Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Other Updates Considered for 2019 and Future GHGIs

1 Background

During development of EPA's 2019 *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI), EPA identified several estimates that might be improved using currently available data. EPA released draft and final memoranda discussing considerations and final revisions to two natural gas industry segments: gathering and boosting (G&B) and liquefied natural gas (LNG) stations and terminals. In October 2018, EPA released a draft memo discussing background and considerations for additional revisions to implement in the 2019 GHGI or later GHGIs: *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Other Updates Under Consideration* ("Other Updates memo")[1]. As an outcome to finalizing the 2019 GHGI, EPA released this updated version of the Other Updates memo to document updates implemented in the final 2019 GHGI as well as updates still under consideration.

Table 1 below documents the topics covered in this memo and identifies whether they were implemented in the final 2019 GHGI or are still under consideration. In addition to the specific stakeholder requests in Section 5 below, EPA continues to seek stakeholder feedback on prioritizing the outstanding revisions for incorporation into the 2020 GHGI and future GHGIs, and on other topics to consider for future GHGI updates.

Table 1. Additional Updates Considered for 2019 and Future GHGIs

Topic	2019 GHGI Status	Memo Section
Incorporating Available GHGRP Data		2
HF oil well completions and workovers	Implemented update	2.1
Flaring N_2O emissions	Implemented update	2.2
Transmission pipeline blowdowns	Implemented update	2.3
Updating Well-related Activity Data		3
Well drilling	Implemented update	3.1
Well completions and workovers	Consider for future GHGIs	3.2
Definition of oil versus gas well	Consider for future GHGIs	3.3
Heavy versus light crude equipment service	Consider for future GHGIs	3.4
Identification of HF wells	Consider for future GHGIs	3.5
Anomalous leak events	Consider for future GHGIs	4

2 Incorporating Available GHGRP Data

Subpart W of the EPA's GHGRP collects annual activity and emissions data on numerous sources from onshore natural gas and petroleum systems that meet a reporting threshold of 25,000 metric tons of CO_2 equivalent (mt CO_2e) emissions. Facilities that meet the subpart W reporting threshold have been reporting since reporting year (RY) 2011; however, data elements for hydraulically fractured (HF) oil well completions and workovers and transmission pipeline blowdowns were first required to be reported in RY2016. Subpart W activity and emissions data have been used in recent GHGIs to calculate CH_4 and CO_2 emissions for many production, processing, and transmission and storage sources.

GHGRP subparts W and Y (petroleum refining) include reporting of N_2O from flaring. The GHGRP calculation methodologies specify that subpart W reporters must calculate N_2O emissions from flares using an EF of 0.0001 kg N_2O per million BTU, and subpart Y reporters using an EF of 0.0003 kg N_2O per million BTU. N_2O emissions are also reported to GHGRP for engine exhaust and other combustion sources, combustion emissions from which are generally included within GHGI estimates from fuel combustion, separate from natural gas and petroleum systems.

[1] https://www.epa.gov/sites/production/files/2018-11/documents/ghgi_2018stakeholders_other.pdf

The GHGRP data used in the analyses discussed in this memo are those reported to the EPA as of August 19, 2018, unless otherwise documented. Appendix A documents the subpart W calculation methodologies for certain sources discussed in this memo. Stakeholders have suggested additional or alternate uses of GHGRP data, such as for certain sources using measurement data only. Stakeholders have also suggested modifications to the reported GHGRP data for use in the GHGI, such as through removal of stakeholder-identified outliers. In the current GHGI, EPA uses the publicly available GHGRP data set without modification for the GHGI, to ensure transparency and reproducibility of GHGI estimates. Prior to public release of the GHGRP data, the EPA has a multi-step data verification process for the data, including automatic checks during data-entry, statistical analyses on completed reports, and staff review of the reported data. Based on the results of the verification process, the EPA follows up with facilities to resolve identified potential issues before public release.

2.1 Incorporating GHGRP Data for HF Oil Well Completions and Workovers (2019 GHGI Update)

As discussed above, HF oil well completions and workovers were newly required to be reported in RY2016. EPA analyzed the subpart W data for this source to consider updates to the existing GHGI methodology. In the 2019 GHGI, EPA used subpart W data to update the estimates for this source, as described below.

2.1.1 Overview of 2018 (Previous) GHGI Methodology

In the 2018 GHGI methodology for HF oil well completions, controlled and uncontrolled CH_4 EFs were developed using data analyzed for the 2015 NSPS OOOOa proposal. The 2018 GHGI estimated CO_2 emissions using CO_2 EFs developed by applying a default production segment ratio of CO_2-to-CH_4 gas content. As such, this approach did not fully account for CO_2 emissions from flaring.

The 2018 GHGI activity data time series (counts of HF oil well completions, which is also referenced in calculating non-HF oil well completions) was developed from analyzing DrillingInfo data on well-level dates of completion or first reported production. The 2018 GHGI methodology also included assumptions to develop activity factors (AFs) for apportioning total counts into control categories. In 2008, Colorado and Wyoming adopted regulations that require reduced emission completions (RECs); the 2018 GHGI assumed that 7% of completions are RECs with 95% control efficiency, from 2008 forward.

For workovers, the 2018 GHGI methodology estimated emissions from all oil well workovers without distinguishing HF from non-HF, using an EF developed for conventional wells and an assumption that 7.5% of all oil wells are worked over in each year.

2.1.2 Analysis of Available Data

EPA analyzed RY2016 subpart W data for HF oil well completions and workovers to consider updating the 2018 GHGI methodology. The new subpart W data allow development of separate GHGI emissions estimates for HF completions and workovers, in parallel control categories that exist for HF gas well events (reflecting combinations of REC use, venting, and flaring).[2]

[2] The GHGI methodology for HF gas well completions and workovers incorporates GHGRP data. For HF gas well completions and workovers, EFs are developed from reporting year-specific GHGRP subpart W data (2011 forward), with year 2011 EFs applied for earlier time series years. The EFs are developed for four control categories: non-REC/vented; non-REC/flared; REC/vented; and REC/flared. The total counts of HF completions are developed from DrillingInfo data for years prior to 2011, and GHGRP data are used for year 2011 forward (as the directly reported counts are higher than DrillingInfo-based estimates). The counts are apportioned into control categories based on year-specific GHGRP data for 2011 forward; for years 1990–2000, it is assumed all events are non-REC, and 10% of events flare; interpolation is used to develop AFs in intermediate years. For HF gas well workovers, it is assumed that 1% of the count of existing HF gas wells in a given year (estimated from analyzing DrillingInfo data) are worked over.

Additionally, as summarized in Section 2.1.1, the 2018 GHGI HF oil well completion CO_2 EF was calculated by applying an associated gas CO_2-to-CH_4 content ratio, which did not account for CO_2 conversion during hydrocarbon combustion. This methodological limitation would be obviated by using subpart W data to directly calculate CH_4 and CO_2 EFs, parallel to the current methodology for HF gas well events.

This section documents the development of EFs and activity data for HF oil well completions and workovers consistent with the general methodology used in the existing GHGI for HF gas well completions and workovers. Section 3 below details considerations for potentially improving the approach to estimating national total activity data for all completions and workovers (e.g., DrillingInfo query methodology, workover rate assumptions).

Table 2 below shows EFs calculated using RY2016 subpart W data for HF oil well completions and workovers for each event type/control category, compared to 2018 GHGI EFs. Table 3 shows AFs for each event type/control category.

Table 2. Emission Factors Calculated from Subpart W Compared to 2018 (Previous) GHGI, for Year 2016

Event Type	Control Category	CH_4 EF (mt/event)		CO_2 EF (mt/event)	
		2018 GHGI	Subpart W	2018 GHGI	Subpart W
Non-REC	Vent	6.76	40.5	0.38	0.9
	Flare		1.2		259.7
REC	Vent	0.34	1.2	0.02	0.1
	Flare		1.3		281.5

Table 3. Activity Factors Calculated from Subpart W Compared to 2018 (Previous) GHGI, for Year 2016

Event Type	Control Category	HF Completions				HF Workovers	
		Subpart W		2018 GHGI[a]		Subpart W	
		# of Events	% of total	# of Events	% of total	# of Events	% of total
Non-REC	Vent	109	3%	11,567	93%	12	4%
	Flare	537	13%			16	6%
REC	Vent	1,448	35%	871	7%	159	57%
	Flare	2,090	50%			93	33%
Total		**4,184**	**100%**	**12,438**	**100%**	**280**	**100%**

a – For years 2008 forward, the current GHGI assumes 7% of HF oil well completions are controlled via REC due to state-specific regulations. The current GHGI does not include specific estimates for HF oil well workovers.

To develop national total activity data for HF oil well completions, EPA analyzed counts derived from the DrillingInfo data set compared to reported counts. For HF gas well completions, counts reported under GHGRP exceed DrillingInfo-based estimates, so are assumed to represent national coverage and used directly as national total activity in the GHGI. For HF oil well completions, this is not the case; DrillingInfo-based counts exceed reported counts. Therefore, to develop the national emissions estimates presented in Section 2.1.4, DrillingInfo-based activity data are used.

Workover data are not contained within EPA's DrillingInfo analysis data set, so an assumption of 1% annual workover rate is applied for HF gas wells in the current GHGI. In each year of the time series, 1% of existing HF wells (estimated from the DrillingInfo data set) are assumed to undergo workovers. For HF gas wells, this approach results in national total activity data that exceed HF workover counts reported under subpart W. For the national emissions estimates presented in Section 2.1.4, EPA applies the same assumption to HF oil wells to calculate national total workover activity. Similar to HF gas wells, this approach results in national total activity data that exceed HF oil well workover counts reported under subpart W.

As stated above, Section 3 details considerations for potentially improving the approach to estimating national total activity data for all completions and workovers in the GHGI, which might include refining the DrillingInfo query methodology and/or further incorporating subpart W data. For example, a preliminary analysis discussed in Section 3.2 showed that within the RY2015–2016 subpart W data for gas wells, an overall workover rate is 5-6% in recent years (compared to the current GHGI assumption of 4.35% for non-HF gas wells and 1% for HF gas wells).

2.1.3 Regional Variability and Time Series Considerations

For HF oil well completions and workovers, the updates considered for the 2019 GHGI were developed to parallel the 2018 GHGI methodology to develop estimates for HF gas well events; EFs and AFs are calculated at the national level. EPA requested stakeholder feedback on whether a region-specific approach should be considered for these sources.

To develop the time series AFs for HF oil well completions and workovers based generally on the 2018 GHGI methodology for gas well events, and incorporating current control assumptions for HF oil well events, the following assumptions were applied:

- For years 1990-2007, all completions and workovers are non-REC, and 10% of events flare.
- For the first year in which subpart W data are available, 2016, control fractions across the four categories are developed directly from reported subpart W data.
- For intermediate years, 2008–2015, control fractions are developed through linear interpolation.

This produces AFs across the time series that are generally consistent with the 2018 GHGI assumption that oil well RECs are introduced beginning in year 2008, during which 7% of completions and workovers are REC, and 10% of both REC and non-REC events flare.

To apply EFs across the time series in the 2019 GHGI, EPA applied year-specific EFs for GHGRP years, and EFs from the earliest GHGRP year to all prior years, consistent with the approach for HF gas well events. For the 2019 GHGI, this approach means that EFs calculated from RY2016 data are applied for years 1990–2016, and RY2017 data are used to develop EFs for year 2017.

2.1.4 Updated Methodology and National Emissions in the 2019 GHGI

Stakeholder feedback generally supported incorporating GHGRP data for this source, using an approach consistent with that currently used for HF gas well events. Stakeholders expressed interest in developing separate EFs for completions versus workovers (in the current approach for both gas and oil well events, both types of events are combined). EPA reviewed available data and notes that due to the approach wherein year-specific EFs are calculated for each of four control categories, the number of data points in some categories is relatively small. Therefore, EPA determined it was appropriate to implement the existing approach in the 2019 GHGI, wherein HF oil well completions and workovers data are combined to calculate EFs (while activity for each event type is separately estimated).

EPA implemented the following updates to the methodology for HF oil well completions and workovers in the 2019 GHGI, using the latest subpart W data (reported to EPA as of August 19, 2018):

- To develop national total activity data for HF oil well completions, analyze DrillingInfo data set.
- To develop national total activity data for HF oil well workovers, apply the assumption used for HF gas wells, that 1% of total national HF wells are worked over annually.
- To develop the time series AFs (split among four control categories) assume:
    - For years 1990-2007, all completions and workovers are non-REC, and 10% of events flare.
    - For years in which subpart W data are available, 2016 forward, control fractions across the four categories are developed directly from reported subpart W data.
    - For intermediate years, 2008–2015, control fractions are developed through linear interpolation.

- Apply year-specific EFs for GHGRP years (2016 forward), and EFs from the earliest GHGRP year to all prior years, consistent with the approach for HF gas well events.

Table 4 below shows resulting national total activity data, CH_4 and CO_2 emission factors, and CH_4 and CO_2 emissions for select time series years.

Table 4. National EFs, Activity, and Emissions Estimates for HF Oil Well Completions and Workovers, Select Years

Data Element	1990	2000	2005	2010	2015	2016	2017
CH_4 emission factors (mt/event)							
Non-REC/Vent	40.5	40.5	40.5	40.5	40.5	40.5	14.4
Non-REC/Flare	1.2	1.2	1.2	1.2	1.2	1.2	1.5
REC/Vent	1.2	1.2	1.2	1.2	1.2	1.2	0.6
REC/Flare	1.3	1.3	1.3	1.3	1.3	1.3	1.6
CO_2 emission factors (mt/event)							
Non-REC/Vent	0.9	0.9	0.9	0.9	0.9	0.9	1.3
Non-REC/Flare	259.7	259.7	259.7	259.7	259.7	259.7	350.2
REC/Vent	0.1	0.1	0.1	0.1	0.1	0.1	0.0
REC/Flare	281.5	281.5	281.5	281.5	281.5	281.5	307.5
HF oil well completions (#)	**3,029**	**2,241**	**4,719**	**8,203**	**12,136**	**6,680**	**8,866**
Non-REC/Vent (%)	90%	90%	90%	61%	12%	3%	2%
Non-REC/Flare (%)	10%	10%	10%	11%	13%	13%	13%
REC/Vent (%)	0%	0%	0%	12%	31%	35%	41%
REC/Flare (%)	0%	0%	0%	17%	44%	50%	44%
HF oil well workovers (#)	**854**	**859**	**961**	**1,250**	**1,934**	**1,913**	**1,929**
Non-REC/Vent (%)	90%	90%	90%	61%	14%	4%	0%
Non-REC/Flare (%)	10%	10%	10%	9%	6%	6%	4%
REC/Vent (%)	0%	0%	0%	19%	50%	57%	57%
REC/Flare (%)	0%	0%	0%	11%	30%	33%	39%
2019 GHGI CH_4 emissions (kt)	**142**	**113**	**208**	**238**	**87**	**21**	**15**
2018 GHGI CH_4 emissions (kt)[a]	*21*	*15*	*31*	*52*	*79*	*79*	*n/a*
2019 GHGI CO_2 emissions (kt)	**104**	**83**	**152**	**690**	**2,105**	**1,370**	**1,877**
2018 GHGI CO_2 emissions (kt)[a]	*1*	*1*	*2*	*3*	*4*	*4*	*n/a*

a – Does not include estimate for workovers. The 2018 GHGI does not specifically estimate emissions from HF oil well workovers; the estimate for all (non-HF and HF) oil well workovers is negligible compared to the magnitude of other estimates shown in this table (<0.1 kt across the time series).

2.2 Incorporating GHGRP Data for Flaring N_2O Emissions (2019 GHGI Update)

The 2018 GHGI did not estimate N_2O emissions for natural gas and petroleum systems. However, with recent updates that use GHGRP data to estimate CH_4 and CO_2 flaring emissions, EPA sought stakeholder feedback on implementing updates in the 2019 GHGI to incorporate N_2O emissions for the same flaring sources. Based on stakeholder feedback supporting the update, EPA applied the existing source-specific methodologies for using GHGRP CH_4 data to develop N_2O EFs.

Table 5 presents newly calculated N_2O flaring emissions by source in the 2019 GHGI.

Table 5. National N_2O Emissions Estimates (mt) for Flaring Sources in Natural Gas and Petroleum Systems, Select Years

Emission Source	1990	2000	2005	2010	2015	2016	2017
Natural Gas & Petroleum Production							
Tank Flaring	**0.4**	**4.7**	**6.2**	**8.6**	**18.0**	**13.7**	**9.6**
NG: Large Condensate Tanks w/Flares	0.4	0.4	0.5	0.9	1.5	1.1	0.5
NG: Small Condensate Tanks w/Flares	NO	+	0.1	0.1	0.2	0.0	0.1
Petro: Large Oil Tanks w/Flares	NO	3.6	4.9	6.5	14.0	12.5	8.4
Petro: Small Oil Tanks w/Flares	NO	0.6	0.8	1.1	2.3	+	0.6
Associated Gas	**14.8**	**11.1**	**11.0**	**14.1**	**35.5**	**25.9**	**28.2**
Petro: Associated Gas Flaring	14.8	11.1	11.0	14.1	35.5	25.9	28.2
NG: Flared Gas Well Completions and Workovers	**0.9**	**1.6**	**3.7**	**3.2**	**11.4**	**0.5**	**1.7**
HF Completions - Non-REC with Flaring	0.8	1.4	2.5	1.7	0.4	+	0.2
HF Completions - REC with Flaring	NO	NO	0.7	1.0	7.8	0.3	0.7
Non-HF Completions - flared	+	+	+	+	0.9	+	+
HF Workovers - Non-REC with Flaring	0.1	0.2	0.4	0.5	0.1	+	0.2
HF Workovers - REC with Flaring	NO	NO	+	+	2.1	0.1	0.5
Non-HF Workovers - flared	NO	+	+	+	0.0	NO	NO
Petro: Flared Oil Well HF Completions and Workovers	**0.2**	**0.1**	**0.3**	**1.2**	**3.6**	**2.4**	**2.9**
HF Completions - Non-REC with Flaring	0.1	0.1	0.2	0.4	0.7	0.4	0.6
HF Completions - REC with Flaring	NO	NO	NO	0.7	2.6	1.6	1.8
HF Workovers - Non-REC with Flaring	+	+	+	+	0.1	0.1	+
HF Workovers - REC with Flaring	NO	NO	NO	0.1	0.3	0.3	0.3
Miscellaneous Production Flaring	NO	**2.1**	**3.3**	**4.8**	**11.7**	**6.1**	**6.7**
Natural Gas Systems	NO	1.3	2.1	3.1	5.3	2.2	1.8
Petroleum Systems	NO	0.8	1.2	1.8	6.3	4.0	4.9
Well Testing	**1.2**	**1.4**	**1.8**	**2.1**	**2.2**	**0.1**	**0.1**
Natural Gas Systems	0.8	1.1	1.4	1.7	1.7	NO	+
Petroleum Systems	0.4	0.4	0.4	0.4	0.5	0.1	0.1
Natural Gas Processing							
Flare Stacks	NO	7.2	11.2	16.1	19.4	12.8	10.2
Transmission and Storage							
Transmission Station Flare Stacks	0.1	0.1	0.1	0.1	0.1	0.0	0.1
Storage Station Flare Stacks	+	+	+	+	+	0.1	+
LNG Storage Station Flare Stacks	0.7	0.8	0.8	0.8	0.8	0.8	0.8
LNG Import/Export Station Flare Stacks	+	+	0.1	0.2	0.2	0.4	0.6
Petroleum Refining							
Flare Stacks	30.7	34.6	34.8	35.6	39.1	38.8	36.4

NO – Not occurring
+ Does not exceed 0.05 mt

2.3 Incorporating GHGRP Data for Transmission Pipeline Blowdowns (2019 GHGI Update)

As discussed above, transmission pipeline blowdowns were newly required reporting elements in GHGRP RY2016. EPA analyzed the subpart W data for this source to consider updates to the existing GHGI methodology. In the 2019 GHGI, EPA used subpart W data to update the estimates for this source, as described below.

2.3.1 2018 (Previous) GHGI Methodology

The 2018 GHGI showed emissions from transmission pipeline blowdowns as "pipeline venting for routine maintenance and upsets." Emissions were calculated using a "potential" CH_4 EF from GRI/EPA 1996 and annual transmission pipeline miles from the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA). Reported voluntary reductions (Gas STAR data) were taken into account to calculate "net" CH_4 emissions across the time series. CO_2 emissions were calculated from the CH_4 EF and a default downstream gas profile of 93.4% CH_4 and 1.0% CO_2.

2.3.2 Analysis of Available Data

A subpart W transmission pipeline facility must report blowdown emissions from natural gas transmission pipelines (as defined at 40 CFR 98.238) that it owns and operates. EPA calculated transmission pipeline blowdown EFs from the subpart W data by summing the reported emissions and dividing by the reported transmission pipeline miles. Table 6 shows the calculated subpart W EFs for RY2016 and RY2017 compared to the 2018 GHGI EFs. Note, the subpart W RY2016 data reflect approximately 50% of the total transmission pipeline mileage estimated in the 2018 GHGI for year 2016 (147,000 of 300,000 miles).

Table 6. Preliminary Emission Factors (mt/pipeline mile) Calculated from Subpart W Compared to 2018 (Previous) GHGI, for Years 2016 and 2017

Data Source	CH_4	CO_2
2018 GHGI	0.6	0.01
Subpart W RY2016	0.8	0.02
Subpart W RY2017	0.6	0.02

EPA also compared subpart W RY2016 reporters of this source to a PHMSA data set that includes transmission pipeline mileage by company, state, and type (i.e., interstate or intrastate). Based on a preliminary analysis, approximately 71% of the national total interstate transmission pipeline miles and 11% of intrastate transmission pipeline miles were reported to subpart W in RY2016. EPA may further consider this distinction and calculate unique EFs for interstate and intrastate pipelines in future GHGIs, which would be paired with activity data specific to each type.

2.3.3 Time Series Considerations

EPA sought stakeholder feedback as to whether the EFs used in the 2018 GHGI (based on the 1996 GRI/EPA study) or the newly calculated subpart W-based EFs best represent emissions over the time series. EPA considered various approaches for developing EFs to apply over the time series, including: (1) applying the 1996 GRI/EPA EFs to early years of the time series (1990-1992) and linearly interpolating to the year 2016 subpart W EFs, (2) applying the 2018 GHGI EFs for 1990-2015 and year-specific subpart W EFs for 2016 forward, and (3) applying subpart W-based EFs (average EFs or year-specific EFs) to all years of the time series. Based on currently available data (see Table 6), there is not an obvious difference in EFs calculated from historic data compared to more recent subpart W data.

Stakeholder feedback suggested that companies are making concerted efforts to reduce blowdown emissions, which may lead to a downward trend over time that would be reflected in the future subpart W data. Stakeholder feedback also suggested that the reported subpart W data for this source might not be representative of national emissions in recent years (e.g., facilities meeting the reporting threshold might generally have larger-diameter pipelines leading to higher emissions per mile). As discussed above, EPA considered and sought additional stakeholder feedback regarding whether sufficient data are available to develop separate EFs and accompanying activity data for interstate versus intrastate pipelines as a potential means to recognize differences in the reporting versus nonreporting population. Establishing subcategories might offer improved representativeness, but is dependent on identifying an accurate method for categorizing subpart W data (interstate versus instrastate

designation is not directly reported but might be inferred through analysis of external data sets such as published by PHMSA) and the statistical characterization of reported data points in each category (e.g., whether the data set size and variance support establishing separate EFs).

2.3.4 Updated Methodology and National Emissions Estimates

Table 7 below shows national total emissions for select time series years based on the approach that EPA implemented in the 2019 GHGI based on stakeholder feedback:

- Use existing GHGI activity (pipeline miles) for all years.
- Use existing EFs for years 1990 through 2015.
- Use newly calculated year-specific EFs from subpart W data starting in year 2016.
- Do not take into account historical voluntary reductions (Gas STAR data).

Table 7. National Emissions Estimates for Transmission Pipeline Blowdowns, Select Years

Data Element	1990	2000	2005	2010	2015	2016	2017
2018 GHGI							
# Pipeline miles	291,925	298,957	300,468	304,803	300,376	300,645	n/a
CH_4 EF (mt/mile)	0.61	0.61	0.61	0.61	0.61	0.61	n/a
CO_2 EF (mt/mile)	0.018	0.018	0.018	0.018	0.018	0.018	n/a
Total CH_4 emissions (kt)	178	182	183	186	184	183	n/a
Total CO_2 emissions (kt)	5	5	5	5	5	5	n/a
2019 GHGI							
CH_4 EF (mt/mile)	0.61	0.61	0.61	0.61	0.61	0.83	0.61
CO_2 EF (mt/mile)	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total CH_4 emissions (kt)	178	182	183	186	184	250	184
Total CO_2 emissions (kt)	5	5	5	5	5	7	5

n/a – Not applicable

3 Updating Well-related Activity Data

Appendix B provides a table that shows all well-related activity data over the time series as used in the 2018 GHGI, as well as data elements from updates considered for and implemented in the 2019 GHGI, as discussed below. Note that several of the existing and updated GHGI methodologies (e.g., developing counts of active wells) rely on EPA's analysis of DrillingInfo's subscription-based digital DI Desktop raw data feed[3]; this data set is referred to throughout this memo as "DrillingInfo data."

3.1 Well Drilling (2019 GHGI Update)

The U.S. Department of Energy's Energy Information Administration (DOE/EIA) no longer maintains the *Monthly Energy Review* well drilling activity data set that was used to develop well drilling activity inputs in the 2018 and earlier GHGIs (most recent estimates cover through 2010), so the 2019 GHGI required a new data source for the entire time series, or at least from 2011 forward.

EPA did not identify another data set published by EIA that provides complete well drilling activity over the GHGI time series. EPA developed a methodology for querying the DrillingInfo data set to develop estimates of wells drilled and presented preliminary results to solicit stakeholder feedback. The DrillingInfo-based approach is:

- Count all wells drilled in time series year N with:
  - Onshore location **-and-**
  - Spud date within year N **-or-** spud date not reported, but date of first production within year N+1

[3] https://info.drillinginfo.com/products/di-plus/

- Apportion counts between oil, gas, and dry production types
    - Dry or temporarily inactive (TIA) wells drilled: spud date within year N, but no production is reported in year N+1
    - Gas wells drilled: GOR in year N+1 >100 mcf/bbl
    - Oil wells drilled: GOR in year N+1 ≤ 100 mcf/bbl
- Apportion dry/TIA counts to natural gas and petroleum systems according to the year-specific split between gas wells drilled and oil wells drilled.

Stakeholder feedback on the DrillingInfo-based approach noted that preliminary estimates appeared reasonable for incorporation into the GHGI.

For a DrillingInfo-based methodology, EPA also sought feedback on a few additional considerations. First, whether this approach adequately accounts for dry wells (which are spud but do not achieve reportable production levels). Based on preliminary analysis of results, this approach does appear to sufficiently represent dry wells at comparable levels to the EIA data set; on average, dry wells (not including TIA wells which report production after year N+1) contribute 10% of total wells drilled. Second, whether this approach is overly inclusive of wells that may not be drilled for oil and gas production purposes but are present in the DrillingInfo data set. EPA has not received stakeholder feedback on this topic nor quantified this potential population, but it is expected to be minimal. Third, how to account for time series coverage issues. For states without recently released data, EPA developed a surrogate methodology wherein an early year's data are assigned to recent years to fill state-level data gaps, similar to the existing approach for counts of active wells. Additionally, total wells drilled in most recent time series year cannot be fully estimated by the current approach (i.e., GOR in year N+1 is not available); EPA developed a surrogate approach of using the previous year's estimate.

In the 2019 GHGI, EPA implemented the DrillingInfo-based approach to develop well drilling activity across the time series, for both Natural Gas and Petroleum Systems. Appendix B shows well drilling counts across the time series in the 2018 GHGI and updated estimates that appear in the 2019 GHGI based on the DrillingInfo data analysis approach described above.

3.2 Well Completions and Workovers (Consider for Future GHGIs)

As described above, the current methodology for well completion and workover event counts involves a mix of DrillingInfo data analyses, GHGRP data analyses, and historical assumptions.

EPA has conducted a preliminary analysis to assess how completion counts and workover rates reflected in the subpart W data compare to current GHGI assumptions. Regarding workover rates, the subpart W data reporting structure and requirements limit the level of detail for such an analysis, due to: (1) there is not a specific reporting element indicating whether reported wells are HF or non-HF; and (2) non-HF oil well workovers are not reported. EPA therefore analyzed the number of completion and workover events and the overall gas well workover rate using historical RY2015 and RY2016 data (reported as of August 5, 2017), as summarized in Table 8.

In response to stakeholder feedback, EPA developed the following considerations based on this analysis and the estimation that approximately 70% of gas wells in the U.S. are covered by subpart W reporting:

- Non-HF gas well completion counts might be *over-estimated* in recent years of the GHGI.
- Non-HF gas well workover counts might be *under-estimated* in recent years of the GHGI.
- HF gas well workover counts might be *over-estimated* in recent years of the GHGI.

Table 8. Comparison of Gas Well Event Activity Data and Calculated Workover Rate

Activity Data Element	Current GHGI			GHGRP As-reported	
	Basis	2015	2016	2015	2016
# Non-HF gas well completions	Scaled from 400 events/year in 1992	786	770	108	88
# Non-HF gas well workovers	4.35% of active non-HF gas wells	7,549	7,315	18,031	14,957
# HF gas well workovers	1% of active HF gas wells	2,521	2,487	263	103
Overall gas well workover rate	4.35% of active non-HF gas wells; 1% of active HF gas wells			6%[a]	5%[a]

a – Calculated using number of reported gas well workover events (with and without HF) divided by the number of producing wells at the end of the calendar year (reported under 40 CFR 98.236(aa), found in the "sub-basin characterization" table).

Appendix B shows all categories of completion and workover counts across the entire time series in the 2018 GHGI. EPA did not make updates for this data element in the 2019 GHGI and continues to seek stakeholder feedback on improving the current methodology in future GHGIs; see Section 5 for specific stakeholder feedback requests.

3.3 Definition of Oil versus Gas Well (Consider for Future GHGIs)

The current methodology estimates the count of active gas wells in a given year as all wells in the DrillingInfo data set with a GOR > 100 mcf/bbl in that year, and active oil wells as those with GOR ≤ 100 mcf/bbl. By this definition, oil wells include associated gas wells.

Other data sets (e.g., those published by EIA) use different GOR thresholds for defining oil versus gas wells and might have different underlying assumptions regarding whether associated gas wells are a subset of oil wells. A value of 6 mcf/bbl is another common definition threshold, based on the oil and gas energy equivalence factor (6 mcf gas provides roughly the same amount of energy as 1 bbl oil equivalent (BOE); BOE is commonly used in financial statements to combine oil and gas production into a single measure).

EPA reviewed available data reported under GHGRP subpart W to evaluate how reported GOR values compare to the current GHGI methodology and consider whether the current production type delineation threshold of 100 mcf/bbl is appropriate. Per subpart W, oil wells are defined as producing from an oil formation, not defined by a specific GOR threshold.

Table 9 below summarizes reported GOR data based on EPA's review of historic subpart W RY2015-2016 summary data (Envirofacts table EF_W_FACILITY_OVERVIEW, containing data for over 400,000 wells reported to the EPA as of August 5, 2017). For most oil wells reported under subpart W (73%), the sub-basin level average GOR falls within the current GHGI definition (≤100 mcf/bbl); while a significant fraction (27%) have higher average GORs. At a lower delineation threshold (e.g., 6 mcf/bbl), an even higher fraction of subpart W oil wells (roughly 50%) would be considered gas wells. Therefore, based on this analysis, EPA finds support for the current approach to delineating oil versus gas wells.

Table 9. 2018 GHGI Well-Related Activity Data Summary

Reporting Year	# Oil Wells with Specified GOR (mcf/bbl)			
	GOR ≤10	10< GOR ≤100	100< GOR ≤1,000	GOR >1,000
2015	123,446 [58%]	28,104 [13%]	11,674 [6%]	48,091 [23%]
2016	117,538 [57%]	33,346 [16%]	21,068 [10%]	32,781 [16%]
Combined	240,984 [58%]	61,450 [15%]	32,742 [8%]	80,872 [19%]

In response to recent stakeholder feedback, EPA calculated oil and gas well counts across the time series by two different GOR delineation thresholds (100 mcf/bbl and 6 mcf/bbl). The results of this sensitivity analysis are shown in Figure 1.

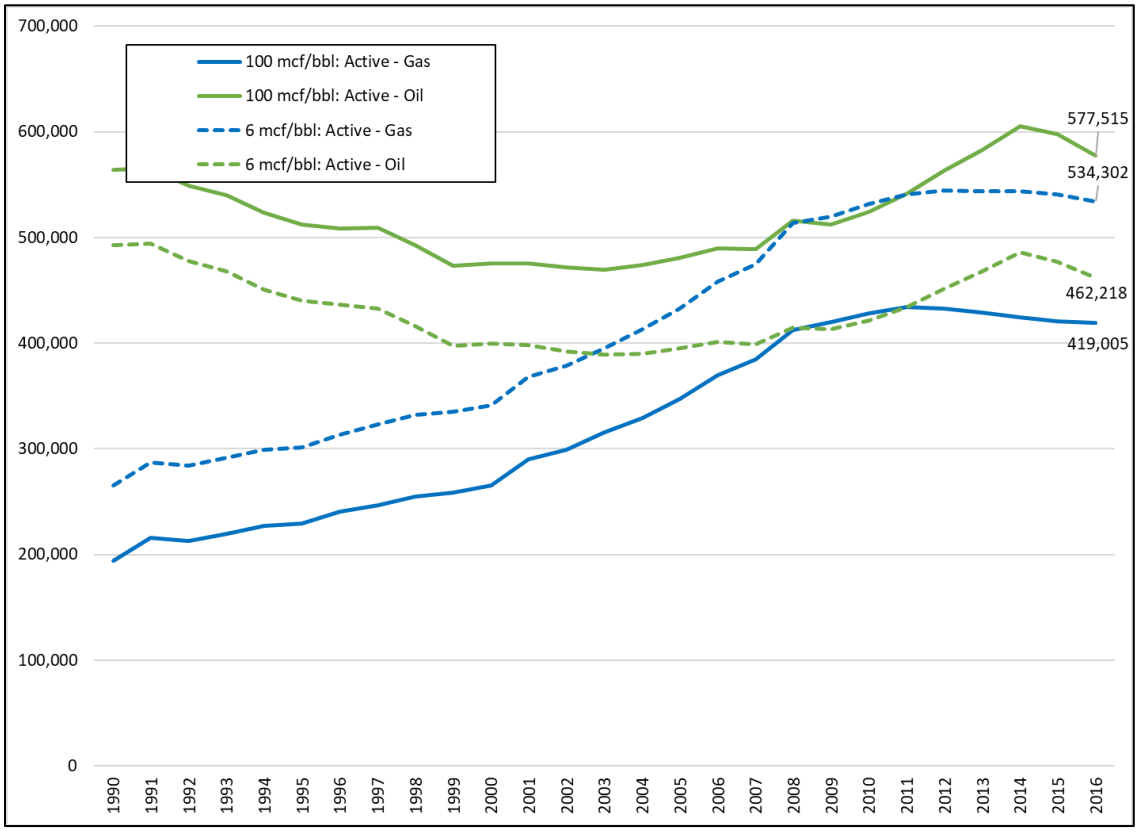

Figure 1. Active Oil and Gas Well Counts by Two Different GOR Delineation Thresholds

EPA did not make updates for this data element in the 2019 GHGI and continues to seek stakeholder feedback on improving the current methodology in future GHGIs; see Section 5 for specific stakeholder feedback requests.

3.4 Heavy versus Light Crude Equipment Service (Consider for Future GHGIs)

Heavy crude is defined as oil with lower than 20° API gravity. The GHGI uses separate EFs and activity data for wellheads, separators, and headers in heavy versus light crude service. Currently, the total counts of wellheads and headers are split into heavy versus light crude categories using an assumed split between heavy crude wells (7.05% of all oil wells) and light crude wells (92.95%). As documented in the 1999 EPA/ICF report[4], this assumption, and its extension to wellhead and header activity, was developed for a 1995 base year; this split is currently applied to calculate equipment counts in all time series years. The split between heavy and light crude separators in base year 1995 is also documented in the 1999 EPA/ICF report: EPA assumed 90.1% of separators are in light crude service, and 9.9% in heavy crude service, and applied this split to all time series years. EPA has identified multiple data sources that might facilitate improvement to the current methodology by allowing calculation of the heavy versus light crude equipment splits in recent years.

GHGRP subpart W collects average API gravity data associated with production in all oil sub-basins. Based on an analysis of historical RY2015 and RY2016 data (reported as of August 5, 2017), 19% and 18%, respectively, of oil wells reporting to GHGRP produce heavy crude. This value is higher than the current assumption of 7.05% of wells

[4] Estimates of Methane Emissions from the U.S. Oil Industry (Draft Report). Prepared by ICF International. Office of Air and Radiation, U.S. Environmental Protection Agency. October 1999.

producing heavy crude (and subsequent assumption that 7.05% of wellheads and headers are in heavy crude service). To follow the existing methodology which assumes that per well equipment counts are the same for heavy crude and light crude wells (with the exception of separators, where on average over the time series each heavy crude well has 0.47 separators while each light crude well has 0.32 separators), EPA might analyze subpart W data specifically for facilities that produce heavy crude versus light crude. For this approach, however, only a subset of onshore production facility data can be analyzed—those with either all heavy crude sub-basin formation types or all light crude sub-basin formation types—since equipment counts (e.g., separators) are reported at a basin level. Table 10 summarizes the data availability and preliminary estimates of separator activity factors based on this approach. EPA might use subpart W data to update the equipment count splits in recent years and reflect updated industry trends.

Table 10. Subpart W Equipment Counts[a]

	Count of Separators		Count of Wellheads		Separators/ Wellhead		Number of Data Points (Facilities)		
Data Set	2015	2016	2015	2016	2015	2016	2015	2016	Notes/Methodology
All onshore oil prod	76,690	86,890	213,380	221,326	0.36	0.39	319	315	Counts from records classified in Table R.4 as "Crude oil production equipment"[b]
Heavy crude-only facilities	1,818	345	40,894	40,063	0.04	0.01	14	14	Counts from records in Table R.4 – from facilities that produce only heavy crude (all sub-basins are oil with API gravity <20 in Table AA.1.ii)
Light crude-only facilities	22,153	23,048	54,098	51,428	0.41	0.45	102	103	Counts from records in Table R.4 – from facilities that produce only light crude (all sub-basins are oil with API gravity ≥20 in Table AA.1.ii)

a - Data reported as of August 5, 2017.
b - For this approach, data from all facilities reporting presence of crude oil production equipment for equipment leak calculations can be used (ignoring the reported sub-basin formation type(s)).

EPA also reviewed the methodology documented in the 1999 Radian report which was the basis for the 1999 EPA/ICF report estimates. The 1999 Radian report methodology analyzed state-level reported heavy oil production as a fraction of total oil production, then applied that fraction to state-level oil well counts to estimate heavy oil well counts in each state, and finally summed heavy oil well counts to estimate the national population fraction. This approach does not facilitate development of a heavy versus light split for equipment other than wellheads (e.g., a specific split for separators as in the current methodology); additionally, inherent in this approach is an assumption that heavy and light crude wellheads have the same average production rates. EPA recently reviewed EIA state-level production and API gravity data and estimated that 4-5% of crude produced in the lower 48 states in recent years is heavy crude. Due to the assumptions and limitations of this analysis (i.e., using production split between heavy and light as surrogate for wellhead split), EPA is focusing further efforts toward how subpart W data, such as that summarized in Table 10, might be used to update the GHGI for recent time series years.

EPA did not make updates for this data element in the 2019 GHGI and continues to seek stakeholder feedback on the data sources and approaches described above, or other methodologies to consider for improving this aspect of the oil production segment major equipment activity estimates; see Section 5 for specific stakeholder feedback requests on this topic.

3.5 Identification of HF Wells (Consider for Future GHGIs)

Appendix B shows 2018 GHGI estimates of HF gas and oil well counts. There are limited public data estimating national total counts comparable to the GHGI; Appendix B shows year 2016 estimates from EIA's *Today in Energy* website.

EPA did not make updates for this data element in the 2019 GHGI and continues to seek stakeholder feedback on data sources and methodologies that might be used to update the current approach for identifying HF gas and oil wells within the DrillingInfo data set; see Section 5. EPA might retain the current assumption that all horizontally drilled wells are hydraulically fractured but update the methodology for identifying wells that do not report horizontal drill type but would be expected to be hydraulically fractured based on location in an unconventional formation. EPA is considering reviewing subpart W sub-basin-level (county-level) data to assess whether a crosswalk of location and HF indication might be constructed from or verified using reporting data, in order to estimate total national HF well counts (at least for recent time series years).

4 Anomalous Leak Events (Consider for Future GHGIs)

In recent GHGIs, EPA incorporated an emissions estimate for the Aliso Canyon gas leak during years 2015 and 2016 in the storage well category. EPA used the California Air Resources Board (CARB) published estimate of the methane release from the leak.[5]

EPA did not make updates for this type of source in the 2019 GHGI and continues to seek stakeholder feedback on existing data sources or suggested methodologies for identifying similar events across natural gas and petroleum systems, with emissions beyond what is likely accounted for in GHGI EFs; see Section 5.

5 Requests for Stakeholder Feedback

The following questions may be considered for the stakeholder process for the 2020 or future GHGIs.

Well Completions and Workovers (Section 3.2)

1. EPA seeks stakeholder feedback on how to use available data to improve national activity estimates for well completion and workover events—specifically, how DrillingInfo and subpart W data sets might be used in conjunction, or if one data set should be used to develop estimates and the other to verify estimates.

Definition of Oil vs. Gas Well (Section 3.3)

2. EPA seeks stakeholder feedback on whether the current methodology for counting and allocating active well counts between oil and gas should be updated, and if so, how.

Heavy vs. Light Crude Equipment Service (Section 3.4)

3. Based on historical RY2015 and RY2016 subpart W data, 19% and 18%, respectively, of oil wells in that data set produce heavy crude (API gravity less than 20), compared to the current GHGI basis of 7.05%. This updated heavy crude fraction is based on reported data for approximately 210,000 active oil wells (out of approximately 580,000 active oil wells nationwide). EPA seeks stakeholder feedback on incorporating this updated fraction into the GHGI time series.
    a. Should EPA consider developing geographic-specific (e.g., NEMS region-level) estimates of heavy crude well fractions?
    b. Should EPA retain the estimate of 7.05% of oil wells producing heavy crude (developed for base year 1995) for early years of the time series, and interpolate to the updated fraction based on subpart W data? Or is a different approach more appropriate—for example, where the heavy

[5] https://www.epa.gov/sites/production/files/2017-04/documents/2017_aliso_canyon_estimate.pdf

crude fraction is more tailored to the specific time period, rather than a set or linearly increasing value? EPA seeks information on data sources that might offer information to implement a more tailored approach.

4. How should EPA use API gravity data in conjunction with equipment count data reported under subpart W to improve oil production segment major equipment activity estimates? For example, Table 10 above presents activity factors for separators per oil well developed specifically for heavy and light crude populations.
    a. Should EPA retain the current approach of extending the heavy/light crude well count split to wellhead and header activity data (for example, 19% of oil wells produce heavy crude, therefore 19% of headers are in heavy crude service)?
    b. Should EPA retain the current approach of developing specific activity factors for separators in heavy versus light crude service, as shown in Table 10?

Identification of HF Wells (Section 3.5)

5. EPA seeks stakeholder feedback on whether it is reasonable to retain the current assumption that all wells with horizontal drill type according to the DrillingInfo data set are hydraulically fractured, or if there are recommendations for improving this assumption.
6. EPA seeks input on publicly available data sources and methodologies that might be used to identify wells that do not report horizontal drill type in the DrillingInfo data set but would be expected to be hydraulically fractured based on location in an unconventional formation (i.e., used to create a new formation type crosswalk).
    a. EPA specifically seeks feedback on how GHGRP subpart W data might be used in this step to construct or verify such a crosswalk.

Anomalous Leak Events (Section 4)

7. EPA seeks stakeholder feedback on existing data sources or suggested methodologies for identifying similar events across natural gas and petroleum systems, with emissions beyond what is likely accounted for in GHGI EFs.
8. EPA seeks information from stakeholders on any anomalous leak events that have occurred during the GHGI time series or more recent years that should be included in future GHGIs, in addition to the Aliso Canyon leak in years 2015 and 2016.

Appendix A. GHGRP Measurement Methodologies

Emission Source	Measurement and/or Calculation Type	# Sources	Location & Representativeness	EF Calculation Method
Oil Well HF Completions and Workovers	Emissions calculated for each event, based on (1) measured actual flowback gas volumes from the well or (2) calculated flowback gas volume based on well parameters (e.g., pressure differentials, temps). If flared, then flare control efficiency is applied.	Emissions data (for 2016) are available for 4,059 completions and 330 workover events at HF oil wells	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, the EPA used reported data to calculate, event/control category specific (e.g., REC, flare), average EFs
Flare Stacks	CH_4 and CO_2 emissions calculated using: (1) gas volume sent to the flare, (2) combustion efficiency (from manufacturer or assume 98%), fraction of feed gas sent to an un-lit flare, and (3) gas composition for CO_2, CH_4, and hydrocarbon constituents. N_2O emissions calculated using amount of fuel combusted, fuel heating value, and prescribed EF of 1.0 × 10−4 kg N_2O/mmBtu	Varies by industry segment .	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, to estimate emissions for each source, EPA calculated a ratio of the GHGRP reported N_2O emissions to CO_2 emissions and then multiplied the N_2O-to-CO_2 ratio by the 2018 GHGI CO_2 emissions
Transmission Blowdown Vent Stack	Emissions calculated using: • Blowdown volumes, number of blowdowns, and the ideal gas low modified for compressibility; or • Flow meter to measure emissions for all equipment associated with a blowdown event. Blowdown volumes <50 scf are exempt.	Emissions data (for 2016) are available from 9,093 blowdowns (which occurred over 147,187 miles).	Facilities in the U.S. that exceed 25,000 mt CO2e reporting threshold.	For this memo, EPA calculated EFs as a straight average of all available data.

Appendix B. Well-Related Activity Data

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Well counts																												
2018 GHGI																												
Non-HF gas wells	135,552	141,052	139,823	140,834	142,127	142,245	144,501	144,082	148,078	148,112	144,545	156,621	157,696	162,506	167,595	168,855	175,567	178,970	187,366	186,667	187,098	187,153	182,776	179,300	179,305	173,544	168,151	n/a
HF gas wells	62,074	78,538	76,875	82,527	88,242	90,423	99,399	103,820	108,880	113,260	122,364	135,526	142,815	154,003	162,832	179,615	195,683	207,348	227,138	234,576	242,301	248,162	250,614	248,528	252,141	252,107	248,730	n/a
Total active gas wells	197,626	219,590	216,698	223,361	230,369	232,668	243,900	247,902	256,958	261,372	266,909	292,147	300,511	316,509	330,427	348,470	371,250	386,318	414,504	421,243	429,399	435,315	433,390	427,828	431,446	425,651	416,881	n/a
Non-HF oil wells *	469,317	467,760	454,605	446,499	432,774	423,199	418,579	419,582	401,394	381,938	382,314	379,071	375,274	372,953	372,994	374,960	379,859	380,541	391,513	387,949	389,226	393,598	401,244	404,373	405,284	398,424	373,608	n/a
HF oil wells *	84,582	88,843	86,070	87,745	87,088	84,442	86,754	87,650	84,935	82,132	84,785	86,243	86,547	88,223	91,457	94,672	98,627	97,217	112,992	113,657	123,494	135,121	151,260	165,297	184,166	191,593	188,356	n/a
Total active oil wells	553,899	556,603	540,675	534,244	519,862	507,641	505,333	507,232	486,329	464,070	467,099	465,314	461,821	461,176	464,451	469,632	478,486	477,758	504,505	501,606	512,720	528,719	552,504	569,670	589,450	590,017	561,964	n/a
Total HF wells *	**146,656**	**167,381**	**162,945**	**170,272**	**175,330**	**174,865**	**186,153**	**191,470**	**193,815**	**195,392**	**207,149**	**221,769**	**229,362**	**242,226**	**254,289**	**274,287**	**294,310**	**304,565**	**340,130**	**348,233**	**365,795**	**383,283**	**401,874**	**413,825**	**436,307**	**443,700**	**437,086**	n/a
Total active wells	**751,525**	**776,193**	**757,373**	**757,605**	**750,231**	**740,309**	**749,233**	**755,134**	**743,287**	**725,442**	**734,008**	**757,461**	**762,332**	**777,685**	**794,878**	**818,102**	**849,736**	**864,076**	**919,009**	**922,849**	**942,119**	**964,034**	**985,894**	**997,498**	**1,020,896**	**1,015,668**	**978,845**	n/a
EIA *Today in Energy (May 5, 2016)*																												
Total HF wells	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	**670,000**	n/a
Total active wells	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	NPA	**977,000**	n/a
Drilling event counts																												
2018 GHGI																												
Gas wells drilled (incl. fraction of dry)	15,096	13,066	10,887	13,047	12,232	10,465	11,498	14,473	14,507	14,564	19,863	25,350	20,041	23,582	27,180	31,969	36,536	36,255	35,824	20,266	18,837	18,837	18,837	18,837	18,837	18,837	18,837	n/a
Oil wells drilled (incl. fraction of dry)	17,234	16,796	12,540	11,744	9,587	10,679	11,255	14,105	9,575	5,818	9,424	10,208	7,830	9,251	9,877	12,053	14,893	14,816	18,478	12,537	17,774	17,774	17,774	17,774	17,774	17,774	17,774	n/a
Total wells drilled	**32,330**	**29,862**	**23,427**	**24,791**	**21,819**	**21,144**	**22,753**	**28,578**	**24,082**	**20,382**	**29,287**	**35,558**	**27,871**	**32,833**	**37,057**	**44,022**	**51,429**	**51,071**	**54,302**	**32,803**	**36,611**	**36,611**	**36,611**	**36,611**	**36,611**	**36,611**	**36,611**	n/a
2019 GHGI (update described in Section 3.1)																												
Gas	13,903	7,194	7,945	7,298	7,685	8,130	8,920	9,261	8,871	10,330	14,346	16,970	14,216	17,094	19,924	22,711	24,640	24,735	23,536	11,622	11,939	9,205	5,343	4,671	4,484	2,567	1,709	1,709
Oil	15,390	11,434	12,047	11,105	9,558	10,598	15,228	12,477	7,528	7,922	10,755	11,125	9,542	11,429	13,418	15,502	16,961	19,004	18,688	12,520	20,627	25,961	30,023	30,368	30,342	14,071	8,706	8,706
Dry/TIA	8,431	6,062	5,618	5,017	4,630	4,299	4,678	4,935	4,078	3,795	5,492	7,256	5,384	5,839	7,056	7,571	9,735	8,582	10,529	5,369	6,226	6,899	6,496	6,313	7,955	4,306	2,091	2,091
Gas wells drilled (incl. fraction of dry/TIA)	17,805	9,780	10,463	9,379	10,011	10,155	10,823	11,709	11,238	12,804	17,764	21,767	17,720	20,848	24,417	27,568	30,902	29,725	29,556	14,235	14,388	11,337	6,585	5,681	5,871	3,585	2,264	2,264
Oil wells drilled (incl. fraction of dry/TIA)	19,919	14,910	15,147	14,041	11,862	12,872	18,003	14,964	9,239	9,243	12,829	13,584	11,422	13,514	15,981	18,216	20,434	22,596	23,197	15,276	24,404	30,728	35,277	35,671	36,910	17,359	10,242	10,242
Total wells drilled	**37,724**	**24,690**	**25,610**	**23,420**	**21,873**	**23,027**	**28,826**	**26,673**	**20,477**	**22,047**	**30,593**	**35,351**	**29,142**	**34,362**	**40,398**	**45,784**	**51,336**	**52,321**	**52,753**	**29,511**	**38,792**	**42,065**	**41,862**	**41,352**	**42,781**	**20,944**	**12,506**	**12,506**
Completion event counts																												
2018 GHGI																												
Gas well non-HF completions	365	405	400	412	425	429	450	458	474	482	493	539	555	584	610	643	685	713	765	778	793	804	800	790	796	786	770	n/a
Gas well HF completions	3,769	3,630	2,630	3,425	3,322	3,034	4,057	5,352	4,785	4,583	6,881	8,675	7,536	8,911	10,459	12,866	14,176	14,206	15,223	8,811	8,691	9,749	7,665	7,382	7,141	5,272	3,105	n/a
Oil well non-HF completions	9,764	9,644	6,395	5,916	4,742	5,855	6,203	7,671	5,359	3,476	5,844	5,791	4,285	4,618	5,046	6,185	7,369	7,142	8,305	6,117	7,565	3,252	0	0	0	3,315	3,315	n/a
Oil well HF completions	3,075	2,944	3,007	2,940	2,606	2,393	2,633	3,535	2,323	1,329	2,246	3,097	2,490	3,511	3,743	4,594	6,016	6,229	8,328	5,073	8,188	12,501	16,335	17,332	19,154	12,438	12,438	n/a

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Workover event counts																												
2018 GHGI																												
Gas well non-HF workovers	5,897	6,136	6,082	6,126	6,183	6,188	6,286	6,268	6,441	6,443	6,288	6,813	6,860	7,069	7,290	7,345	7,637	7,785	8,150	8,120	8,139	8,141	7,951	7,800	7,800	7,549	7,315	n/a
Gas well HF workovers	621	785	769	825	882	904	994	1,038	1,089	1,133	1,224	1,355	1,428	1,540	1,628	1,796	1,957	2,073	2,271	2,346	2,423	2,482	2,506	2,485	2,521	2,521	2,487	n/a
Oil well workovers	41,542	41,745	40,551	40,068	38,990	38,073	37,900	38,042	36,475	34,805	35,032	34,899	34,637	34,588	34,834	35,222	35,886	35,832	37,838	37,620	38,454	39,654	41,438	42,725	44,209	44,251	42,147	n/a

* Values not published in the GHGI, but underlie the current estimates of HF oil well completion event counts

N/A - Not applicable

NPA - Not publicly available