1,260,259**	**886,382**	**1,130,899**	**1,015,080**

3 Storage Tanks

3.1 2022 (Previous) GHGI Methodology

In the 2022 GHGI, EPA estimated CH_4 and CO_2 emissions for production storage tanks using AFs and EFs that were specific to condensate tanks (i.e., tanks that store liquids produced from gas wells) and oil tanks (i.e., tanks that store liquids produced from oil wells) and each control category. The six control categories are large tanks with flares, large tanks with vapor recovery units (VRUs), large tanks without control, small tanks with flares, small tanks without flares, and malfunctioning separator dump valves.

EPA calculated two types of AFs: (1) production fraction sent to tanks and (2) throughput fraction for each control category. EPA calculated the production fraction sent to tanks separately for condensate and oil using subpart

[6] The basin-level annex spreadsheet tables for the 1990 – 2021 Inventory can be accessed from this page: https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems

W data for RY2015 and applied the resulting value to all years. EPA calculated year-specific throughput fractions for each condensate and oil tank control category using subpart W data for RY2015 forward. The RY2015 fraction of throughput in each control category was applied to years 2011 to 2015. To estimate the control category throughput fractions for years without GHGRP data (i.e., 1990-2010), EPA applied different assumptions to condensate and oil tank activity in 1990. For large condensate tanks in 1990, EPA assumed 50% of condensate was sent to tanks without controls, 50% was sent to tanks with flares, and 0% was sent to tanks with VRUs. For small condensate tanks in 1990, EPA assumed all throughput was sent to tanks without flares. For large and small condensate tanks for 1992-2010, EPA used linear interpolation between 1990 to 2011 values for each control category. For oil tanks in 1990, EPA assumed all throughput was sent to tanks in the uncontrolled categories and then used linear interpolation between 1990 and 2011 for each control category.

EPA calculated year-specific EFs for each production tank control category using subpart W data for RY2015 forward. The EFs calculated for RY2015 were then applied to 1990 through 2014.

3.2 Update Implemented in the 2023 GHGI for Basin-Level EFs and AFs

For the 2023 GHGI update, EPA calculated year-specific AFs for each condensate and oil tank control category at the basin-level using subpart W data for 2015 through 2021. For basins without subpart W data, EPA applied national average AFs. For the production fraction sent to tanks at the basin-level, EPA calculated the fraction of total liquids production (condensate plus oil production) sent to tanks using subpart W data for RY2015 forward, and applied the same production fraction to both condensate and oil tanks. This differs from the 2022 GHGI, which calculated the condensate production fraction and oil production fraction sent to tanks separately. The basin-level methodology for throughput fractions is similar to the national-level methodology, although the fractions are in relation to total liquids sent to tanks and not specific to condensate production sent to tanks and oil production sent to tanks. For example, EPA calculated the throughput fraction for large oil tanks with flares at the basin-level as the volume of oil stored in this control category divided by the total liquids production sent to tanks. Conversely, the 2022 GHGI methodology for this example equals the volume of oil stored in this control category divided by the total oil production sent to tanks. EPA calculated the basin-level AFs using total liquids production as the reference point because total condensate production and oil production are not available at the basin-level in subpart W. Table 6 and Table 7 present the RY2021 AFs for oil tanks and condensate tanks for select basins. The basins shown are the highest CO_2 emitting basins in year 2021.

Table 6. Oil Tank AFs for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Production Fraction Sent to Tanks	Large Tanks With Flares	Large Tanks With VRUs	Large Tanks Without Controls	Small Tanks With Flares	Small Tanks Without Flares
2022 GHGI[a]		*63%*	*65%*	*21%*	*10%*	*1%*	*3%*
Anadarko	360	88%	58%	3%	9%	1%	6%
Gulf Coast	220	41%	66%	5%	5%	2%	4%
Permian	430	48%	40%	25%	17%	0%	1%
Powder River	515	74%	90%	5%	3%	1%	0%
Williston	395	95%	95%	2%	2%	1%	0%

a. The 2022 GHGI equals the average of all subpart W data for RY2020. The AFs are also unique to oil production.

Table 7. Condensate Tank AFs for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Production Fraction Sent to Tanks	Large Tanks With Flares	Large Tanks With VRUs	Large Tanks Without Controls	Small Tanks With Flares	Small Tanks Without Flares
2022 GHGI[a]		*79%*	*66%*	*10%*	*5%*	*8%*	*11%*
Anadarko	360	88%	12%	1%	4%	0%	5%
Gulf Coast	220	41%	11%	3%	2%	1%	1%
Permian	430	48%	7%	4%	5%	0%	0%
Powder River	515	74%	0%	0%	0%	0%	0%
Williston	395	95%	0%	0%	0%	0%	0%

a. The 2022 GHGI equals the average of all subpart W data for RY2020. The AFs are also unique to condensate production.

The basin-level methodology for storage tank EFs is identical to the national-level methodology. EPA calculated year-specific EFs for each production tank control category at the basin-level using subpart W data for RY2015 forward. For basins without subpart W data, EPA applied a national average EF. Table 8 through Table 11 present the RY2021 EFs for oil tanks and condensate tanks for select basins and compare to the 2022 GHGI. The basins shown are the highest CO_2 emitting basins in year 2021.

Table 8. Oil Tank CH_4 EFs (scf CH_4/bbl) for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Large Tanks With Flares	Large Tanks With VRUs	Large Tanks Without Controls	Small Tanks With Flares	Small Tanks Without Flares
2022 GHGI[a]		*0.15*	*0.12*	*5.0*	*0.08*	*2.4*
Anadarko	360	0.22	0.01	7.6	0.06	3.4
Gulf Coast	220	0.15	0.26	9.7	0.09	1.4
Permian	430	0.15	0.08	1.9	0.11	3.2
Powder River	515	0.25	<0.01	14.3	0.16	2.7
Williston	395	0.12	0.06	3.4	0.05	2.0

a. The 2022 GHGI equals the average of all subpart W data for RY2020.

Table 9. Oil Tank CO_2 EFs (scf CO_2/bbl) for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Large Tanks With Flares	Large Tanks With VRUs	Large Tanks Without Controls	Small Tanks With Flares	Small Tanks Without Flares
2022 GHGI[a]		*85*	*0.03*	*0.3*	*12*	*1.4*
Anadarko	360	72	<0.01	0.3	13	5.8
Gulf Coast	220	77	0.01	0.7	8	2.3
Permian	430	49	0.08	0.6	14	5.1
Powder River	515	93	<0.01	0.8	9	4.0
Williston	395	150	<0.01	0.1	12	3.1

a. The 2022 GHGI equals the average of all subpart W data for RY2020.

Table 10. Condensate Tank CH_4 EFs (scf CH_4/bbl) for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Large Tanks With Flares	Large Tanks With VRUs	Large Tanks Without Controls	Small Tanks With Flares	Small Tanks Without Flares
2022 GHGI[a]		*0.1*	*0.2*	*14*	*0.2*	*27*
Anadarko	360	0.3	0.01	5	0.3	29
Gulf Coast	220	0.2	1.2	7	0.3	33
Permian	430	0.2	0.3	4	0.1	27
Powder River	515	0.2	<0.01	25	0.2	6

Basin Name	Basin Number	Large Tanks With Flares	Large Tanks With VRUs	Large Tanks Without Controls	Small Tanks With Flares	Small Tanks Without Flares
Williston	395	<0.01	<0.01	<0.01	0.04	2

a. The 2022 GHGI equals the average of all subpart W data for RY2020.

Table 11. Condensate Tank CO_2 EFs (scf CO_2/bbl) for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Large Tanks With Flares	Large Tanks With VRUs	Large Tanks Without Controls	Small Tanks With Flares	Small Tanks Without Flares
2022 GHGI[a]		*68*	*<0.01*	*0.5*	*15*	*5*
Anadarko	360	95	<0.01	0.3	37	6
Gulf Coast	220	104	<0.01	0.4	12	6
Permian	430	264	<0.01	0.4	11	9
Powder River	515	61	<0.01	1.3	9	4
Williston	395	264	<0.01	<0.01	6	1

a. The 2022 GHGI equals the average of all subpart W data for RY2020.

3.3 Time Series Considerations

For the 2023 GHGI update, EPA used subpart W AFs and EFs for 2015 through 2021. For the production fraction sent to tanks, EPA applied the RY2015 AF to 1990 through 2014. For the throughput fraction for each control category, EPA maintained the 2022 GHGI AF assumptions for 1990 and linearly interpolated from the 1990 to 2015 AFs. EPA applied the EFs calculated for RY2015 for 1990 through 2014.

3.4 National Emissions for Storage Tanks in the 2023 GHGI

EPA estimated national estimates by applying the basin-level AF and EF methodologies presented in sections 3.2 and 3.3. Table 12 through Table 15 present a summary of national CH_4 and CO_2 estimates from oil and condensate storage tanks for select time series years and compare to the 2022 GHGI. Details on the emissions, EFs, AFs, activity data, data sources, and methodologies for each year from 1990 to 2021 are available in spreadsheet file annexes.[7]

Table 12. National Oil Tank CH_4 Emissions (Metric Tons)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI	*218,419*	*60,186*	*61,098*	*57,412*	*35,266*	*29,613*	*N/A*
2023 GHGI Update							
Large Tanks w/Flares	0	993	5,142	6,330	4,226	3,715	3,108
Large Tanks w/VRU	0	721	9,334	2,410	2,320	1,026	513
Large Tanks w/o Control	105,668	40,150	42,112	42,679	26,491	21,294	12,290
Small Tanks w/Flares	0	15	45	16	23	29	68
Small Tanks w/o Flares	7,438	3,448	2,991	3,326	2,755	2,709	3,598
Malfunctioning Separator Dump Valves	2,397	1,472	4,247	785	428	338	320
Total	**115,503**	**46,799**	**63,871**	**55,546**	**36,243**	**29,112**	**19,896**

[7] The basin-level annex spreadsheet tables for the 1990 – 2021 Inventory can be accessed from this page: https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems

Table 13. National Oil Tank CO_2 Emissions (Metric Tons)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI	*114,701*	*2,505,440*	*4,312,648*	*6,189,224*	*6,682,129*	*6,537,103*	*N/A*
2023 GHGI Update							
Large Tanks w/Flares	0	716,264	3,771,444	5,348,119	5,973,929	5,212,454	5,381,419
Large Tanks w/VRU	0	3,011	3,542	3,509	5,719	2,008	1,245
Large Tanks w/o Control	23,733	7,675	4,811	4,422	4,871	5,841	5,426
Small Tanks w/Flares	0	2,632	11,232	6,850	8,578	10,208	9,201
Small Tanks w/o Flares	11,736	5,435	4,352	5,109	4,318	4,462	4,863
Malfunctioning Separator Dump Valves	11,539	12,910	32,278	30,403	26,096	20,254	36,508
Total	**47,008**	**747,928**	**3,827,658**	**5,398,412**	**6,023,510**	**5,255,229**	**5,438,663**

Table 14. National Condensate Tank CH_4 Emissions (Metric Tons)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI	*16,421*	*11,331*	*21,493*	*24,435*	*21,194*	*17,294*	*N/A*
2023 GHGI Update							
Large Tanks w/Flares	505	336	1,016	1,273	789	600	606
Large Tanks w/VRU	0	27	205	143	905	525	371
Large Tanks w/o Control	16,161	6,867	6,622	15,416	2,446	4,284	4,916
Small Tanks w/Flares	0	51	249	237	208	201	168
Small Tanks w/o Flares	89,757	31,176	40,152	43,448	63,168	47,749	37,959
Malfunctioning Separator Dump Valves	7	4	648	40	80	254	197
Total	**106,429**	**38,461**	**48,892**	**60,556**	**67,595**	**53,613**	**44,217**

Table 15. National Condensate Tank CO_2 Emissions (Metric Tons)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI	*298,202*	*380,108*	*1,131,470*	*844,112*	*634,177*	*573,973*	*N/A*
2023 GHGI Update							
Large Tanks w/Flares	578,973	421,656	1,804,309	1,356,381	840,013	795,330	825,379
Large Tanks w/VRU	0	2,365	298	46	886	849	649
Large Tanks w/o Control	2,019	747	855	36,514	662	580	1,367
Small Tanks w/Flares	0	13,434	71,617	87,043	81,718	40,631	27,855
Small Tanks w/o Flares	47,128	17,500	23,266	26,491	33,134	23,526	17,784
Malfunctioning Separator Dump Valves	32	19	1,640	405	46	621	7
Total	**628,152**	**455,720**	**1,901,984**	**1,506,880**	**956,460**	**861,538**	**873,041**

4 Well Pad Equipment Leaks and Chemical Injection Pumps

4.1 2022 (Previous) GHGI Methodology

EPA calculated leak emissions from certain well pad emission sources and venting emissions from chemical injection pumps. EPA calculated leak emissions at gas wells for separators, heaters, dehydrators, meters/piping, and compressors and calculated leak emissions at oil wells for separators, heater-treaters, and headers.

The AFs applied to gas wells are unique to the National Energy Modeling System (NEMS) region in which the well resides. From 2015 forward, EPA applied national level AFs (e.g., average number of separators per gas well) calculated using RY2015 subpart W data for separators, heaters, dehydrators, meters/piping, compressors, and chemical injection pumps. Early year (1990 through 1992) AFs at gas wells are from a 1996 GRI/EPA study. EPA applied linear interpolation between the 1992 and 2015 AFs.

For oil wells, EPA calculated AFs for separators, heater-treaters, and headers for 1990 through 1993 based on a 1999 Radian report.[8] EPA also used the 1999 Radian report to calculate the fraction of oil wells that are light crude and heavy crude and the fraction of separators and headers at light crude versus heavy crude wells. The chemical injection pumps AF for 1990 through 1993 is based on an estimate from the 1999 Radian report and an industry assumption that 25% of pumps use methane.[9] EPA calculated AFs for all equipment on oil wells using RY2015 subpart W data and applied these AFs for 2011 through 2021. Linear interpolation is applied between 1993 and 2011.

The EFs used in the 2022 GHGI are derived from several different sources. At gas wells, EPA calculated the chemical injection pumps EF using RY2014 subpart W data and applied it for years 2011 forward. EPA used a different EF from the 1996 GRI/EPA study[10] for 1990 through 1993. Linear interpolation between the two values was used for 1994 through 2010. For all other well pad equipment at gas wells, EPA applied either an east or west EF from the 1996 GRI/EPA study for all years. The east or west determination was based on the NEMS region the wells fall in, with the northeast and midcontinent region classified as east and all others classified as west.

For chemical injection pumps at oil wells, EPA calculated the EF using RY2014 subpart W data and applied it to all years of the time series. The EFs used for all other equipment at oil wells are based on values from a 1996 API workbook. Distinct EFs are used for wellheads, separators, and headers at heavy crude oil wells and at light crude oil wells. The same value EFs are applied to all years of the time series.

4.2 Update Implemented in the 2023 GHGI for Basin-Level AFs

For the 2023 GHGI update, EPA calculated year-specific AFs and EFs for each emission source at the basin-level using subpart W data for RY2015 through RY2021.

For gas wells, the AF methodology at the basin-level is identical to the national-level methodology. EPA summed equipment counts and pump counts for each basin with subpart W data (e.g., number of separators) and divided by the number of gas wells in that basin. Note that different well counts are used to estimate the equipment AFs and chemical injection pump AFs. For the equipment AFs (i.e., separators, heaters, dehydrators, meters/piping, compressors), EPA used the wellhead counts reported under the subpart W equipment leaks reporting section

[8] Radian International. Methane Emissions from the U.S. Petroleum Industry. 1999. EPA-600/R-99-010.
[9] Ron Rayman from Dresser Texsteam-25% pumps use methane (1 million CIPs, 80-85% for Pet E&P, 25% on methane)
[10] GRI/EPA. Methane Emissions from the Natural Gas Industry. 1996. EPA-600/R-96-080a.

to ensure consistency in the equipment leaks data.[11] For chemical injection pump AFs, EPA used the well counts reported under the subpart W facility overview section. EPA applied national average AFs to basins without subpart W data.

For oil wells, the AF methodology at the basin-level is similar to the national-level methodology, but EPA evaluated additional data to distinguish between separators and headers at light crude and heavy crude oil wells. For chemical injection pumps and heater-treaters, EPA applied basin-specific AFs calculated in the same way as the 2022 GHGI, using year-specific subpart W data specific to each basin.

For separators and headers at oil wells, EPA evaluated basin-level data to allocate equipment to heavy crude and light crude oil wells. First, EPA analyzed subpart W data to identify basins reporting heavy crude (i.e., an API gravity of less than 20, as reported under subpart W Facility Overview information) at any time in RY2015 through RY2021. Nineteen basins reported heavy crude data during this timeframe: Anadarko, Arctic Coastal Plains Province, Arkla, Coastal, East Texas, Fort Worth Syncline, Gulf Coast, Los Angeles, Michigan, Mid-Gulf Coast, Paradox, Permian, Powder River, San Joaquin, Santa Maria, Sedgwick, Strawn, Williston, and Wind River. Of these, the San Joaquin Basin accounted for the majority of the heavy crude data; 83 percent of wells reported in a heavy crude subbasin were in the San Joaquin basin. EPA developed three groups of basins for oil well data: (1) the San Joaquin basin (where 32 to 87 percent of wells are heavy crude wells for RY2015 through 2021), (2) the other 18 basins that have heavy crude wells (where 1 to 4 percent of wells are heavy crude wells for RY2015 through 2021), and (3) the remaining basins which have only light crude wells. Next, EPA assessed the equipment leaks data for the basins with heavy crude and light crude wells, and focused on facilities that only reported heavy crude wells and that only reported light crude wells. EPA calculated separator and header AFs for these two subsets of populations; facilities with only light crude wells had noticeably higher AFs than facilities with only heavy crude wells. For example, facilities with only light crude wells averaged 0.5 separators per well and facilities with only heavy crude wells averaged 0.05 separators per well. Considering separators for facilities with both light and heavy crude wells, the average number of separators per well in these basins was between those values but skewed towards the higher separator AF for facilities with only light crude wells. This meant that most oil well separators were for light crude wells. The subpart W data analysis for oil well headers led to a similar result. EPA calculated the percentage of separators at heavy crude wells for RY2015 through RY2021 to vary between 0.3% and 5.1% and the percentage of headers at heavy crude wells for RY2015 through RY2021 to vary between 3% and 15%; these percentages were calculated and applied uniquely for each year. To calculate the basin-level AFs for separators and headers for basins with light crude and heavy crude wells, EPA applied the percentage of separators and headers at heavy crude wells to the reported equipment counts in the numerator and the percentage of wells that were heavy crude wells to the denominator. For basins that did not report heavy crude, EPA used all equipment counts and well counts to calculate the AFs for separators and headers in each basin.

EPA did not change emission factors for the update. In addition, EPA did not change the methodology used to develop CO_2 emissions estimates for the update. However, EPA will apply the same basin-level AF methodology that is used to estimate CH_4 emissions to calculate CO_2 emissions in future versions of the GHGI.

Table 16 presents the updated activity factors for natural gas wellhead equipment and Table 17 presents the updated activity factors for oil wellhead equipment, compared to the 2022 GHGI activity factors based on RY2015. The basins presented are the top five emitters for equipment leaks and chemical injection pump emissions in RY2021.

[11] Facilities have the option to calculate equipment leak emissions in subpart W using population counts or leak survey data. Equipment counts and wellhead counts are reported under the equipment leaks section only if the population count methodology is applied. As a result, the reported counts are a subset of the reporting population.

Table 16. Gas Well Pad Equipment Leak and Chemical Injection Pump AFs (RY2021 Subpart W)

Basin Name	Basin Number	Compressors AF	Dehydrators AF	Heaters AF	Meters/ Piping AF	Separators AF	Chemical Injection Pumps AF
2022 GHGI[a]		*0.08*	*0.03*	*0.13*	*0.8*	*0.7*	*0.2*
East Texas	260	0.04	0.01	0.03	1.1	0.6	0.3
Gulf Coast	220	0.06	0.02	0.05	1.2	0.7	0.2
Permian	430	0.2	<0.01	0.04	1.3	0.8	0.04
Powder River	515	0.8	0	0	30	0.5	<0.01
San Juan	580	0.2	<0.01	0.96	1.0	0.96	0.02

a. The 2022 GHGI equals the average of all subpart W data for RY2015.

Table 17. Oil Well Pad Equipment Leak and Chemical Injection Pump AFs (RY2021 Subpart W)

Basin Name	Basin Number	Headers AF (Light Crude)	Heater-Treaters AF	Separators AF (Light Crude)	Chemical Injection Pumps AF
2022 GHGI		*0.2*	*0.2*	*0.4*	*0.1*
East Texas	260	0.3	0.2	0.6	0.5
Gulf Coast	220	0.3	0.3	0.9	0.4
Permian	430	0.2	0.2	0.4	0.01
Powder River	515	0.4	1.3	0.9	<0.01
San Juan	580	0.01	0.01	1.0	0.02

a. The 2022 GHGI equals the average of all subpart W data for RY2015.

4.3 Time Series Considerations

In the 2023 GHGI update, EPA retained the 2022 GHGI AFs for 1990 through 1992 for all gas well emission sources and basins (e.g., the same national-level AFs were applied to all basins) and applied linear interpolation between the 1992 and 2015 factors at the basin level.

EPA retained the 2022 GHGI oil well equipment AF assumptions for 1990 through 1993 and applied these at the basin-level. EPA also adjusted the default percentage of heavy crude wells from the Radian report to a value specific to the subset of 19 basins with heavy crude wells and applied that factor to years 1990 to 1993. Specifically, 7.05% of oil wells are heavy crude at the national level and EPA back-calculated that 13.5% of oil wells were crude wells in the 19 basins with heavy crude wells. Linear interpolation was used between the 1993 and 2015 AFs at the basin level.

4.4 National Emissions for Well Pad Equipment Leaks and Chemical Injection Pumps in the 2023 GHGI

Based on applying the basin-level AF methodologies presented in section 4.2 and 4.3, Table 18 and Table 19 present a summary of national CH_4 emissions estimates for gas and oil well pad equipment for select time series years and compare to the 2022 GHGI. Details on the emissions, EFs, AFs, activity data, data sources, and methodologies for each year from 1990 to 2021 are available in spreadsheet file annexes.[12]

[12] The basin-level annex spreadsheet tables for the 1990 – 2021 Inventory can be accessed from this page: https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems

Table 18. Gas Well Pad Equipment Leaks and Chemical Injection Pump Emissions (MT CH4)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI (leaks and pumps)	*66,003*	*327,970*	*91,883*	*389,876*	*384,333*	*376,575*	*N/A*
2023 GHGI Update							
Chemical Injection Pumps	25,345	183,832	113,726	120,984	108,546	84,002	76,315
Compressors	29,585	64,877	73,000	72,026	64,471	60,157	73,963
Dehydrators	12,722	12,796	4,485	5,552	3,739	3,133	4,128
Heaters	12,116	20,307	20,068	80,312	16,421	19,223	17,694
Meters/Piping	42,205	72,148	78,403	81,139	85,625	154,544	135,476
Separators	40,745	92,060	129,978	124,339	128,675	132,409	112,425
Total	**162,992**	**446,020**	**419,661**	**484,351**	**407,476**	**453,468**	**420,001**

Table 19. Oil Well Pad Equipment Leaks and Chemical Injection Pump Emissions (MT CH4)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI (leaks and pumps)	*128,631*	*153,932*	*181,178*	*179,080*	*177,578*	*171,205*	*N/A*
2023 GHGI Update							
Chemical Injection Pumps	47,401	105,458	121,469	138,866	387,416	116,080	115,678
Headers	3,323	12,434	12,754	13,217	15,595	8,075	8,444
Heater/Treaters	11,119	20,741	16,245	17,492	22,706	18,734	21,307
Separators	10,970	17,514	30,021	42,001	38,510	29,356	27,107
Wellheads	56,524	51,563	60,557	59,195	60,877	58,632	60,029
Total	**129,337**	**207,709**	**241,047**	**270,770**	**525,104**	**230,877**	**232,565**

5 Liquids Unloading

5.1 2022 (Previous) GHGI Methodology

In the 2022 GHGI, EPA estimated emissions from natural gas well liquids unloading with and without plunger lifts. EPA used national-level AFs and EFs calculated using subpart W data (RY2011-RY2020) to estimate CH_4 and CO_2 emissions from liquids unloading.

The AFs consisted of national-level fraction of all gas wells requiring liquids unloading, and fractions of liquids unloading events with and without plunger lifts. These AFs were year-specific for 2011 through 2020. For 1990, EPA used AFs developed from API/ANGA data (56.3% of all gas wells required liquids unloading and 100% of liquids unloading was conducted without plunger lifts).[13] AFs for the remaining time series years without GHGRP data (i.e., 1991-2010) were developed using linear interpolation between the 1990 values from API/ANGA and the 2011 values that were developed using subpart W data.

EPA also estimated national-level CH_4 and CO_2 EFs (scfd/venting well) using year-specific subpart W data for 2011 through 2020. These EFs were calculated separately for liquids unloading with and without plunger lifts. Emission factors developed using subpart W data for RY2011 were used for the time series years without GHGRP data (i.e., 1990-2010).

[13] API/ANGA 2012. Characterizing Pivotal Sources of Methane Emissions from Natural Gas Production – Summary and Analysis of API and ANGA Survey Responses. Final Report. American Petroleum Institute and America's Natural Gas Alliance. September 2012.

EPA then applied the AFs and EFs to the national-level gas well counts from Enverus to estimate national-level emissions of CH_4 and CO_2 from liquids unloading.

5.2 Update Implemented in the 2023 GHGI for Basin-Level EFs and AFs

For the 2023 GHGI update, EPA calculated year-specific AFs at the basin-level using subpart W data. EPA used the same methodology as the national methodology in the 2022 GHGI to estimate basin-level AFs for this update. Subpart W data includes basin-level counts for gas wells, gas wells that conducted liquids unloading with plunger lifts, and gas wells that conducted liquids unloading without plunger lift in the reporting year. Using these basin-level data, EPA estimated the fraction of all gas wells conducting liquids unloading, and fractions of liquids unloading with and without plunger lifts. Year-specific basin-level AFs were calculated for RY2011 through RY2021. For basins without subpart W data, EPA applied national average AFs. Table 18 presents liquids unloading AFs for select basins for 2021. The basins shown in the table are the highest emitting basins and collectively contributed almost 80% of national emissions in 2021.

Table 20. Liquids Unloading AFs for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	Fraction of All Gas Wells Conducting Liquids Unloading	Fraction of Liquids Unloading with Plunger Lifts	Fraction of Liquids Unloading without Plunger Lifts
2022 GHGI[a]		*13%*	*67%*	*33%*
Appalachian (Eastern Overthrust)	160A	14%	30%	70%
Arkla	230	11%	24%	76%
East Texas	260	6%	31%	69%
Arkoma	345	48%	77%	23%
San Juan	580	25%	97%	3%

a. The 2022 GHGI equals the average of all subpart W data for RY2020.

EPA also calculated year-specific basin-level EFs for CH_4 and CO_2 using subpart W data. EPA calculated EFs separately for liquids unloading with and without plunger lifts for RY2011 through RY2021. Year-specific EFs were calculated using reported basin-level emissions and number of wells that conducted liquids unloading with and without plunger lifts. For basins without subpart W data, EPA applied national average EFs. Table 19 presents CH_4 and CO_2 EFs for select basins for 2021.

Table 21. Liquids Unloading EFs (scfy/venting well) for Select Basins (RY2021 Subpart W)

Basin Name	Basin Number	CH_4 EF – With Plunger Lifts	CH_4 EF – Without Plunger Lifts	CO_2 EF – With Plunger Lifts	CO_2 EF – Without Plunger Lifts
2022 GHGI[a]		*78,846*	*213,224*	*1,293*	*3,115*
Appalachian (Eastern Overthrust)	160A	54,308	171,114	90	287
Arkla	230	192,754	296,902	8,140	12,374
East Texas	260	21,568	1,486,005	884	53,648
Arkoma	345	60,100	76,996	1,436	1,642
San Juan	580	172,452	268,877	2,851	5,099

a. The 2022 GHGI equals the average of all subpart W data for RY2020.

5.3 Time Series Considerations

In the 2022 GHGI, EPA used AFs for 1990 from API/ANGA. AFs for the remaining time series years (i.e., 1991-2010) were developed using linear interpolation between the 1990 values and the 2011 values that were developed using subpart W data. Emission factors developed using subpart W data for RY2011 were used for the time series years without GHGRP data (i.e., 1990-2010).

In this 2023 GHGI update, EPA used AFs and EFs from the 1994 GRI study for 1990-1992.[14] The GRI study data indicates that 41.4 percent of all gas wells required liquids unloading and all liquids unloading was conducted without using plunger lifts (i.e., 100%). The GRI study also included CH_4 EF for liquids unloading without plunger lifts (49,570 scfy/venting well). The same GRI data were used for all basins for 1990-1992. Basin-level AFs for the remaining time series years (i.e., 1993-2010) were developed using linear interpolation between 1992 and 2011 values. Basin-level CH_4 EFs for liquids unloading without plunger lifts for the remaining time series years (1993-2010) were also developed using linear interpolation between 1992 and 2011 values. Basin-level CH_4 EFs for liquids unloading with plunger lifts and the CO_2 EFs (with and without plunger lifts) developed using RY2011 subpart W data were used as constant for time series years without subpart W data (i.e., 1990-2010).

5.4 National Emissions for Liquids Unloading in the 2023 GHGI

Based on applying the basin-level AF methodologies presented in sections 5.2 and 5.3, Tables 20 and 21 present a summary of national CH_4 and CO_2 estimates from liquids unloading for select time series years. Details on the emissions, EFs, AFs, activity data, data sources, and methodologies for each year from 1990 to 2021 are available in spreadsheet file annexes.[15]

Table 22. National CH_4 Estimates from Liquids Unloading (Metric Tons)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI	*373,528*	*379,184*	*155,178*	*207,603*	*175,156*	*129,831*	*N/A*
2023 GHGI Update							
Liquids Unloading With Plunger Lifts	0	144,856	68,633	99,159	85,536	60,280	39,456
Liquids Unloading Without Plunger Lifts	76,815	214,070	116,012	166,014	124,428	98,687	80,690
Total	**76,815**	**358,925**	**184,645**	**265,173**	**209,964**	**158,968**	**120,145**

Table 23. National CO_2 Estimates from Liquids Unloading (Metric Tons)

Source	1990	2005	2017	2018	2019	2020	2021
2022 GHGI	*83,155*	*67,087*	*7,487*	*9,181*	*8,284*	*5,491*	*N/A*
2023 GHGI Update							
Liquids Unloading With Plunger Lifts	0	11,926	3,376	4,212	2,864	2,606	1,967
Liquids Unloading Without Plunger Lifts	44,810	40,806	5,390	7,227	7,270	3,562	3,733
Total	**44,810**	**52,733**	**8,767**	**11,439**	**10,134**	**6,168**	**5,700**

[14] GRI/EPA (1996) 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.

[15] The basin-level annex spreadsheet tables for the 1990 – 2021 Inventory can be accessed from this page: https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems

6 Requests for Stakeholder Feedback

EPA sought stakeholder feedback on the approaches under consideration through webinars, memos, and in the public review draft of the GHGI. EPA received comments from one stakeholder, and their feedback is summarized here.

The stakeholder supported the continued use of GHGRP subpart W data, recommended that EPA consider application of the basin-level approach to only basins with 50 percent coverage or more, and stated that liquids unloading is a source that may be particularly well-suited to a basin-level approach.

The requests for stakeholder feedback below were not updated for this memorandum and are copied from the February 2023 Production Disaggregation memo:

EPA seeks stakeholder feedback on the updates under consideration discussed in this memo and the questions below.

1. The potential benefits and potential disadvantages of updating the GHGI to use an approach that incorporates additional basin-level calculations.
2. Approaches for quantifying emissions for the full time series.
3. Use of basin-specific data for all basins, or application of a coverage threshold for use of basin-specific data for a basin versus a national or other average value.
4. Type and level of coverage threshold (e.g., percentage total activity covered by subpart W, a certain number of wells included in the data set), and the rationale for a threshold.
5. If a coverage threshold were to be applied, approaches for basins with coverage below a threshold (e.g., combining data for basins below the threshold to develop EFs/AFs for all basins below the threshold or using data from all basins to apply to basins below the threshold).
6. Approaches for basins that have subpart W data reported in certain years (e.g., RY2015-RY2017, RY2019, RY2021), but not all GHGRP years (e.g., no data in RY2018, RY2020). For example, using a basin's data from surrounding years, applying average data (based on multiple basins) to those years, or assume the activity did not occur in that year.
7. Data sources in addition to GHGRP that EPA should consider for disaggregating emissions data to a basin-level.
8. Additional emission sources and industry segments for which EPA should consider basin-/state-level approaches.