American Petroleum Institute

anga
America's Natural Gas Alliance

Characterizing Pivotal Sources of Methane Emissions from Natural Gas Production

Summary and Analysis of API and ANGA Survey Responses

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Executive Summary

This document presents the updated results from a collaborative effort among members of the American Petroleum Institute (API) and America's Natural Gas Alliance (ANGA) to gather data on key natural gas production activities and equipment emission sources that are essential to developing estimates of methane emissions from upstream natural gas production.

API and ANGA members undertook this effort as part of an overall priority to develop new and better data about natural gas production and make this information available to the public. This information acquired added importance in 2011, when the EPA released an inventory of U.S. greenhouse gases (GHG) emissions that substantially increased estimates of methane emissions from Petroleum and Natural Gas Systems. Public comments submitted by both trade associations reflected a number of concerns – most notably that EPA's estimates were based on a small set of data submitted by a limited number of companies in a different context (i.e., data not developed for the purpose of estimating nationwide emissions).

The API/ANGA data set (also referred to as ANGA/API) provides data on 91,000 wells distributed over a broad geographic area and operated by over 20 companies. This represents nearly one-fifth (18.8%) of the estimated number of total wells used in EPA's 2010 emissions inventory.[1] The ANGA/API data set is also more than 10 times larger than the set of wells in one of EPA's key data sources taken from an older Natural Gas Star sample that was never intended for developing nationwide emissions estimates. ***Although more and better data efforts will still be needed, API/ANGA members believe this current collaborative effort is the most comprehensive data set compiled for natural gas operations.***

As Table ES-1 demonstrates, survey results in two source categories – liquids unloading and unconventional gas well re-fracture rates - substantially lower EPA's estimated emissions from natural gas production. The right-hand column of this table shows the impact of ANGA/API data on the estimated emissions for each source category. Gas well liquids unloading and the rate at which unconventional gas wells are re-fractured are key contributors to the overall GHG emissions estimated by EPA in the national emissions inventory. For example, methane emissions from liquids unloading and unconventional well re-fracturing accounted for 59% of EPA's estimate for overall natural gas production sector methane emissions. Overall, API/ANGA activity data for these two source categories indicate that EPA estimates of potential emissions from the production sector of "Natural Gas Systems" would be 53% lower if EPA were to use ANGA/API's larger and more recent survey results.

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[1] EPA's 2010 national inventory indicates a total of 484,795 gas wells (EPA, 2012).

TABLE ES-1. EMISSION COMPARISON BETWEEN EPA AND INDUSTRY DATA

Source Category	EPA		API/ANGA		Impact on Source Category Emissions
	Metric tons of CH4	% of EPA Emissions Total	Metric tons of CH4	% of Revised Emissions Total	API & ANGA - EPA EPA % Difference
Gas Wells Liquids Unloading	4,501,465 *	51%	319,664	8%	-93%
Unconventional Well Re-fracture Rates	712,605 *	8%	197,311	5%	-72%
Other Production Sector Emissions**	3,585,600	41%	3,585,600	87%	
Total Production Sector Emissions	8,799,670		4,102,575		-53%

* EPA's estimates are adjusted to industry standard conditions of 60 degrees F and 14.7 psia for comparison to the ANGA/API emission estimates.

**The "Other Production Sector Emissions" are comprised of over 30 different source categories detailed in Table A-129 in the Annex of the EPA's 2012 national inventory. The "Other Production Sector Emissions" are the same values for this comparison between the EPA national inventory and the API/ANGA survey to focus the comparison on quantified differences in emission estimates for gas well liquids unloading and unconventional well re-fracture rates.

As mentioned above, the differences between EPA and ANGA/API estimates hinge on the following key differences in activity data and thus considerably impact overall emissions from Natural Gas Systems:

- ***Liquids unloading and venting.*** API/ANGA data showed lower average vent times, a significantly lower percentage of wells venting for liquids unloading, and a higher number of vents per vented well than EPA assumed in their inventory calculation. The API/ANGA survey also found a slightly larger percentage of wells with plunger lifts than EPA assumed, but a significant percentage of wells with artificial lift which EPA had not considered. These findings are particularly significant because liquids unloading accounted for 51% of EPA's total "Natural Gas Systems" methane emissions in the 2010 inventory. Applying emission factors based on ANGA/API data reduces the calculated emissions for this source by 93% (from 4,501,465 metric tons of CH_4 to 319,664 metric tons of CH_4 when compared on an equivalent basis) from EPA's 2010 national GHG inventory.
- ***Re-fracture rates for unconventional wells***. API/ANGA members collected data on re-fracture rates for unconventional wells in two phases. The first phase collected data for all well types (conventional and unconventional), while the second phase targeted unconventional gas wells. Both phases of the survey data show significantly lower rates of well re-fracturing than the 10% assumption used by EPA. As discussed in detail in

this report, the re-fracture rate varied from 0.7% to 2.3%. The second phase of the survey gathered data from only unconventional well activity and using the re-fracture rate data from this second phase of the ANGA/API survey reduces the national emission estimate for this source category by 72%, - from 712,605 metric tons of CH_4 to 197,311 metric tons of CH_4 when compared on an equivalent basis.

This report also discusses an important related concern that the government lacks a single coordinated and cohesive estimate of well completions and well counts. Although the 2010 national GHG inventory appears to under-represent the number of well completions according to the numbers reported through both the API/ANGA data and IHS CERA, differences in national well data reporting systems make it difficult to accurately investigate well completion differences with any certainty. The EPA inventory, which uses data from the Energy Information Administration, various state governments and privately sourced data, such as HPDI, does not consistently distinguish between conventional and unconventional wells.

The concept of conventional and unconventional wells is used differently by different stakeholders, is not particularly helpful from an emissions standpoint, and should be abandoned in favor of classifications more relevant to the emission source categories being evaluated. For instance, the scale of emissions from well completions is primarily associated with whether the wells are hydraulically fracture stimulated, the size/stages of the hydraulic fracture stimulation, and practices for handling the well clean-up/flow-back post fracture stimulation.

Without a consistent measure for the quantity and type of wells, it is difficult to be confident of the accuracy of the number of wells that are completed annually, let alone the amount of emissions from them. Natural gas producers strongly believe that the effects of any possible under-representation of well completions will be offset by a more realistic emission factor for the rate of emissions per well. Analysis of the data reported under Subpart W of the GHG reporting rule should be used to inform a more realistic emission factor for well completions.

This survey also collected data on centrifugal compressors and pneumatic controllers. While the sample sizes are too small to make strong conclusions, the results discussed in the body of the report indicate that further research is necessary to accurately account for the different types of equipment in this area (e.g., wet vs. dry seal centrifugal compressors and “high bleed,” “low bleed,” and “intermittent bleed” pneumatic controllers).

As government and industry move forward in addressing emissions from unconventional gas operations, three key points are worth noting:

- ***In addition to the voluntary measures undertaken by industry, more data will become available in the future.*** Emission reporting requirements under Subpart W of the national Greenhouse Gas Reporting Program (GHGRP) went into effect January 1, 2011 with the first reporting due in the fall of 2012. As implementation of the GHGRP progresses from year to year, the natural gas industry will report more complete and more accurate data. If EPA makes use of the data submitted and transparently communicates their analyses, ANGA/API members believe this will increase public confidence in the emissions estimated for key emission source categories of the Natural Gas Systems sector.

- ***Industry has a continuous commitment to improvement.*** It is clear that companies are not waiting for regulatory mandates or incentives to upgrade equipment, or to alter practices like venting and flaring in favor of capturing methane where practical. Instead, operators are seizing opportunities to reduce the potential environmental impacts of their operations. Industry is therefore confident that additional, systematic collection of production sector activity data will not only help target areas for future reductions but also demonstrate significant voluntary progress toward continually 'greener' operations.
- ***Members of industry participating in this survey are committed to providing information about the new and fast-changing area of unconventional oil and gas operations. API and ANGA members look forward to working with the EPA to revise current assessment methodologies as well as promote the accurate and defensible uses of existing data sources.***

1. Overview

The accuracy of GHG emission estimates from natural gas production has become a matter of increasing public debate due in part to limited data, variability in the complex calculation methodologies, and assumptions used to approximate emissions where measurements in large part are sparse to date. Virtually all operators have comprehensive methane mitigation strategies; however, beyond the requirements of the Environmental Protection Agency's (EPA) Mandatory Reporting Rule or incentives of programs like the EPA's Natural Gas Star program, data is often not gathered in a unified way that facilitates comparison among companies.

In an attempt to provide additional data and identify uncertainty in existing data sets, the American Petroleum Institute (API) and America's Natural Gas Alliance (ANGA) began a joint study on methane (CH_4) emissions from natural gas production operations in July 2011. The first part of this section offers context to the decision to conduct this survey, while the second offers a brief introduction to the survey itself.

1.1 Context

Onshore gas resources, including shale, will undoubtedly play a key role in America's energy future, and additional information must be collected to better quantify the methane emissions from natural gas production. Meaningful, publicly available data is a priority, especially in light of EPA's 2011 revision of its calculation methodology for Natural Gas Systems in the 2009 national inventory (EPA, 2011c). (EPA added two new sources for unconventional gas well completions and workovers, and also significantly revised its estimates for liquids unloading and made adjustments to other source categories.) These changes substantially increased EPA's estimated GHG emissions for the production sector of the Natural Gas Systems by 204%. Equally problematic is the methodology used by EPA to credit voluntary and regulatory reductions from the emissions reported in Table A-128 in the 2010 inventory. These reductions are taken as a "lump sum" reduction at the segment (e.g. production) level with no transparency of what source categories the reductions are applied towards. Presentation of the pre-reduction values in Table A-129 (over a 300% increase) coupled with lack of source specific transparency has led many stakeholders to use the emissions in Table A-129 directly in their various advocacy actions. API recommends that the EPA change their methodology of crediting reductions to be transparent down to the source type/category and that the post-reduction emissions be reported in the future analogues to Table A-129.

Industry was alarmed by the upward adjustment, especially since previous EPA estimates had been based on a 1996 report prepared by the EPA and GRI – and did not take into account the considerable improvements in equipment and industry practice that have occurred in the fifteen years between 1996 and 2011 (GRI, 1996).

An EPA technical note to the 2009 inventory attributed the changes to adjustments in calculation methods for existing sources, including gas well liquids unloading, condensate storage tanks, and centrifugal compressor seals. EPA also added two new sources not previously included in its inventories, namely unconventional gas well completions and workovers (re-completions) (EPA, 2011f).

Industry did not have an adequate opportunity to examine EPA's rationale for the new emissions factor prior to its initial release due to the structure of the inventory process and the lack of formal opportunity for meaningful input. Unlike changes in regulatory requirements, EPA is not required to initiate a formal comment process for changes in methodologies like emission factors and calculations methods in the national GHG inventory. As such, EPA is not compelled to incorporate or consider input provided by stakeholders and experts. Indeed, changes to methodologies are often made without the benefit of dialogue or expert review. Although EPA further acknowledged in the 2010 inventory (released in 2012), that their natural gas calculations needed work, their practice is to continue using the same numbers until adjusted estimates have been made. It is important to note that EPA has indicated a willingness to engage and discuss this matter with some members of industry. API and ANGA look forward to working collaboratively with EPA to improve the national GHG inventory.

Under the best of circumstances, EPA had remarkably little information to draw on in determining their new emission estimates. Input from industry on this topic was not directly solicited, specific guidance or information did not exist on the international level, nor was it available from other national regulators. A review of the Intergovernmental Panel on Climate Change (IPCC) and other inventories submitted to the United Nations Framework Convention on Climate Change (UNFCCC) indicate that the U.S. is currently the only country to date to differentiate between conventional and unconventional natural gas production. As discussed above, the distinction between conventional and unconventional natural gas production is not particularly useful from an emission estimation standpoint and should be abandoned. Regulators, academics, and environmentalists around the world therefore considered the new estimated emission factor as an unprecedented development in a controversial issue.

Widespread criticism of the figures and analysis of the assumptions and methodologies revealed problematic methodology and less justification for the underlying numbers than originally anticipated. In a paper entitled *Mismeasuring Methane*, the well-respected energy consultancy IHS CERA succinctly detailed several concerns about the revisions – most notably that EPA's new estimate was based on only four (4) data points that natural gas well operators had submitted voluntarily under the Natural Gas Star Program, which highlights emissions reductions. Together, the four data points cover approximately 8,880 wells – or roughly 2% of those wells covered in the EPA's national greenhouse gas inventory. Those numbers, which were submitted in the context of showcasing achieved emissions reductions and not to estimate emissions, were then extrapolated to over 488,000 wells in the 2009 emissions inventory (IHS CERA, 2011).

With an emerging topic like shale energy development, however, the impact of EPA's revised estimates was, and continues to be, enormous. Emission estimates from production using EPA's figures were used to question the overall environmental benefits of natural gas and have led to speculation of the role natural gas can play in a clean energy future.. They were cited widely by unconventional gas opponents - many of whom used the new figures selectively, inappropriately using the pre-reduction (voluntary and regulatory) figures, and without caveats like "estimated" to argue against further development of shale energy resources. For example, an article published by ProPublica cited the revised EPA emission factors as "new research" which "casts doubt" on whether natural gas contributes lower GHG emissions than other fossil fuels (Lustgarten, 2011). Many of these studies – e.g., the work of Howarth *et al.* were widely reported in the popular press (Zellers, 2011) with little attention to the quality of analysis behind their conclusions.

Notably, other authors using more robust and defensible scientific methodologies argued that - even with undoubtedly high emissions estimates - natural gas still possessed a lifecycle advantage when its comparative efficiency in electricity generation was taken into account. For example, a study by Argonne National Laboratory utilizing the same EPA data sources concluded that taking into account power plant efficiencies, electricity from natural gas shows significant life-cycle GHG benefits over coal power plants (Burnham, 2011). Unfortunately, the complex technical arguments in these studies generated considerably less media and public attention.

It is important to understand that the ongoing debate about the accuracy of EPA's adjusted emission factor as contained in the 2009 inventory did not keep these numbers from being used in a series of rules that have wide ranging ramifications on national natural gas policies both in the United States and globally. Many countries considering shale energy development remain bound by the emissions reduction targets in the Kyoto Protocol and their regulatory discussions reflect greenhouse gas concerns. In addition to the very real risk that other countries could adopt the emission factor before the EPA can refine its calculations, the possibility of higher emissions (even if only on paper) might deter other nations from developing their own unconventional energy resources.

By the summer of 2011, it was clear to ANGA/API members (also referred to as API/ANGA members) that gathering additional data about actual emissions and points of uncertainty during unconventional gas production was essential to improve GHG life cycle analysis (LCA) of natural gas for the following reasons: 1) to focus the discussion of emissions from natural gas production around real data; 2) to promote future measurement and mitigation of emissions from natural gas production; and 3) to contribute to improving the emission estimation methods used by EPA for the natural gas sector in their annual national GHG inventory and its use globally.

1.2 Introduction to the API/ANGA Survey

API and ANGA members uniformly believed that EPA's current GHG emissions estimates for the natural gas production sector were overstated due to erroneous activity data in several key areas - including liquids unloading, well re-fracturing, centrifugal compressors, and pneumatic controllers. Members worked cooperatively to gather information through two data requests tailored to focus on these areas and collect reasonably accessible information about industry activities and practices. Specifically, information was requested on gas well types, gas well venting/flaring from completions, workovers, and liquids unloading, and the use of centrifugal compressor and pneumatic controllers.

The actual data requests sent to members can be found in Appendix A, and Appendix B provides more detailed data from the ANGA/API well survey information**.**

Survey results and summaries of observations, including comparisons to EPA's emission estimation methods, are provided in the following sections.

2. Well Data

This section examines well data gathered by API and ANGA members. Overall, ANGA/API's survey effort gathered activity data from over 20 companies covering nearly 91,000 wells and 19 of the 21 American Association of Petroleum Geologists (AAPG) basins[2] containing over 1% of the total well count in EPA's database of gas wells. Members believe that the API/ANGA survey represents the most comprehensive data set compiled for natural gas operations and, as such, provides a much more accurate picture of operations and emissions than the information EPA has relied on for its emission estimates.

Information to characterize natural gas producing wells was collected by survey in two parts:

- The first part of the survey requested high-level information on the total number of operating gas wells, the number of gas well completions, and the number of gas well workovers with hydraulic fracturing. Data on over 91,000 wells was collected primarily for 2010, with some information provided for the first half of 2011.
- The second part of the survey requested more detailed well information about key activities. The well information collected through the two surveys is provided in Appendix B.

Section 2.1 looks at overall natural gas well counts, Section 2.2 examines completion data from ANGA/API members, and Section 2.3 briefly identifies several unresolved issues concerning well counts and classifications that could benefit from future analysis for examination. For the purposes of this report, unconventional wells are considered to be shale gas wells, coal bed wells, and tight sand wells which must be fractured to produce economically.

2.1 National Gas Well Counts

To provide context for the information collected by API and ANGA, comparisons were made to information about national gas wells from EPA and the U.S. Energy Information Administration (EIA). Unfortunately, the government lacks a single coordinated and cohesive set of estimates for gas wells.

Industry grew concerned when it became apparent that significant discrepancies existed among different sources of national gas well data. The EPA inventory, the EIA, and IHS data EPA published in conjunction with the GHGRP all reported different well counts that do not consistently distinguish between key areas used by the inventory like conventional and unconventional wells. Furthermore, there does not appear to be a single technical description for classifying wells that is widely accepted. Without consistent measures and definitions for the

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[2] Basins are defined by the American Association of Petroleum Geologists (AAPG) AAPG–CSD Geologic Provinces Code Map: AAPG Bulletin, Prepared by Richard F. Meyer, Laure G. Wallace, and Fred J. Wagner, Jr., Volume 75, Number 10 (October 1991) and the Alaska Geological Province Boundary Map, Compiled by the American Association of Petroleum Geologists Committee on Statistics of Drilling in Cooperation with the USGS, 1978.

quantity and type of wells, it is difficult to reach agreement on the number of hydraulically fractured and unfractured natural gas wells completed annually - let alone their emissions.

Both the EIA data and the EPA data accompanying the national GHG inventory lack sufficient detail for well classifications to provide a basis for helpful comparison with the survey data reported here. Instead, national well data developed as part of mandatory emissions reporting is used for comparison because it has the most appropriate level of detail in well categories (EPA, 2011e).

In EPA's database gas well count (EPA, 2011e), 21 of the AAPG basins each have more than 1% of the total well count. The API/ANGA survey has wells from 19 of those 21 basins. In terms of wells represented by these basins, 92% of the total EPA database well count is accounted for by wells in those 21 basins, while 95% of the ANGA/API surveyed gas wells are accounted for by those 21 basins. These results are summarized in Table 1 and illustrated in Figure 1. This indicates that the API/ANGA survey results have good representation for the basins with the largest numbers of wells nationally.

TABLE 1. COMPARISON OF GAS WELL COUNT DATA BY AAPG BASIN: SUMMARY STATISTICS

	EPA Database Gas Well Count*	API/ANGA Survey Data	ANGA/API as a % of EPA
Total number of U.S. gas wells	355,082 gas wells	91,028 gas wells	26%
Number of significant AAPG basins**	21 basins	Data on wells in 19 of those 21 basins	90%
Number of wells in significant AAPG basins	325,338 wells	86,759 wells	27%
% of total wells in significant AAPG basins	92%	95%	

[*] EPA's database gas well count (EPA, 2011e) differs from the well count provided in EPA's 2010 national inventory, but provides more detail on the types of wells. Additional details are provided in Appendix B.

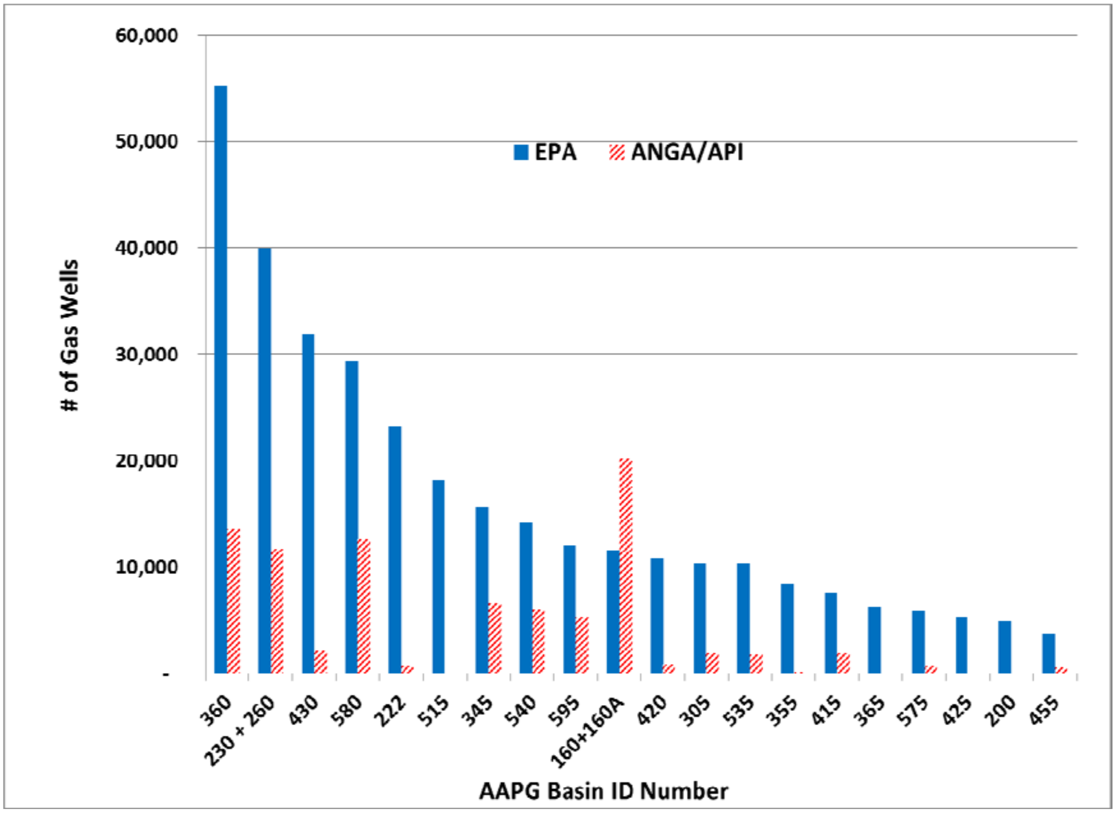
[**] Significant basins are defined as basins with more than 1% of the total national gas wells.

As shown in Figure 1, the API/ANGA survey results more heavily represent gas wells in specific AAPG basins when compared to EPA's basin-level well counts (EPA, 2011d). Unlike the EPA data, the ANGA/API data is more heavily influenced by AAPG 160 and 160A. AAPG basins 360, 230, and 580 are important for both data sets.

The smaller data set provided by EPA (2011e) may not include all of the Marcellus shale wells (particularly in Pennsylvania), and the well classification system used in this smaller data set could probably be made more rigorous. Although this comparison may not show a perfect distributional match for the basin by basin distribution of the API/ANGA survey data presented here, it does not change the fundamental conclusion that the ANGA/API survey information is the largest and most representative data set yet collected for onshore U.S. gas production, since this data set does cover 90% of the basins and 27% of the national gas well count for the significant basins as reported by EPA (EPA, 2011e). The data discussed in this report provides substantial new information for understanding the emissions from Natural Gas Systems and offers a compelling justification for re-examining the current emission estimates for unconventional gas wells.

Appendix B contains more detail about the industry well data sample compared to the overall data maintained by the government. Unless otherwise noted, further statistical comparisons of well data throughout this paper are done with reference to the EPA data furnished with the Subpart W sub-basin categorization because it was the only one which effectively parsed the data by well type (EPA, 2011e).

FIGURE 1. COMPARISON OF EPA TO API/ANGA GAS WELL COUNT DATA BY AAPG BASIN



2.2 Gas Well Completions

Acknowledging the somewhat different time periods covered, the API/ANGA survey data represents 57.5% of the national data for tight gas well completions and 44.5% of shale gas well completions, but only 7.5% of the national conventional well completions and 1.5% of coal-bed methane well completions. About one-third of the surveyed well completions (2,205) were not classified into the well types requested (i.e., tight, shale, or coal-bed methane) by the respondents. The survey results for well completions are provided in Table 2 and compared to national data provided to ANGA by IHS.[3]

[3] Data provided in e-mail from Mary Barcella (IHS) to Sara Banaszak (ANGA) on August 29,2011. Data were pulled from current IHS well database and represent calendar year 2010.

EPA's 2010 inventory showed 4,169 gas well completions with hydraulic fracturing (EPA, 2012, Table A-122); however, EPA does not provide a breakout of completions by well type (shale gas, tight gas or coal-bed methane). In comparing the EPA 2010 count of gas well completions with hydraulic fracturing (4,169 completions) to both the survey results and data provided by IHS, it seems that EPA's national GHG inventory underestimates the number of well completions. Even accounting for the difference in time periods (2010 for EPA compared to 2010/2011 data from the ANGA/API survey), the national inventory appears to under-represent the number of well completions.

TABLE 2. API/ANGA SURVEY – SUMMARY OF GAS WELL COMPLETIONS BY NEMS REGION AND WELL TYPE* (FIRST SURVEY DATA REQUEST PHASE)

NEMS Region	Conventional Wells	Shale	Coal-bed Methane	Tight	Unspecified	Regional Total
API/ANGA Survey Data Gas Well Completions						
Northeast	2	291	3	67	126	489
Gulf Coast	81	588	-	763	374	1,806
Mid-Continent	22	734	-	375	270	1,401
Southwest	425	442	-	346	310	1,523
Rocky Mountain	10		30	977		1,017
Unspecified	-	-	-	-	1,125	1,125
Survey TOTAL	540	2,055	33	2,528	2,205	7,361
% of Survey Total	7.3%	27.9%	0.4%	34.3%	30.0%	
2010 IHS Gas Well Completions						IHS Total
2010 National Well Completions (from IHS)[1]	7,178	4,620	2,254	4,400		18,452
	38.9%	25.0%	12.2%	23.8%		
API/ANGA as % of IHS National Well Counts	7.5%	44.5%	1.5%	57.5%		

* ANGA/API survey data represents well counts current for calendar year 2010 or the first half of 2011.

** EPA's national GHG inventory does not designate gas wells by classifications of "shale", "coal bed methane" or "tight".

As shown in Table 3, the ANGA/API survey noted 7,361 gas well completions for 2010 and the first half of 2011. This is equivalent to approximately 40% of the gas well completions reported by IHS for 2010. Although EPA's 2010 national GHG inventory appears to under-represent the number of gas well completions according to the numbers reported through both the API/ANGA data and the IHS, differences in national well data reporting systems make it difficult to accurately investigate well completion differences with certainty. Data used in the EPA inventory, which includes information from the Energy Information Administration, various state governments, and privately sourced data, such as HPDI, does not consistently distinguish between conventional and unconventional wells. Without a consistent measure for the quantity and type of wells, it is difficult to be confident of the accuracy of how many wells are completed annually, let alone to estimate their emissions. Industry strongly believes that the effects of any current under-representation of well completions will be offset by a more realistic emission factor for the rate of emissions per well.

TABLE 3. SUMMARY OF GAS WELL COMPLETIONS DATA (FIRST SURVEY DATA REQUEST PHASE)

	# Completions for Gas Wells without hydraulic fracturing	# Completions for Gas Wells with hydraulic fracturing	Total Completions
2010 National Well Completions (from EPA; EPA 2012)	702	4,169	4,871
% of National Total	14%	86%	
API/ANGA Survey Well Completions	540	6,821	7,361
% of Survey Total	7%	93%	
Well Completions from IHS	7,178	11,274	18,452
% of National Total	39%	61%	

Table 4 provides detailed data for well completions from the ANGA/API survey. From the survey, 94% of gas well completions in 2010 and the first half of 2011, were conducted on wells with hydraulic fracturing. About one-half of all gas well completions for this time period were for tight wells, and about one-half of all gas well completions were for vertical wells with hydraulic fracturing. Any differences in totals between Tables 2, 3 and 4 are because these tables were derived from the two different data requests sent to member companies as described previously in the introduction to Section 2.

TABLE 4. API/ANGA SURVEY – ADDITIONAL DETAILS ON GAS WELL COMPLETIONS (SECOND SURVEY DATA REQUEST PHASE)

	# Completions for Gas Wells with hydraulic fracturing (HF)				Gas Wells without hydraulic fracturing		Total Completions
	# Vertical wells completions	# Horizontal well completions	Total Wells with HF	% of Wells with HF	# Completions	% of Wells without HF	
TOTAL Conventional	315	57	372	69%	164	31%	536
TOTAL Shale	317	1,863	2,180	99%	30	1%	2,210
TOTAL Tight	2,054	368	2,422	96%	106	4%	2,528
TOTAL Coal Bed Methane	27	3	30	91%	3	9%	33
TOTAL OVERALL	**2,713**	**2,291**	**5,004**	**94%**	**303**	**6%**	**5,307**

The following points summarize survey information provided in Tables 2, 3 and 4. These tables represent a snapshot of well activity data during this time.

- Overall, the survey showed 94% of the 5,307 wells reported in the API/ANGA data set as completed in 2010 and the first half of 2011 used hydraulic fracturing.
- *536 conventional gas wells were completed in 2010 and the first half 2011.*
  - 59% were vertical wells with hydraulic fracturing,
  - 11% were horizontal wells with hydraulic fracturing, and
  - 31% were wells without hydraulic fracturing.
- *2,210 shale gas wells were completed in 2010 and the first half 2011.*
  - 14% were vertical wells with hydraulic fracturing,
  - 84% were horizontal wells with hydraulic fracturing, and
  - 1% were wells without hydraulic fracturing.
- *2,528 tight gas wells were completed in 2010 and the first half 2011.*
  - 81% were vertical wells with hydraulic fracturing,
  - 15% were horizontal wells with hydraulic fracturing, and
  - 4% were wells without hydraulic fracturing.
- *33 coal-bed methane wells were completed in 2010 and the first half 2011.*
  - 82% were vertical wells with hydraulic fracturing,
  - 9% were horizontal wells with hydraulic fracturing, and
  - 9% were wells without hydraulic fracturing.

2.3 Data Limitations Concerning Wells

In response to follow-up questions on well data, EPA indicated that they classified gas well formations into four types (conventional, tight, shale, and coal-bed) (EPA, 2011e). When developing the gas well classifications, EPA applied their judgment where data were not available in the database. ANGA and API are interested in using the well database compiled by IHS or a similar database, to more completely classify gas wells at some point in the future. The API/ANGA survey did not specifically define conventional wells for collecting the well data presented in this section, leaving the respondents to determine the classification of wells based on their knowledge of the well characteristics or state classifications. As such, this well classification may vary somewhat according to the respondent's classification of wells.

It should be noted that there is not a generally accepted definition for "gas wells." Producers might be producing from several zones in the same formation, and different states define "gas" or "oil" wells differently due to the historical structure of royalties and revenues. There is also no commonly used definition of "conventional" gas wells. Thus, different definitions of these terms may have produced inconsistency in the classification of wells between gas and oil, and conventional and unconventional for the surveyed results, as well as for the EPA and EIA national data. For the purposes of this report, unconventional wells are considered to be shale gas wells, coal bed wells, and tight sand wells which must be fractured to produce economically. Given the counts of wells in the 2010 inventory versus the API/ANGA survey it is clear that the definition of conventional versus unconventional wells is not uniform and that the definition used by the individual companies responding to the survey likely differs from whatever distinction EPA uses.

3. Gas Well Liquids Unloading

Gas well clean ups, also known as liquids unloading, account for 51% of total CH_4 emissions from the natural gas production sector in EPA's national GHG inventory (EPA, 2012).[4] Methane emissions from well venting for liquids unloading in the 2010 inventory represent a dramatic increase from the 6% of CH_4 emissions that liquids unloading represented in the 2008 inventory. The magnitude of the increase, the accuracy of the underlying assumptions, and the methodology used in estimating emissions from well venting for liquids unloading became major concerns to API/ANGA members.

As the name indicates, 'Venting Wells for Liquids Unloading' is a technique to remove water and other liquids from wellbores to improve the flow of natural gas in gas wells.

In EPA's national inventory, emissions from gas well liquids unloading are based on the following assumptions (EPA, 2011a and Hanle, 2011):

- 41.3% of conventional wells require liquids unloading.
- 150,000 plunger lifts are in service, which equates to 31% of the gas wells in the national inventory.
- The average gas well is blown down to the atmosphere 38.73 times per year.
- The average casing diameter is 5 inches.
- A gas well is vented to the atmosphere for 3 hours.

Due to the dramatic increase in EPA's estimated emissions from this source and ANGA/API's concern, a survey of member companies was conducted to gather data on current operating practices from a large and broad cross-section of the industry regarding well venting for liquids unloading. The survey was structured to gather activity information along with data required for estimating emissions using the methodologies from the GHGRP Subpart W. Sixty-one data sets with information relevant to liquids unloading covering 59,880 wells and 18 AAPG basins were received.

The following information was requested:

- Geographic area represented by the information provided;
- Time period – data were annualized to 12 months if the information was provided for a partial year;
- Number of operated gas wells represented by the information provided;
- Number of gas wells with plunger lift installed;
- Number of gas wells with other artificial lift (beam pump; ESP; etc.);
- Total number of gas well vents;
- Number of wells with and without plunger lifts that vent to the atmosphere;

[4] See EPA Table A-129, of Annex 3 of the 2010 inventory report.

- Total count of gas well vents for time period with and without plunger lifts;
- Average venting time for wells with and without plunger lifts;
- Average daily production of venting gas wells (Mcf/day);
- Average depth of venting wells (feet);
- Average casing diameter of venting gas wells (inches);
- Average tubing diameter of venting gas wells with plunger lift (inches); and
- Average surface pressure of venting gas wells (psig).

Not all respondents reported information for each parameter requested in the survey. Hence, the subsequent analysis determining the sample size and other factors used the well counts and other information from only those data sets which included information for the parameter being determined or analyzed. As a result, the analysis of the survey data reflects three levels of information:

1. High-level data were used to relate the survey information to national well counts. This survey data set provided the broadest representation of wells, totaling 59,880 total gas wells in the liquids unloading data sets.
2. Mid-level data consisted of survey information used to determine the fraction of both plunger equipped and non-plunger equipped gas wells that vent gas due to liquids unloading. The mid-level survey data represented a total of 49,124 wells.
3. Detailed survey data were used to calculate emissions using the methodologies in the GHGRP Subpart W and to compare the survey data to assumptions EPA used in deriving the emissions for the 2010 national inventory. Detailed survey information was provided for a total of 42,681 wells.

Although the survey was split into "conventional" and "unconventional" categories, this specific distinction was not carried forward into the liquids unloading analysis. Liquid loading of well-bores is a function of the physics of flow up the well-bore and the fluids' properties; the type of producing formation is not relevant when the conditions for liquid loading occur.

Table 5 summarizes the high-level results from the API/ANGA survey and characterizes the national well population in EPA's 2010 inventory using the survey derived information. Based on the survey results, 36% of gas wells are equipped with plunger lift. Applying this percentage to the national gas well count results in 174,743 wells nationally with plunger lift.

TABLE 5. LIQUIDS UNLOADING HIGH LEVEL DATA SUMMARY

High Level Survey Data		
Gas wells with plunger lifts (59,648 in sample)	21,500	wells (36.0%)
Gas wells with artificial lift (54,660 in sample)	7,329	wells (13.4%)
Gas Wells Vented to the atmosphere for Liquids Unloading (49,124 in sample)	6,462	wells (13.2%)
# Vents per vented well	145.1	vents/vented well
Total gas well vents represented by the data sets	937,663	vents
National Well Characterization		
National # of wells from 2010 Inventory	484,795	wells
Calculated national # wells with plunger lift	174,743	wells
Calculated national # wells without plunger lift	310,052	wells
Calculated national # wells with artificial lift (subset of wells without plunger lift	65,003	wells
Methane mole percentage from EPA 2010 national inventory	78.8%	

The survey also collected information on gas wells with artificial lift. A key distinction is that wells with artificial lift do not build up liquid columns in the well bore and hence are not vented for liquids unloading. The ANGA/API survey results indicated that 13.4% of wells use artificial lift which yields approximately 65,000 wells with artificial lift when extrapolated on a national basis. EPA has acknowledged that their current emission estimation method for liquids unloading does not account for activities used to reduce CH_4 emissions by many different artificial lift methods used in industry.

Table 6 summarizes the mid-level API/ANGA survey results, which characterizes the national **venting** well population, and applies the survey derived annual emissions per venting well to calculate national emissions. Based on the mid-level survey data, 21.1% of plunger equipped wells vent gas for liquids unloading, and 9.3% of wells without plunger lift vent gas for liquids unloading. These percentages were applied to the calculated national gas well counts with and without plunger lift (shown in Table 5) and are used to estimate the number of wells with and without plunger lift that vent for liquids unloading (36,806 and 28,863 wells, respectively, shown in Table 6).

Emissions were calculated for the survey data by applying Equation W-8 or W-9 from the EPA GHG reporting rule in 40 CFR 98 Subpart W, where Equation W-8 applies to gas wells without plunger lifts, and Equation W-9 applies to gas wells with plunger lifts. Appendix C summarizes the survey data used to estimate the emissions shown in Table 6. The total volume of gas emitted based on the survey data was converted to methane emissions by applying the methane content used in the national inventory (78.8%). When the total volume is divided by the number of venting wells represented by the survey data, it results in an emission factor of approximately 254 Mscfy CH_4/well.

TABLE 6. LIQUIDS UNLOADING EMISSION ESTIMATION BASED ON SURVEY DATA

Mid-Level Survey Data		
Total number of wells with plunger lift (42,681 in sample)	11,518	wells
Total number of wells without plunger lift (42,681 in sample)	31,163	wells
Number of plunger equipped wells that vent (42,681 in sample)	2,426	wells (21.1%)
Number of non-plunger equipped wells that vent (42,681 in sample)	2,901	wells (9.3%)
Total annual volume gas vented for venting wells	1,719,843,596	scf gas/year
Calculated volume vented gas per venting well	322,854	scfy gas/well
Calculated methane volume vented per venting well	**254,409**	scfy ch4/well
Calculated National Well Data		
Calculated national # wells with plunger lift that vent for unloading	36,806	wells
Calculated national # wells without plunger lift that vent for unloading	28,863	wells
National Emission Calculations		
Total gas venting for liquids unloading volume (scaled for national wells)	21,201,410,618	scf gas/yr
Total methane venting for liquids unloading (scaled for national wells)	16,706,711,567	scf CH_4/yr
Total liquid unloading vented methane (scaled for national wells)	319,664	metric tons CH_4/yr
Comparison to 2010 National Inventory Liquids Unloading		
2010 National Inventory CH_4 emissions from Liquids Unloading	4,501,465	metric tons CH_4/yr
% difference between survey and national data	-92.9%	

For comparison to EPA's estimated emissions from liquids unloading, the survey calculated emission factor was applied to the calculated national number of gas wells with and without plunger lift. When extrapolated to a national basis, as shown above, the survey data estimates that 319,664 tonnes of CH_4 are emitted from liquids unloading, compared to EPA's national emissions of 4,501,465 tonnes CH_4 (based on industry standard conditions of 60 °F and 14.7 psia) – for the same activities. Hence, the results of the ANGA/API survey would predict emissions that are a factor of 14 times lower than the emissions reported in the 2010 national GHG inventory for liquids unloading.

Table 7 summarizes the detailed API/ANGA survey results for relevant individual parameters used in the emission calculation. These are compared to EPA's assumptions to demonstrate why the survey results produce a much lower emissions than EPA's assumptions. It should be noted, the ANGA/API parameters from each data set were weighted by the number of vents in that particular data set, where appropriate.

TABLE 7. DETAILED SURVEY DATA COMPARED TO EPA ASSUMPTIONS

Detailed Survey Data		Survey Data		EPA Assumptions	
Total national number of wells that vent for liquids unloading		65,669	wells	179,391	wells
Average number of vents	per venting plunger well	343.72	vents/well	38.7	vents/well
	per venting non-plunger well	32.57	vents/well		
Average time per vent	plunger equipped wells	0.11	hour	3	Hours
	non-plunger equipped wells	1.90	hours		
Average depth	plunger equipped wells	4,370	feet	6,000	Feet
	non-plunger equipped wells	5,433	feet		
Average tubing diameter - plunger equipped wells		2.15	inches	2	inches
Average casing diameter - non-plunger equipped wells		4.57	inches	5	inches
Average production rate	plunger equipped wells	104.3	Mcfd gas		
	non-plunger equipped wells	45.9	Mcfd gas		
Average pressure	plunger equipped wells	91.0	psig	100 psig sales line pressure (200-1000 psig shut-in pressure)	
	non-plunger equipped wells	110.8	psig		
Calculated methane volume venting per venting wells		254,409 scf CH4/well		1,316,750 scf CH4/well	

As noted previously, the data sets used to derive the liquids unloading emission estimates are summarized in Appendix C. When examining Appendix C, it is important to note the presence of several data responses that can be viewed as outliers. Two data responses for operations with conventional wells reported very high frequencies of vents to the atmosphere. These data sets represent 174 gas wells with plunger lifts that vent to the atmosphere and are located in the Mid-Continent region (out of a total 1,140 conventional gas wells represented by the two data sets). The wells represented by these data points have plunger lifts that vent to the atmosphere for each plunger cycle. The information was confirmed by the two data respondents and is an artifact of the plunger control for these wells which results in very short venting durations (between 4 and 5 minutes) for each plunger cycle, which is not the operating practice assumed by the EPA in the equations that are used to estimate emissions associated with liquids unloading. Accounting for the high frequency of plunger lift cycles for these wells results in a high average vent frequency, but still leads to the derivation of a lower emission factor than the one derived by EPA in accordance with their assumptions about liquids unloading operations. The survey derived factor is likely somewhat high due to the calculation assumption that the entire tubing string is de-pressured in each venting event which is not likely for the two "outlier" data sets discussed above.

These variances among operators in the ANGA/API data demonstrate the challenge of applying national emissions estimates to conditions in which there can be considerable variation in wells and operating techniques, among and even within various regions. As member companies have noted in various comments to regulators, oil and natural gas production operations vary considerably according to factors such as local geology, hydrology, and state law.

As production companies continue to collect and report information for EPA's mandatory GHG reporting program, better information on liquids unloading frequency and emissions will be available. One area that would benefit from additional information is an investigation of regional differences, or plunger lift control practices, in view of the high frequency of vents observed for two data sets containing conventional gas wells with plunger lifts in the Mid-Continent region.

Key findings of the API/ANGA survey on liquids unloading are:

- ***Overall, the change in emission factors based on data collected from the ANGA/API survey reduces estimated methane emissions for this source by 93% from the methane emissions reported in EPA's 2010 national GHG inventory. This is a factor of 14 times lower than EPA's reported methane emissions.***
- ***When compared to EPA's assumptions used to derive the national GHG emission estimates for liquids unloading, the API/ANGA survey data indicated a lower percent of gas wells that vent for liquids unloading and a much shorter vent duration. The difference in these two parameters from EPA's assumptions more than offset the higher number of vents observed from the survey data.***

4. Hydraulic Fracturing and Re-fracturing (Workovers)

A well workover refers to remedial operations on producing natural gas wells to try to increase production. Starting with the 2009 inventory, EPA split the estimation of emissions from producing gas wells into conventional (i.e., without hydraulic fracturing) and unconventional (i.e., with hydraulic fracturing). For workovers of wells without hydraulic fracturing, the 2009 and 2010 national inventories used emission factors of the same order of magnitude as the 2008 inventory (2,454 scf of CH_4/workover). In contrast, the unconventional (with hydraulic fracturing) well workover emission factor increased by a factor of three thousand (3,000).

EPA did acknowledge that the new emission factor for well workovers was based on limited information (EPA, 2011b). Moreover, several publications including *Mismeasuring Methane* by IHS CERA underscored the perils of extrapolating estimates using only four (4) data points representing approximately two percent (2%) of wells – particularly when the data was submitted in the context of the Natural Gas Star program, which was designed to highlight emissions reduction options (IHS CERA, 2011). Unfortunately, even if the EPA's workover factor is high, it must be used in estimated emissions calculations until it is officially changed.

EPA's new emission factor is 9.175 MMscf of natural gas per re-fracture (equivalent to 7.623 MMscf CH_4/re-fracture). Additionally, EPA used this new emission factor in conjunction with an assumed re-fracture rate of 10% for unconventional gas well workovers each year to arrive at their GHG emission estimate for this particular category.

4.1 API/ANGA Survey

The ANGA/API survey requested counts for gas well workovers or re-fractures in two separate phases of the survey, covering 91,028 total gas wells (Table 8 covering 2010 and first half of 2011 data) and 69,034 unconventional gas wells (Table 9, 2010 data only), respectively.

The first phase of the survey was part of the general well data request. Counts of workovers by well type (conventional, tight, shale, and coal bed methane) and by AAPG basin were requested. The frequency of workovers was calculated by dividing the reported workover rates by the reported total number of each type of gas well. These results are summarized in Table 8, which includes a comparison to national workover data from EPA's annual GHG inventory. The high number of workovers in the Rocky Mountain region is discussed further below.

Table 8 indicates that even for the high workover rates associated with unconventional tight gas wells in the Rocky Mountain region, the workover rate is much less than EPA's assumed 10% of gas wells re-fractured each year. Based on this first phase of the survey,

- The overall workover rate involving hydraulic fracturing was 1.6%.
- However, many of these workovers were in a single area, AAPG-540, where workovers are known to be conducted more routinely than in the rest of the country (as described in more detail below Table 9). Excluding AAPG 540, the overall workover rate involving hydraulic fracturing was 0.7% which is a more likely range for a national re-fracture rate.

- For shale, coal-bed methane, and tight formation wells in Table 8, the overall workover rate involving hydraulic fracturing was 2.2%. Excluding AAPG 540, the overall workover rate involving hydraulic fracturing was 0.5%.

Table 8. API/ANGA Survey – Summary of Gas Well Workovers with Hydraulic Fracturing in 2010 and First Half of 2011 by NEMS Region and Well Type (First Phase Data Survey)

NEMS Region	Conventional Wells	Unconventional Wells			Unspecified
		Shale	Coal-bed Methane	Tight	
Northeast	-	-	-	-	-
Gulf Coast	-	5	-	38	73
Mid-Continent	8	1	-	73	33
Southwest	60	25	-	8	7
Rocky Mountain	4	-	25	901	-
West Coast	-	-	-	-	-
Unspecified	-	-	-	-	200
Survey TOTAL	72	31	25	1,020	313
		1,076			
% of national	0.3%	21.3%			
Overall Survey Total	1,461				
% of national	5.6%				

National Workover Counts (from EPA's 2010 national inventory)	Conventional Wells	Unconventional Wells
	21,088	5,044
	80.7%	19.3%
	26,132	

	Conventional Wells	Unconventional Wells			Unspecified
		Shale	Coal-bed Methane	Tight	
% Workover Rate with Hydraulic Fracturing (from ANGA/API Survey)	0.3%	0.3%	0.5%	3.0%	2.4%
Tight w/out AAPG 540				0.5%	
Unconventional Wells		2.2%			
W/out AAPG 540		0.5%			
All Wells	1.6%				
All Wells w/out AAPG 540	0.7%				

A second phase of the survey was conducted which targeted collecting gas well re-fracture information for 2010 to provide a comparator for EPA's assumption that 10% of wells are re-fractured each year. This portion of the ANGA/API survey requested information just for "unconventional" gas wells (i.e., those located on shale, coal-bed methane, and tight formation reservoirs), where the formations require fracture stimulation to economically produce gas. A re-fracture or workover was defined for this second phase of the survey as a re-completion to a different zone in an existing well or a re-stimulation of the same zone in an existing well. These results are summarized in Table 9.

While there likely is significant overlap of unconventional well data reported in the first and second phases of the survey (which covered over 62,500 unconventional wells and 69,000 unconventional wells respectively), combined these data indicate an unconventional well re-fracture rate of 1.6% to 2.3% including AAPG 540 and 0.7% to 1.15% excluding AAPG 540.

AAPG Basin 540 (i.e. DJ Basin) which is part of the Rocky Mountain Region stands out in Tables 8 and 9. After four (4) to eight (8) years of normal production decline, the gas wells in this basin can be re-fractured in the same formation and returned to near original production. Success of the re-fracture program in the DJ Basin is uniquely related to the geology of the formation, fracture reorientation, fracture extension and the ability to increase fracture complexity. Also, most DJ Basin gas wells are vertical or directional, which facilitates the ability to execute re-fracture operations successfully and economically. These characteristics result in a high re-fracture or workover rate specific to this basin/formation.

ANGA and API believe the high re-fracture rate observed in the DJ Basin is unique and not replicated in other parts of the country. This was a limited program that was occurring during the data survey activities and has currently stopped. There may be a few other formations in the world that have similar performance, but the successful re-fracture rate in the DJ Basin is not going to be applicable to every asset/formation and there is no evidence of the high re-fracture rate in any of the other 22 AAPGs covered in the API/ANGA survey. It is highly dependent on the type of rock, depositional systems, permeability, etc. For these reasons, re-fracture rates for tight gas wells and all gas wells with and without AAPG Basin 540 are summarized in Tables 8 and 9.

4.2 WRAP Survey

Other information on re-fracture rates is available in a survey conducted by the Western Regional Air Partnership (WRAP). WRAP conducted a survey of production operators in the Rocky Mountain Region (Henderer, 2011) as part of the initiative to develop GHG reporting guidelines for a regional GHG cap and trade program.

Table 9. API/ANGA Survey – Summary of 2010 Gas Well Workovers on Unconventional Wells by AAPG Basin and NEMS Region (Second Phase Survey Data)

NEMS Region	AAPG Basin	Number of Unconventional Operating Gas Wells	Number of Hydraulic Fracture Workovers on Previously Fracture Stimulated Wells	% Wells re-fractured per year	Regional % Wells re-fractured per year
Northeast	160	1,976	0	0.00%	0%
	160A	760	0	0.00%	
Gulf Coast	200	2	0	0.00%	0.91%
	220	649	2	0.31%	
	222	629	3	0.48%	
	230	820	4	0.49%	
	250	13	0	0.00%	
	260	2,830	36	1.27%	
Mid-Continent	345	3,296	11	0.33%	0.95%
	350	213	3	1.41%	
	355	282	8	2.84%	
	360	7,870	89	1.13%	
	375	12	0	0.00%	
	385	1	0	0.00%	
	400	64	0	0.00%	
Southwest	415	1,834	0	0.00%	1.04%
	420	838	8	0.95%	
	430	1,548	36	2.33%	
	435	2	0	0.00%	
Rocky Mountain	515	1	0	0.00%	4.7%
	540	5,950	866	14.55%	
	580	8,197	8	0.10%	
	595	5,222	32	0.61%	
Not specified		26,025	487	1.87%	1.87%
Unconventional TOTAL (all wells)		**69,034**	**1,593**	**2.31%**	
Unconventional Median		790	3		
Rocky Mountain Region Unconventional Total		19,370	906	4.68%	
Unconventional TOTAL (Without AAPG 540)		63,084	727	1.15%	

Within each basin in this region, the top oil and gas producers were identified and invited to participate in the survey. The goal was to have operator participation that represented 80% of the production for the region. The spreadsheet survey requested information on the completions, workovers, and emissions associated with these activities. An emission factor and frequency of re-fracturing was developed for each basin as a weighted average of the operator responses.

The re-fracture rates from the WRAP survey are shown in Table 10 (Henderer, 2011).

TABLE 10. WRAP SURVEY – SUMMARY OF GAS WELL WORKOVERS BY AAPG BASIN FOR THE ROCKY MOUNTAIN REGION, 2006 DATA

AAPG Basin	# Wells represented by survey	# Wells Recompleted	% Recompleted
515	4,484	121	2.70%
530	731	5	0.68%
535	4,982	201	4.03%
540	8,247	636	7.71%
580	3,475	14	0.40%
595	4,733	275	5.81%
Total	26,652	1,252	
Weighted average			4.70%

AAPG Basin 540 results in the highest re-fracture rate for this data set, consistent with the ANGA/API survey as noted above. It is noteworthy that, while there are differences among individual AAPG Basin results, the weighted average re-fracture rate from the WRAP survey in 2006 is the same as the Rocky Mountain regional 4.7% re-fracture rate from the API/ANGA survey shown in Table 9.

4.3 Impact of Completions and Re-fracture Rate Assumptions

Table 11 compares the considerable reduction in the national GHG inventory that would result from applying a lower re-fracture rate.

EPA indicated that the national inventory assumes 10% of unconventional gas wells are re-fractured each year. Table 11 replaces this value with results from the ANGA/API survey. A re-fracture rate of 1.15% is applied to unconventional gas wells in the Mid-Continent and Southwest regions (No unconventional gas wells were assigned to the Northeast and Gulf Coast regions. The West Coast region is not shown since the API/ANGA survey did not include any responses for gas well operations in this region.) A re-fracture rate of 4.7% is applied to unconventional gas wells in the Rocky Mountain region.

With these adjustments to the re-fracture rate for unconventional gas wells, the national emission estimate is reduced by 72% for this emission source category, from 712,605 metric tons of CH_4 to 197,311 metric tons of CH_4 when compared on a consistent basis.

TABLE 11. API/ANGA SURVEY –GAS WELL WORKOVER EMISSIONS COMPARISON

NEMS Region	Well type	2010 EPA National Inventory # workover	Adjusted # workovers (based on API/ANGA survey)	2010 EPA National Inventory: Emission Factor, scf CH_4/workover	2010 EPA National Inventory: Estimated Emissions, tonnes CH_4*	Revised Emissions, tonnes CH_4 (based on ANGA/API survey)	API & ANGA - EPA / EPA % Difference
Northeast	Wells without Hydraulic Fracturing	8,208	8,208	2,607	409	409	
	Wells with Hydraulic Fracturing	0	0	7,694,435	0	0	
Mid Continent	Wells without Hydraulic Fracturing	3,888	3,888	2,574	191	191	
	Wells with Hydraulic Fracturing	1,328	153	7,672,247	194,950	22,462**	-89%
Rocky Mountain	Wells without Hydraulic Fracturing	3,822	3,822	2,373	174	174	
	Wells with Hydraulic Fracturing	2,342	1,100	7,194,624	322,402	151,432**	-53%
Southwest	Wells without Hydraulic Fracturing	1,803	1,803	2,508	87	87	
	Wells with Hydraulic Fracturing	1,374	158	7,387,499	194,217	22,382**	-89%
Gulf Coast	Wells without Hydraulic Fracturing	3,300	3,300	2,755	174	174	
	Wells with Hydraulic Fracturing	0	0	8,127,942	0	0	
TOTAL					712,605	197,311	-72%

* EPA Estimated emissions = 2010 # Workovers x EPA 2010 Emission Factor, converted to mass emissions based on 60°F and 14.7 psia.

** Revised emissions = Adjusted # Workovers x Emission Factor, converted to mass emissions based on 60°F and 14.7 psia.

4.4 Completion and Re-fracture Emission Factor

In the 2009 GHG national inventory, EPA applies an emission factor of 2,454 scf CH_4/event for conventional gas well workovers, while the emission factor for unconventional gas well completions and workovers was increased to 7,623,000 scf CH_4/event (EPA, 2011c). Similarly, for the 2010 national GHG inventory, EPA maintained the emission factor of 2,454 scf CH_4/event for gas well workovers without hydraulic fracturing, but applied an average emission factor of 7,372,914 to gas well workovers with hydraulic fracturing (EPA, 2012). (EPA applies slightly different emission factors for each NEMS region based on differing gas compositions.)

The ANGA/API survey focused on activity data and did not collect data to revise the emission factor for unconventional gas well completions and workovers.

Emissions Data from WRAP Study

The WRAP study discussed in Section 4.2 also gathered data on emissions from completions. This information supports a revised emission factor but was reported by sources outside the ANGA/API data survey. The results are summarized in Table 12. The WRAP emission factor is 78% lower than EPA's emission factor (9.175 MMscf gas/event). The WRAP survey did not provide a methodology for determining emissions data.

TABLE 12. WRAP SURVEY – SUMMARY OF COMPLETION EMISSIONS FOR THE ROCKY MOUNTAIN REGION, 2006 DATA

AAPG Basin	Weighted average gas emissions from completion, Mcf gas/well	# completions represented
515	167	207
530	268	54
535	76	642
540	59	608
580	6,559	283
595	4,053	819
Total		2,613
Weighted average	2,032 Mcf/well	

4.5 Data Limitations for Completion and Re-fracture Emissions

Although the data sets are limited, it appears that EPA's assumed re-fracture rate of 10% is a significant overestimate. Information from the API/ANGA survey indicates that even including what appears to be unique activity in AAPG-540, the re-fracture rate is much less frequent, ranging from 1.6% to 2.3% based on two sets of survey information (Tables 8 and 9, respectively). The re-fracture rate for AAPG Basin 540 appears to be higher than other areas in the U.S. due to unique geologic characteristics in that region (4.7% based on a weighted average of data reported for that region). Without AAPG Basin 540, the national rate of re-fracturing is between 0.7% and 1.15% of all gas wells annually.

Additionally, limited information on the emissions from completions and workovers with hydraulic fracturing indicate that EPA's GHG emission factor for these activities is significantly overestimated. It is expected that better emissions data will develop as companies begin to collect information for EPA's mandatory GHG reporting program (EPA, 2011d).

5. Other Surveyed Information

EPA had indicated that activity data for centrifugal compressor wet seals and pneumatic devices used in the national inventory is lacking. Note that the need for better equipment data persists throughout the majority of the U.S. inventory and is not unique to the oil and natural gas industry. The ANGA/API survey requested the following information related to centrifugal compressors and pneumatic devices:

- The number of centrifugal compressors, reported separately for production/gathering versus processing;
- The number of centrifugal compressors with wet versus dry seals, reported separately for production/gathering versus processing;
- The number of pneumatic controllers, classified as "high-bleed," "low-bleed," and "intermittent," reported separately for well sites, gathering/compressor sites, and gas processing plants; and
- The corresponding number of well sites, gathering/compressor sites, and gas processing plants, associated with the pneumatic controller count.

5.1 Centrifugal Compressors

Processing Facilities

The API/ANGA survey collected the equivalent of 5% of the national centrifugal compressor count for gas processing operations (38 centrifugal compressors from the survey, compared to 811 from EPA's 2010 national GHG inventory). For the gas processing centrifugal compressors reported through the survey, 79% were dry seal compressors and 21% were wet seals. EPA's 2010 national inventory reported 20% of centrifugal compressors at gas processing plants were dry seal, and 80% were wet seal. EPA's emission factor for wet seals (51,370 scfd CH_4/compressor) is higher than the emission factor for dry seals (25,189 scfd CH_4/compressor).[5]

Based on the ANGA/API survey, EPA appears to be overestimating emissions from centrifugal compressors. If the small sample size from the API/ANGA survey is representative, non-combustion emissions from centrifugal compressors would be 173,887 metric tons of methane compared to 261,334 metric tons of methane from the 2010 national inventory (when applying industry standard conditions of 60 °F and 14.7 psia to convert volumetric emissions to mass emissions). Although based on very limited data, if the ANGA/API survey results reflect the population of wet seal versus dry seal centrifugal compressors, the emissions from this source would be reduced by 34% from EPA's emission estimate in the national inventory. Better data on the number of centrifugal compressors and seal types will be available from companies reporting to EPA under the mandatory GHG reporting program.

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[5] EPA Table A-123, of Annex 3 of the 2010 inventory report.

Production and Gathering Facilities

Very few of the data sets reported through the API/ANGA survey indicate counts of centrifugal compressors associated with production/gathering operations - only 550 centrifugal compressors from 21 participating companies. EPA's 2010 GHG inventory did not include centrifugal compressors in production/gathering operations. On a well basis, the survey responses equate to 0.07 centrifugal compressors per gas well, with 81% dry seal centrifugal compressors and the remaining wet seal compressors. Information reported through EPA's mandatory GHG reporting program will provide additional information to account for GHG emissions from centrifugal compressors in production operations.

5.2 Pneumatic Controllers

Table 13 summarizes the survey responses for pneumatic controllers. For each type of location – gas well sites, gathering compressor sites, and gas processing plants – the count of the number of sites represented by the survey data is shown. Table 13 also shows the percent of each pneumatic controller type for each type of location.

TABLE 13. ANGA/API SURVEY –PNEUMATIC CONTROLLER COUNTS

	Gas Well Sites		Gathering/ Compressor Sites		Gas Processing Plants	
# wells, sites or plants	48,046 wells		1,988 sites		21 plants	
# controllers/well, site or plant	0.99 per well		8.6 per site		7.8 per plant	
# Low Bleed Controllers	12,850	27%	5,596	33%	117	71%
# High Bleed Controllers	11,188	24%	1,183	7%	47	29%
# Intermittent Controllers	23,501	49%	10,368	60%	0	0%

The survey requested that the responses designate pneumatic controllers as either "high bleed", "low bleed", or "intermittent" following the approach each company is using for Subpart W reporting. For example, Subpart W defines high-bleed pneumatic devices as automated, continuous bleed flow control devices powered by pressurized natural gas where part of the gas power stream that is regulated by the process condition flows to a valve actuator controller where it vents continuously (bleeds) to the atmosphere at a rate in excess of 6 standard cubic feet per hour (EPA, 2011d).

EPA does not currently track pneumatic controllers by controller type in the national inventory. This information will be collected under 40 CFR 98 Subpart W starting in September 2012. From the API/ANGA survey, intermittent bleed controllers are the more prevalent type at gas well sites and gathering/compressor sites, while gas plants predominately use low-bleed controllers. No intermittent controllers were reported for gas plants by the survey respondents.

Table 14 compares emission results based on applying the emission factors from the EPA's GHG reporting rule to emissions presented in the 2010 national GHG inventory, using the counts of pneumatic controller from the ANGA/API survey for production operations.

For production, the EPA national inventory combines pneumatic controller counts associated with large compressor stations with pneumatic controllers in production. An emission factor for each NEMS region is applied to the count of total controllers in each NEMS region. For this comparison, a weighted average emission factor of 359 scfd CH_4/device was applied to the count of pneumatic controllers located at well sites and gathering/compressor sites.

Under the EPA mandatory reporting rule (40 CFR 98 Subpart W), separate emission factors are applied to pneumatic controllers based on the controller type and whether the controller is located in the Eastern or Western region of the United States, as specified in the rule (EPA, 2011d). For this comparison, an average of the eastern and western emission factors is applied to each device type in computing the emission estimates resulting from the EPA GHG reporting rule.

TABLE 14. PNEUMATIC CONTROLLER EMISSION COMPARISON – PRODUCTION OPERATIONS

	API/ANGA Survey Count of Controllers			EPA GHG Reporting Rule (Subpart W)		2010 National GHG Inventory	
	Gas Well Sites	Gathering/ Compressor Sites	Total	Emission Factor,* scfh CH_4/device	Emissions, tonnes CH_4/yr	Emission Factor, scfd CH_4/device	Emissions, tonnes CH_4/yr
# Low Bleed Controllers	12,850	5,596	18,446	1.58	4,885	359	46,286
# High Bleed Controllers	11,188	1,183	12,371	42.35	87,814		31,042
# Intermittent Controllers	23,501	10,368	33,869	15.3	86,856		84,987
Total			64,686		179,556		162,315

* Emission factors shown are the average of the eastern and western emission factors from Table W-1A (EPA, 2011d).

Based on the types of pneumatic controllers reported in the ANGA/API survey, EPA's mandatory GHG reporting rule could increase CH_4 emissions 11% over the pneumatic controller portion of the 2010 national GHG inventory. To put this in context, in EPA's inventory report for 2010, emissions from pneumatic controllers accounted for approximately 13% of CH_4 emissions from the natural gas field production stage. Any increase from that initially reported data, however, will likely represent a worst case scenario. It is important to remember that pneumatic controllers operate only intermittently, so variability such as the frequency and duration of the activations will be important information to consider when defining an accurate and effective reporting regime for these sources.

EPA's mandatory GHG reporting rule does not require reporting emissions from pneumatic controllers at gas processing plants, so no emission factors are specified. The GHG national inventory applies an emission factor of 164,721 scfy CH_4 per gas plant for pneumatic controllers. For the national inventory, this results in 1,856 tonnes CH_4 emissions - a very small contribution to CH_4 emissions from onshore oil and gas operations.

6. Conclusions

API and ANGA members believe this to be the most comprehensive set of natural gas data to date and are pleased to share these results with both regulators and the public.

Based on the information gathered from member companies during this project, it appears that EPA has overstated several aspects of GHG emissions from unconventional natural gas production. As summarized in Table 15, the ANGA/API survey data results in significantly lower emission estimates for liquids unloading and unconventional gas well refracturing when compared to EPA's emission estimates in the national inventory. Using the combined emission estimates from the survey for these two key emission sources would indicate a 53% reduction in calculated natural gas production sector emissions compared to EPA's estimates.

TABLE 15. EMISSION COMPARISON BETWEEN EPA AND INDUSTRY DATA

Source Category	EPA National Inventory		API/ANGA Survey		Impact on Source Category Emissions
	Metric tons of CH4	% of EPA Production Total	Metric tons of CH4	% of Revised Production Total	API & ANGA - EPA EPA % Difference in Emissions
Liquids Unloading	4,501,465 *	51%	319,664	8%	-93%
Unconventional Well Re-fracture Rates	712,605 *	8%	197,311	5%	-72%
Other Production Sector Emissions**	3,585,600	41%	3,585,600	87%	
Total Production Sector Emissions	8,799,670		4,102,575		-53%

* EPA's estimates are adjusted to industry standard conditions of 60 degrees F and 14.7 psia for comparison to the ANGA/API emission estimates.

**The "Other Production Sector Emissions" are comprised of over 30 different source categories detailed in Table A-129 in the Annex of the EPA's 2012 national inventory. The "Other Production Sector Emissions" are the same values for this comparison between the EPA national inventory and the API/ANGA survey to focus the comparison on quantified differences in emission estimates for gas well liquids unloading and unconventional well re-fracture rates.

This project was directed toward gathering more robust information on workovers, completions, liquids unloading, centrifugal compressors, and pneumatic controllers with the intent of supporting revisions to the activity factors used in EPA's national inventory and cited by many media publications. Although limited information was collected on centrifugal compressors and pneumatic controllers, the survey results indicated potential additional differences, which are not included in the Table 15 comparison, when comparing total emissions from all sources to the national inventory. Additional future data collection efforts, including more detailed reporting under Subpart W of the GHGRP will likely resolve these differences and continue to inform the overall natural gas emissions data.

While API and ANGA recognize that the data collected for this report represents a sample of the universe of natural gas wells operating in the U.S., we believe that the conclusions drawn from the data analysis are relevant and representative of natural gas production as whole. In EPA's gas well count, 21 of the AAPG basins each have more that 1% of the total well count. The ANGA/API survey has wells from 19 of those 21 basins. In terms of wells represented by these basins, 92% of the total EPA well count is accounted for by wells in those 21 basins, while 95% of the API/ANGA surveyed gas wells are accounted for by those 21 basins. This indicates that the ANGA/API survey results have good representation for the basins with the largest numbers of wells nationally.

Moreover, the API/ANGA survey results are based on a large number of wells - at least an order of magnitude or more - higher than the number of wells used by EPA to develop their revised emission factors that purport to be representative of U.S. industry operations nationwide. Such a richer data set allows for improved granularity of emission characteristics for various operations. A case in point is the information on liquids unloading where the ANGA/API survey results were obtained from over 59,000 gas wells and which indicate that 21% of wells equipped with plunger lift and 9.3% of wells without plunger lift vent for liquids unloading. In comparison, EPA's approach is based on the assumption that the survey of 25 well sites conducted by GRI (1996) for the base year 1992 continues to provide representative data for the fraction of conventional wells requiring unloading, which EPA set at 41.3%. Industry also believes that the systematic approach in which the API/ANGA data were collected and vetted by natural gas experts is an improvement over the *ad hoc* way in which EPA collected some of their data. This study indicates that EPA should reconsider their inventory methodologies for natural gas production particularly in light of more comprehensive and emerging data from the industry. ANGA and API members look forward to working with the agency to continue to educate and evaluate the latest data as it develops about the new and fast-changing area of unconventional well operations.

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Appendix A. API/ANGA Survey Forms

The following provides the survey forms used to gather data presented in this report.

FIGURE A-1. SURVEY INSTRUCTIONS

The attached worksheets request data to support both the API/ANGA Natural Gas Life Cycle Analysis Project, as well as updates to EPA's National GHG Inventory. Portions of this information are consistent with data required for Subpart W, in which case data collected for Subpart W can be provided.

EPA's most recent national inventory significantly increased the emission estimates for gas well completions and workovers with hydraulic fracturing and gas well liquids unloading. These increases prompted public criticism of unconventional natural gas production.
While acknowledging their unconventional well workover activity factors were based on limited data, EPA has also indicated that activity data for centrifugal compressor wet seals and pneumatic devices used in the national inventory is lacking.

API and ANGA are requesting this information to develop more rigorous emission estimates for these important emission sources. This spreadsheet primarily focuses on activity factor information. A second data request will be developed later this year to collect information to support improved emission factors.

Company confidential information will be protected.

Please do not send information responsive to the data request to API or ANGA. Neither API nor ANGA will review member data sent in response to this request. Any submission to API or ANGA that appears to contain information responsive to EPA's data request will be returned to the sender unopened.

Please send the completed spreadsheets to:
Terri_Shires@URScorp.com
Questions may be directed to the same address, or by phone: 512-419-5466

Respondents are asked to complete as much information as possible. Some worksheets request data in varying levels of detail, with guidance on the minimum level of information needed. Some worksheets request data for more than one year or more than one production basin, if available. Gaps in the data are OK if the information is not available.

Additional instructions and guidance are provided on each worksheet.

Schedule:

Data indicated in blue font and shading is requested by August 15

Data indicated in green font is requested by September 16, if this level of information available. This more detailed information will help develop more rigorous emissions estimates for these sources.

FIGURE A-2. GAS WELL SURVEY DATA

Table 1. Producing Gas Wells - Activity Data

Please provide the following information for gas producing wells

		Conventional Wells	Unconventional Wells			Year	Geographic Area Represented	Comments
			Shale	Coal-bed Methane	Tight			
A	Total # of Operating Gas wells							Total of rows A(1) and A(2)
A(1)	*# Wells w/out hydraulic fracturing (anytime in their history)*							
A(2)	*# Wells with hydraulic fracturing (any time in their history)*							If counts are not available by vertical and horizontal, please complete this row
A(2)(a)	*# Vertical wells with hydraulic fracturing (anytime in their history)*							Please provide this level of detail, if available for wells with hydraulic fracturing
A(2)(b)	*# Horizontal wells with hydraulic fracturing (anytime in their history)*							
B	# Gas well Completions							Total of rows B(1), B(2) and B(3)
B(1)	*# Completions for Vertical wells with hydraulic fracturing*							Please provide this level of detail, if available
B(2)	*# Completions for Horizontal wells with hydraulic fracturing*							
B(3)	*# Completions for wells without hydraulic fracturing*							
C	# Gas well Workovers with hydraulic fracturing (refracs)							Total of rows C(1) and C(2)
C(1)	*# Workovers for Vertical wells with hydraulic fracturing*							Please provide this level of detail, if available
C(2)	*# Workovers for Horizontal wells with hydraulic fracturing*							
C(3)	*# Workovers for wells without hydraulic fracturing*							

Guidance:
2010 data is preferred, with U.S. geographic coverage as broad as possible.

Please duplicate the table to provide data for additional calendar years (if available) or additional geographic areas (if needed).

Note that some of this information overlaps with the data requested under the "Re-frac" worksheet.

Please provide information that you have available.

Blue rows are the minimum level of detail needed

Green rows provide more detailed information and have a longer response time

Geographic area:

Please indicate whether the information provided is for all of your operations in the U.S., or just a sub-part (single basin or multiple basins)

FIGURE A-3. GAS WELL WORKOVER SURVEY DATA

Table 2. Gas Well Workover Activity Data: Frequency of Re-fractures

	Year	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001
A	*Geographic area*										
B	*Number of Unconventional Operating Gas Wells*										
C	*Number of Fracture Stimulation Wells Completed each year (New Completions)*										
D	*Number of Fracture Stimulation Jobs conducted each year on Previously Fracture Stimulated Wells (i.e., # of Workovers or re-fracs)*										

Guidance

Please provide information that you have available.

Please provide data that are available for any or all of the years listed. Gaps in the data are OK.

Copy the table to provide data for additional geographic areas

A Geographic Area: Please indicate whether the information provided is for all of your operations in the U.S., or just a sub-part (single basin or multiple basins)

B Provide the number of Unconventional Operating Wells. This refers to wells located on shale, coal-bed Methane, and Tight Formations reservoirs. Unconventional reservoirs are reservoirs that require fracture stimulation to economically produce.

C Provide the number of new completions conducted in the year. This may be the same value provided in the "Well data" worksheet, Item B.

D Provide the number of re-fractures (workovers). A re-frac or workover is defined as a re-completion to a different zone in an existing well or re-stimulation of the same zone in an existing well. This may be the same value provided in the "Well data" worksheet, Item C. Hydraulic Fracture jobs conducted more than 30 days from the end of one stimulation job to the beginning of another stimulation job in the same well-bore is a new re-frac.

Notes

The EPA uses an assumption that 10% of wells are refractured each year to determine the number of re-frac's per year and then multiplies this by 9.175 MMSCF methane per re-frac to arrive at their inventory for this particular category.

For the year reported in Table 1, this table requests redundant information. The purpose of this table is to collect refracture information over a ten-year time period to provide a better estimate to EPA's assumption that 10% of wells are refractured each year.

FIGURE A-4. GAS WELL LIQUIDS UNLOADING SURVEY DATA

Table 3. Gas Well Venting for Liquids Unloading (Well Clean-ups)

A Please indicate if the information provided in Table 3 follows the Subpart W methodologies (yes or no)

		Conventional	Unconventional	Total	Comments
B	Geographic Area				
C	Time Period - Months				
D	Number of Operated Gas Wells Represented by the information provided				Unconventional wells are: Shale, coal-bed methane, and tight formation (sand, carbonate, etc.) that must be fracture stimulated to produce economic quantities of gas
E	Number of Gas Wells with Plunger Lift Installed				
F	Number of Gas Wells with Other Artificial Lift (Beam Pump; ESP; etc.)				
G	Number of Gas Wells Vented to the atmosphere for Liquids Unloading				EPA assumes that 41.3% of conventional gas wells (437,800) are vented for liquids unloading
H	Total number of Gas Well Vents for Time Period				EPA assumes that each venting well vents 38.7 times per year
I	Average Venting Time per Vent				EPA assumes that each venting event is 3 hours duration
J	*Number of Wells with Plunger Lifts that vent to the atmosphere*				This is a sub-category of data item #5. Please indicate here the number of wells that vent to the atmosphere
K	*Total Count of Gas Well Vents for Time Period - w/plunger*				
L	*Total Count of Gas Well Vents for Time Period - w-o/plunger*				
M	*Average Venting Time - w/plunger*				Hours per Vent - fractional hours if appropriate
N	*Average Venting Time - w-o/plunger*				Hours per Vent - fractional hours if appropriate
O	*Average Daily Production of Venting Gas Wells*				mcf/day
P	*Average Depth of Venting Wells*				feet
Q	*Average Casing Diameter of Venting Gas Wells*				inches
R	*Average Tubing Diameter of Venting Gas Wells w/plunger Lift*				inches
S	*Average Surface Pressure - Venting Gas Wells*				psig

Guidance:

This table represents data from a sampling of wells (as opposed to data for all of your wells).

If information is not available by conventional or unconventional wells, just provide data in the "total" column.

A If you do not have data based on Subpart W, please indicate this in data item A by typing yes or no in the shaded box

Copy the table to provide data for additional geographic areas

Please provide information that you have available.

Blue rows are the minimum level of detail needed

Green rows provide more detailed information

B Geographic Area: Please indicate whether the information provided is for all of your operations in the U.S., or just a sub-part (single basin or multiple basins).

C Time period: Indicate the number of months represented by the information provided. Ideally this is based on some portion of 2011 data collected for Subpart W reporting.

J This data line is a sub-category if data item E. From the difference between these two items, we are trying to determine the fraction of plunger equipped wells that do not vent.

K,L Please enter the number of liquids unloading events where gas is released to the atmosphere.

Notes:

Many companies have likely been tracking well venting for liquids unloading for several months due to Subpart W. API is soliciting information from members to correct/confirm EPA's assumptions regarding well un-loading. If you do not have the wells split out into Conventional and Unconventional categories then simply report the total counts and information in the Conventional categories.

Figure A-5. Other Survey Data

Table 4. Other Activity Data

A

Centrifugal Compressors			
	Production/ gathering	Processing	
Year			2010 data is preferred, but available information from any recent year is OK
Number of Centrifugal Compressors			Include both engine/turbine driven and electric driven
Number with Dry Seals			
Number with Wet Seals			

B

Pneumatic Devices (Controllers)				
	Well Sites	Gathering/ Compressor Sites	Gas Processing Plants	
Year				2010 data is preferred, but available information from any recent year is OK
Number of Sites/Plants Covered				The total number of wells sites, gathering compressor sites, of gas processing plants represented by the inventory of devices below
Number of Low Bleed				EPA defines low bleed as <6 scfh
Number of High Bleed				EPA defines high bleed as >6 scfh
Number of Intermittent				

Guidance

For pneumatic devices: Do not include counts of devices operated on compressed air. Designate pneumatic devices between "high bleed", "low bleed", or "intermittent" following the approach your company is using for Subpart W reporting.

Appendix B. ANGA/API Well Survey Information

Responses from the second part of the API/ANGA survey, which focused on more detailed well information, covered more than 60,000 wells and provided data on:

- # of gas wells without hydraulic fracturing (anytime in their history)
- # of gas wells with hydraulic fracturing (any time in their history);
  - # of vertical gas wells with hydraulic fracturing (anytime in their history);
  - # of horizontal gas wells with hydraulic fracturing (anytime in their history);
- # of completions for vertical gas wells with hydraulic fracturing;
- # of completions for horizontal gas wells with hydraulic fracturing;
- # of completions for gas wells without hydraulic fracturing;
- # of workovers for vertical wells with hydraulic fracturing;
- # of workovers for horizontal wells with hydraulic fracturing; and
- # of workovers for wells without hydraulic fracturing.

Table B-1 summarizes the well data collected by the ANGA/API survey and presents its distribution by formation type and region. The regional distribution follows the National Energy Modeling System (NEMS) regions defined by the EIA. The data are compared to EPA's national well counts classified by type as provided in the August 2011 database file (EPA, 2011d).

TABLE B-1. API/ANGA SURVEY – SUMMARY OF GAS WELL COUNTS BY TYPE AND NEMS REGION*

NEMS Region	Conventional Wells	Shale	Coal-bed Methane	Tight	Unspecified
Northeast	12,144	3,541	9	3,874	2,563
Gulf Coast	2,870	1,990	-	7,968	1,521
Mid-Continent	9,081	2,333	-	3,747	5,579
Southwest	646	1,208	-	726	2,326
Rocky Mountain	3,707	366	5,458	18,053	11
West Coast	-	-	-	-	-
Unspecified					1,307
Survey TOTAL	28,448	9,438	5,467	34,368	13,307
% of EPA 2010 Well Counts (from database file)	14.2%	30.1%	11.5%	45.6%	
Overall Survey Total	91,028				
EPA Well Counts (2010, from database file)	200,921	31,381	47,371	75,409	
	56.6%	8.8%	13.3%	21.2%	
	355,082				
EPA National Inventory (2010)	484,795				
EIA National Well Count (2010)	487,627				

* ANGA/API survey data represents well counts current for calendar year 2010 or the first half of 2011.

As shown in Table B-1, data from the API/ANGA survey represent approximately 26% of the national gas wells reported by EPA's database (or 18.7% of the EIA well count data). This includes almost 46% of all tight gas wells and 30% of shale gas wells. This may indicate that the ANGA/API information has an uneven representation of unconventional gas wells, and in particular shale and tight gas wells, but it also appears that EPA's data may mis-categorize these types of wells. For example, the EPA/HPDI data set contains few wells from Pennsylvania and West Virginia while the API/ANGA survey includes 9,422 wells from that area (AAPG 160A).

Table B-2 summarizes additional details on the natural gas wells information collected through the second data collection effort by the ANGA/API survey which covered 60,710 wells.

TABLE B-2. ANGA/API SURVEY – ADDITIONAL DETAILS ON GAS WELL COUNTS*

	# Wells w/out hydraulic fracturing (anytime in their history)	# Wells with hydraulic fracturing (any time in their history)		
		Total	# Vertical wells	# Horizontal wells
TOTAL Conventional	1,498	16,678	14,844	1,834
TOTAL Coal Bed Methane	42	3,475	3,424	42
TOTAL Shale	1,931	9,084	2,012	7,072
TOTAL Tight	122	27,880	24,045	3,835
TOTAL OVERALL	**3,593**	**57,117**	**44,325**	**12,783**

* API/ANGA survey data represents well counts current for calendar year 2010 or the first half of 2011.

Additional information on natural gas wells with and without hydraulic fracturing was provided for approximately two-thirds (60,710 natural gas wells) of the total well data collected by the ANGA/API survey. For this subset of the well data, 94% of the gas wells have been hydraulically fractured at some point in their operating history, including almost 92% of the conventional wells. EPA's 2010 national inventory reported 50,434 gas wells with hydraulic fracturing. This is very similar to the number of unconventional gas wells that EPA reported in the 2009 national inventory. ***Based on the API/ANGA survey results, it appears that EPA has underestimated the number of gas wells with hydraulic fracturing.***

Of the ANGA/API survey responses for wells that have been hydraulically fractured, most (77.6%) are vertical wells. Vertical wells are predominately conventional gas wells, coal-bed methane and tight gas wells; while the majority of shale gas wells are horizontal. EPA does not currently distinguish between vertical and horizontal gas wells.

A Short Note About EPA and EIA's Well Counts

There is a discrepancy of over 132,000 natural gas wells between the EPA database information (EPA, 2011d) and the EIA national gas well counts (EIA, 2012), and a difference of almost 130,000 gas wells between the two EPA data sources (EPA, 2011d and EPA, 2012). This difference needs to be understood since ultimately both the IHS (EIA) and HPDI (EPA) data originate from the same state-level sources of information.

The EIA provides a gas well count of 487,627 for 2010 based on Form EIA-895A[6], the Bureau of Ocean Energy Management, Regulation and Enforcement (formerly the Minerals

[6] Form EIA-895, Annual Quantity And Value Of Natural Gas Production Report; http://www.eia.gov/survey/form/eia_895/form.pdf

Management Service) data, and World Oil Magazine (EIA, 2010). However, the EIA does not classify gas wells by conventional and unconventional, or by formation types, precluding more detailed comparison against the EIA data. For some parameters the classifications were based on qualitative descriptions of the formations' physical properties (e.g. permeability) rather than on actual measurements (i.e. permeability data in millidarcy readings).[7]

EPA provides a similar well count in the 2010 national inventory: 434,361 non-associated gas wells + 50,434 gas wells with hydraulic fracturing, resulting in a total of 484,795 gas wells (EPA, 2012). Further classification of gas wells or description on what constitutes a "non-associated" gas well versus a "gas well with hydraulic fracturing" is not provided in EPA's national inventory.

Small differences in the HPDI and IHS original data may arise from definitional differences as HPDI and IHS compile the raw data. In addition, each state may have a different interpretation of well definitions of gas versus oil wells that introduces differences among states for the wells reported. EPA had indicated in discussions with the API/ANGA group that their database well count information may not include all of the wells in the Marcellus basin. EIA indicates 44,500 gas wells in Pennsylvania in 2010. However, even in accounting for these wells, there is still a large difference (almost 88,000 wells) between EPA's total gas well number from their database source and EIA's well data.

Nevertheless, these discrepancies among the well counts need to be understood since these data all originate from the same state-level sources of information. Differences could arise, for example, from different interpretations of well definitions.

Since the EIA data is the *de facto* benchmark in the energy industry, the difference between the EIA and EPA well count data needs to be understood before any meaningful conclusions can be made from the EPA data.

Since EPA's well count from HPDI was much lower than the EIA, this report does not attempt to come up with a national gas well count but chose to use the 355,082 number from the EPA HPDI database because it was the only available database which parsed the wells into conventional and unconventional categories (EPA, 2011d).

[7] Information provided by Don Robinson of ICF (EPA's contractor).

Appendix C. Emission Estimates for Gas Well Liquids Unloading

Tables C-1 through C-4 summarize the liquids unloading emissions data collected through the API/ANGA survey and the resulting emission estimates. The emission factors reported in Table 4 are based on a regional weighted average of the conventional and unconventional gas wells, with and without plunger lifts. This provided a consistent comparison against the EPA emission factors which are reported only on a regional basis and do not differentiate between conventional and unconventional wells or wells with and without plunger lifts.

TABLE C-1. LIQUIDS UNLOADING FOR CONVENTIONAL GAS WELLS WITHOUT PLUNGER LIFTS

NEMS Region	Northeast		Gulf Coast		Mid-Continent		Southwest
# venting gas wells	190	916	12	6	1	38	220
Total # gas well vents	4,335	39,668	144	60	1	2,444	880
Average casing diameter, inches	5	4.5	5.5	3.65	4.83	4	5.5
Average well depth, feet	3,375	3,448	10,000	19,334	7,033	4,269	8,000
Average surface pressure, psig (for venting wells)	85	50	(Weighted average applied) 65.2	224	25.5	60.8	100
Average venting time, hours	1	2	1	2.5	.25	4.95	1
Average daily production rate, Mscfd	12.83	7.21	300	664	58.43	84	100
Total emissions, scf gas/yr	13,492,728	78,217,933	1,287,782	3,854,938	2,440	38,451,629	9,037,809
Emissions per well, scfy gas/well	71,014	85,391	107,315	642,490	2,440	1,011,885	41,081

TABLE C-2. LIQUIDS UNLOADING FOR CONVENTIONAL GAS WELLS WITH PLUNGER LIFTS

NEMS Region	Northeast		Mid-Continent		
# venting gas wells	33	109	164	2	10
Total # gas well vents	1,272	4,217	489,912	23	7,300
Average tubing diameter, inches	2	2.375	1.995	2	2.375
Average well depth, feet	3,375	3,448	4,269	7,033	9,500
Average surface pressure, psig (for venting wells)	85	50	60.8	25.5	500
Average venting time, hours	1	0.3	0.067	0.75	0.08
Average daily production rate, Mscfd	12.83	7.21	84	58.43	30
Total emissions, scf gas/yr	973,442	1,963,379	232,529,848	23,623	74,495,422
Emissions per well, scfy gas/well	29,498	18,013	1,417,865	11,811	7,449,542

TABLE C-3. LIQUIDS UNLOADING FOR UNCONVENTIONAL GAS WELLS WITHOUT PLUNGER LIFTS

NEMS Region	Northeast	Gulf Coast				
# venting gas wells	337	6	8	27	11	15
Total # gas well vents	27,720	6	104	207	572	15
Average casing diameter, inches	4.5	5.5	5.5	4.5	5.5	10.75
Average well depth, feet	4,845	6,000	11,000	9,000	13,752	16,000
Average surface pressure, psig (for venting wells)	121.6	400	200	50	450	540
Average venting time, hours	1.36	3	1	5.3	2	2
Average daily production rate, Mscfd	26	200	25	130	353	8,500
Total emissions, scf gas/yr	148,079,273	267,095	2,749,066	5,736,344	49,326,199	11,004,804
Emissions per well, scfy gas/well	439,404	44,516	343,633	212,457	4,484,200	733,654

TABLE C-3. LIQUIDS UNLOADING FOR UNCONVENTIONAL GAS WELLS WITHOUT PLUNGER LIFTS, CONTINUED

NEMS Region	Gulf Coast				Mid-Continent			
# venting gas wells	146	2	10	40	177	3	136	215
Total # gas well vents	146	12	120	40	400	7.2	391.2	2,580
Average casing diameter, inches	4.5	5.5	5.5	8.625	5.5	4.92	5.02	5.5
Average well depth, feet	8,500	11,647	11,000	12,500	3,911	10,293	7,888	11,000
Average surface pressure, psig (for venting wells)	15	25	94	530	80	90.04	98.75	200
Average venting time, hours	0.6875	1.5	4	1	2.5	1.58	1.925	0.5
Average daily production rate, Mscfd	99	83	92	6,500	250	727	875	100
Total emissions, scf gas/yr	276,156	82,853	2,985,945	7,496,306	7,908,154	196,019	16,457,032	68,197,984
Emissions per well, scfy gas/well	1,891	41,427	298,594	187,408	44,679	65,340	121,008	317,200

TABLE C-3. LIQUIDS UNLOADING FOR UNCONVENTIONAL GAS WELLS WITHOUT PLUNGER LIFTS, CONTINUED

NEMS Region	Southwest			Rocky Mountain			
# venting gas wells	228	6	3	5	113	2	28
Total # gas well vents	221	6	1	1800	2,004	4	10,584
Average casing diameter, inches	9.625	5.5	5	2.375	4.038	4.7	4.5
Average well depth, feet	8,725	8,000	15,000	11,597	11,149	11,056	10,844
Average surface pressure, psig (for venting wells)	516	50	200	476	250	250	198
Average venting time, hours	1	0.5	6.67	0.77	1.616	0.75	3.18
Average daily production rate, Mscfd	1,500	12	150	41.54	127	433	83
Total emissions, scf gas/yr	35,075,995	34,759	65,227	76,746,923	42,212,132	95,677	262,702,911
Emissions per well, scfy gas/well	153,842	5,793	21,742	15,349,385	373,559	47,839	9,382,247

TABLE C-4. LIQUIDS UNLOADING FOR UNCONVENTIONAL GAS WELLS WITH PLUNGER LIFTS

NEMS Region	Northeast			Gulf Coast				
# venting gas wells	308	103	5	3	2	22	59	5
Total # gas well vents	63,840	75,190	194	156	2	22	354	5
Average tubing diameter, inches	2.375	2.375	2.375	2.375	2.375	2.375	2.375	2.375
Average well depth, feet	4,845	2,500	7,000	13,752	16,000	8,500	11,647	12,500
Average surface pressure, psig (for venting wells)	121.6	200	130	450	540	15	25	530
Average venting time, hours	0.221	0.05	0.1	2	1	0.875	0.3	0.5
Average daily production rate, Mscfd	26	15	628	353	8,500	99	83	6,500
Total emissions, scf gas/yr	87,985,573	84,228,892	410,107	5,522,367	391,212	45,622	341,615	71,050
Emissions per well, scfy gas/well	285,667	817,756	82,021	1,840,789	195,606	2,074	5,790	14,210

TABLE C-4. LIQUIDS UNLOADING FOR UNCONVENTIONAL GAS WELLS WITH PLUNGER LIFTS, CONTINUED

NEMS Region	Mid-Continent				Southwest	
# venting gas wells	48	4	64	29	18	60
Total # gas well vents	155,742	9.6	170.4	348	25	60
Average tubing diameter, inches	2.375	3.88	4.11	2.4	1.995	2.375
Average well depth, feet	3,911	10,293	7,888	(Average Applied) 7,888	8,725	6,800
Average surface pressure, psig (for venting wells)	80	90.04	98.75	74.69	516	110
Average venting time, hours	0.0833	2.99	2.6	0.5425	0.5	0.2
Average daily production rate, Mscfd	250	727	875	(Weighted average Applied) 371	1500	25
Total emissions, scf gas/yr	120,385,033	781,741	13,999,323	751,651	170,468	106,183
Emissions per well, scfy gas/well	2,508,022	195,435	218,739	25,919	9,470	1,770

TABLE C-4. LIQUIDS UNLOADING FOR UNCONVENTIONAL GAS WELLS WITH PLUNGER LIFTS, CONTINUED

NEMS Region	Rocky Mountain				
# venting gas wells	247	23	296	19	793
Total # gas well vents	1,476	51.43	2,080	21,888	9,516
Average tubing diameter, inches	1.997	1.92	2.375	2.375	2.375
Average well depth, feet	11,149	11,164	11,056	10,844	7,400
Average surface pressure, psig (for venting wells)	250	290	250	198	150
Average venting time, hours	0.407	1.12	2.1	0.455	0.67
Average daily production rate, Mscfd	127	454	433	83	46
Total emissions, scf gas/yr	6,427,381	841,788	72,746,777	105,363,947	27,245,035
Emissions per well, scfy gas/well	26,022	36,599	245,766	5,545,471	34,357

The calculated emissions shown in Tables C-1 through C-4 are based on applying Equation W-8 from 40 CFR 98 Subpart W to gas well liquid unloading without plunger lifts and Equation W-9 to gas well liquid unloading with plunger lifts. The equations and the terms are provided below.

98.233(f)(2) *Calculation Methodology 2.* Calculate the total emissions for well venting for liquids unloading using Equation W–8 of this section.

$$E_{s,n} = \sum_{p=1}^{W}\left[V_p \times \left(\left(0.37\times10^{-3}\right)\times CD_p^2 \times WD_p \times SP_p\right) + \sum_{q=1}^{V_p}\left(SFR_q \times \left(HR_{p,q} - 1.0\right)\times Z_{p,q}\right)\right] \quad \text{(Eq. W-8)}$$

Where:

$E_{s,n}$= Annual natural gas emissions at standard conditions, in cubic feet/year.

W = Total number of wells with well venting for liquids unloading for each sub-basin.

0.37×10^{-3}= {3.14 (pi)/4}/{14.7*144} (psia converted to pounds per square feet).

CD_p= Casing internal diameter for each well, p, in inches.

WD_p= Well depth from either the top of the well or the lowest packer to the bottom of the well, for each well, p, in feet.

SP_p= Shut-in pressure or surface pressure for wells with tubing production and no packers or casing pressure for each well, p, in pounds per square inch absolute (psia) or casing-to-tubing pressure of one well from the same sub-basin multiplied by the tubing pressure of each well, p, in the sub-basin, in pounds per square inch absolute (psia).

V_p= Number of vents per year per well, p.

SFR_p= Average flow-line rate of gas for well, p, at standard conditions in cubic feet per hour. Use Equation W–33 to calculate the average flow-line rate at standard conditions.

$HR_{p,q}$= Hours that each well, p, was left open to the atmosphere during unloading, q.

1.0 = Hours for average well to blowdown casing volume at shut-in pressure.

$Z_{p,q}$= If $HR_{p,q}$ is less than 1.0 then $Z_{p,q}$ is equal to 0. If $HR_{p,q}$ is greater than or equal to 1.0 then $Z_{p,q}$ is equal to 1.

98.233(f)(3) *Calculation Methodology 3.* Calculate emissions from each well venting to the atmosphere for liquids unloading with plunger lift assist using Equation W–9 of this section.

$$E_{s,n} = \sum_{p=1}^{W}\left[V_p \times \left(\left(0.37\times10^{-3}\right)\times TD_p^2 \times WD_p \times SP_p\right) + \sum_{q=1}^{V_p}\left(SFR_q \times \left(HR_{p,q} - 0.5\right)\times Z_{p,q}\right)\right] \quad \text{(Eq. W-9)}$$

Where:

$E_{s,n}$= Annual natural gas emissions at standard conditions, in cubic feet/year.

W = Total number of wells with well venting for liquids unloading for each sub-basin.

0.37×10^{-3}= {3.14 (pi)/4}/{14.7*144} (psia converted to pounds per square feet).

TD_p= Tubing internal diameter for each well, p, in inches.

WD_p= Tubing depth to plunger bumper for each well, p, in feet.

SP_p= Flow-line pressure for each well, p, in pounds per square inch absolute (psia), using engineering estimate based on best available data.

V_p= Number of vents per year for each well, p.

SFR_p= Average flow-line rate of gas for well, p, at standard conditions in cubic feet per hour. Use Equation W–33 to calculate the average flow-line rate at standard conditions.

$HR_{p,q}$= Hours that each well, p, was left open to the atmosphere during each unloading, q.

0.5 = Hours for average well to blowdown tubing volume at flow-line pressure.

$Z_{p,q}$= If $HR_{p,q}$ is less than 0.5 then $Z_{p,q}$ is equal to 0. If $HR_{p,q}$ is greater than or equal to 0.5 then $Z_{p,q}$ is equal to 1.