October 2021

Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2020: Updates Under Consideration for Anomalous Events including Well Blowout and Well Release Emissions

This memorandum discusses updates under consideration for emissions from anomalous leak events with event-specific quantified emissions occurring in petroleum and natural gas systems, including specifically for petroleum and natural gas onshore production well blowouts for the *2021 U.S. Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI). The memorandum also discusses updates under consideration for other oil and gas well blowout and release events.

1 Background and Current GHGI Methodology

The 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [1] included guidance on calculating "anomalous leak events" for national GHG Inventories. The 2019 IPCC Refinement provides examples of anomalous events, including emergency pressure relieving equipment and well blowouts, and specifies that these events should be evaluated and estimated on a case-by-case basis using the best available data. The GHGI currently incorporates an estimate for one anomalous leak event, the Aliso Canyon storage well event in 2015/2016.[2] The EPA is considering updating the GHGI to include additional anomalous leak events from two recent well blowout events as discussed in this memorandum.

The GHGI currently includes well blowouts emission estimates from newly drilled onshore oil wells. The data used in the GHGI is sourced from an "Industry Review Panel." The GHGI estimates the number of blowouts on a frequency of 1 blowout per 300 oil wells drilled. The GHGI estimates emissions as 2.5 MMScf CH_4/blowout and the corresponding CO_2 emissions quantity is estimated using the methane factor and the average ratio of CO_2 to CH_4 in associated gas (from API 4697). Well releases from onshore oil wells and well blowouts and releases from onshore gas wells are currently not included in the GHGI.

2 Summary and Discussion of Available Data

A literature review was conducted for emissions data and activity data for onshore oil and gas anomalous leak events and other well blowouts and releases as documented herein. Targeted literature included studies that quantify emissions from these events and literature that provides activity data for developing emission estimates (e.g., well blowout frequency).

Oil and gas well blowouts are uncontrolled high-pressure releases of oil, gas, and/or salt water from offshore or onshore oil and gas production wells which occur when well control techniques (i.e., well blowout preventer) fail. There are three main types of blowouts: surface blowouts, underground blowouts, and subsea blowouts. Well blowouts most often occur during the drilling or completion phase of a new well, prior to production or use. An oil and gas well release is different than an oil and gas well blowout, and is characterized as a short period of uncontrolled release[3] followed by a period of controlled release in which control techniques are successfully implemented.

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[1] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Energy. Available online at: <https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol2.html>

[2] Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2015: Incorporating an Estimate for the Aliso Canyon Leak. Available online at: <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2015-ghg>.

[3] Not the controlled pre-separation stage of well flowback in a hydraulically fractured completion

Well blowouts and releases present challenges for quantification including evasion of initial detection if the well is located in a remote area, limited emissions data available in many cases (e.g., limited satellite overpasses, limited aircraft overflights), significant variation in the event duration and emissions rate, and the creation of hazardous conditions at the event site as a consequence of the blowout or release.

2.1 Well Blowout and Well Release Emissions Quantification

2.1.1 Well Blowout Events with Event-Specific Emissions Quantification

Several studies have attempted to quantify well blowouts using a combination of satellite, aircraft, and ground-based measurements including a study of a gas well blowout in Belmont County, Ohio in 2018 ("Satellite observations reveal extreme methane leakage from a natural gas well blowout" by Pandey et al.)[4]; and a gas well blowout in the Eagle Ford Shale near Victoria, TX in 2019 ("Multisatellite Imaging of a Gas Well Blowout Enables Quantification of Total Methane Emissions" by Cusworth et al.)[5].

In Pandey et al., satellite measurements of total column CH_4 (XCH_4) from the spaceborne Tropospheric Monitoring Instrument (TROPOMI) were used to quantify emissions from a 20-day gas well blowout episode in early 2018 in Belmont County, Ohio. Data from cloud-free and low aerosol conditions covering at least a quarter of the blowout region were selected. Only two days of data from the episode met this selection criteria. Only one of these days had measurements downwind of the blowout, so this day was selected for emission quantification. The Weather Research and Forecasting (WRF) model was used to simulate a blowout plume to match the TROPOMI-observed XCH_4 measurements and estimated an emission rate at 120 ± 32 metric tons/hr. Assuming this emission rate, which was calculated for the 13th day in the blowout period, is the representative average emission rate during the blowout period, the total CH_4 emissions of the episode were estimated to be 60,000 ± 15,000 metric tons. The authors note that this amount is equivalent to a quarter of the annual oil and gas CH_4 emissions reported to EPA's Greenhouse Gas Reporting Program (GHGRP) in the state of Ohio.

As documented in Cusworth et al., in November 2019 a gas well blowout occurred in the Eagle Ford Shale at a surface site consisting of four co-located horizontally drilled gas wells. On the 14th day of the event, the wellhead was capped, and gas was diverted to an open pit where it was flared. On the 20th day, the well was deeply injected with fluid resulting in an effective shut in.

The Cusworth et al. study used a combination of monitoring data from space and from the ground to estimate emissions from the gas well blowout event. Ground level data included in situ volatile organic compound measurements within 5 km of the blowout at several sites. Additionally, the study used other downwind measurements at state-operated air quality monitoring stations for emissions estimates. These measurements were used with chemical transport modeling and well compositional data to infer CH_4 concentrations to estimate emissions from the event. Data from space included a combination of measurements from TROPOMI, the GHG-Sat-D satellite, the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument (CH_4 concentrations inferred from the radiant heat of flaring), and the PRecursore

[4] Pandey, S., Gautam, R., Houweling, S., van der Gon, H. D., Sadavarte, P., Borsdorff, T., et al. (2019). Satellite observations reveal extreme methane leakage from a natural gas well blowout. *Proceedings of the National Academy of Sciences*, 116, 26376– 26381. https://doi.org/10.1073/pnas.1908712116

[5] Cusworth, D.H., Duren, R.M., Thorpe, A.K., Pandey S., Maasakkers, J.D., Aben, I., et al. (2021). Multisatellite imaging of a gas well blowout enables quantification of total methane emissions. *Geophysical Research Letters*, 48, e2020GL090864. https://doi.org/10.1029/2020GL090864

IperSpettrale della Missione Applicativa (PRIMSA) satellite imaging spectrometer. In situ sampling and satellite measurements were combined to fully capture the event and overcome certain equipment limitations including spatial coverage, spatial resolution, revisit frequency, weather specific issues and the presence of flaring. The observation dates in Cusworth et al. (20X) are listed below:

TROPOMI: November 2, 3, 15, and 18.
GHGSat-D: November 10.
in situ VOC measurements (i.e., pentanes and butanes): November 2, and 5-8.
PRISMA: November 15.
SkySat: November 15.
VIIRS: November 15-20.

The total estimated integrated emissions rate for the event was 4,830 ± 980 metric tons of CH_4.

2.1.2 Other Well Blowout and Release Emission Data

In our literature review, we did not identify any source in the literature on emissions data resulting from other well blowouts or releases.

2.2 Well Blowout and Well Release Event Activity Data

A few studies and state datasets have information on the frequency of well blowouts and well releases in the U.S. This section covers well blowout and release frequency data obtained from:

- California District 4;
- Texas Railroad Commission; and
- New Mexico Energy, Minerals and Natural Resources Department.

2.2.1 California District 4 Report

A historical review of California well blowout event data was reported in "Well blowout rates in California Oil and Gas District 4--Update and Trends" by Jordan et al.[6] In this report, more than 100 well blowouts between 1991 and 2008 in California District 4 were analyzed to determine rate of incident as well as correlations between stage, location and type of drilling process. The study found that blowout rates are "relatively constant" between onshore and offshore drilling operations, differing by less than an order of magnitude and ranging from 10,000 – 60,000 well-years. Approximately one third of blowouts occurred during well construction, a third from wells in operation, one fifth from well servicing, and the balance from inactive wells. The probability of a blowout occurring during well construction in a non-thermal[7] field is 1 in 2,500 wells, and 1 in 1,700 for construction in thermal fields. The probability of a blowout from steam injection is 1 in 10,000 well-years. For both events during well construction and steam injection the rate of incidents has steadily decreased since 1991 to 1 blowout per year in 2005. Between the same years, annual blowouts in District 4 have declined by about 80% despite a steady production of fluids and a slight increase in the number of wells drilled.

[6] Jordan, Preston D, and Benson, Sally M. (2009). Well blowout rates in California Oil and Gas District 4--Update and Trends. *Exploration and Production – Oil and Gas Review*, Vol. 7 Issue 2. United States. https://www.osti.gov/servlets/purl/981460.

[7] Unconventional hydrocarbons can be produced using thermal methods such as steam injection and non-thermal methods such as CO_2 injection.

2.2.3 State Level Programs

2.2.3.1 Texas

Under Texas Administrative Code Title 16 Part 1 Chapter 3 Rule 3.20(b) any oil or gas release/blowout must be reported if more than 5 BBLs are spilled in the aggregate. This includes any well release resulting in a loss of contaminant. Information on incidents involving well-control problems was pulled from the Texas Railroad Commission (RRC) website.[8] These reported data include identifying information such as the API well ID number, the drill permit, the field name, county etc. and a general remarks field. The general remarks field contains a description of the event. The data do not provide information on the type of well or whether the incident occurred during drilling, production or well maintenance operations. It also does not differentiate between a well blowout or a well release. The only information available in the reporting records which could be used to estimate the type and size of the event is that which is contained in the general remarks field. In reviewing the general remarks field for reporting records for the period 2000 - 2021, we attempted to categorize the events by severity using the criteria noted in Table 1 below.

Table 1. Event Severity Ranking Criteria

Severity Ranking	Criteria
Normal	Did not meet the criteria of moderate or severe.
Moderate	Remarks mentioned a road closure, area of the spill (typically on the order of 100 - 1000 ft^2), or a reported volume leaked of less than 100 barrels of oil.
Severe	Remarks mentioned residential evacuations, or a reported volume leaked of greater than 100 barrels of oil.

The severity of the incident provides some insight into whether the incident should be categorized as a well release or blowout. Severe incidents would most likely be considered a blowout due to the scale of the event, whereas moderate and normal incident are most likely well-releases.

The Texas RRC also collects information on well activity, including the number of wells drilled per year.[9] These data were combined with the release data in the context of the aforementioned severity index, to generate Table 2 below:

Table 2. Texas RRC Reported Well Release Incidents and Drilling Activity Data

Year	# of Well Release Incidents				Holes Drilled	Frequency (per year)	5 year Rolling Average
	Normal	Moderate	Severe	Total			
2007	24	1	6	31	14247	2.18E-03	-
2008	15	2	3	20	17337	1.15E-03	-
2009	11	3	2	16	15279	1.05E-03	-
2010	17	2	0	19	9939	1.91E-03	-

[8] Texas Railroad Commission, Well Control Problems. Last Accessed July 15, 2021. Retrieved from https://www.rrc.texas.gov/oil-and-gas/compliance-enforcement/blowouts-and-well-control/

2011	17	2	1	20	8790	2.28E-03	1.71E-03
2012	11	0	0	11	15041	7.31E-04	1.42E-03
2013	26	1	3	30	24922	1.20E-03	1.43E-03
2014	24	0	4	28	29554	9.47E-04	1.41E-03
2015	14	0	1	15	19503	7.69E-04	1.19E-03
2016	18	2	1	21	10468	2.01E-03	1.13E-03
2017	11	1	2	14	6914	2.02E-03	1.39E-03
2018	11	1	1	13	10986	1.18E-03	1.39E-03
2019	11	0	5	16	9238	1.73E-03	1.54E-03
2020	4	2	2	8	10899	7.34E-04	1.54E-03
2021	1	0	0	1	3283	3.05E-04	1.20E-03

As previously described, well blowouts and releases can occur during all phases of operation, but EPA has chosen to estimate the blowout and release frequency from the Texas report on a per well drilled basis based on the information in the General Remarks of the reports (many mention drilling) and the concept in the literature that these events typically happen most commonly during drilling. We acknowledge that the estimated frequency likely includes some events that occurred during non-drilling phases of operation.

The average annual total of well incidents in Texas was 19.6 with a standard deviation of ±8.2. The average frequency of incidents was 1 incident for every 740 wells drilled each year. Assuming severe incidents are blowouts, there would be approximately 1 blowout for every 6,400 wells drilled each year. Similarly, assuming the sum of normal and moderate incidents are representative of well releases, this would be equivalent to 1 well-release for every 840 wells drilled each year. Both of these are far less frequent than the GHGI cited national frequency of 1 blowout for every 300 oil wells drilled per year.

2.2.3.1 New Mexico

In accordance with section 19.15.29.10 of the New Mexico Administrative Code (NMAC), responsible parties must report major and minor releases using form C-141 within 15 days of discovery. Definitions of major release and minor release are provided in section 19.15.29.7 NMAC. Major releases are in excess of 25 barrels or 500 MCF; or releases that result in fire, have a reasonable probability to reach water course or endanger public health, or releases that substantially damage property or the environment. Minor releases are releases that do not meet the criteria of being a major release and that have a release volume between 5-25 barrels or between 50-500 MCF. A query of the New Mexico incident database[10] was performed by applying filters where the type description is blowout and incident date ranges were between 2000-2021. The query yielded a total of 28 reported incidents. A second query of the well permit database for "new" wells during each calendar year was performed to estimate the number of wells drilled, but this yielded a new well count that seemed exceedingly low. Instead, we utilized the count of wells drilled by year from the Enverus software to estimate the frequency of well blowouts/releases as shown in Table 3 below. Similar to the Texas RRC data, the releases are not distinguished by well type, operation, release quantity or other characteristics, but our

[10] New Mexico Energy, Minerals and Natural Resources Department, OCD Data Statistics – Well Information Spill and Incidents (Search and Listing). Last Accessed July 23, 2021. Retrieved from https://wwwapps.emnrd.state.nm.us/OCD/OCDPermitting/Data/Incidents/Incidents.aspx

frequencies are estimated on a per well drilled basis. The 5-year average incident rate is 1 event per 2,000 wells drilled.

Table 3. NM Reported Blowout Incident Data and Well Drilling Activity Data

Year	Blowout Incident Count	Enverus Wells Drilled	Est. Freq.
2000	0	1697	0.00E+00
2001	3	1834	1.64E-03
2002	5	1594	3.14E-03
2003	3	1865	1.61E-03
2004	3	1862	1.61E-03
2005	1	2052	4.87E-04
2006	1	2236	4.47E-04
2007	0	1970	0.00E+00
2008	1	2062	4.85E-04
2009	0	1406	0.00E+00
2010	0	1435	0.00E+00
2011	2	1690	1.18E-03
2012	1	1528	6.54E-04
2013	0	1359	0.00E+00
2014	0	1336	0.00E+00
2015	0	890	0.00E+00
2016	1	493	2.03E-03
2017	0	738	0.00E+00
2018	3	1129	2.66E-03
2019	1	1205	8.30E-04
2020	0	907	0.00E+00
2021	3	542	5.54E-03

1) Incident count for the type description of "blowout"

3 Analysis of Available Data

3.1 Emissions Data

Aside from the emissions quantification for anomalous leak events (e.g., Belmont, OH blowout; Victoria, TX Blowout; as discussed in section 2.1.1), we are unaware of data to update the emissions per event assumption currently used in the GHGI (i.e., 2.5 MMScf CH_4/event). EPA is considering applying this value (2.5 MMScf CH4/event) to oil and gas well blowouts and well releases.

EPA is considering the inclusion of anomalous leak events using event-specific published emissions. We note that the EPA has taken this approach in the past for the Aliso Canyon incident.

3.1 Activity Data

Using data from the published literature, EPA is considering updating the existing activity data for blowouts from onshore oil wells and estimating analogous activity data for onshore gas wells. The

current GHGI activity data for the existing onshore oil blowout emission source is recorded as the annual count of well blowout events. These activity data values are estimated using the frequency of onshore oil well blowouts (i.e., 1 well blowout per 300 wells drilled) and the annual count of oil wells drilled. The same estimation method could be used to estimate the number of well blowout and release events from onshore gas wells. A discussion of these approaches is included in the following sections.

3.1.2 Onshore Activity Data

The data reviewed for onshore well blowout and well releases from California, Texas and New Mexico did not provide well type specific (e.g., oil or gas) or phase specific (e.g., drilling, completions, etc.) data. The data did, however, provide frequencies of events. We note that the event frequencies across all 3 data sources for onshore wells yields comparable values. The most robust set of data is that from Texas's RRC. The Texas RRC data included sufficient information to estimate both a well blowout and well release frequency and EPA is considering use of this data to form the basis of the frequency of events for both oil and gas wells. Using the RRC data, the frequency for onshore well blowouts would be 1 in every 6,400 wells drilled and the frequency for onshore well releases would be 1 in every 840 wells drilled irrespective of well type or phase.

As described in section 2.2.3.1, the events included in the Texas RRC dataset likely include events in non-drilling phases of production. The estimated frequencies, however, are on a per well drilled basis only. The EPA seeks stakeholder comments on this approach.

4 Time Series Considerations

Well blowouts and well releases are unpredictable and episodic. For large events with event-specific quantified emissions, EPA is considering incorporating available emissions data into the GHGI. For the estimation of other well blowouts and well releases, EPA is considering using frequency information from Texas's RRC. We note the Jordan et al. report indicated that emissions from well incidents have been declining in the state of California while production rates during the study period (1991-2008) were steady and the average number of wells drilled slightly increased. We also find in the time period covered by the GHGI that technological advancements in blowout prevention systems have been implemented which are likely the cause of the emissions reductions. Based on the limited available data on well blowouts and releases, EPA is considering using the revised activity data approach and emission factors across all years of the GHGI.

5 Preliminary National Emissions Estimates for well blowouts in the 2022 GHGI

Based on the data sources and considerations discussed in Sections 3 and 4, this section summarizes the approaches EPA is considering for the 2022 GHGI.

As discussed, EPA is considering updating the existing activity data for onshore oil well blowouts and adding activity data and emission estimates for well releases at onshore oil wells and well blowouts and releases at onshore gas wells. EPA is considering using this information to include well blowouts and well releases for emission estimates in both the natural gas and petroleum systems exploration category.

Tables 4 and 5 summarize the results for each emission source type under consideration, using year 2019 as an example.

Table 4. Year 2019 Petroleum Systems Exploration Segment Well Blowout and Well Releases

Emission Source Type	Emission Factor		Activity Data				2019 Emissions (MT CH_4)
	Data Source	Value (CH_4 MMScf/Event)	Data Source	Event / Well Drilled	Wells Drilled / Yr	Event/Yr	
Onshore Oil Well Blowout	Industry Review Panel	2.5	TX RRC	1.56E-04	16,166	3	121
Onshore Oil Well Release	Industry Review Panel	2.5	TX RRC	1.19E-03	16,166	19	924
Oil well blowouts and releases (combined)	**Industry Review Panel**	**2.5**	**TX RRC**	**1.35E-03**	**16,166**	**22**	**1,045**
Previous GHGI							
Oil well blowouts	*Industry Review Panel*	*2.5*	*Industry Review Panel*	*3.33E-03*	*16,166*	*54*	*2,595*

Table 5. Year 2019 Natural Gas Systems Exploration Segment Well Blowout and Well Releases

Emission Source Type	Emission Factor		Activity Data				2019 Emissions (MT CH4)
	Data Source	Value (CH_4 MMScf/Event)	Data Source	Event / Well Drilled	Wells Drilled / Yr	Event/Yr	
Onshore Gas Well Blowout	Industry Review Panel	2.5	TX RRC	1.56E-04	3,533	1	26
Onshore Gas Well Release	Industry Review Panel	2.5	TX RRC	1.19E-03	3,533	4	202
Gas well blowouts and releases (combined)	Industry Review Panel	2.5	TX RRC	1.35E-03	3,533	5	228
Event-Specific Estimate	Cusworth et al.	N/A	N/A	N/A	N/A	N/A	4,830
Total Emissions from Gas Well Blowouts and Releases							**5,058**
Previous GHGI							
NA	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

6 Requests for Stakeholder Feedback

1. EPA seeks stakeholder feedback on the incorporation of data on well blowouts with event-specific emissions quantification.
    a. EPA seeks stakeholder feedback on the data currently available, including on measurement methods and quantification approaches used in the two highlighted studies.
    b. EPA seeks stakeholder feedback on the number of observations used to develop an estimate for an anomalous leak event. The 2018 blowout event study had one day of emissions data (from a TROPOMI concentration observation) the 2019 event had data for around 13 days from a variety of instruments and approaches.

   c. EPA seeks stakeholder feedback on assumptions applied to calculate emissions rate when data are unavailable. Pandey et al. assumed that the emission rate quantified for the observed day was applicable for the duration of the event. Other events such as the blowout quantified in Cusworth et al. and the Aliso Canyon event as incorporated into the GHGI had data over several days of the event which were used to quantify a changing emission rate over time.
   d. EPA seeks information on well blowouts with event-specific emission quantification in addition to the two identified in this memorandum.
2. EPA seeks stakeholder feedback on incorporation of additional types of anomalous events, including on the types of events that could be considered and data availability.
3. EPA seeks stakeholder feedback on approaches for estimating emissions from anomalous events where measurement data are unavailable but other records exist.
4. EPA seeks stakeholder feedback on updating the current estimate for well blowouts without event-specific quantification and the incorporation of an estimate for well releases.
   a. EPA requests stakeholder feedback on the use of the same emissions value (i.e., 2.5 MMScf CH_4/event) for well blowouts and well releases and whether there are additional/updated data that should be considered for adjusting these emissions values.
5. If there are not additional sources of emissions data, EPA is considering including a single source of emissions by well type (e.g., onshore gas well blowouts and releases; onshore oil well blowouts and releases) as opposed to separate emissions sources for well blowouts and well releases for each well type as presented in Tables 6 and 7.
6. EPA seeks stakeholder feedback on the use of the Texas RRC data (rather than a combination of identified sources in the literature) for establishing a national average frequency of well release and well blowout events.
   a. EPA seeks stakeholder feedback on the general methodology to assign events to the categories of well release and well blowouts used with the Texas RRC data.
7. EPA seeks stakeholder feedback on the time-series approach in section 4 of this memorandum.

Appendix A – Study Design Information

Emission Source Type	Measurement Type	Description/Number of Sources	Location and Representativeness	Emissions / Activity Data Calculation Method
Onshore Well Blowout and Well Release Frequency	N/A	Texas RRC data of well control problems as self-reported by operators; since 2007 approximately 260 events have been reported and included in our analysis	Limited to TX, but data compared to similar data published in NM and a study published including data from CA. The TX data is comparable to the incident rate reported in NM and CA.	Activity data factors estimating the frequency of well blowouts and well releases reported by well type based on industry collected data.
Event with Event-Specific Quantification	TROPOMI Satellite and simulation modeling using the WRF model	Gas well blowout in Belmont, OH occurring over a 20-day period in February of 2018.	Each event is unique and is being considered as a line-item reporting rather than reflected in an average emissions value so location/representativeness were not considered.	The combination of satellite measurements and simulation modeling yielded a 120-130 metric tons per hour emissions rate which was applied to the entire duration of the event yielding an estimated event total emissions of 60,000 metric tons CH_4 released.
Event with Event-Specific Quantification	Satellite measurements including: TROPOMI, GHG-Sat-D, VIIRS, and PRIMSA; Simulation techniques including WRF and the integrated methane enhancement algorithm.	Gas well blowout in Victoria, TX at a surface site consisting of four horizontally drilled wells occurring over a 20-day period.	Each event is unique and is being considered as a line-item reporting rather than reflected in an average emissions value so location/representativeness were not considered.	The combination of satellite measurements and simulation modeling yielded an event estimate of 4,800 metric tons CH_4 released.