

Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016: Abandoned Oil and Gas Wells

In previous versions of this memo released in June and October 2017, and during stakeholder webinars and workshops held in April, June, and August 2017, and March 2018, EPA presented preliminary considerations and sought stakeholder feedback on incorporating an estimate for emissions from abandoned oil and gas wells in the 2018 Inventory of U.S. Greenhouse Gas Emissions and Sinks (GHGI). This version of the memo is updated to document the methodology implemented in the final 2018 GHGI which reflects stakeholder feedback. EPA continues to seek stakeholder feedback to improve estimates for this source (see pages 10–12).

1. Background

Recent studies have investigated methane leakage from abandoned wells in the U.S. The term "abandoned wells" as typically used in published scientific articles and this memo encompasses various types of wells:

- Wells with no recent production, and not plugged. Common terms (such as those used in state databases) might include: inactive, temporarily abandoned, shut-in, dormant, idle.
- Wells with no recent production and no responsible operator. Common terms might include: orphaned, deserted, long-term idle, abandoned.
- Wells that have been plugged to prevent migration of gas or fluids.

Emissions from abandoned oil and gas wells were not included in previous GHGIs. Commenters on previous GHGIs supported including this source, but noted that the current data were limited, and suggested reviewing data that will become available in the future. EPA identified studies with emissions and activity data on abandoned wells (Kang et al. 2014¹, Kang et al. 2016², Townsend-Small et al. 2016³, Brandt et al. 2014⁴) and developed an estimate for this source in the 2018 GHGI.

2. Available Emissions Data

EPA identified and reviewed available emissions data to characterize emissions from abandoned wells, including data from the Kang et al. and Townsend-Small et al. studies.

The Kang et al. 2014 study made direct measurements of methane flow rates from 19 wells in Pennsylvania during 2013 and 2014. The wells were not well-documented in state records, so researchers categorized each studied well as plugged or unplugged based on surface observations. The study did not find significantly different emission rates between the two categories. The Kang et al. 2016 study involved additional measurements to fill data gaps from the earlier study. Kang et al. 2016 measured 88 wells and developed emission factors (EFs) for categories observed to exhibit significantly different emissions levels in that data set: well type (gas versus oil or co-producing), plugging status (plugged versus unplugged), and coal area designation (as Pennsylvania requires wells in regions where mineable coal seams exist to be plugged and vented).

Table 1 showing these EFs (in units of grams per hour per well, g/h/well) is reproduced from the Kang et al. 2016 study, with minor edits for clarification in the context of this memo.

¹ <http://www.pnas.org/content/111/51/18173.full>

² <http://www.pnas.org/content/113/48/13636.full>, <http://www.pnas.org/content/114/29/E6025.full>

³ <http://onlinelibrary.wiley.com/doi/10.1002/2015GL067623/full>

⁴ <http://science.sciencemag.org/content/343/6172/733>

Table 1. Methane EFs from Kang et al. 2016 Study

Well production type and coal area designation	Number of Measured Wells		Mean (g/h/well)		Standard Error (g/h/well)	
	Unplugged	Plugged	Unplugged	Plugged	Unplugged	Plugged
All production types						
All	53	35	22	15	9.2	10
Coal	17	12	1.2	43	0.99	29
Noncoal	36	23	31	0.45	13	0.28
Oil and combined oil and gas production						
All	34	13	0.19	0.33	0.097	0.26
Coal	13	1	0.000011	0.000012	0.00091	n/a
Noncoal	21	12	0.31	0.36	0.15	0.28
Gas production						
All	19	22	60	24	24	16
Coal	4	11	5.2	47 ^a	3.9	32
Noncoal	15	11	75	0.54	29	0.51

a - The measured plugged wells in coal areas are vented as required by regulations.

The Townsend-Small et al. study measured emissions from 138 abandoned wells in the Powder River Basin in Wyoming, Denver-Julesburg Basin in Colorado, Uintah Basin in Utah, and Appalachian Basin in Ohio, during 2015. Townsend-Small et al. developed EFs for categories observed to exhibit significantly different emissions levels: plugged versus unplugged (including inactive, temporarily abandoned, shut in, dormant, orphaned, and abandoned), and eastern versus western U.S. regions. Table 2 showing these EFs is reproduced from the Townsend-Small et al. study.

Table 2. Methane EFs from Townsend-Small et al. Study

Well Category	Number of Measured Wells	Mean (g/h/well)	95% Upper Confidence Limit (g/h/well)
All wells (entire U.S.)	138	1.38	3.17
All wells (eastern U.S.)	12	14.00	32.87
All wells (western U.S.)	126	0.18	0.41
Plugged wells (entire U.S.)	119	0.002	0.005
Unplugged wells (entire U.S.)	19	10.02	22.47
Plugged (eastern U.S.)	6	0	NA
Unplugged (eastern U.S.)	6	28.01	64.00
Plugged (western U.S.)	113	0.002	0.005
Unplugged (western U.S.)	13	1.71	3.83

Bold indicates value used in the 2018 GHGI.

EPA considered several options for developing EFs and stratifying the EFs to reflect differences between populations that were observed in studies. EPA considered developing separate factors by plugging status, by region, and/or by production type; and whether and how to combine Townsend-Small et al. and Kang et al. data to develop these EFs. Table 3 shows EFs calculated by combining data from Kang et al. 2016 and Townsend-Small 2016 study measurements for the Appalachian basin. While Kang et al. 2014 did not find significant differences between plugged and unplugged well emissions, both Kang et al. 2016 and Townsend-Small et al. 2016 studies did. Limited emissions data are available to support potentially stratifying EFs based on producing formation or production type. Townsend-Small et al. measured wells in both the east (Appalachian Basin) and newer formations in the west, and observed significantly different emission rates; however, the data available do not include characterization of abandoned wells in other major producing regions such as Texas and California. Kang

et al. 2016 observed significantly different emission rates between gas and oil/coproducing wells, and between coal and non-coal areas; however, all such data were collected in Pennsylvania, so they might not represent national emissions.

Table 3. Appalachian Basin Methane EFs Developed from Combining Studies

Data Source	Number of Measured Wells	Mean (g/h/well)
Plugged wells		
Kang et al. 2016 – All production types, noncoal areas	23	0.45
Townsend-Small et al. 2016 – Eastern U.S.	6	0
Combined	29	0.36
Unplugged wells		
Kang et al. 2016 – All production types, noncoal areas	36	31
Townsend-Small et al. 2016 – Eastern U.S.	6	28.01
Combined	42	30.57

Bold indicates value used in the 2018 GHGI.

Based on analysis of various options (refer to the October 2017 memo) and stakeholder feedback, EPA calculated abandoned well emissions using the plugging status-specific EFs presented in Table 2 and Table 3 above. EPA applied "Appalachian" unplugged, combined and plugged, combined EFs (Table 3) to abandoned wells in Appalachian Basin region states (Ohio, Pennsylvania, West Virginia, New York, Kentucky, and Tennessee), and applied Townsend-Small "entire U.S." unplugged and plugged EFs to all other abandoned wells. Emission estimates are discussed further and presented in Section 4.

3. Available Activity Data

EPA identified and reviewed available activity data to pair with methane EFs described above. Activity data for this source are counts of abandoned wells in each year of the 1990-2016 time series; counts are subcategorized by attributes to parallel the EFs—i.e., plugging status (plugged vs. unplugged) and location (Appalachia vs. remainder of U.S.).

3.1 Total Abandoned Well Counts

Estimates in the literature for the total national population of abandoned onshore wells in the U.S. in recent years range from over 2.3 million (Townsend-Small et al. 2016) to approximately 3 million (Brandt et al. 2014).

EPA considered multiple approaches to develop the count of total abandoned wells in each year of the time series. For example: (1) Counting the total number of wells existing but no longer reporting production as of a given year; or (2) Counting wells drilled as of a given year, then subtracting the number of actively producing wells in that year (refer to the June 2017 memo for additional information on this approach).

For the 2018 GHGI, EPA used key fields in the DrillingInfo data set to count wells existing but no longer reporting production as of a given year, within the DrillingInfo data set. EPA's current methodology for counting abandoned wells in the DrillingInfo data set in each year is (note, DrillingInfo field names are shown in parentheses):

- Abandoned oil wells: last date of reported production (LAST_PROD_DATE) is before [year], cumulative hydrocarbon liquids production (LIQ_CUM) is greater than zero, and cumulative gas production (GAS_CUM) is either zero or results in gas-to-oil ratio of less than 100 mcf/bbl.
- Abandoned gas wells: last date of reported production (LAST_PROD_DATE) is before [year], cumulative gas production (GAS_CUM) is greater than zero, and cumulative hydrocarbon liquids production (LIQ_CUM) is either zero or results in gas-to-oil ratio of equal to or greater than 100 mcf/bbl.

- Abandoned dry wells: last date of reported production (LAST_PROD_DATE) is null; and spud date (SPUD_DATE) is before [year], or spud date is null and completion date (COMP_DATE) is before [year]; and status (STATUS) is not reported as injection.

To account for very old wells with installation and abandonment pre-dating DrillingInfo coverage, EPA developed an independent estimate of abandoned wells existing in 1975 through reviewing historical records. The DrillingInfo data set is likely relatively complete beginning ca. 1975, but sparsely populated before this timeframe. Where available (e.g., for Texas), EPA used data from state online databases containing historical drilling records by year and production type. EPA also compiled estimates such as those published in *The Derrick's Handbook of Petroleum*⁵ and the United States Geological Survey's (USGS) *Mineral Resources of the United States Annual Yearbooks*⁶. Based on historical records, EPA estimates approximately 2.56 million wells (characterized as oil, gas, or dry) had been drilled in the U.S. by 1973 (and could be assumed to be producing in 1975 if not shutdown/dry). In 1975, approximately 630,000 oil and gas wells were operating in the U.S., based on USGS estimates⁷. Therefore, EPA estimates 1.93 million abandoned wells existed in 1975 (2.56 million – 630,000 = 1.93 million). See Appendix A for additional details on how this estimate was developed. Based on querying the DrillingInfo data set's key date fields as described above, 776,000 wells in the DrillingInfo database could be considered abandoned as of 1975 (i.e., had stopped reporting production prior to 1975 or been installed prior to 1975 and never reported production). Comparing the counts (i.e. 1.93 million abandoned wells from analysis of historical records and USGS data, and 776,000 abandoned wells in the DrillingInfo database), EPA estimates that 1.15 million abandoned wells in the U.S. are not captured in the DrillingInfo-based methodology. EPA added this 1.15 million abandoned well count to the DrillingInfo-based total to develop a complete count of abandoned wells existing in each year of the time series, as shown in Section 4.

For the most recent year of the 2018 GHGI time series (year 2016), the DrillingInfo query approach would likely overestimate abandoned well counts, because many wells might be spud and not reporting production—not because they are dry/abandoned, but due to the time required for completion. Therefore, EPA used year 2015 abandoned well counts as a surrogate estimate for year 2016, and will implement a similar approach in future GHGIs (use the next-to-most-recent year as a surrogate for the most recent year).

After developing a total count of abandoned wells, EPA then separated the total abandoned well population into subcategories based on plugging status to assign appropriate EFs (as discussed in Section 2). Considerations toward plugging status assignment are discussed further in Section 3.2.

Lastly, EPA separated the abandoned well population into state groupings to assign region-specific EFs, as discussed in Section 2. Both the historical data sets and the DrillingInfo data set provide counts at a state level which are used to develop activity data for such an approach.

3.2 Plugging Status Assignment

EPA considered several data sources to generate the estimated split between plugged and unplugged abandoned well counts for each year.

⁵ *The Derrick's Handbook of Petroleum: A Complete Chronological and Statistical Review of Petroleum Developments From 1859 to 1898* (V.1), (1898-1899) (V.2)

⁶ <https://minerals.usgs.gov/minerals/pubs/usbmmyb.html>

⁷ <http://images.library.wisc.edu/EcoNatRes/EFacs2/MineralsYearBk/MinYB1975v1/reference/econatres.minyb1975v1.gkoelling.pdf> (Table 6) and <http://images.library.wisc.edu/EcoNatRes/EFacs2/MineralsYearBk/MinYB1975v1/reference/econatres.minyb1975v1.wharper.pdf> (Table 10)

Townsend-Small et al. offer limited observations that might be considered a “snapshot” of plugging status based on wells encountered for testing in year 2015 in the eastern and western U.S. As shown in Table 2 above, 50 percent of the 12 eastern wells tested were plugged; and 90 percent of the 126 western wells tested were plugged. The Kang et al. 2016 Pennsylvania study observed that of the 88 wells sampled, 40 percent were plugged. For both studies, due to the relatively small sample size compared to the national abandoned wells population and other factors of study design (e.g., certain wells could not be located based on records, and certain wells could not be physically accessed), other data sets or approaches might better represent the national population split between plugged and unplugged for purposes of developing GHGI estimates.

For the 2018 GHGI, EPA used status codes in the DrillingInfo database to split the population of abandoned wells into the plugged and unplugged categories. The DrillingInfo database contains the reported status for nearly 3.6 million wells. The status code is updated on an ongoing basis as reported to states (i.e., is not modified or standardized by DrillingInfo); the definition of a given status code might vary by state. As of early 2017, over 95 percent of well records in the DrillingInfo database report the status codes identified in the left-most column of Table 4. EPA identified status codes assumed to represent abandoned wells (e.g., inactive, P&A, abandoned, shut in, plugged), then assigned the count of wells reporting each such code as plugged or unplugged. The right-most column of Table 4 indicates assigned plugging status using an approach that considers wells with the status codes “P&A (plugged and abandoned)” and “PLUGGED” to be plugged. EPA continues to seek feedback on how to assign plugging status, particularly for codes with * in this column; as a default approach, EPA currently assigns "unplugged" status to these codes.

Table 4. DrillingInfo Status Codes Reported as of Early 2017

Status Code	Number of Wells (millions)	Percent of All Wells in DrillingInfo	Abandoned Well Assigned Plugging Status
INACTIVE	1.5	42%	Unplugged*
ACTIVE	0.9	27%	n/a
P&A (plugged and abandoned)	0.7	20%	Plugged
DRY	0.1	3%	Unplugged*
ACTIVE INJ (active injection)	0.07	2%	n/a
ABANDONED	0.03	1%	Unplugged*
EXPIRED PERMIT	0.03	1%	n/a
SHUT IN	0.02	1%	Unplugged*
PLUGGED	0.02	1%	Plugged
All other codes	0.1	1%	*

* EPA seeks stakeholder feedback on assigning as plugged or unplugged.

n/a – Status code does not indicate likely abandonment.

This approach allowed EPA to approximate the split representing the most recent time series year. Using the assigned plugging status values shown in the last column of Table 4, 69 percent of abandoned wells are considered unplugged, and 31 percent of abandoned wells plugged, in year 2016. Since this data set likely does not include the oldest wells in the U.S., this value might over-estimate the fraction of the well population that is currently plugged. Because this approach is based on the most recent available state data as compiled by DrillingInfo, it reflects impacts of state- or industry-led plugging efforts (e.g., orphaned well plugging programs⁸), assuming that plugging status is generally kept up to date in state databases.

⁸ Examples include California's Idle and Orphan Well Program; Louisiana's Oilfield Site Restoration Program; Michigan's Orphan Well Program; Ohio's Orphan Well Program; Pennsylvania's Abandoned and Orphan Well Plugging Program.

Regarding the status code “INACTIVE” in the DrillingInfo database, the vast majority of wells reporting this code are not included in the GHGI active well count data. Some wells with INACTIVE status might also report production within a given calendar year, and therefore be counted in the GHGI as active wells. However, the current methodology presented in this memo avoids double counting of wells between the abandoned wells and the active wells categories in the GHGI. The methodology discussed here for activity data relies on the DrillingInfo status field only for estimating the abandoned wells population split between plugged and unplugged. The approach discussed in this memo to develop national estimates of abandoned wells excludes any wells that report production within the given year. The current GHGI estimates emissions from wells that report production within a given year. Therefore, implementing the GHGI update as described in this memo does not result in double-counting of wells as both active and abandoned.

The National Petroleum Council (NPC) Paper #2-25⁹, released in 2011, describes the historical evolution of plugging approaches and effectiveness. Oil and gas drilling in the U.S. began in Pennsylvania in 1859, and 1893 in Texas. For decades, regulations regarding plugging did not exist. Over time, states began instituting guidance and regulations regarding plugging; but in the meantime, wells were being drilled with very limited documentation of locations, etc. Regulations grew more stringent in the 1950s, requiring cement for sealing the producing intervals and the top of the wellbore. Prior to the 1950s, thousands of wells were left unplugged or ineffectively plugged (e.g., using very little cement). In the 1970s, regulations developed further to focus on environmental protection. According to NPC, “modern regulatory standards in all U.S. jurisdictions require specific provisions for plugging and documenting oil and natural gas wells before they are abandoned. Most wells are still plugged with cement using methods and materials developed in the 1970s.”

To develop estimates for fraction of wells plugged in each year of the 1990-2016 time series, EPA developed an assumption that in 1950, all abandoned wells were effectively unplugged (based on the above information on historical practices), applied the percentage of wells plugged (31 percent) in 2016 developed from the DrillingInfo analysis, and applied linear interpolation for 1990-2015. While various programs and efforts have identified and plugged some abandoned wells, due to the estimated order of magnitude of these very old wells (approximately 2 million), most of this population might still be unplugged or ineffectively plugged. This assumption is generally supported by the DrillingInfo analysis discussed above (two-thirds of abandoned wells are unplugged as of 2016).

4. 2018 GHGI Estimates of Methane from Abandoned Wells

Table 5 shows estimates of total abandoned wells developed by querying the DrillingInfo data set and incorporating an assessment of historical data sources, as described in Section 3.1.

Table 6 shows estimates of abandoned well counts by production type. EPA allocated the total abandoned well counts shown in Table 5 to gas and oil production categories to support incorporation into the GHGI natural gas and petroleum systems source categories, respectively, using the following methodology:

- The abandoned wells not included in the DrillingInfo database (i.e., counted based on review of historical data sources) are reported by production type within the historical data source—as gas, oil, or dry. EPA assigned gas wells as gas wells, and oil wells as oil wells (as data are not consistently available to assign production type using the GOR-based method used for wells in the GHGI).
- For wells resulting from the DrillingInfo query surrounding date of last production, EPA applied the existing GHGI convention to analyze the cumulative reported production from each well—if the ratio of

⁹ https://www.npc.org/Prudent_Development-Topic_Papers/2-25_Well_Plugging_and_Abandonment_Paper.pdf

cumulative gas to oil production exceeded 100 mcf/bbl, EPA counted the well as gas; otherwise, it was counted as oil.

- For wells resulting from the DrillingInfo query to count wells reporting spud date but no production, EPA assigned these wells as “dry.”
- Lastly, for the total count of “dry” wells in a given year (from historical data sources and DrillingInfo), EPA allocated such wells to gas and oil categories based on the split already calculated for such year.

Table 7 shows estimates of abandoned well counts by production type and plugging status, using the approach described in Section 3.2 (assuming 100 percent unplugged in 1950, 69 percent unplugged in 2016, and interpolation to assign the split in intermediate years).

Table 8 shows estimated emissions from abandoned wells across the time series once region-specific activity allocation and EFs are applied; "Appalachian" EFs (Table 3) apply to abandoned wells in the Appalachian Basin region (within Ohio, Pennsylvania, West Virginia, New York, Kentucky, and Tennessee), while Townsend-Small "entire U.S." EFs apply to all other abandoned wells. Between 1990 and 2016, 28–30% of abandoned gas wells, and 23–26% of abandoned oil wells, are estimated to be located in Appalachia.

Table 5. Estimates of Total Abandoned Wells Over the GHGI Time Series (millions)

Year	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16
DrillingInfo (Raw)	1.22	1.25	1.28	1.31	1.34	1.37	1.40	1.42	1.45	1.48	1.52	1.54	1.57	1.59	1.61	1.63	1.65	1.68	1.70	1.73	1.76	1.79	1.82	1.85	1.90	1.96	1.96
Not included in DrillingInfo^a	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Total^b	2.37	2.40	2.43	2.46	2.49	2.52	2.55	2.57	2.60	2.63	2.67	2.69	2.72	2.74	2.76	2.78	2.80	2.83	2.85	2.88	2.91	2.94	2.97	3.00	3.05	3.11	3.11

a – Based on assessment of historical data sources including Derrick’s Handbook of Petroleum and the USGS Mineral Resources of the United States Annual Yearbooks, as described in Section 3.1.

b – Previous rows show rounded values; totals shown may not equal sum.

Table 6. Estimates of Total Abandoned Wells Over the GHGI Time Series, by Production Type (millions)

Year	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16
Total^a	2.37	2.40	2.43	2.46	2.49	2.52	2.55	2.57	2.60	2.63	2.67	2.69	2.72	2.74	2.76	2.78	2.80	2.83	2.85	2.88	2.91	2.94	2.97	3.00	3.05	3.11	3.11
Gas^b	0.32	0.32	0.33	0.34	0.34	0.35	0.35	0.36	0.36	0.37	0.37	0.38	0.39	0.39	0.40	0.40	0.41	0.42	0.43	0.44	0.45	0.47	0.48	0.50	0.52	0.55	0.55
Oil^b	2.05	2.07	2.10	2.12	2.15	2.17	2.19	2.22	2.24	2.26	2.30	2.31	2.33	2.35	2.36	2.38	2.39	2.41	2.42	2.44	2.46	2.47	2.49	2.51	2.52	2.56	2.56

a – Rounded values; totals shown may not equal sum of rows below.

b – Including allocated dry hole counts.

Table 7. Estimates of Plugged and Unplugged Abandoned Wells Over the GHGI Time Series, by Production Type

Year	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16
Total (millions)^a	2.37	2.40	2.43	2.46	2.49	2.52	2.55	2.57	2.60	2.63	2.67	2.69	2.72	2.74	2.76	2.78	2.80	2.83	2.85	2.88	2.91	2.94	2.97	3.00	3.05	3.11	3.11
Unplugged (%)	81%	81%	80%	80%	79%	79%	79%	78%	78%	77%	77%	76%	76%	75%	74%	74%	73%	73%	72%	72%	72%	71%	71%	70%	70%	69%	69%
Plugged (%)	19%	19%	20%	20%	21%	21%	21%	22%	22%	23%	23%	24%	24%	25%	25%	26%	26%	27%	27%	28%	28%	28%	29%	29%	30%	30%	31%
Gas^b (millions)	0.32	0.32	0.33	0.34	0.34	0.35	0.35	0.36	0.36	0.37	0.37	0.38	0.39	0.39	0.40	0.40	0.41	0.42	0.43	0.44	0.45	0.47	0.48	0.50	0.52	0.55	0.55
Unplugged	0.26	0.26	0.27	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.29	0.29	0.29	0.29	0.30	0.30	0.30	0.31	0.31	0.32	0.33	0.33	0.34	0.35	0.37	0.38	0.38
Plugged	0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.12	0.12	0.13	0.13	0.14	0.15	0.16	0.17	0.17
Oil^b (millions)	2.05	2.07	2.10	2.12	2.15	2.17	2.19	2.22	2.24	2.26	2.30	2.31	2.33	2.35	2.36	2.38	2.39	2.41	2.42	2.44	2.46	2.47	2.49	2.51	2.52	2.56	2.56
Unplugged	1.67	1.68	1.69	1.70	1.71	1.71	1.72	1.73	1.74	1.75	1.76	1.76	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.78	1.77
Plugged	0.38	0.40	0.41	0.43	0.44	0.46	0.47	0.49	0.50	0.52	0.54	0.55	0.57	0.58	0.60	0.61	0.63	0.64	0.66	0.67	0.69	0.70	0.72	0.74	0.75	0.78	0.79

a – Rounded values; totals shown may not equal sum of rows below.

b – Including allocated dry hole counts. Rounded values; totals shown may not equal sum of rows below.

Table 8. Estimates of Abandoned Well CH₄ Emissions over GHGI Time Series (MMT CO_{2e})

Year	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16
Total^a	6.50	6.54	6.58	6.62	6.65	6.68	6.71	6.73	6.76	6.79	6.84	6.85	6.86	6.87	6.87	6.88	6.88	6.89	6.90	6.92	6.94	6.95	6.97	7.01	7.06	7.156	7.11
Gas	0.90	0.91	0.92	0.93	0.95	0.96	0.97	0.97	0.98	0.99	1.01	1.01	1.02	1.03	1.04	1.05	1.07	1.08	1.10	1.12	1.16	1.18	1.21	1.25	1.30	1.37	1.36
Oil	5.60	5.63	5.66	5.68	5.71	5.73	5.74	5.76	5.78	5.80	5.84	5.84	5.84	5.83	5.83	5.83	5.82	5.81	5.80	5.79	5.78	5.77	5.77	5.76	5.76	5.79	5.75

a – Rounded values; totals shown may not equal sum of rows below.

5. 2018 GHGI Estimates of CO₂ from Abandoned Wells

CO₂ emission estimates for select time series years are published in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016* (April 2018). EPA developed abandoned well CO₂ EFs using the CH₄ EFs and an assumed ratio of CO₂-to-CH₄ gas content, similar to the approach used to calculate CO₂ emissions for many sources in Petroleum Systems and Natural Gas Systems. For abandoned oil wells, EPA used the Petroleum Systems default production segment associated gas ratio of 0.020 MT CO₂/MT CH₄, which was derived through API TankCalc modeling runs. For abandoned gas wells, EPA used the Natural Gas Systems default production segment CH₄ and CO₂ gas content values (GRI/EPA 1996¹⁰, GTI 2001¹¹) to develop a ratio of 0.044 MT CO₂/MT CH₄.

6. 2018 GHGI Uncertainty Estimate for Abandoned Wells

The development of the uncertainty range surrounding abandoned wells emissions estimates is documented in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016* (April 2018). To characterize uncertainty surrounding estimates of abandoned well emissions, EPA conducted a quantitative uncertainty analysis using the IPCC Approach 2 methodology (Monte Carlo simulation technique). EPA used Microsoft Excel's @RISK add-in tool to estimate the 95 percent confidence bound around total methane emissions from abandoned oil and gas wells, then applied the calculated bounds to both CH₄ and CO₂ emissions estimates for each population. The @RISK add-in provides for the specification of probability density functions (PDFs) for key variables within a computational structure that mirrors the calculation of the inventory estimate. EPA used measurement data from the Kang et al. (2016) and Townsend-Small et al. (2016) studies to characterize the CH₄ emission factor PDFs. For activity data inputs (e.g., total count of abandoned wells, split between plugged and unplugged), EPA assigned default uncertainty bounds of +/- 10% based on expert judgment.

The results presented below in Table 9 provide the 95 percent confidence bound within which actual emissions from abandoned oil and gas wells are likely to fall for the year 2016, using the recommended IPCC methodology.

Table 9. Quantitative Uncertainty Estimates for CH₄ and CO₂ Emissions from Abandoned Wells (MMT CO₂e and Percent)

Source	Gas	Year 2016 Emission Estimate (MMT CO ₂ e)	Uncertainty Range Relative to Emission Estimate			
			Lower Bound (MMT CO ₂ e)	Upper Bound (MMT CO ₂ e)	Lower Bound (%)	Upper Bound (%)
Abandoned oil wells	CH ₄	5.8	1.0	18.1	-83%	+215%
Abandoned gas wells	CH ₄	1.4	0.2	4.3	-83%	+215%
Abandoned oil wells	CO ₂	0.005	0.001	0.015	-83%	+215%
Abandoned gas wells	CO ₂	0.007	0.001	0.022	-83%	+215%

¹⁰ 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.

¹¹ GTI (2001) Gas Resource Database: Unconventional Natural Gas and Gas Composition Databases. Second Edition. GRI-01/0136.

7. Additional Considerations

7.1 Emission Factors

Recent studies summarized in this memorandum suggest additional considerations (listed below) regarding the representativeness of the data used to develop EFs. EPA will review additional data relevant to these research questions as data emerge.

- What is the impact of nearby production or storage on emissions from abandoned wells?
- Are average emissions rates from abandoned wells in unstudied major production areas in the U.S. (e.g., Texas) similar to those in studied areas?
- What further subcategorization (e.g., well plugging timeframe, well type) is appropriate for EF development?
- How do methane flow rates from abandoned wells vary over long periods of time?

Regarding the last consideration above, for purposes of developing an estimate in the GHGI, EPA currently assumes that abandoned wells leak over long periods of time at relatively steady rates, based on available data. In the Townsend-Small et al. data set, 6 out of 138 wells were found to have measurable emissions in 2015. Based on available records, three such wells were completed prior to the 1950s, and therefore likely became abandoned several years, or even decades, prior to the Townsend-Small et al. measurement campaign (the state does not have a record of the last reported production for these wells). This supports an assumption that even very old wells (that produced in the late 1800s and early 1900s) might continue to leak over long periods of time, if left unplugged or ineffectively plugged. Kang et al. 2016 conducted repeat measurements over a time span of two years and observed that flow rates of high emitters are sustained through that period of time.

7.2 Activity Data

Recent studies also suggest additional considerations (listed below) regarding the representativeness and completeness of activity data estimates that might be used in the GHGI. EPA will review additional relevant data as they emerge.

- What is the magnitude of undocumented abandoned wells?
- Should certain types of wells be included in the national count—for example, injection wells drilled for enhanced oil recovery, and dry wells?
- What data sources and methodology might be used to estimate national total activity for vented abandoned wells, such as the coal area wells measured in the Kang studies in Pennsylvania? Do other states have similar venting requirements as Pennsylvania?

8. Requests for Stakeholder Feedback

The EPA initially sought feedback on the questions below in the version of this memo released October 2017. The EPA discusses feedback received, and further planned improvements to the GHGI methodology, in Chapter 3.8 of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016* (April 2018). The EPA continues to welcome additional stakeholder feedback on these questions for potential updates to future GHGIs.

1. What additional data sources are available to estimate EFs for abandoned wells?
2. How might region-specific EFs be used to estimate national emissions?
3. What subcategories of abandoned wells should be represented in the GHGI (taking into account data availability and differences between emissions rates for subcategories). For example:

- plugging status
 - production type (e.g., oil, gas, dry, injection, other)
 - region (e.g., state or basin)
 - unplugged wells abandoned while shut-in versus while orphaned (i.e., no responsible owner on record, usually applying to very old wells)
 - other?
4. What additional data sources and methods are available to estimate the total population of wells abandoned prior to 1990 (considering that the production phase of many such wells likely pre-dates DrillingInfo coverage)?
 5. What additional data sources or methodologies might be appropriate to estimate the total population of abandoned wells existing in each year of the time series (1990–2016)?
 - Section 3.1 discusses an approach in which certain DrillingInfo date fields are analyzed to count abandoned wells as of a given year (in particular, the reported date of spud/completion and of last production). A count of wells not included in the DrillingInfo data set is currently developed from historical data sources (based on review of Derrick's Handbook of Petroleum, the USGS Mineral Resources of the United States Annual Yearbooks, and/or EIA historical drilling records). This value is added to the abandoned well counts developed from DrillingInfo. Activity data developed by this approach for various time series years are presented in Table 5. EPA seeks feedback on this approach.
 - What other data sources and/or methodologies might EPA consider?
 6. For the most recent year of the 2018 GHGI time series (year 2016), the DrillingInfo query approach described in Section 3.1 might overestimate abandoned well counts, because many wells might be spud and not reporting production—not because they are dry/abandoned, but due to the time required for completion. Therefore, EPA currently uses year 2015 abandoned well counts as a surrogate estimate for year 2016, and plans to apply a similar approach in future GHGIs (use the next-to-most-recent year as surrogate for most recent year). EPA seeks feedback on this approach or other approaches to consider.
 7. Are additional data sources or methodologies available to estimate the split between plugged and unplugged wells existing in each year of the time series (1990–2016)?
 - Section 3.2 discusses available data in the DrillingInfo database to characterize wells in recent year(s), an NPC 2011 paper to characterize wells in early years, and an interpolation approach that might be used. EPA seeks feedback on this approach, including on how might the DrillingInfo "Status" field be interpreted to indicate plugging status, considering the list of most commonly reported status codes described in Table 4. EPA currently implements an approach that identifies status codes that represent abandoned wells (e.g., inactive, P&A, abandoned, shut in, plugged), then assigns the count of wells reporting each such code as plugged or unplugged. The right-most column of Table 4 indicates assigned plugging status that considers wells with the status codes "P&A (plugged and abandoned)" and "PLUGGED" to be plugged. EPA seeks feedback on how to potentially improve accuracy in assigned plugging status, particularly for codes with * in this column.
 - What other data sources and/or methodology might EPA consider?
 8. Based on the discussion of historical plugging effectiveness in Section 3.2, what year (e.g., 1950) might be appropriate to assume that zero percent of existing abandoned wells were effectively plugged (such an estimate would serve as a tie point for use in interpolation to develop plugged versus unplugged activity fractions)?
 9. What data are available to answer the research questions posed in Section 7, regarding additional considerations for calculating emission estimates for this source?

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10. Are there any additional ongoing or planned studies related to abandoned wells that may be incorporated to refine future GHGs?
11. Are data sources and methods available to estimate EFs and activity data for related derelict infrastructure (e.g., flow lines)?

Appendix A.
Development of independent estimate of abandoned wells existing in 1975 through reviewing historical records

Table A-1 shows estimates compiled from historical data sources of wells drilled in each state, by production type (including dry), from 1871 to 1973. Where available (e.g., for Texas), EPA used data from state online databases containing historical drilling records by year and production type. For most counts, EPA relied on estimates published in United States Geological Survey's (USGS) Mineral Resources of the United States Annual Yearbooks. Note that these state-level estimates were compiled for the purpose of developing a national-level total. In several instances, historical data sources presented counts for a combined set of states, and the table below attributes counts to one of the multiple states represented; therefore, the state-level totals shown below might be inaccurate for certain states, although the national totals would not be impacted. The righthand column of Table A-1 generally notes where this occurred.

Table A-2 shows estimates from USGS of wells producing in each state, by production type, as of 1975.

To develop an estimate of abandoned wells existing in 1975, EPA subtracted the total producing oil and gas wells as of 1975 from the total drilled by 1973 (wells drilled by 1973 were assumed to be producing by 1975, if not shutdown).

2,556,411 (wells drilled, see Table A-1) – 630,697 (wells producing, see Table A-2) = 1,925,714 abandoned wells in 1975.

Table A-1. Wells Drilled by State and Production Type (1871-1973)

State	Gas	Oil	Dry	Citation	Notes
AK	56	66	559	State data ^a	
AL	33	512	121	State data ^b	
AR	1,527	14,120	9,016	USGS ^c	State data ^d were also reviewed; USGS appeared to be more complete.
CA	2,388	77,518	19,975	USGS ^c	
CO	1,943	5,240	12,764	USGS ^c	Includes some UT, WY wells (states reported together in USGS for certain years)
FL	0	214	445	State data ^e	EPA analysis attributed O&G wells to oil.
IL	1,263	66,910	39,721	USGS ^c	
IN	9,668	26,662	19,895	USGS ^c	Derrick's Handbook ^f data were also reviewed; USGS appeared to be more complete.
KS	17,485	95,786	65,115	USGS ^c	
KY	8,351	42,594	29,168	USGS ^c	
LA	14,684	63,249	45,887	USGS ^c	
MI	2,263	11,082	13,942	USGS ^c	
MS	434	5,807	9,166	USGS ^c	
ND	1	1,250	1,686	USGS ^c	
NE	133	3,648	8,131	USGS ^c	
MT	1,839	8,355	9,004	USGS ^c	
NM	9,032	21,943	8,949	USGS ^c	
NY	2,458	4,434	1,079	USGS ^c	Partial totals, some counts included in PA total (states reported together in USGS for certain years). Derrick's Handbook ^f data were also reviewed.
OH	24,515	101,447	32,974	USGS ^c	Partial totals, some counts included in PA total (states reported together in USGS for certain years). Derrick's Handbook ^f data were also reviewed.
OK	22,535	195,237	87,437	USGS ^c	State data ^g were also reviewed; USGS seemed more complete.
PA	46,289	272,674	49,394	USGS ^c	Includes some OH, NY, WV wells (states reported together in USGS for certain years). State data ^h and Derrick's Handbook ^f data were also reviewed.
SD	0	41	344	USGS ^c	
TN	121	380	855	USGS ^c	
TX	79,716	447,527	277,630	State data ⁱ , USGS ^c	State data ⁱ where available, otherwise USGS.
UT	5	2	17	USGS ^c	Partial totals, some wells included with WY and CO.
VA	321	34	135	State data ^j	
WV	28,951	26,094	11,727	USGS ^c	Partial totals, some counts included in PA total (states reported together in USGS for certain years).
WY	1,675	17,333	13,430	USGS ^c	Partial totals, some counts included in CO total (states reported together in USGS for certain years).
Subtotal	277,686	1,510,159	768,566		
Total	2,556,411				

a. Alaska Oil and Gas Conservation Commission, <http://doa.alaska.gov/ogc/publicdb.html>

b. Geological Survey of Alabama, Oil & Gas Board, <https://www.gsa.state.al.us/ogb/>

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- c. United States Geological Survey's (USGS) Mineral Resources of the United States Annual Yearbooks, <https://minerals.usgs.gov/minerals/pubs/usbmmyb.html>
- d. Arkansas Geological & Conservation Commission, "List of Oil & Gas Wells - Data From November 1, 1936 to January 1, 1955.", http://www.geology.ar.gov/pdf/IC-10%20SUPPLEMENT_v.pdf
- e. Florida Department of Environmental Protection - Oil and Gas Program, http://www.dep.state.fl.us/water/mines/oil_gas/index.htm
- f. The Derrick's Handbook of Petroleum: A Complete Chronological and Statistical Review of Petroleum Developments From 1859 to 1898 (V.1), (1898-1899) (V.2)
- g. "Oklahoma Oil: Past, Present, and Future." Oklahoma Geology Notes, Oklahoma Geological Survey v. 62 no. 3, 2002 pp .97-106
- h. Pennsylvania Department of Environmental Protection, Oil and Gas Reports - Oil and Gas Operator Well Inventory. http://www.portal.state.pa.us/portal/server.pt/community/oil_and_gas_reports/20297
- i. Texas Railroad Commission, Oil and Gas Division, "History of Texas Initial Crude Oil, Annual Production and Producing Wells, Crude Oil Production and Well Counts (since 1935)." <http://www.rrc.state.tx.us/oil-gas/research-and-statistics/production-data/historical-production-data/crude-oil-production-and-well-counts-since-1935/>
- j. Virginia Department of Mines Minerals and Energy, "Wells Drilled for Oil and Gas in Virginia prior to 1962.", Virginia Division of Mineral Resources, https://www.dmme.virginia.gov/commercedocs/MRR_4.pdf.

Table A-2. Producing Wells by State and Production Type in 1975 from USGS Data¹²

State	Gas	Oil
AK	61	205
AL	9	608
AR	1,128	7,308
AZ	1	28
CA	1,585	41,029
CO	1,662	2,450
FL	0	143
IL	41	23,373
IN	478	4,798
KS	8,865	41,945
KY	7,386	13,905
LA	9,182	27,734
MD	15	0
MI	209	3,655
MO	3	163
MS	248	2,237
MT	1,235	3,247
ND	18	1,994
NE	19	1,190
NM	10,352	13,715
NV	0	6
NY	900	4,975
OH	10,382	16,611
OK	9,769	71,576
PA	17,500	32,095
SD	20	38
TN	5	172
TX	26,184	160,603
UT	271	1,323
VA	186	7
WV	21,700	13,750
WY	950	9,450
Subtotal	130,364	500,333
Total	630,697	

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<http://images.library.wisc.edu/EcoNatRes/EFacs2/MineralsYearBk/MinYB1975v1/reference/econatres.minyb1975v1.gkoelling.pdf> (Gas wells, Table 6); and
<http://images.library.wisc.edu/EcoNatRes/EFacs2/MineralsYearBk/MinYB1975v1/reference/econatres.minyb1975v1.wharper.pdf> (Oil wells, Table 10)