# Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019: Updates for Produced Water Emissions

This memorandum discusses the updates implemented in EPA's 2021 *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI) for produced water emissions within the natural gas and petroleum systems production sectors. Additional considerations for produced water were previously discussed in a memorandum released in September 2020 (*Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019: Updates Under Consideration for Produced Water Emissions*).[1]

## 1 Background and 2020 (Previous) GHGI Methodology

EPA's definition of produced water is: "the water (brine) brought up from the hydrocarbon-bearing strata during the extraction of oil and gas, and can include formation water, injection water, and any chemicals added downhole or during the oil/water separation process".[2] Produced water is the largest wastewater source by volume generated during oil and gas extraction. The ratio of produced water to recovered hydrocarbon is extremely variable across the U.S. ranging from less than 1:1 to more than 100:1.[3] Produced water is also referred to as "production salt water" – the specific salinity of produced water is quite variable and is dependent upon the formation's geochemistry. The Bakken and Marcellus shale formations can have produced waters that have 10 times the salinity of seawater, while other areas may have produced water that is considerably less saline than seawater.[4,5]

In the 2020 (previous) GHGI, the emission calculation methodology for emissions from produced water in the Natural Gas Systems sector was limited to two individual coal bed methane (CBM) formations: Powder River Basin (in Wyoming) and Black Warrior Basin (in Alabama). The 2020 (previous) GHGI emission calculation methodology used relevant activity data multiplied by emission factors.

### 1.1 Activity Data

For the Powder River Basin, EPA obtained produced water production data from the Wyoming Oil and Gas Conservation Commission (WOGCC) in units of barrels per month.[6]

For the Black Warrior Basin, EPA obtained monthly producing well counts (beginning in April 1996) from the Alabama Oil and Gas Board (AOGB).[7] From the monthly data, EPA calculated annual average well counts beginning in 1996. EPA obtained annual well counts for the Black Warrior Basin for 1990 and 1994 from a Gas Research Institute (GRI) technical document.[8] EPA then developed annual well count estimates for 1991, 1992, 1993, and 1995 by scaling the 1994 annual well count with coalbed methane production. EPA used 2013 data as proxy data for all subsequent years (i.e., 2014 through 2018).

Table 1 presents the applicable activity data for the Powder River Basin and the Black Warrior Basin, for select years from the 2020 (previous) GHGI methodology.

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[1] Stakeholder materials including draft and final memoranda for the current 1990-2019 Inventory and previous Inventories are available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems.
[2] 40 CFR §435.11(bb).
[3] *Summary of Input on Oil and Gas Extraction Wastewater Management Practices Under the Clean Water Act*. Final Report. EPA-821-S19-001. U.S. Environmental Protection Agency, Engineering and Analysis Division, Office of Water. Washington, D.C. May 2020.
[4] "What is produced water?" American Geosciences Institute. Internet address: https://www.americangeosciences.org/critical-issues/faq/what-produced-water
[5] *Natural Produced Waters Geochemical Database.* U.S. Geological Survey (USGS). Internet address: https://eerscmap.usgs.gov/pwapp/
[6] Wyoming Oil and Gas Conservation Commission (WOGCC). Internet address: http://pipeline.wyo.gov/coalbedchart.cfm
[7] Alabama Oil and Gas Board (AOGB). Internet address: https://www.ogb.state.al.us/
[8] *A Guide to Coalbed Methane Reservoir Engineering*. GRI-94/0397. Gas Research Institute. 1996

**Table 1. 2020 (Previous) GHGI Produced Water Activity Data**

| Basin | 1990 | 2005 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|
| Powder River ($10^6$ gallons produced water) | 25 | 23,422 | 12,670 | 12,670 | 12,670 | 12,670 | 12,670 |
| Black Warrior (wells) | 1,300 | 4,246 | 5,480 | 5,480 | 5,480 | 5,480 | 5,480 |

## 1.2 Emission Factors

For the Powder River Basin, the 2020 (previous) GHGI applied a base emission factor (EF) of 2.0522 x $10^{-9}$ Gg $CH_4$/gallon of water drainage. For the Black Warrior Basin, the 2020 (previous) GHGI applied a base EF of 2.0694 x $10^{-3}$ Gg $CH_4$/well. These values were developed using an assumed methane concentration in water of 542.9 mg/l (or 0.19 lbs/bbl) at 700 foot well depth. Additional details on these EFs are unavailable. The EFs were then adjusted by the year-specific methane contents for the Rocky Mountain and Gulf Coast regions, respectively.

Table 2 shows the EFs for the Powder River Basin and the Black Warrior Basin, for select years.

**Table 2. 2020 (Previous) GHGI Produced Water Emission Factors**

| Basin | 1990 | 2005 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|
| Powder River (Gg $CH_4$/ gallon water) | 1.744 x $10^{-9}$ | 2.135 x $10^{-9}$ | 2.313 x $10^{-9}$ | 2.328 x $10^{-9}$ | 2.373 x $10^{-9}$ | 2.373 x $10^{-9}$ | 2.373 x $10^{-9}$ |
| Black Warrior (Gg/well) | 2.096 x $10^{-3}$ | 2.327 x $10^{-3}$ | 2.334 x $10^{-3}$ | 2.334 x $10^{-3}$ | 2.335 x $10^{-3}$ | 2.335 x $10^{-3}$ | 2.335 x $10^{-3}$ |

## 1.3 Emissions

Combining the produced water activity data (presented in Section 1.1) with the produced water emission factors (presented in Section 1.2) resulted in the emissions for the Powder River Basin and the Black Warrior Basin, for select years as shown in Table 3.

**Table 3. Produced Water $CH_4$ Emissions (metric tons)**

| Basin | 1990 | 2005 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|
| Powder River | 43 | 50,005 | 47,638 | 47,957 | 48,877 | 48,877 | 48,877 |
| Black Warrior | 2,724 | 9,879 | 12,790 | 12,788 | 12,796 | 12,796 | 12,796 |
| **Total** | **2,768** | **59,884** | **60,428** | **60,745** | **61,674** | **61,674** | **61,674** |

# 2 Analysis of Available Data

The details of available data for the update (i.e., both activity data and emission factors) are described below.

## 2.1 Activity Data

EPA reviewed the 2017 Nonpoint Oil and Gas Emission Estimation Tool (2017 Oil and Gas Tool)[9] to assess produced water activity data. For the 2017 Oil and Gas Tool, EPA developed source category emission

[9] *2017 Nonpoint Oil and Gas Emission Estimation Tool, Version 1.2*. Prepared for U.S. Environmental Protection Agency by Eastern Research Group, Inc. (ERG), Morrisville, North Carolina. October 2019.

estimation methodologies for 19 individual source categories; one of these source categories is produced water tanks. The activity parameter used for the produced water tanks source category was produced water production at oil wells and produced water production at gas and CBM wells; produced water production quantities are in units of barrels per year (bbl/year).

The primary data source in the 2017 Oil and Gas Tool for produced water production quantities is Enverus data, but additional data sources are used for some states. The 2017 Oil and Gas Tool used the following sources of produced water activity data:

- Enverus – 27 states (i.e., Alabama, Alaska, Arizona, Arkansas, California, Colorado, Florida, Kentucky, Louisiana, Michigan, Mississippi, Missouri, Montana, Nebraska, Nevada, New Mexico, New York, North Dakota, Ohio, Oklahoma, Oregon, South Dakota, Tennessee, Texas, Utah, Virginia, and Wyoming)
- State oil and gas commissions – 3 states (i.e., Idaho, Indiana, and Pennsylvania)
- State environmental agencies – 1 state (i.e., Kansas)
- Multiple sources – 3 states (i.e., Illinois [state oil and gas commission and EIA], Maryland [Enverus DrillingInfo and Energy Information Administration], and West Virginia [Enverus DrillingInfo and state environmental agency])

In general, the sources of produced water roughly parallel the sources of well counts used in the annual GHGI.

Table 4 presents the "Current Values" (i.e., year 2017 volumes) for produced water and the "Previous Values" (i.e., year 2014 volumes) for produced water, as shown in the Production Module of the 2017 Oil and Gas Tool[10]:

**Table 4. 2017 NEI Production Water Volumes (bbl)**

| Well Type | Previous Value (Year 2014) | Current Value (Year 2017) |
|---|---|---|
| CBM Wells | 512,318,013 | 378,446,711 |
| Gas Wells | 973,980,331 | 1,113,855,869 |
| Oil Wells | 15,545,896,708 | 15,858,915,589 |

Compared to the "Previous Values" (i.e., year 2014 volumes) for produced water from the 2017 Oil and Gas Tool Production Module, the year 2017 total produced water quantities increased by 1.9% (i.e., CBM decreased by 26.2%, gas increased by 14.4%, and oil increased by 2.0%).

For the update, EPA assessed Enverus data and the other datasets to estimate produced water volumes over the GHGI time series. EPA also combined data for gas wells and CBM wells to develop a single produced water volume applicable to all gas wells.

## 2.2 Emission Factors

There are a number of documents that address produced water emissions; however, the EFs used in all of these documents all ultimately trace back to a 1996 Gas Research Institute (GRI)/EPA study.[11] Table 5 is an extract of Table 5.5 from that document which presents methane emissions from production salt water (i.e., produced water) tanks. The emission estimates were estimated using an ASPEN PLUS process simulation, rather than actual measurements. Three key assumptions used in this simulation are as follows:

[10] See Footnote 8.

[11] *Methane Emissions from the Natural Gas Industry, Volume 6: Vented and Combustion Source Summary, Final Report*. GRI-94/0257.23 and EPA-600/R-96-080f. Gas Research Institute and U.S. Environmental Protection Agency. June 1996.

- The natural gas industry produces 497 million barrels of salt water annually, including approximately 100 million barrels from coal bed methane wells.[12]
- 70 percent of the water from gas wells is reinjected with the remaining 30 percent stored in atmospheric tanks.[13]
- Hydrocarbon composition is 100 percent methane.

**Table 5. Salt Water Tank Emissions from 1996 GRI/EPA Study**

| Salt Content (Wt %) | Pressure (psi) | Methane Emissions ($10^6$ lb/yr) |
|---|---|---|
| 20 | 50 | 1.6 |
| | 250 | 10.8 |
| | 1000 | 38.8 |
| 10 | 250 | 16.4 |
| | 1000 | 58.7 |
| 2 | 250 | 19.4 |
| | 1000 | 69.5 |

More recently, the 1996 GRI/EPA study produced water EFs shown in Table 5 were incorporated into the API *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry*.[14] Within the API *Compendium* (Table 5-10), the presentation of EFs were rearranged and the units were converted from units of million pounds per year to units of metric tons per thousand barrels, based upon the annual U.S. total of 497 million barrels of produced water cited in the 1996 GRI/EPA study. In addition, average EFs were calculated for each pressure (i.e., 50, 250, and 1,000 psi). Table 6 reproduces the EFs from the API *Compendium* (Table 5-10). This identical table is also included in a guidance document developed by The Climate Registry.[15]

**Table 6. Produced Salt Water Tank Methane Flashing Emission Factors from API *Compendium***

| Separator Pressure (psi) | Produced Water Salt Content (%) | EF (GRI/EPA initial units – $10^6$ lb $CH_4$/year) | Converted EF (metric tons/ 1000 bbl produced water)[a] |
|---|---|---|---|
| 50 | 20 | 1.6 | 0.0015 |
| 250 | 20 | 10.8 | 0.00986 |
| | 10 | 16.4 | 0.0150 |
| | 2 | 19.4 | 0.0177 |
| | Average[b] | – | 0.0142 |
| 1000 | 20 | 38.8 | 0.0354 |
| | 10 | 58.7 | 0.0536 |
| | 2 | 69.5 | 0.0634 |
| | Average[b] | | 0.0508 |

[a] Converted EFs calculated based on 497 million barrels of produced water generated annually.
[b] Average EFs calculated based on a simple average of EFs for 2, 10, and 20 percent produced water salt content.

[12] *Atlas of Gas Related Produced Water for 1990*. 95/0016. Produced by Energy Environmental Research Center, University of North Dakota, and ENSR Consulting and Engineering for Gas Research Institute. May 1995.
[13] See Footnote 12.
[14] *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry*. Produced by URS Corporation for American Petroleum Institute. August 2009
[15] *Oil & Gas Production Protocol, Annex II to the General Reporting Protocol*, Version 1.0. The Climate Registry. February 2010.

An early oil and gas emission inventory that included produced water emissions was the 2011 CenSARA Oil and Gas Emission Inventory.[16] The 2011 CenSARA inventory cited the produced water emission factors included in The Climate Registry document.

The Production Module of the 2017 Oil and Gas Tool[17] cited the average produced water EFs used in the 2011 CenSARA Oil and Gas Emission Inventory. The average EFs were converted to units of pounds $CH_4$/barrel produced water and assigned to specific well types. Table 7 summarizes the produced water EFs used in the 2017 Oil and Gas Tool. The 2017 Oil and Gas Tool applies the "low pressure oil wells" EF to oil wells that require an artificial lift to increase production. Most counties in the 2017 Oil and Gas Tool used a default average of 73 percent of oil wells using an artificial lift; this average is based on CenSARA data.

**Table 7. Produced Water Emission Factors, by Well Type, from 2017 Oil and Gas Tool**

| Well Type | Separator Pressure (psi) | Average $CH_4$ EF (lb/bbl) |
|---|---|---|
| Low Pressure Oil Wells | 50 | 0.0033 |
| Regular Pressure Oil Wells | 250 | 0.0313 |
| Gas and CBM Wells | 1000 | 0.112 |

Finally, various recent technical analyses of the U.S. oil and gas supply chain[18,19,20] cite the produced water EFs described above.

For the update, EPA applied the average EFs presented in Table 7. To estimate gas well produced water emissions, EPA applied the "gas and CBM wells" EF of 0.112 lb/bbl. For comparison, the previous GHGI EF (applied only to certain CBM formations) is 0.22 lb/bbl. To estimate oil well produced water emissions, EPA applied the "regular pressure oil wells" EF of 0.0.0313 lb/bbl and the "low pressure oil wells" EF of 0.0033 lb/bbl, based on the estimated population of wells that require an artificial lift. Data on the population of oil wells at various well pressures are unavailable.

# 3 Time Series Considerations

In general, produced water data for the entire time series are obtainable from the same datasets cited in the 2017 Oil and Gas Tool Production Module. In particular, Enverus data are available over the time series. However, those states that rely on non-Enverus data may not have produced water volumes readily available each year. For missing data in the middle of the time series, linear interpolation was used for gap filling.

# 4 National Emissions Estimates

Based on the data sources and considerations discussed in Sections 2 and 3, this section summarizes the approach EPA implemented in the 2021 GHGI. EPA used the following equation and applied the produced water volumes in Table 4, the EFs in Table 7, and a default average of 73 percent of oil wells use artificial lifts (see Section 2.2). Table 8 summarizes the resulting 2018 emissions estimates. Appendix A provides the

[16] *2011 Oil and Gas Emission Inventory Enhancement Project for CenSARA States*. Produced by ENVIRON International Corporation and Eastern Research Group, Inc. (ERG) for Central States Air Resources Agencies (CenSARA). December 2012.
[17] *Instructions for Using the 2017 EPA Nonpoint Oil and Gas Emissions Estimation Tool, Production Module*. Produced by Eastern Research Group, Inc. (ERG) for U.S. Environmental Protection Agency. October 2019.
[18] D. Zavala-Araiza et al., "Super-emitters in natural gas infrastructure are caused by abnormal process conditions". *Nature Communications*. January 16, 2017.
[19] R.A. Alvarez et al., Supplementary Materials for "Assessment of methane emissions from the U.S. oil and gas supply chain". *Science*. June 21, 2018.
[20] J. Littlefield et al., *Life Cycle Analysis of Natural Gas Extraction and Power Generation*. DOE/NETL-2019/2039. National Energy Technology Laboratory. April 19, 2019.

complete time series of emissions for the 2021 GHGI update compared to the previous 2020 GHGI (Table A-1 for natural gas and Table A-2 for petroleum).

$$Emissions_w = PW_w \times EF_w \times \left(\frac{453.6\ g}{1\ lb}\right) \times \left(\frac{1\ metric\ ton}{10^6 g}\right)$$

Where:

| | | |
|---|---|---|
| $Emissions_w$ | = | Annual produced water emissions from well type *w* (mt); |
| $PW_w$ | = | Annual produced water quantities from well type *w* (bbl); and |
| $EF_w$ | = | Emission factor for produced waste emissions from well type *w* (lb/bbl). |

**Table 8. Comparison of Year 2018 Produced Water National $CH_4$ Emissions Estimates (metric tons)**

| Well Type | Produced Water Volume (bbl) | EF (lb/bbl) | Year 2018 Emissions (mt) |
|---|---|---|---|
| **2021 GHGI** | | | |
| Oil Wells – Low Pressure | 12,271,147,893 | 0.0033 | 18,368 |
| Oil Wells – Regular Pressure | 4,538,643,741 | 0.0313 | 64,438 |
| Gas Wells | 3,712,404,487 | 0.112 | 188,601 |
| **Total** | | | **271,407** |
| **2020 GHGI** | | | |
| Powder River | 490,393,575 | 0.22 | 48,877 |
| Black Warrior | 131,591,163 | 0.21 | 12,796 |
| **Total** | | | **61,674** |

The EFs presented in Section 2.2, including the Table 7 EFs implemented in the 2021 GHGI update, are documented with an assumption from the 1996 GRI/EPA study that 30 percent of generated produced water is stored in tanks while 70 percent is reinjected (see the assumptions underlying the emissions data at the beginning of Section 2.2). See discussion of stakeholder feedback below.

# 5 Requests for Stakeholder Feedback

EPA sought stakeholder feedback on the update under consideration through two 2020 workshops, in the September 2020 memo, and in the public review draft of the GHGI. EPA received feedback on this update through its September 2020 memo and through the public review draft of the Inventory. Feedback is summarized here.

A stakeholder supported using the same emission factors for produced water from natural gas wells and CBM wells, which was implemented by EPA. A stakeholder indicated the typical practice is to route produced water to a tank battery once it reaches the surface and has been separated from the oil and gas. A stakeholder also requested that data from the latest 2017 Ground Water Protection Council produced water management practices survey be used to determine the percent of produced water that is stored in tanks. The stakeholder indicated that approximately 16 percent of produced water has the potential of being stored in a tank battery that could potentially flash (based on the 2012 Ground Water Protection Council produced water management practices survey). After further assessment of the 2012 and 2017 water management practice surveys, EPA has maintained the approach in the proposed approach which incorporated an assumption that all produced water goes through tanks and emissions are flashed at that time.

A stakeholder commented that current regulations under 40 CFR 60 subpart OOOOa require that certain storage vessels route emission vapors to a recovery device, flare, or other control device. Currently data are unavailable to assess the use of controls on produced water tanks but EPA will continue to assess this issue in future inventories should additional data become available.

The questions below were not updated for this memorandum and are copied from the September 2020 memo.

**Questions to Stakeholders**

EPA seeks stakeholder feedback on the approach under consideration and the questions below.

1. EPA seeks feedback on the fraction of oil wells that are low pressure, including whether it is reasonable to apply an average of 73 percent of oil wells using artificial lifts.
2. EPA seeks feedback on the percent of produced water that releases emissions (e.g., through tank flashing or evaporation in a pond), including whether the assumption that 30 percent of produced water undergoes tank flashing is reasonable.
3. EPA seeks feedback on updating the current GHGI EF for gas wells, currently applied to only certain CBM formations, to instead use the updated EF for all gas well produced water.

# Appendix A: Produced Water Emission Estimates from Previous 2020 GHGI and 2021 GHGI

**Table A-1. Data for 2018 from Previous 2020 GHGI and 2021 GHGI Emissions – Natural Gas**

| Year | 2018 Emissions from 2020 GHGI (metric tons $CH_4$) | 2018 Emissions from 2021 GHGI (metric tons $CH_4$) |
|---|---|---|
| 1990 | 2,768 | 82,250 |
| 1991 | 3,722 | 87,876 |
| 1992 | 5,315 | 86,223 |
| 1993 | 6,195 | 85,646 |
| 1994 | 6,862 | 84,757 |
| 1995 | 7,729 | 83,456 |
| 1996 | 8,093 | 84,213 |
| 1997 | 10,156 | 87,333 |
| 1998 | 12,569 | 88,561 |
| 1999 | 19,300 | 92,330 |
| 2000 | 38,203 | 105,319 |
| 2001 | 51,504 | 120,606 |
| 2002 | 58,810 | 118,648 |
| 2003 | 58,970 | 125,401 |
| 2004 | 57,318 | 130,881 |
| 2005 | 59,884 | 139,453 |
| 2006 | 71,581 | 154,006 |
| 2007 | 73,169 | 162,558 |
| 2008 | 76,391 | 181,897 |
| 2009 | 66,048 | 187,284 |
| 2010 | 62,846 | 175,800 |
| 2011 | 59,822 | 174,296 |
| 2012 | 59,782 | 177,342 |
| 2013 | 60,047 | 178,105 |
| 2014 | 60,428 | 182,320 |
| 2015 | 60,745 | 171,523 |
| 2016 | 61,674 | 154,394 |
| 2017 | 61,674 | 157,488 |
| 2018 | 61,674 | 188,601 |
| 2019 | Not Estimated | 187,070 |

**Table A-2. Data for 2018 from Previous 2020 GHGI and 2021 GHGI Emissions – Petroleum**

| Year | 2018 Emissions from 2020 GHGI (metric tons $CH_4$) | 2018 Emissions from 2021 GHGI (metric tons $CH_4$) |
|---|---|---|
| 1990 | Not Estimated | 91,478 |
| 1991 | Not Estimated | 90,124 |
| 1992 | Not Estimated | 85,099 |
| 1993 | Not Estimated | 80,122 |
| 1994 | Not Estimated | 75,304 |
| 1995 | Not Estimated | 72,411 |
| 1996 | Not Estimated | 70,511 |
| 1997 | Not Estimated | 69,072 |
| 1998 | Not Estimated | 65,394 |
| 1999 | Not Estimated | 61,025 |
| 2000 | Not Estimated | 62,654 |
| 2001 | Not Estimated | 61,164 |
| 2002 | Not Estimated | 60,272 |
| 2003 | Not Estimated | 69,555 |
| 2004 | Not Estimated | 61,329 |
| 2005 | Not Estimated | 62,184 |
| 2006 | Not Estimated | 62,520 |
| 2007 | Not Estimated | 64,906 |
| 2008 | Not Estimated | 67,491 |
| 2009 | Not Estimated | 67,131 |
| 2010 | Not Estimated | 68,353 |
| 2011 | Not Estimated | 71,110 |
| 2012 | Not Estimated | 75,456 |
| 2013 | Not Estimated | 79,261 |
| 2014 | Not Estimated | 83,701 |
| 2015 | Not Estimated | 82,392 |
| 2016 | Not Estimated | 77,278 |
| 2017 | Not Estimated | 78,739 |
| 2018 | Not Estimated | 82,806 |
| 2019 | Not Estimated | 84,726 |