Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019: Updates Under Consideration to Natural Gas Underground Storage Well Emissions

This memorandum discusses updates under consideration for the 2021 *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI) for underground storage well equipment leak emissions.

1 Current GHGI Methodology

The current GHGI uses a methane (CH_4) emission factor (EF) for underground storage well equipment leaks that was developed in the 1996 GRI/EPA study.[1] To develop that emission factor for storage wells, GRI/EPA determined an average mix and count of wellhead components based on site visits to five storage facilities, and then applied component-specific emission factors developed from measurement data collected from onshore gas production wellhead components in the western United States, resulting in an average underground storage well equipment leak CH_4 EF of 115 standard cubic feet (scf)/day.

To develop storage well counts over the time series, the current GHGI uses a storage well count estimate of 17,999 wells in 1992 developed by an AGA survey and reported in AGA Gas Facts[2] (and also used in the GRI/EPA study) and scales this value to all other years using the ratio of residential gas consumption in a given year to 1992 residential gas consumption.

2 Available Data

New data on underground storage wellhead component counts and emissions are available from a recent research study and Subpart W of the EPA Greenhouse Gas Reporting Program; each are discussed here.

2.1 GSI 2019 Study

One recent study provides emissions data for underground storage well leaks.

GSI Environmental conducted a study of above-ground components at underground gas storage wellheads from three active storage facilities (GSI 2019).[3] Natural gas can be stored underground in three types of reservoirs: depleted oil and gas fields, aquifers, and salt domes. GSI measured methane emissions at one depleted field in the Clay Basin of Utah and two salt domes in the Gulf Coast region during two measurement campaigns in March and October of 2017. The study used infrared optical gas imaging (FLIR) and a Bascom-Turner Gas Rover to screen for leaking components at the storage wellheads. The Gas Rover is generally able to detect methane in the air at 10 ppm or greater. For a subset of the wellheads with leaks, GSI quantified emission rates, using a custom high-flow sampling system which included a Los Gatos Research Ultraportable Greenhouse Gas Analyzer (UGGA). The UGGA was able to detect methane concentrations up to 1000 ppm with a low-concentration laser and greater than 1000 ppm with a high-concentration laser. Readings from both lasers were recorded for all samples.

GSI classified each component encountered into one of seven categories: connectors, valves, pressure relief valves, meters, gauges, regulators, and open-ended lines. Some categories, such as valves and connectors, had subcategories such as whether a connector was flanged or not. Component counts at each storage facility wellhead included the aboveground piping connected to the wellhead.

[1] GRI/EPA, 1996. Methane Emissions from the Natural Gas Industry, Volume 8: Equipment Leaks.

[2] American Gas Association, 1992. Gas Facts: 1991 Data, Arlington, VA.

[3] GSI Environmental Inc., 2019. Long-term Methane Emissions Rate Quantification and Alert System for Natural Gas Storage Wells and Fields. DOE Report DE-FE0029085.

For the depleted gas field, in the spring campaign, emissions were quantified at twenty-four randomly selected wells. The facility was engaged in both gas injection and withdrawal at the time of the measurements. In the fall campaign, emissions were quantified at twenty randomly selected wells. The facility was engaged in gas injection and conducting a shut-in pressure test at the time of the measurements. Components were counted at wellheads where emissions were quantified (29 wells total). The depleted gas field site had a total of 43 storage wells.

The salt cavern storage facilities were engaged in gas injection and withdrawal during both measurement campaigns. Information is not available on the number of wells measured. The sites had a total of 9 storage wells.

Table 1 shows the screened population and measurement counts, from both measurement campaigns combined.

Table 1. GSI 2019 Screened Population and Measurement Counts

Component Type	Depleted Fields		Salt Dome	
	Screened Population	Measurement Count	Screened Population	Measurement Count
Valve, Large	433	46	142	31
Valve, Small	1,833	69	672	14
Connector, Flanged	1,376	38	854	13
Connector, Other	8,128	23	2,618	47
Pressure Relief Valve	0	0	20	2
Open-Ended Line	369	12	2	1
Meter	0	0	10	0
Gauge	522	23	138	6
Regulator	242	3	36	3
Total, Components	**12,903**	**214**	**4,492**	**117**
Total, Fields	**1**		**2**	
Total, Wellhead [a]	**43**		**9**	

a – Emission rates were not quantified at all wellheads, but all wellheads were screened for leaks during each measurement campaign.

GSI found that emissions from specific components at depleted field and salt dome wellheads did not differ significantly. The average count of component types at each wellhead were different, with the salt dome wells having higher average component counts for almost all component types. Average component type counts are shown in Table 2.

GSI calculated component-specific leaker EFs and population EFs for each of the six categories where measurements were taken. No measurements were taken at meters. Not all components where leaks were found by the FLIR or Gas Rover were measured, as only a subset of the total wellheads at the depleted field were sampled. In those cases, the unmeasured leaking components were incorporated into the population EF calculations by applying the leaker EF for a given component type to the number of emitting components identified but not measured. The component population EFs are also included in Table 2.

Table 2. GSI Average Component Counts Per Wellhead and Component Population CH_4 EFs

Component Type	Average Count Per Wellhead		CH_4 EF (scf/hr/component)
	Depleted Fields	Salt Domes	
Valve, All	26	45	0.10
Valve, Large	5	7.9	0.46
Valve, Small	21	37	0.016
Connector, All	111	197	0.0023
Connector, Flanged	16	47	0.0013
Connector, Other	95	145	0.0029
Pressure Relief Valve	0	1.1	0.10
Open-Ended Line	4.3	0.1	0.0053
Gauge	6.1	7.7	0.027
Regulator	2.8	2	0.009

2.2 Subpart W

Subpart W of the EPA's Greenhouse Gas Reporting Program (GHGRP) collects annual activity and emissions data on certain sources from underground natural gas storage facilities that meet a reporting threshold of 25,000 metric tons of CO_2 equivalent (mt CO_2e) emissions. Facilities that meet the subpart W reporting threshold have been reporting underground storage wellhead component leak emissions since reporting year (RY) 2011. EPA evaluated RY2015 through RY2018 data in this memo. The GHGRP data used in the analyses discussed in this memo are those reported to the EPA as of August 4, 2019. Table 3 presents the total number of reported wellhead components and the corresponding count of facilities for RY2015 through RY2018. While facilities report the number of wellhead components at a facility, they do not report the related number of wells.

Table 3. Subpart W Reported Underground Storage Wellhead Component Counts for RY2015 - RY2018

Component Type	2015	2016	2017	2018
Valves	52,557	47,688	44,082	43,521
Connectors	158,491	172,051	148,015	145,548
Open-Ended Lines	7,464	7,866	7,424	6,671
Pressure Relief Valves	1,692	1,447	1,257	1,249
Facilities Reporting	49	47	41	40

3 Analysis of Available Data

This section summarizes EPA's analyses of the GSI 2019 study and subpart W data and considerations to update the EF and activity data for underground storage wells in the 2021 GHGI.

3.1 Emission Factors

EPA first reviewed component EFs to assess their impact on 'per wellhead' EFs. Table 4 compares component EFs for the GRI/EPA 1996 study, subpart W (which also uses GRI/EPA 1996 EFs), and the GSI 2019 study.

Table 4. Underground Storage Wellhead Component CH_4 EF Comparison (scf/hr/component)

Component Type	1996 GRI/EPA	Subpart W	GSI 2019 Study
Valves	0.10	0.10	0.10
Connectors	0.01	0.01	0.0023
Open-Ended Lines	0.03	0.03	0.0053
Pressure Relief Valves	0.17	0.17	0.10

EPA also reviewed component count data and found that valves and connectors account for more than 90% of the total number of components present at underground storage wellheads (see Table 2, Table 3, and Table 9). Valve EFs are similar between each of the data sources, but the GSI Study measured lower emission rates for connectors.

EPA calculated a unique weighted average EF for wellheads at depleted fields and salt domes using the average component count per wellhead for each storage facility type and component-specific EFs from the GSI 2019 study (see Table 2). Table 5 presents the calculated EFs.

Table 5. Average Wellhead CH_4 EFs Calculated from GSI Data for Depleted Fields and Salt Domes

Storage Field Type	GSI Based CH_4 EF (scf/day/wellhead)
Depleted Field	72
Salt Dome	117

Next, EPA assessed underground storage field count data from the U.S. Energy Information Administration (EIA) (EIA-191) to determine how to calculate an overall average wellhead EF, taking into account the mix of storage field types. The distribution of storage field counts between each field type has little variation over the 2005-2018 time series (years of available data) in the EIA dataset. EPA calculated the average percentage of storage fields that are aquifers, depleted fields, and salt domes using data from 2005-2018; see Table 6. GSI measured wellhead emissions at one depleted field and two salt dome facilities and did not measure emissions from wellheads at aquifers. EPA applied an assumption that the component makeup of wellheads at aquifers most closely resembles that of depleted fields, but requests feedback on this assumption and other data on aquifer wellheads (see Section 6). EPA then calculated an overall weighted average EF to be applied to wells at all facility types. Table 6 shows the storage field type percentages and applicable EF, the calculated overall weighted average EF, and the current GHGI EF.

Table 6. Average Percentage of Storage Fields by Facility Type and Weighted Average CH_4 EF

Storage Field Type	EIA Average Percentage of Field Type, for 2005-2018	GSI Based CH_4 EF (scf/day/wellhead)
Aquifer	11%	72
Depleted Field	80%	72
Salt Dome	9%	117
Weighted Average CH_4 EF		**76**
Current GHGI EF		*115*

The GSI-based salt dome EF is comparable to the current GHGI EF but the GSI-based depleted field EF is lower. Because depleted fields account for a majority of the total underground storage fields, the calculated weighted average wellhead EF is lower than the current GHGI EF.

EPA also assessed emissions from storage well components on a per station basis. An approach using annual storage station estimates would require fewer assumptions than one using annual storage well count estimates (where an estimate of the total national number of storage wells would be developed by applying an assumed well count per unit of gas consumption or per station count, and the number of components on an aquifer wellhead would also be needed). A 'per station' EF requires data on the number of storage well components per station, which are available from subpart W; subpart W components per station are discussed in detail in Section 3.2. EPA calculated a 'per station' EF by multiplying the subpart W components per station (see Table 10) times the GSI study's component-specific EFs (see Table 4). The resulting emissions per station are summarized in Table 7. As previously noted, the distribution of storage fields between each field type has little variation over the time series and EPA applied the average percentage of each field type to the emissions per station to calculate a weighted average 'per station' EF; see Table 8.

Table 7. Underground Storage Wellhead Component CH_4 Emissions Per Station, by Field Type

Field Type / Component	Average Components per Facility, Based on Subpart W RY2015-2018	GSI Study Component CH_4 EF (scf/hr)	Station CH_4 EF (scf/day/station)
Depleted Fields			
Valves	1,030	0.1	2,472
Connectors	3,199	0.0023	177
OEL	188	0.0053	24
PRV	12	0.1	29
Total	**4,430**	N/A	**2,702**
Salt Domes			
Valves	198	0.1	474
Connectors	523	0.0023	29
OEL	5	0.0053	1
PRV	7	0.1	17
Total	**733**	N/A	**521**
Aquifers			
Valves	2,786	0.1	6,686
Connectors	10,887	0.0023	601
OEL	326	0.0053	41
PRV	195	0.1	468
Total	**14,194**	N/A	**7,796**

Table 8. Weighted Average Underground Storage Wellhead Component CH_4 Emissions Per Station

Field Type	EIA Average Percentage of Field Type, for 2005-2018	Station CH_4 EF (scf/day/station)
Aquifer	11%	7,796
Depleted Field	80%	2,702
Salt Dome	9%	521
Weighted Average CH_4 EF		**3,085**

3.2 Activity Data

EPA is considering updates to the activity data approach used to calculate underground storage well emissions in the 2021 GHGI. EPA is considering a 'per wellhead' EF that would be applied to an estimate of storage well counts and a 'per station' EF that would be applied to an estimate of storage station counts. Approaches to estimate underground storage well counts are discussed further below.

Underground storage station counts are already available in the GHGI and the 'per station' EF would be applied to these counts; additional analyses are not necessary for this approach and the number of wells is not needed. Underground storage field counts are available for certain years of the time series: 1992 (from GRI/EPA) and annually from 2005 to present from EIA. EPA applies a factor of 0.89 stations per field to develop the annual number of storage stations. For more information, please see the 2016 memo, *Inventory of U.S.*

Greenhouse Gas Emissions and Sinks 1990-2014: Revisions to Natural Gas Transmission and Storage Emissions.[4]

Underground storage well counts are not directly available in recent years, but several approaches are available to estimate well counts. An estimate of storage wells in the U.S. in 1992 was provided in AGA Gas Facts.. The current GHGI approach scales the 1992 value annually using residential gas consumption.

Alternate approaches EPA is considering to estimate storage well counts include:

- Retaining the current general approach to estimate storage well counts, but relying on total gas consumption rather than residential gas consumption to scale the 1992 estimate.
- Relating well counts to storage station counts because station counts are available for recent years and may be more closely related to well counts than consumption data. The following presents EPA's examination of activity data (component counts per wellhead and components per station) from the 1996 GRI/EPA study, the GSI 2019 study, and subpart W to assess the relationship between underground storage well counts and stations.

Table 9 compares the average component counts per wellhead from the GRI/EPA 1996 study and the GSI 2019 study and provides the wellheads per station found by GSI 2019.

Table 9. 1996 GRI/EPA and GSI 2019 Study Component Population Comparison

Component Type	1996 GRI/EPA		GSI 2019			
			Depleted Fields		Salt Dome	
	Avg. Count/ Wellhead	% of Total	Avg. Count/ Wellhead	% of Total	Avg. Count/ Wellhead	% of Total
Valve	30	24%	26	17%	45	18%
Connector	89	70%	111	74%	193	78%
Open-Ended Line	7	6%	4.3	3%	0.1	<1%
Pressure Relief Valve	1	<1%	0	0%	1.1	<1%
Other [a]	0	0%	8.9	6%	9.7	4%
Total	**127**	-	**150.2**	-	**248.9**	-
Stations	5		1		2	
Wellheads	Unknown		43		9	
Wellheads/Station	Unknown		43		4.5	

a – Includes gauges and regulators. Counts for these components are not available in the GRI/EPA study.

The GSI 2019 data indicates the average number of components per wellhead are very different for depleted field and salt dome wellheads, though the relative number of each component-type is similar. The GRI/EPA study did not identify the type of storage field evaluated, but the number of components per wellhead are similar to results for depleted fields from the GSI study. In addition, the GRI/EPA study aligns with the GSI 2019 study in that valves and connectors are the most prevalent component types.

Subpart W underground storage facilities report total storage well component counts (see Table 3) but do not directly report field type or well counts. EPA assigned each Subpart W facility to a field type by matching each Subpart W facility to a storage field in the EIA-191 dataset. Based on these assignments, Table 10 presents the average Subpart W component count per storage station, based on RY2015 through RY2018 data.

[4] https://www.epa.gov/sites/production/files/2016-08/documents/final_revision_ng_trans_storage_emissions_2016-04-14.pdf. Note that EPA has identified a potential error in the storage station counts for years 1990-2004 of the GHGI time series, please see Appendix D for additional detail.

Table 10. GHGRP RY2015 – RY2018 Average Component Counts Per Station, by Field Type

Component Type	Depleted Field		Salt Dome		Aquifer	
	Count	% of Total	Count	% of Total	Count	% of Total
Valve	1,030	23%	198	27%	2,786	20%
Connector	3,199	72%	523	71%	10,887	77%
Open-Ended Line	188	4%	5	1%	326	2%
Pressure Relief Valve	12	<1%	7	1%	195	1%
Total	4,430	-	733	-	14,194	-
Facility Count in 2018	27		8		5	

To develop an estimate of wellheads per station in the subpart W data, EPA used the Subpart W average number of components per facility (assuming that each facility is a single storage station) (Table 10) and the average number of components per wellhead from the GSI 2019 study (Table 9). Since valves and connectors account for more than 90% of the components, EPA only used counts for those two components in the calculations. The GSI 2019 study did not count components at aquifers, so EPA used the depleted field wellhead component counts for the wellheads per station calculations at aquifers (treating aquifers similarly to depleted fields is the same assumption applied in Section 3.1). Table 11 shows the average wellheads per station at each underground storage field type, based on the subpart W and GSI 2019 data.

Table 11. Average Wellheads Per Station Calculated Using Subpart W and GSI 2019 Data

Component Basis	Depleted Field	Salt Dome	Aquifer
Valve[a]	40	4	107
Connector[b]	29	3	98
Average Wellheads/Station	**34**	**3**	**103**

a - Calculated by dividing the Subpart W average number of wellhead valves per station (Table 10) by the GSI average number of valves per wellhead (Table 9).

b - Calculated by dividing the Subpart W average number of connectors per station (Table 10) by the GSI average number of connectors per wellhead (Table 9).

Similar to the EF calculations in Section 3.1, EPA calculated an overall average number of wellheads per station that accounts for all station types. As noted above, the distribution of EIA-191 storage field counts between each field type has little variation over the reported 2005 – 2018 time series. Therefore, EPA applied the average percentage of each field type to the average wellheads per station for each field type to calculate a weighted average wellheads per station value. Table 12 presents the field type percentages and average wellheads per station. Table 13 compares the underground storage station well counts calculated for the update under consideration to the current GHGI for year 2018.

Table 12. Average Percentage of Storage Fields by Facility Type and Average Wellheads Per Station

Storage Field Type	EIA Average Percentage of Field Type, for 2005-2018	Average Wellheads per Station
Aquifer	11%	103
Depleted Field	80%	34
Salt Dome	9%	3
Weighted Average		**39**
Current GHGI (1992 estimate)		*47*

Table 13. Comparison of Year 2018 Underground Storage Well Counts for the Update Under Consideration and Current GHGI

Parameter	Update Under Consideration	Current GHGI
Underground Storage Station Wellheads	13,636	19,089
Underground Storage Stations	343	343
Wellheads / Station	39	56

a - Since the current GHGI estimates well counts by scaling the 1992 well counts value using residential gas consumption, the estimate of wellheads per station varies over time. The number of wellheads per station ranges from 47 wellheads per station in early years of the time series (see Table 12) to 56 wellheads per station in year 2018.

4 Time Series Considerations

EPA is considering how to use the more recent data over the inventory time series, and the considerations are similar whether a 'per wellhead' EF or 'per station' EF is applied. To calculate emissions over the time series, EPA could replace the current GHGI EF with the more recent emissions data from the GSI 2019 study for the full time series or could retain the previous data for early years of the time series and apply the more recent data for more recent years. If the current GHGI EF is retained for early years (1990-1992), the EF would gradually decrease via linear interpolation to the weighted average EF under consideration which would be used for year 2017 (year of GSI measurements) and forward.

As shown in Table 6 for 'per wellhead' EFs, the current GHGI EF is similar to the updated EF for salt domes, but the updated weighted average EF is lower because the depleted field EF is lower and most storage stations are of this type.

The various activity data approaches discussed in section 3.2 have different impacts over the time series. Updating the activity data to rely on the average wellheads per station from subpart W and GSI study data leads to lower estimated wellhead counts over the entire time series than in the current GHGI, which uses residential gas consumption to scale wellhead counts each year. Approaches using station counts or well counts based on station counts result in similar trends as the key activity input (station counts) is the same. Scaling well counts with total gas consumption data would result in an increase in storage well counts in recent years of the time series compared with the current GHGI.

5 Preliminary National Emissions Estimates for Underground Storage Wells in the 2021 GHGI

Based on the data sources and considerations discussed in Sections 3 and 4, this section summarizes the approaches EPA is considering for the 2021 GHGI. EPA is considering updates to both the EF and the activity data for underground storage wells.

EPA is considering two different approaches to develop storage well counts:

1. EPA applied the activity factor discussed in section 3.2 (39 wells per storage station) to the storage station counts that are already estimated in the GHGI for 2015 through 2018, retained the current GHGI well counts for 1990 through 1992, and applied linear interpolations between 1992 and 2015 (see "Well counts based on AF and station counts" in Table 14)
2. Scaled the 1992 well estimate to all other years using total gas consumption (see "Well counts scaled using total gas consumption" in Table 14)

EPA is considering two different EF approaches, applicable to both 'per wellhead' and 'per station' EFs:

1. EPA applied the weighted average EF from the GSI study in Table 6 or Table 8 over the time series (see "GSI EF all years" in Table 14)
2. EPA applied the weighted average EF from the GSI study in Table 6 or Table 8 to recent years (2017 through 2018) and the current GHGI EF to early years (1990 through 1992), with linear interpolation between 1992 and 2017 (see "GRI EF and GSI EF with interpolation between" in Table 14)

If EPA uses a 'per station' EF, then EPA would apply the station counts that already exist in the GHGI (see "Station counts from GHGI" " in Table 14)

Table 14 summarizes the results for each scenario for the underground storage wells update under consideration for select years. Appendix A provides time series emissions data for each scenario, and Appendix B provides time series activity data for each scenario.

Table 14. Underground Storage Well Component Leak CH_4 Emissions Estimates Calculated by Various Approaches (mt CH_4)

EF Approach	Activity Approach	1992	2005	2018
Well-based Approaches				
Current GHGI - GRI EF all years	*Well counts scaled using residential gas consumption*	*14,488*	*14,910*	*15,365*
GSI EF all years	Well counts based on station counts	9,616	7,744	7,139
GRI EF and GSI EF with interpolation between		14,488	9,627	7,139
GSI EF all years	Well counts scaled using total gas consumption	9,616	10,464	14,241
GRI EF and GSI EF with interpolation between		14,488	13,008	14,241
Station-based Approaches				
GSI EF all years	Station counts from GHGI	8,371	7,431	7,431
GRI EF and GSI EF with interpolation between		14,488	10,037	7,431

6 Requests for Stakeholder Feedback

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

1. EPA seeks feedback on the most appropriate EFs to apply for underground storage wells. This includes whether average EFs using the GSI 2019 data should be applied or if the current GHGI EFs should be retained.
2. EPA seeks feedback on whether a 'per station' or 'per wellhead' EF approach is appropriate.
3. EPA seeks feedback on the potential application of different EFs over the time series. EPA is considering applying the current GHGI EF to early years of the time series and the weighted average EF calculated from GSI data to recent years, with linear interpolation between.
4. EPA seeks feedback on factors that may have decreased emissions per storage well over the time series.
5. EPA seeks feedback on whether the wellhead EF for depleted fields or for salt domes from the GSI 2019 study is most applicable to wellhead emissions from aquifers. EPA applied the depleted field wellhead EF to aquifers to calculate the weighted average EF in Table 6. Alternatively, EPA seeks average component counts for aquifer wellheads that could be paired with the component EFs in Table 2 to estimate an aquifer wellhead EF.

6. EPA seeks feedback on the GSI 2019 study, including on whether data collected in the sampling period (March and October) can be used to represent average annual emissions.
7. EPA seeks feedback on an approach relying on storage well counts under consideration, which applies an average of 39 wellheads per storage station to estimate well counts and has resulted in a decrease in the number of storage wells over time instead of relying on residential gas consumption to scale the 1992 estimate of wells.
8. EPA is considering revising its approach for estimating storage station counts from 1990-2004. Please see Appendix D for more information. EPA seeks feedback on its assessment of the 1992 station count value from GRI/EPA, i.e., that it represents the count of storage fields and not storage stations. EPA seeks feedback on approaches to update the 1990-2004 time series with an EIA data set on storage fields instead of using the GRI/EPA value and interpolation. If implemented, this update would have no impact on station count estimates for 2005-2019, and would result in an average decrease of 4% in the station counts estimated for 1990-2004.

Appendix A – Time Series CH_4 Emissions (metric tons) for the Update Under Consideration for Underground Storage Wells

Approach	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Well-based Approaches															
Current GHGI	13,565	14,073	14,488	15,311	14,975	14,983	16,191	15,395	13,963	14,598	15,433	14,739	15,102	15,690	15,040
GSI EF, well counts based on station counts	9,004	9,341	9,616	9,466	9,323	9,160	9,020	8,880	8,721	8,584	8,447	8,292	8,158	8,025	7,875
GRI and GSI EF interpolated, well counts based on station counts	13,565	14,073	14,488	14,069	13,667	13,244	12,858	12,478	12,078	11,714	11,357	10,981	10,638	10,302	9,949
GSI EF, well counts scaled using total gas consumption	9,115	9,300	9,616	9,883	10,101	10,557	10,748	10,809	10,576	10,651	11,092	10,572	10,937	10,590	10,644
GRI and GSI EF interpolated, well counts scaled using total gas consumption	13,732	14,011	14,488	14,690	14,808	15,263	15,322	15,190	14,647	14,536	14,913	14,000	14,262	13,594	13,447
Station-based Approaches															
GSI EF, station count from GHGI	7,838	8,131	8,371	8,299	8,227	8,154	8,082	8,010	7,937	7,865	7,793	7,720	7,648	7,576	7,503
GRI and GSI EF interpolated, station count from GHGI	13,565	14,073	14,488	14,120	13,757	13,397	13,042	12,692	12,345	12,003	11,665	11,331	11,001	10,676	10,354

Approach	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Well-based Approaches														
Current GHGI	14,910	13,494	14,586	15,112	14,763	14,772	14,562	12,820	15,127	15,714	14,250	13,428	13,629	15,365
GSI EF, well counts based on station counts	7,744	7,749	7,634	7,718	7,681	7,644	7,627	7,570	7,551	7,475	7,269	7,214	7,195	7,139
GRI and GSI EF interpolated, well counts based on station counts	9,627	9,476	9,181	9,126	8,926	8,729	8,554	8,337	8,163	7,929	7,564	7,360	7,195	7,139
GSI EF, well counts scaled using total gas consumption	10,464	10,309	10,983	11,066	10,891	11,451	11,636	12,141	12,434	12,642	12,952	13,047	12,888	14,241
GRI and GSI EF interpolated, well counts scaled using total gas consumption	13,008	12,607	13,209	13,084	12,657	13,075	13,051	13,371	13,442	13,411	13,477	13,311	12,888	14,241
Station-based Approaches														
GSI EF, station count from GHGI	7,431	7,489	7,431	7,586	7,605	7,624	7,682	7,682	7,721	7,721	7,566	7,508	7,489	7,431
GRI and GSI EF interpolated, station count from GHGI	10,037	9,897	9,603	9,581	9,383	9,184	9,029	8,805	8,623	8,398	8,009	7,728	7,489	7,431

Appendix B – Underground Storage Well Counts and Station Counts Over the Time Series for the Update Under Consideration for Underground Storage Wells

Approach	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Well Counts - Current GHGI	16,853	17,483	17,999	19,021	18,604	18,614	20,115	19,126	17,347	18,136	19,174	18,311	18,762	19,493	18,685
Well Counts Based on AF and Station Counts	16,853	17,483	17,999	17,717	17,449	17,145	16,882	16,620	16,323	16,066	15,810	15,521	15,270	15,021	14,739
Well Counts Scaled Using Total Gas Consumption	17,061	17,406	17,999	18,499	18,906	19,760	20,117	20,232	19,794	19,936	20,762	19,788	20,472	19,822	19,922
Station Counts - Current GHGI	361	375	386	383	379	376	373	369	366	363	359	356	353	349	346

Approach	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Well Counts - Current GHGI	18,524	16,765	18,122	18,774	18,340	18,352	18,091	15,926	18,793	19,522	17,703	16,682	16,932	19,089
Well Counts - Based on AF and Station Counts	14,494	14,503	14,289	14,446	14,377	14,308	14,275	14,169	14,133	13,991	13,606	13,502	13,467	13,363
Well Counts - Scaled Using Total Gas Consumption	19,585	19,295	20,558	20,712	20,385	21,433	21,780	22,724	23,273	23,662	24,242	24,420	24,122	26,655
Station Counts - Current GHGI	343	345	343	350	351	352	354	354	356	356	349	346	345	343

Appendix C – GSI 2019 Study Design Information

Storage Field Type	Measurement Type	Number of Sources	Location and Representativeness	EF Calculation Method
Depleted Field	If leak detected, custom high flow sampler used to measure fugitive emissions at components	1 facility; components at 29 wells were measured with high flow and used to develop component counts. 43 wells were present at the site	Single facility in Utah	GSI developed component population EFs based on the components sampled.
Salt Dome	If leak detected, custom high flow sampler used to measure fugitive emissions at components	2 facilities; 9 wells were present at the sites	Two facilities in the Gulf Coast region	GSI developed component population EFs based on the components sampled.

Appendix D– Storage Station Counts for Early Years of Time Series

The current GHGI methodology to quantify storage station counts differs by year of estimate:

- Year 2005 forward: active field counts (from EIA-191,[5] referred to in this memo as Detailed EIA-191) are multiplied by a factor of 0.89 stations/field (from Zimmerle et al. 2015)
    - Field counts from Detailed EIA-191 for 2005 forward are shown in Table 15.
    - The corresponding estimated station count for 2005 forward is shown under "Stations (Current GHGI)"
- Year 1992: use of a value of 386 stations from the GRI/EPA study. This value is highlighted orange in "Stations (Current GHGI)" in Table 15
    - When updating the underground storage methodology in 2016, after assessing the GRI/EPA terminology and due to a lack of other data, EPA retained the existing assumption for 1992.
- Years 1993-2004: station counts are estimated using linear interpolation from 1992 value (386) and 2005 value (343). The cells highlighted green for "Stations (Current GHGI)"are those estimated using linear interpolation
- Years 1990-1991: The 1992 station count is scaled using residential gas consumption.

An additional EIA dataset[6] (referred to in this memo as Simple EIA-191) provides an annual number of existing storage fields (existing = active + inactive) over the full GHGI time series. The storage field counts from the Simple EIA-191 dataset are also shown Table 15. Comparing the Detailed EIA-191 and Simple EIA-191 datasets, the count of active plus inactive fields generally shows agreement over 2005 through 2018. Based on this comparison, EPA is considering the Simple EIA-191 dataset as a reference for total field counts over the entire time series. With this, we compared the 1992 value from the GRI/EPA study (386 storage stations, in orange) to the Simple EIA-191 dataset (388 storage fields, in yellow) and they are very similar. This indicates the 1992 estimate in the GRI/EPA data is the number of storage fields and not stations.

Using the Simple EIA-191 data set would result in a revision to the station count methodology for 1990-2004. EPA would apply an assumption to the count of total fields to determine the number of active fields. For this initial analysis, EPA applied the 2005 inactive field count (9 inactive fields) to all prior years to estimate active fields counts; 2005, 2006, and 2008 agree with about 8-9 inactive fields for those years, and EPA assumed those years were most representative of years prior to 2005. The updated full time series of active fields is shown under the "Update Under Consideration" heading in Table 15. EPA then applied the Zimmerle et al. ratio of 0.89 stations/field to estimate stations over the time series, which is also shown under the "Update Under Consideration" heading in Table 15. The 1992 station count decreases from 386 in the current GHGI to 337 with the updated approach. If implemented, this update would have no impact on station count estimates for 2005-2019, and would result in an average decrease of 4% in the station counts estimated for 1990-2004. This update would impact several sources in the underground storage segment, but only for years prior to 2005.

[5] https://www.eia.gov/naturalgas/ngqs/#?report=RP7&year1=2005&year2=2019&company=Name

[6] https://www.eia.gov/dnav/ng/NG_STOR_CAP_A_EPG0_SAD_COUNT_A.htm

Table 15 Active and Inactive Fields (Detailed EIA Dataset)

Approach	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Stations (Current GHGI)	361	375	386	383	379	376	373	369	366	363	359	356	353	349	346
Detailed EIA-191															
Active Field Counts															
Inactive Field Counts															
Active + Inactive Fields															
Simple EIA-191															
Active Field Counts	383	378	379	380	388	394	397	409	401	404	404	409	398	382	384
Inactive Field Counts[a]	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Active + Inactive Fields	392	387	388	389	397	403	406	418	410	413	413	418	407	391	393
Update Under Consideration															
Active Fields	383	378	379	380	388	394	397	409	401	404	404	409	398	382	384
Stations	341	336	337	338	345	351	353	364	357	360	360	364	354	340	342

a – Inactive field counts equal active plus inactive fields from Simple EIA-191 minus the active field counts from detailed EIA-191. This value was set equal to 9 for 1990 through 2004, based on 2005, 2006, and 2008 data.

Approach	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Stations (Current GHGI)	343	345	343	350	351	352	354	354	356	356	349	346	345	343
Detailed EIA-191														
Active Field Counts	385	388	385	393	394	395	398	398	400	400	392	389	388	385
Inactive Field Counts	10	9	8	9	15	16	12	16	18	18	23	26	26	25
Active + Inactive Fields	395	397	393	402	409	411	410	414	418	418	415	415	414	410
Simple EIA-191														
Active Field Counts	385	388	385	393	394	395	398	398	400	400	392	389	388	385
Inactive Field Counts[a]	9	9	15	8	15	16	12	16	19	18	23	26	26	25
Active + Inactive Fields	394	397	400	401	409	411	410	414	419	418	415	415	414	410
Update Under Consideration														
Active Fields	385	388	385	393	394	395	398	398	400	400	392	389	388	385
Stations	343	345	343	350	351	352	354	354	356	356	349	346	345	343

a – Inactive field counts equal active plus inactive fields from Simple EIA-191 minus the active field counts from detailed EIA-191. This value was set equal to 9 for 1990 through 2004, based on 2005, 2006, and 2008 data.