# Understanding Greenhouse Gas Emissions from Unconventional Natural Gas Production

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## ABSTRACT

Natural gas comprises almost one-fourth of all energy used in the U.S. New technologies, sometimes referred to as "unconventional" have enabled the production of more natural gas and have expanded domestic energy reserves.

Natural gas is generally recognized as a clean-burning fuel source, producing less greenhouse gas (GHG) emissions per quantity of energy consumed than either coal or oil. However, a number of recent studies are raising questions as to the impact of these new production techniques - especially hydraulic fracturing - on the carbon footprint of natural gas. Current published assessments rely mostly on highly uncertain information provided in EPA's November 2010 Technical Support Document (TSD) for mandatory GHG reporting from petroleum and natural gas systems, and from information associated with EPA's Inventory of Greenhouse Gas Emissions and Sinks: 1990-2009.

It is becoming increasingly important to document the GHG emissions associated with the different stages of natural gas production in order to demonstrate the continued environmental benefits of natural gas. Therefore, technically sound quantification and assessment of GHG emissions from its lifecycle - from production to delivery to end-users - is essential. This paper will summarize results from a technical review of the emissions data used to develop EPA's 2009 national inventory and the 2010 inventory updates. The paper will also discuss a collaborative effort between the American Petroleum Institute (API) and America's Natural Gas Alliance (ANGA) to gather industry-specific information on emissions from key emission sources associated with unconventional natural gas production.

## INTRODUCTION

In 2011, the U.S. Environmental Protection Agency (EPA) introduced a new calculation method with substantially increased greenhouse gas (GHG) emission factors for unconventional wells that caused calculated emissions from natural gas systems to more than double.[1] The new numbers were based on an extremely limited data set. Although EPA has acknowledged a need for new data in order to improve their estimate, their existing emission factors (which overestimate emissions), continue to be used in studies evaluating environmental impacts of natural gas production.[2]

In fact, EPA's numbers are one of the few commonalities to the many studies claiming to do a "lifecycle" analysis of natural gas. Differences in scope, methodology, and factors like the time horizon for radiative forcing of atmospheric methane, contribute to the conflicting results though they are rarely reported effectively in the popular press. Nevertheless, a growing number of studies indicate natural gas results in lower greenhouse gas emissions for a wide range of assumed parameters– even when using the EPA's inflated estimates.

In the field, operations grow continuously 'greener' thanks to new technology and evolving regulatory and corporate methane mitigation strategies.[3] Additional voluntary emission reduction measures are also often incentivized by state or federal mitigation programs. Furthermore, recently finalized mandatory GHG reporting requirements are expected to produce improved data that will document this progress and better inform calculation methodologies for future inventories. Yet, as this article indicates, developing a more robust methodology from the upstream (or production) segment of natural gas is clearly a pivotal first step in assessing the climate impacts of unconventional wells.

The accuracy of GHG emission estimates from unconventional 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 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 (CH4) emissions from unconventional gas 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.

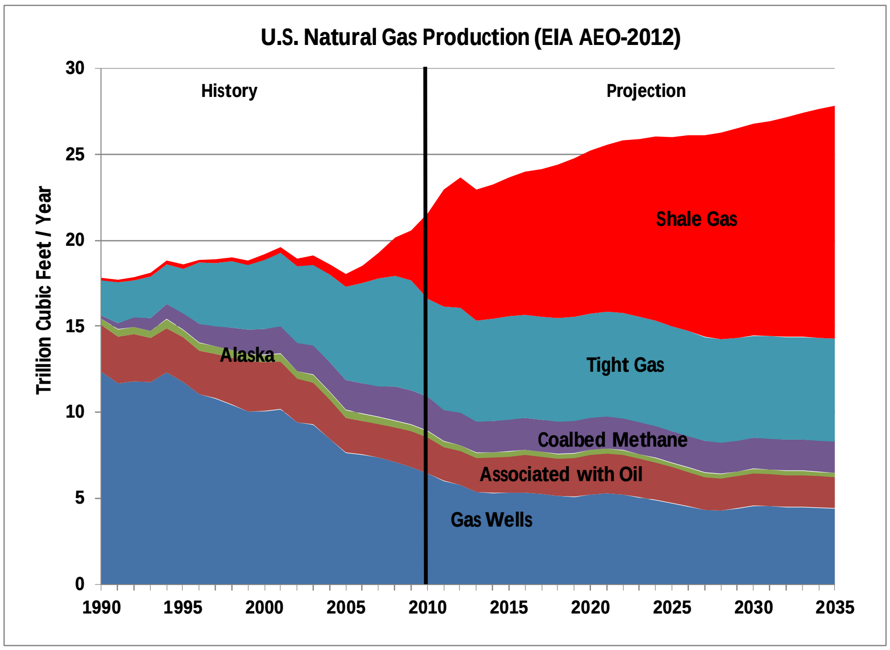
## NATURAL GAS SYSTEMS METHANE EMISSIONS

Despite a broad range of federal and state regulations and a myriad of reporting requirements – little reported field data currently exists for quantifying methane emissions. Prior to the mandatory GHG Reporting Program (GHGRP), the EPA had not outlined a clear methodology for detailed and consistent GHG data collection from natural gas systems. While not yet complete, this information will provide a valuable start to regulatory and academic assessments, as well as offer a basis for refining individual corporate emissions mitigation strategies. These new data will augment limited data that currently exists through voluntary state or federal incentive programs like the EPA's Natural Gas Star.

## Emerging Role of New Natural Gas Production Techniques

Natural gas produced from shale formations represents a "paradigm shift" for U.S. energy supplies. In 2005, shale gas accounted for only 4% of US natural gas production. The Energy Information Administration (EIA) projects that, combined with tight gas as shown in Figure 1, it will account for over 70% of production by 2035. Shale gas produced through hydraulic fracturing is essential to the growth of U.S. energy supplies; however, little robust publicly available data exists to document methane emissions from current unconventional natural gas production practices.

**FIGURE 1 .U.S. NATURAL GAS PRODUCTION HISTORY AND PROJECTION ESTIMATES**




Both shale gas and tight gas are produced with hydraulic fracturing, which "has opened up natural gas resources that would not [otherwise] be commercially viable."[4] Without hydraulic fracturing, U.S. natural gas production would be fundamentally different than EIA's new 2012 outlook.

Hydraulic fracturing techniques developed in the 1940s involve high pressure injection of "fracturing fluids" (consisting primarily of water and sand) to create fissures allowing natural gas to flow freely into production piping. When hydraulic fracturing is combined with horizontal drilling (a technique which allows long lengths of pipe to follow horizontal shale deposits for thousands of feet), significant production is possible from a single well site.

Although shale gas and hydraulic fracturing promise to significantly improve the U.S. and global energy futures, their potential environmental impact cannot be overlooked. Some opponents of fracturing have expressed concern that a 100 year supply of domestic natural gas will prevent an overall switch to renewable energy. To bolster their arguments, they allege an intensive production process that includes large-scale drilling equipment and considerable quantities of both sand and water, and results in greater emissions.

Natural gas advocates cite its comparative efficiency in generating a readily accessible cleaner burning fuel, rather than importing liquid natural gas (LNG) as the U.S. would continue to do without shale gas production. Natural gas is acknowledged to be a "cleaner" fuel. EPA concludes on its website on electricity generation that compared to "coal-fired generation, natural gas produces half as much carbon dioxide, less than a third as much nitrogen oxides, and one percent as much sulfur oxides at the power plant."[5]

Horizontal drilling and hydraulic fracturing pose unique challenges from an emissions perspective. Most notably, drilling, completions, and workovers of natural gas wells may lead to flaring and venting of excess gas that cannot be captured commercially during these initial stages.

**Impact of EPA's Revised Methodology on Methane Emissions from Natural Gas Systems**

In 2011, when EPA published the U.S. GHG inventory for 1990 – 2009 it cited two Natural Gas STAR presentations as the source of information for the development of the set of distinct emission factors for unconventional natural well completion/workover operations.[6]

Table 1 presents EPA's estimates for the contribution of Natural Gas and Petroleum Systems to total U.S. methane and GHG emissions between 2005 and 2010. The 1990 – 2010 updated data series published recently by EPA[7] indicates that natural gas systems contribute - on average - 31.9 % and petroleum systems contribute 4.6 % of national methane emissions respectively[i].

Table 1. **EPA[A] ESTIMATED CONTRIBUTION OF NATURAL GAS AND PETROLEUM SYSTEMS TO U.S. METHANE AND TOTAL GHG EMISSIONS (MILLION METRIC TONNES OF CO2E [B])**

| Source Category | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|
| Natural Gas Systems | 190.5 | 217.7 | 205.3 | 212.7 | 220.9 | 215.4 |
| Petroleum Systems | 29.2 | 29.2 | 29.8 | 30.0 | 30.7 | 31.0 |
| **Methane - Total US** | **625.8** | **664.6** | **656.2** | **667.9** | **672.2** | **666.5** |
| **TOTAL US GHGs** | **7,204.2** | **7,159.3** | **7,252.8** | **7,048.3** | **6,608.3** | **6,821.8** |

**Notes:**
[A] EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010" (Final), Table ES-2.
[B] Note: per UN-FCCC requirements for national inventories, EPA uses a GWP of 21 for methane.

As Figure 2 shows, production accounts for a significant percentage of the oil and gas sector's aggregate methane emissions.

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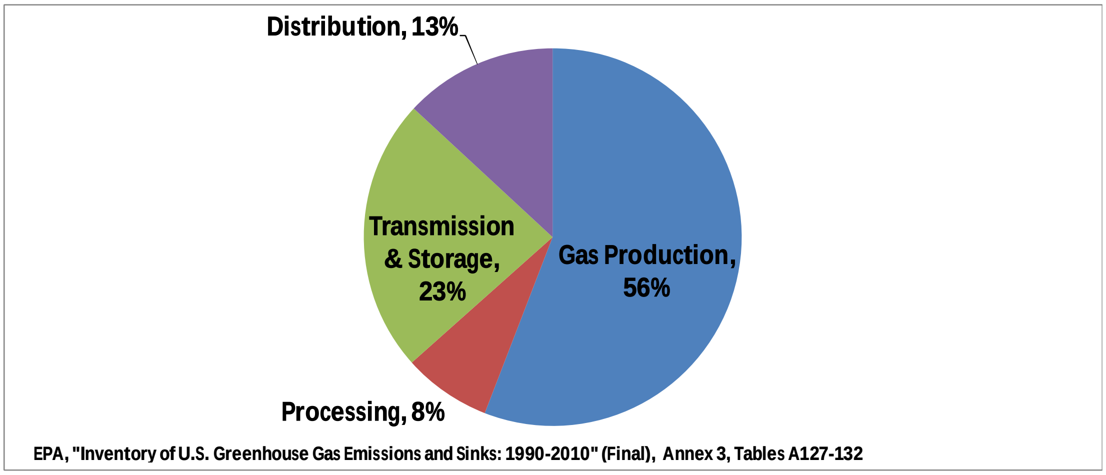
[i] *Unless otherwise indicated, numbers cited in this article are "as reported by EPA" – meaning that they match published estimates which rarely reflect an appropriate number of significant digits.*)

**FIGURE 2 . COMPONENTS OF NATURAL GAS SYSTEM METHANE EMISSIONS**



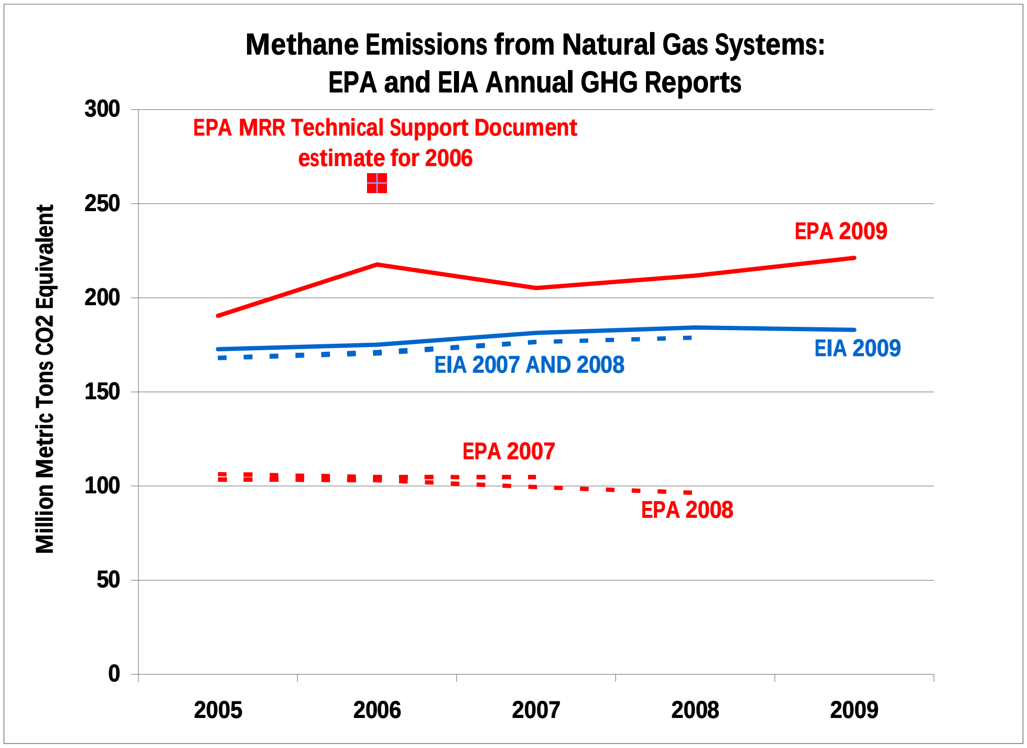

The revised methodology published by EPA in 2011 for the 2009 national inventory, significantly impacted methane emissions estimates from natural gas systems. Previous EPA emissions estimates for natural gas systems were based on a 1996 report conducted by the EPA and the Gas Research Institute (GRI). While these estimates needed updating, the GRI report was carefully designed to include a representative sample of wells from a broad base of geographic areas.

In contrast, EPA's revised estimate was based on data from only four (4) sources submitted voluntarily in a very unique accounting context – operators had provided the information to the EPA's Natural Gas Star Program, which incentivized emissions reduction. Although the four initial points represented only approximately 8,800 wells, their data were extrapolated to apply to the over 350,000 gas wells in the emissions inventory. Since publication in 2009, the EPA's methodology has been widely criticized – even by the internationally renowned energy consultancy IHS CERA.[8]

Although EPA itself has acknowledged a need to revisit its estimates, the emission factor was used again in EPA's 2010 inventory (published in 2012). EPA's emissions estimates also continue to be used by individuals arguing against shale gas production; consequently, understanding their impact is of paramount importance.

Since it is common practice to recalculate the entire inventory time-series (from 1990) when a new methodology is introduced, it is necessary to compare the 'before' and 'after' time series in order to understand the impact. Figure 3 provides a graphical comparison of methane emissions based on EIA's and EPA's respective methodologies. It clearly demonstrates how EPA's revised emission factors caused estimated emissions from natural gas systems to more than double.

**FIGURE 3. IMPACT OF METHANE EMISSIONS RECALCULATIONS ON NATURAL GAS SYSTEMS EMISSIONS ESTIMATES**[9]




The impact of EPA's revised emission factor on calculated methane emissions can be best illustrated by examining methane emission sources for venting during new well completion or existing well workovers to stimulate production. For the 2009 inventory, EPA split the estimation of emissions from producing gas wells into conventional (i.e. without fracturing), and unconventional (i.e., with hydraulic fracturing). The technical support document (TSD) for Subpart W provides further details on the data specifically used in developing the Subpart W average emission factor which was set at 9,175 Mscf of natural gas/completion.[10]

Based on this limited data, as described above, gas wells with hydraulic fracturing activities were suddenly assigned an emission factor that is over 3,000 times higher than the one used for gas wells without hydraulic fracturing. The numerical consequences for estimated emissions associated with completions and workovers are striking. In the 2009 national inventory, gas well workovers with no hydraulic fracturing had regional emission factors ranging from 2,442 Scf/event to 2,861 Scf/event. In contrast, EPA's new regional emission factors for gas well completions and workovers with hydraulic fracturing range from 7,194,624 Scf $CH_4$/event to 7,694,435 Scf $CH_4$/event.

## API/ANGA SURVEY

When reviewing EPA's 2009 National GHG Emissions Inventory, which was published in 2011, it became evident that EPA's methane emissions estimates for Natural Gas Systems might have some underlying errors when compared to actual emissions for the industry segment due to potentially unrepresentative data for some key activities and inaccurate emission factors that are used by EPA to convert these activities to emissions. Specifically, EPA's raw estimate of methane emissions from natural gas systems for the 2009 inventory is about 8.9 million tonnes (8,898.20 Gg)[1] without accounting for reductions due to state regulations and voluntary reductions reported to Natural Gas Star.

EPA's raw data indicates that the major contributing sources are:

- Gas wells liquids unloading – about 51%
- Gas wells completions and workovers with hydraulic fracturing - about 14.8%;
- Venting from pneumatic controllers - about 13.5%;
- Venting from compressors gas engines - about 3%; and
- Other sources – almost 18%.

For the 2009 inventory EPA did document a total of 22.5% and 8.25% emission reductions, respectively, for natural gas production, based on reporting to Natural Gas Star and existing state regulations. However, the information provided by EPA is not transparent enough to allow linking any of these reductions to specific emission sources.

The American Petroleum Institute (API) and America's Natural Gas Alliance (ANGA) have therefore initiated a collaborative study (referred to below as the API/ANGA survey) to gather information about industry activities and practices in order to improve understanding of the emissions associated with these key contributing sources to overall methane emissions from the natural gas sector. Further details about the survey, survey results and summaries of observations can be found in the final report for this phase of the study[11]. This paper focuses on the findings when characterizing gas well activities with their associated well completions and recompletion (or workover) rates nationwide and their impact on estimated methane emission.

## Gas Well Data

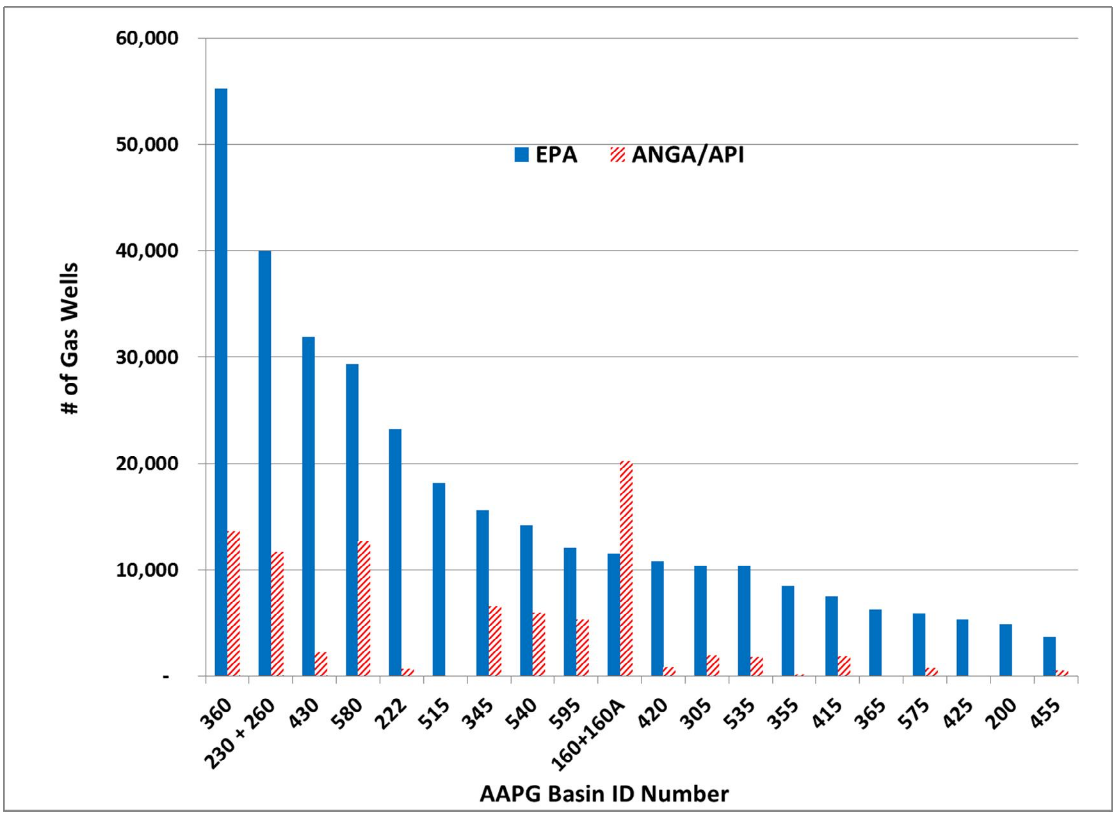
Overall, the API/ANGA survey effort gathered activity data from over 20 companies covering nearly 91,000 wells and 19 of the 21 producing geological basins, as defined by the American Association of Petroleum Geologists (AAPG)[12]. The survey data includes information on each of the producing basins containing over 1% of the total well count in EPA's national gas wells database. This represents the most comprehensive data set ever compiled for natural gas operations and, as such, provides a much more accurate picture of operations and emissions to enable improving on the data presented by EPA in the past national GHG emission inventories.

To provide context for the information collected by the ANGA/API survey, the data were compared to information about the national gas wells databases provided by the U.S. EPA, the U.S. Energy Information Administration (EIA), and IHS (the information arm of the Cambridge Energy Consultants). This comparison made it apparent that significant discrepancies exist among different sources of national gas well data. The EPA inventory, the EIA, and IHS all reported different well counts that do not consistently distinguish between key categories such as conventional and unconventional wells. Furthermore, there does not appear to be a single widely accepted technical description or definition for classifying wells into each of these categories.

As shown in Figure 4, the API/ANGA survey results more heavily represent gas wells in a few specific AAPG basins (160 and 160A) when compared to EPA's basin-level well counts. AAPG basins 360, 230, and 580 seem to be important for both data sets.[13]

The data set provided by EPA probably did not include all of the Marcellus Shale gas wells (particularly in Pennsylvania), and the well classification system used could have been more rigorous. Although this comparison does not show a perfect distributional match basin by basin, it does demonstrate that the API/ANGA survey covers 90% of the basins and 27% of the national gas well count for the significant basins as reported by EPA. The data discussed in the API/ANGA report[11] 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.

**FIGURE 4. COMPARISON OF EPA TO API/ANGA GAS WELL COUNT DATA BY AAPG BASIN**




## Gas Well Completions

The API/ANGA survey results provide data for 2010 and the first half of 2011 and they represent 57.5% of the national tight gas wells completions data and 44.5% of shale gas well completions, with 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) could not be classified into the well types requested (i.e., tight, shale, or coal-bed methane). The survey results for well completions are provided in Table 2 and compared to national data provided to ANGA by IHS and to the data provided by EPA for the 2010 national inventory. It is evident from the data presented in Table 2 that the API/ANGA data provides more information about completions with hydraulic fracturing, where new data is needed.

**TABLE 2. API/ANGA SURVEY: COMPARISONS OF GAS WELL COMPLETIONS COUNTS**

| | Completions without Hydraulic Fracturing | | Completions with Hydraulic Fracturing | | Total Completions |
|---|---|---|---|---|---|
| | # Completions | % of Total | # Completions | % of Total | |
| 2010 National Well Completions (from EPA 2012 report) | 702 | 14 | 4,169 | 86 | 4,871 |
| API/ANGA Survey Well Completions | 540 | 7 | 6,821 | 93 | 7,361 |
| Well Completions from IHS | 7,178 | 39 | 11,274 | 61 | 18,452 |

Examining the detailed data from the API/ANGA survey results indicate that the vast majority (93%) of gas well completions (as indicated: 2010 and first half of 2011 for sites that reported data) were conducted on wells with hydraulic fracturing. The completions that were reported to use hydraulic fracturing were almost evenly split between vertical wells and horizontal wells; vertical wells completion in tight formations and horizontal wells completions in shale formations accounted for 41% and 37%, respectively, of all reported completions with hydraulic fracturing. For the data collected by the API/ANGA survey only 7% were conventional gas well completions, where 31% were with hydraulic fracturing and 69% without hydraulic fracturing, which is close to the national breakdown for well completions reported by IHS.

In contrast, the data provided by EPA's 2010 inventory accounts for 4,169 gas well completions with hydraulic fracturing, and 702 completions without hydraulic fracturing, without providing a breakout of completions by well type (shale gas, tight gas or coal-bed methane).[14] In comparing the EPA 2010 count of gas well completions to both the API/ANGA survey results and the data provided by IHS, it seems that EPA's national GHG inventory underestimates the number of gas well completions even when accounting for the slight difference in time periods covered (2010 for EPA's inventory as compared to 2010/2011 data from the API/ANGA survey).

This discrepancy highlights the recurring differences among the various national well data reporting systems, which makes it difficult to accurately assess well completion emissions data with certainty. The EPA inventory uses data from HPDI and the EIA, while IHS uses state reported data and EIA data, with the addition of privately sourced data. All of these sources report different well counts that do 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.

**Hydraulic Fracturing and Re-fracturing (Workovers)**

Following well completions and a period of routine production, a well may experience a production decline that requires an intervention beyond basic well servicing. Such an intervention is known as a well workover and it refers to the remedial operations on producing natural gas wells to try and increase their production. The emissions that would be associated with the well workover operations could be very similar to that of the original completion. Therefore, overall emissions will depend to a large extent on both the emission factor assumed for each completion/workover and the rate of performing such workovers.

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), and the applicable emission estimates for these sources (i.e. completions and workovers with and without hydraulic fracturing). For completions and workovers of gas 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 CH4/event). In contrast, for unconventional (with hydraulic fracturing) gas well completions or workovers the emission factor increased by a factor of three thousand (3,000). EPA's new emission factor amounts to 9,175,000 scf of natural gas/event (equivalent to assuming emissions of 7,623,000 scf CH4/per event). Additionally, EPA also assumed that the rate of refracture (workover) for unconventional wells is 10% per year. The combination of these new emission factors in conjunction with an assumed re-fracture rate of 10% for unconventional gas well workovers each year has led to the substantial increase in emissions estimated for the 2009 and 2010 natural gas systems contribution to the national inventory.

The API/ANGA survey requested counts for gas well workovers or re-fractures in two separate phases of the survey. In the first phase responses received covered 91,028 total gas wells (for the period of 2010 and first half of 2011 data), and 69,034 unconventional gas wells (2010 data only) were represented in the second phase. Table 4 presents a summary of the second phase data that targeted collecting gas well re-fracture information for 2010 to test the validity of EPA's assumption that 10% of wells are re-fractured each year. For this phase, information was requested 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.

**Table 4. API/ANGA Survey – Summary of 2010 Gas Well Workovers on Unconventional Wells by AAPG Basin and NEMS Region (2ND Phase Survey Data)**

| NEMS Region | AAPG Basin ID | 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%** | |
| **Rocky Mountain Region (AAPG 540) Unconventional** | | **19,370** | **906** | **4.68%** | |
| **Unconventional TOTAL (Without AAPG 540)** | | **63,084** | **727** | **1.15%** | |

The API/ANGA survey collected information on the number of workovers for vertical and horizontal unconventional gas wells. Nearly 99% of the unconventional gas well workovers were on vertical wells. Additionally, 18% of the gas well workovers from the API/ANGA survey were conducted on gas wells without hydraulic fracturing.

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 and 69,000 unconventional gas wells, respectively), combining these data indicate an unconventional well re-fracture rate of 1.6% to 2.3% if we include the Rocky Mountain Region (AAPG 540) and 0.7% to 1.15% when excluding AAPG 540, which has a uniquely high and uncharacteristic workover rate.

AAPG Basin 540 (i.e. DJ Basin) which is part of the Rocky Mountain Region stands out in Table 4. After 4 – 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 workover operations successfully and economically. These characteristics result in a high re-fracture or workover rate that is specific to this formation.

The API/ANGA survey shows that the high re-fracture rate observed in the DJ Basin is unique and not replicated in other parts of the country. 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 Table 4.

Table 5 compares the reduction in the national GHG emission estimate that would result from applying a lower re-fracture rate. According to EPA the national inventory assumes that 10% of unconventional gas wells are re-fractured each year. Table 5 replaces this value with results from the API/ANGA 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.

**TABLE 5. API/ANGA SURVEY – GAS WELL WORKOVER EMISSIONS COMPARISON**

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

## CONCLUSIONS

The API/ANGA survey provides an important contribution to estimating national GHG emissions by presenting the most comprehensive set of natural gas activity data collected to date for key emission sources that significantly contribute to the national GHG emissions inventory.

Based on the information gathered in this survey, it appears that EPA has overstated GHG emissions from unconventional natural gas production.

Analysis of the API/ANGA survey data highlights the following needs for further investigation:

- Improved consistency in the national well count database to eliminate the observed discrepancy;
- Widely acceptable and technically valid definitions of what constitutes conventional vs. unconventional production;
- Better classification of the types and rates of industry activities for better representation in the national inventory; and
- Updated emission factors representing current practices and operations including emission reductions at the source level.

It is clear that additional data is required to improve our understanding of emissions from natural gas systems. The API/ANGA survey results provide an initial start that enriches the currently available database and contributes site specific data from over 90,000 well sites, with information that has been vetted and verified by natural gas production experts. Furthermore, as past history reveals, the rapid advancement of emissions control technologies will likely create a lag between existing data on GHG emissions and what is actually taking place in operations. The key is to promote transparent estimation methods that account for emission reduction credits for each specific source.

Furthermore, an initial batch of industry data will be transmitted to the U.S. EPA by September, 2012. The reported data will provide detailed information about the extent of activities and emissions by industry segment and for onshore production by geological basin and sub-basin categories. These newly reported data will provide even more valuable information about emissions from all industry sources with particular emphasis on improving and understanding methods for estimating emissions from the fast growing segment of unconventional natural gas production.

**REFERNCES**

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[2] DOE/NETL-2011/1522, "Life Cycle Greenhouse Gas Inventory of Natural Gas Extraction, Delivery and Electricity Production", October 24, 2011, Section 2.5.3 Data for Natural Gas Extraction

[3] U.S. Environmental Protection Agency, "Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants", Final Rule, signed April 17, 2012

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