Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019: Update Under Consideration for Mud Degassing Emissions

This memo discusses an update under consideration for the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI) to include emission estimates for mud degassing.

1 Current GHGI Methodology

At this time, greenhouse gas (GHG) emissions from mud degassing are not included in the GHGI. The update under consideration presented in this memo would incorporate an estimate for mud degassing emissions in the GHGI, in the exploration segment estimates for natural gas and petroleum systems.

2 Background

Drilling mud is a mixture of clays and additives with water, oil, or synthetic matter. Heat is generated by the drill bit as it removes rock at the bottom of the bore hole. While drilling, the drilling mud is continuously pumped through the drill string and out the bit to cool and lubricate the drill bit, and move cuttings through the wellbore to the surface. The drilling mud also provides stability to the bore hole. Mud density must be controlled to counteract formation pressure.

There are 3 types of drilling muds that are currently used in the oil and gas industry – water-based muds, oil-based muds, and synthetic-based muds. Oil-based and synthetic muds are generally expensive and difficult to dispose, but are effective when drilling deep, high temperature holes in which water-based muds solidify.[1] Water-based muds are the most widely used drilling muds, and are used to drill approximately 80% of all wells according to a 2004 report.[2] Market/industry business reports indicate that water-based drilling muds dominate the drilling muds market domestically and also at the global-level.[3] One market analysis report indicates that water-based drilling muds accounted for approximately 56% of the global drilling muds market in 2016 (market share based on market value, $) and oil-based muds accounted for slightly less than half of the water-based muds market value.[4]

Mud degassing refers to the practice of safely removing pockets of free gas entrained in the drilling mud once it is outside of the wellbore. It is necessary to remove the gas because it reduces the mud weight. The gases entrained in the drilling mud are separated from the mud in a mud separator and are flared or vented to the atmosphere, releasing methane (CH_4) and other pollutants. Finally, the rock cuttings are screened out of the mud in a shaker and the conditioned drilling mud is recycled back to the well to be used again.

[1] Lyons, William C. Working Guide to Drilling Equipment and Operations. Amsterdam: Gulf Pub./Elsevier, 2010. <http://public.eblib.com/EBLPublic/PublicView.do?ptiID=535200>.
[2] Oilfield Market Report 2004. Spears & Assoc. Inc., Tulsa, Oklahoma, www.spearsresearch.com. Summary data provided at https://petrowiki.org/Drilling_fluid_types.
[3] Drilling Fluids Market Analysis Report, Grand View Research. https://www.grandviewresearch.com/industry-analysis/drilling-fluids-market-analysis.
[4] Drilling Fluids Market Information Research Report: Information, By Type (Water Based, Oil-Based, and Synthetic Based), By Application (Onshore, Offshore) and By Region (North America, Latin America, Europe, APAC, Middle East & Africa)–Forecast Till 2023. https://www.marketresearchfuture.com/reports/drilling-fluids-market-4329.

3 Analysis of Available Data

3.1 Emission Factors

Several groups' inventory estimates have incorporated estimates for mud degassing emissions using a 1977 EPA publication.[5] Use of the 1977 EPA study by other groups is discussed in section 3.3 below.

The 1977 EPA publication "Atmospheric Emissions from Offshore Oil and Gas Development and Production" estimated two total hydrocarbon (THC) emission factors (EFs), for water-based mud and oil-based mud degassing, based on engineering calculations. The water-based mud degassing EF represents gas liberated from rock drilled out of the wellbore and that is entrained in the mud, when drilling through a producing formation. The EF calculation in the 1977 EPA report assumes a penetration rate of 400 feet per day, 25% porosity, and reservoir pressure of 4,000 psig. Applying these assumptions resulted in a THC EF of 400 kg/drilling day.

A second type of emission from the mud separation system occurs in instances where oil-based drilling muds are used. Mud is dissolved in oil rather than water in such instances and as the mud passes through the shaker, the oil vapors are vented to the atmosphere. The 1977 EPA publication's oil-based mud degassing emission rate assumed degassing emissions were analogous to emissions from a fixed-roof storage tank for distillate fuels with a turnover factor of 0.5. The calculation assumed an average mud flow of 400 gallons/minute and the resulting THC EF is 90 kg/drilling day. Although the mud turnover, or bottom-up speeds, vary over the course of the drilling event (i.e., to flush out cuttings), this was not considered in the 1977 EPA publication.

The 1977 EPA publication did not include emissions information on synthetic muds. Two inventory (BOEM and CenSARA) estimates used the 1997 EPA oil-based mud degassing emission factor for synthetic-based mud degassing operations.

The EPA calculated CH_4 EFs for consideration in updating the GHGI by applying the GHGI default methane fraction (by weight) of 61.2% for associated gas. Table 1 presents the resulting mud degassing EFs for water- and oil-based mud. The EFs assume the emissions are vented to atmosphere and are not controlled.

Table 1. Mud Degassing Vented CH_4 Emission Factors

Mud Type	CH_4 EF (mt /drilling day)[a]
Water-based	0.32
Oil-based	0.07

a. Based on default GHGI gas content for associated gas production, 61.2 weight percent CH_4.[6]

3.2 Activity Data

EPA evaluated two activity data components, the number of drilling days per well and the number of wells drilled.

[5] U.S. EPA, 1977. Atmospheric Emissions from Offshore Oil and Gas Development and Production. Office of Air Quality Planning and Standards, Research Triangle Park, NC. PB272268.

[6] EPA considered applying separate CH_4 weight percentages to mud degassing of gas wells versus oil wells. However, the natural gas systems onshore production default CH_4 content of 78.8 mol% leads to a weight percent similar to the petroleum systems default of 61.2 wt%. Therefore, EPA applied the same methane fraction to oil and gas wells for this analysis.

A 2014 study reported natural gas drilling data from a survey of gas well operators in the Marcellus Shale. [7] For the purposes of this memo, EPA applied a default assumption from the Marcellus Shale study of 26 drilling days/well. The Marcellus Shale study average drilling day value falls in the range of drilling durations applied in the national emissions inventory (NEI). The NEI oil and gas tool assigns one of seven drilling durations, ranging from 5.4 to 66.5 days, based on operator surveys sponsored by Central States Air Resource Agencies (CenSARA).[8] For the public review draft, Enverus DrillingInfo (which includes drilling beginning and end dates) will be assessed to determine an average drilling duration.

The GHGI already estimates the number of gas and oil wells drilled, based on Enverus DrillingInfo data. Table 2 presents the well drilling counts, as developed for the 2020 GHGI.

Table 2. Total US Wells Drilled (including fraction of dry wells) from 2020 GHGI

Year	Gas Wells Drilled	Oil Wells Drilled
1990	17,936	19,959
1991	9,871	15,542
1992	10,588	16,944
1993	9,485	14,381
1994	10,194	12,161
1995	10,216	13,204
1996	10,915	18,361
1997	11,833	15,320
1998	11,287	9,563
1999	13,298	10,289
2000	18,156	13,631
2001	21,685	13,512
2002	17,906	11,628
2003	21,122	14,003
2004	25,198	16,491
2005	27,671	18,481
2006	31,529	20,762
2007	30,039	22,814
2008	29,914	23,544
2009	14,277	15,505
2010	14,513	24,997
2011	11,194	31,262
2012	6,717	35,659
2013	5,715	36,365
2014	5,890	37,507
2015	3,433	17,639
2016	2,213	10,606
2017	3,639	19,076
2018	3,639	19,076

[7] Anirban Roy A., Adams Peter J., & Robinson Allen L. (2014). Air pollutant emissions from the development, production, and processing of Marcellus Shale natural gas. Journal of the Air & Waste Management Association, 64(1), 19–37. Retrieved from https://doi.org/10.1080/10962247.2013.826151

[8] 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.

3.3 Estimates From Other Inventories

Other inventories have estimated emissions from mud degassing from both the offshore and onshore segments using the emissions factors developed from the 1977 EPA study. Table 3 summarizes relevant emissions and activity data from each study.

- New York State Oil and Gas Sector Methane Emissions Inventory for 1990-2017 (NYSERDA)[9] – The methane emissions inventory for New York State estimated emissions from mud degassing from oil and gas wells. The estimates were developed for 1990-2017.
- 2011 Oil and Gas Emission Inventory Enhancement Project for CenSARA States[10] – Onshore mud degassing emissions were estimated for 2011 for the CenSARA states (Texas, Oklahoma, Louisiana, Arkansas, Kansas, Nebraska, and Missouri).
- Emissions from Oil & Gas Production Facilities in Texas[11] – 2005 base year criteria pollutant emissions were estimated for onshore and offshore oil and gas exploration and production facilities in Texas. VOC emissions were estimated for mud degassing from onshore and offshore production.
- BOEM Gulfwide Emissions Inventory Studies[12] - These studies developed base year 2008, 2011, 2014, and 2017 air pollution emissions inventories for all outer continental shelf (OCS) oil and gas production-related sources in the Gulf of Mexico (GOM), including non-platform sources. Annual CH_4 and CO_2 emissions were estimated from mud degassing at offshore platforms.

Table 3. Annual (Regional) Estimates From Other Studies

Study Area (Author)	Year	Annual CH4 (MT)	Activity Info
NY (NYSERDA)	1990	851.0	3,267 drilling days, assumed water-based muds only
	2007	3,073.9	11,800 drilling days. Maximum annual emissions over the time-series.
	2015	173.2	665 drilling days, back-calculated average drilling days for both oil and gas wells across the time-series (1990-2017) = 24 days.
	2016	162.8	625 drilling days
	2017	107.8	414 drilling days. For activity data outliers (drilling days >50), 22 drilling days were used as surrogate[4].
TX, OK, LA, AR, KS, NE, MI (CenSARA)	2011	69,094.3	629,601 active wells; 12,134 spuds; assumed water-based muds only. Back-calculated average drilling days per spud = 22 days.
Offshore GOM (BOEM)	2008	194.0	In 2008 there was a total of 39,805 days of drilling in the GOM.
	2011	505.0	Data from 22 active mud degassing operations in GOM. In 2011 there was a total of 19,863 days of drilling in the GOM. Activity data used to estimate emissions indicate 92% of drilling operations were performed using water-based muds and 8% used synthetic-based muds.
	2014	175	

[9] New York State Energy Research and Development Authority (NYSERDA). 2019. "New York State Oil and Gas Sector Methane Emissions Inventory." NYSERDA Report Number 19-36. Prepared by Abt Associates, Rockville, MD and Energy and Environmental Research Associates, LLC, Pittsford, NY. nyserda.ny.gov/publications.

[10] 2011 Oil and Gas Emission Inventory Enhancement Project for CenSARA States. Prepared for Central States Air Resources Agencies (CenSARA), Prepared by Environ and ERG. Internet address: http://www.censara.org/filedepot_download/56064/14.

[11] Emissions From Oil & Gas Production Facilities, Prepared for TCEQ, Prepared by ERG, 2007. Internet address: https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY0701-20090831-ergi-ei_from_old_gas_facilities.pdf.

[12] Each BOEM GEI study is available online: https://www.boem.gov/Gulfwide-Offshore-Activity-Data-System-GOADS/

Study Area (Author)	Year	Annual CH4 (MT)	Activity Info
	2017	86	Activity data used to estimate emissions indicate 48% of drilling operations were performed using water-based muds, 37% used oil-based muds, and 15% used synthetic-based muds.
TX (TCEQ)	2005	< 9,683.3	Study calculated VOC emissions from Onshore exploration. Assumed water-based muds only.
		< 63.5	Study calculated VOC emissions from Offshore. Assumed water-based muds only.

The only segment required to report mud degassing emissions under GHGRP is the offshore production segment [98.230(a)(1)]. Annual GHG emissions from mud degassing were first reported in reporting year 2015. These emissions are calculated using the same methods as the BOEM inventory. Emissions from different types of drilling muds are available in Table 4. Detailed data on usage of different types of drilling muds are not available from subpart W data. Offshore facilities report mud degassing emissions by type of drilling mud. Reported emissions data for 2015-2018 indicate that approximately 83% of total mud degassing emissions are reported using water-based muds.

Table 4. GHGRP Subpart W Mud Degassing Summary – Offshore Production

Reporting Year	Number of Reporters[a]	Water-based muds		Oil-based muds		Synthetic-based muds	
		CH4 (MT)	CO2 (MT)	CH4 (MT)	CO2 (MT)	CH4 (MT)	CO2 (MT)
2015	7	202.4	417.5	0	0	7.8	0.03
2016	7	210.6	0.8	4.8	0.02	5.1	0.02
2017	7	40.9	0.4	32.8	0.3	6.9	0.06
2018	6	66.3	0.6	2.8	0.03	6.3	0.06

a – Number of facilities reporting non-zero estimates for mud degassing.

4 Time Series Considerations

EPA is proposing to hold the EFs in Table 1 constant over the time series. However, EPA seeks information on the use of water-based muds, oil-based muds, and synthetic-based muds over the time series. Available information suggests a range of usage rates for water-based muds in drilling operations. Some inventories assume all muds used are water-based, while other data suggests about half of muds used are water-based. In addition, in this memo, EPA has applied a constant drilling duration of 26 days per well. Available information (see Table 3) indicate that the average drilling duration may be lower. EPA will assess Enverus DrillingInfo data to determine if an improved estimate for drilling days can be developed and whether the average drilling duration changes over time or is different for natural gas wells and oil wells.

5 Preliminary National Emissions Estimates

EPA calculated preliminary national-level CH_4 emission estimates for the update under consideration for mud degassing using 2 different scenarios: 1) EPA assumed 80% of drilling operations were performed using water-based muds and the remaining 20% used oil-based muds; and 2) EPA assumed 100% of drilling operations were performed using water-based muds. EPA applied an average of 26 drilling days per well, as discussed in Section 3.2, to the wells drilled counts in Table 2 for both scenarios. Table 5 presents the resulting preliminary national estimates for 1990-2018 for scenario 1 and Table 6 presents preliminary national estimates for 1990-2018 for scenario 2.

Table 5. Preliminary National CH_4 Emissions Estimates for Mud Degassing (CH_4 in metric tons) – 80% water-based muds and 20% oil-based muds usage

Year	Gas Wells (mt)	Oil Wells (mt)	Total (mt)
1990	95,133	105,862	200,995
1991	52,355	82,436	134,791
1992	56,158	89,872	146,030
1993	50,307	76,279	126,585
1994	54,066	64,505	118,571
1995	54,187	70,032	124,220
1996	57,893	97,387	155,280
1997	62,765	81,255	144,020
1998	59,866	50,723	110,588
1999	70,535	54,570	125,105
2000	96,300	72,299	168,598
2001	115,017	71,668	186,685
2002	94,974	61,675	156,648
2003	112,033	74,270	186,303
2004	133,648	87,470	221,118
2005	146,766	98,024	244,790
2006	167,227	110,124	277,351
2007	159,325	121,007	280,332
2008	158,663	124,879	283,541
2009	75,727	82,236	157,964
2010	76,979	132,582	209,561
2011	59,373	165,813	225,187
2012	35,626	189,136	224,762
2013	30,314	192,878	223,192
2014	31,239	198,939	230,178
2015	18,211	93,555	111,766
2016	11,736	56,256	67,992
2017	19,301	101,179	120,480
2018	19,301	101,179	120,480

Table 6. Preliminary National CH_4 Emissions Estimates for Mud Degassing (CH_4 in metric tons) – 100% water-based mud usage.

Year	Gas Wells (mt)	Oil Wells (mt)	Total (mt)
1990	111,922	124,543	236,465
1991	61,594	96,983	158,577
1992	66,068	105,732	171,800
1993	59,184	89,739	148,924
1994	63,607	75,888	139,495
1995	63,750	82,391	146,141
1996	68,109	114,573	182,682
1997	73,841	95,594	169,435
1998	70,430	59,674	130,104
1999	82,982	64,200	147,183
2000	113,294	85,057	198,351
2001	135,314	84,315	219,629
2002	111,734	72,558	184,292
2003	131,803	87,377	219,180

Year	Gas Wells (mt)	Oil Wells (mt)	Total (mt)
2004	157,233	102,906	260,139
2005	172,666	115,322	287,988
2006	196,738	129,558	326,296
2007	187,441	142,362	329,803
2008	186,662	146,916	333,578
2009	89,091	96,749	185,840
2010	90,564	155,978	246,542
2011	69,851	195,075	264,925
2012	41,913	222,513	264,426
2013	35,664	226,915	262,579
2014	36,752	234,045	270,797
2015	21,425	110,065	131,489
2016	13,808	66,183	79,991
2017	22,707	119,035	141,742
2018	22,707	119,035	141,742

6 Requests for Stakeholder Feedback

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

1. EPA seeks feedback on using the EFs in Table 1 to estimate emissions for onshore mud degassing.
2. EPA seeks information on other available data sources that evaluate emissions from drilling mud.
3. EPA seeks feedback on potential adjustments to the EFs to reflect changes in drilling over time. For example, the factor was calculated assuming 400 ft/day drilling rate. The current average drilling rates might be different than what was used to develop the EF. The equation used to calculate the original EF is unavailable, so it will not be possible to update the drilling rate data and recalculate the EF. Can/should another approach be applied to adjust the EF? Further, has the increased prevalence of directional drilling increased the time that exploratory drilling travels through a rock containing exploitable quantities of hydrocarbons?
4. EPA seeks feedback on the most appropriate methane content (wt%) to apply to the THC EFs to calculate CH_4 EFs for gas and oil wells. A default methane content of 61.2 wt% is used in the preliminary estimates presented in this memo. This default value is from a 1996 API report (Calculation Workbook For Oil and Gas Production Equipment Fugitive Emissions, API publication 4638, July 1996). The 1996 API report also cites a value of 68.7 wt% CH_4 for gas streams (Table 2 in the report). EPA is considering applying 68.7 wt% CH_4 to gas wells and 61.2 wt% CH_4 to oil wells, but seeks feedback on the methane content values and other data sources that should be reviewed to estimate these values for oil wells and gas wells.
5. EPA seeks feedback on the split between water and oil use, and if there is regional or temporal variability in mud type usage (i.e., water, oil, and synthetic) that should be incorporated into the methodology.
6. EPA seeks feedback on the variance of drilling duration over the time series and for each well type.
7. EPA seeks feedback on the usage of flares on mud gas separators. Are there other pollution control devices that are in use other than flares? How should these be taken into account?