**The Dissertation Committee for Daniel Zavala Araiza certifies that this is the approved version of the following dissertation:**

# Atmospheric Emissions and Air Quality Impacts of Natural Gas Production from Shale Formations

**Committee:**

_____

**David Allen, Supervisor**

_____

**Michael Webber**

_____

**Elena McDonald-Buller**

_____

**Lea Hildebrandt Ruiz**

_____

**Thomas Edgar**

# Atmospheric Emissions and Air Quality Impacts of Natural Gas Production from Shale Formations

by

**Daniel Zavala Araiza, B. S.**

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# Dedication

For Yazmin, my soulmate.

“So, these things –formerly mute and said to be objective because passive like the slaves of an activity that would belong only to us - these coding-coded things, as though awakened, speak just as much and perhaps better than us, they also say, write, sing, communicate among themselves, through a kind of reciprocal encoding, a kind of common language, a kind of music, harmonic, disharmonic.”

- *Michel Serres, Biogea*

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Finally, blessings to my family, may light, love, and compassion, always be present, thanks for believing in me.

# Atmospheric Emissions and Air Quality Impacts of Natural Gas Production from Shale Formations

Daniel Zavala Araiza, Ph.D.

The University of Texas at Austin, 2014

Supervisor: David Allen

Natural gas is at the core of the energy supply and security debates; new extraction technologies, such as horizontal drilling and hydraulic fracturing, have expanded natural gas production. As with any energy system, however, natural gas has an environmental footprint and this thesis examines the air quality impacts of natural gas production.

Greenhouse gas (GHG), criteria pollutant, and toxic emissions from natural gas production have been subject to a great amount of uncertainty, largely due to limited measurements of emission rates from key sources. This thesis reports direct and indirect measurements of emissions, assessing the spatial and temporal distributions of emissions, as well as the role of very high emitting wells and high emitting sources in determining national emissions. Direct measurements are used to identify, characterize and classify the most important sources of continuous and episodic emissions, and to analyze mitigation opportunities. Methods are proposed and demonstrated for reconciling these

direct measurements of emissions from sources with measurements of ambient concentrations.

Collectively, the direct source measurements, and analyses of ambient air pollutant measurements in natural gas production regions reported in this work improve the estimation, characterization, and methods for monitoring air quality implications of shale gas production.

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# 1 INTRODUCTION

## 1.1 Importance of Natural Gas Production from Shale Formations

New technologies have revolutionized natural gas production in the United States. This gas boom is based on the extraction of natural gas from shale formations, which have very low permeability, requiring more intensive drilling and the use of horizontal drilling and hydraulic fracturing production techniques. While conventional natural gas resources in the United States are declining, the extraction of shale gas and unconventional gas may allow the United States to become a net energy exporter [1].

It is expected that by the year 2035, 49% of U.S natural gas production will come from shale gas, with total natural gas production increasing by roughly 30% [2]. Figure 1-1 shows the geographical location of shale plays in the United States. There are important geological differences between plays, leading to differences in extraction and production methods used in each of the regions.

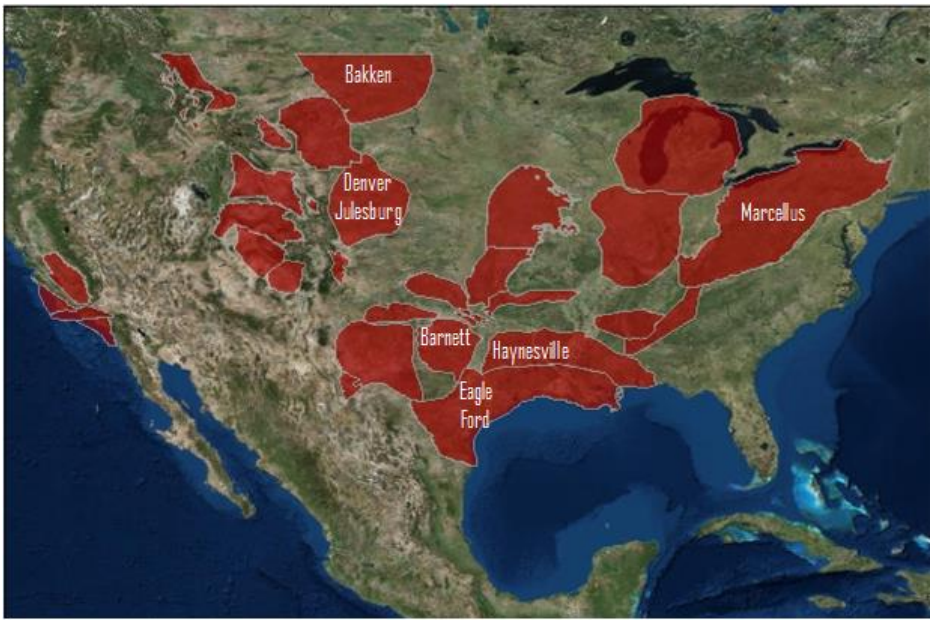


**Figure 1-1.** Geographical location of shale plays in the United States. (Adapted from EIA, Annual Energy Outlook [2].

Of the various shale plays in the United States, the Barnett Shale (the focus of much of the work reported here), located in North Central Texas has among the longest histories of production. Over the course of a decade, production increased from 0.11 billion cubic feet per day (bcf/d) in 2000, to 5 bcf/d by 2011 [3-4], making the Barnett Shale one of the largest shale gas production regions in the U.S.. In comparison, the Haynesville region currently produces 7 bcf/d, the Marcellus produces 4.5 bcf/d, and Fayetteville produces 3 bcf/d [5]. Total U.S. natural gas production is approximately 75 bcf/d.

The technological developments that allow the extraction of natural gas from shale formations have been mainly developed and used in the United States, nevertheless, shale resources around the world are vast and a number of countries have started to explore the possibility of extracting shale gas and shale oil. An example of this is Mexico, where recent policy reforms have opened the door to assessment and development of national resources [6-7]. Figure 1-2 shows the ten countries with the largest estimated technically recoverable shale gas resources. The country with the most extensive Shale Gas resources is China (1,115 Trillion cubic feet (Tcf)), followed by Argentina (802 Tcf), and Algeria (707 Tcf)[8].

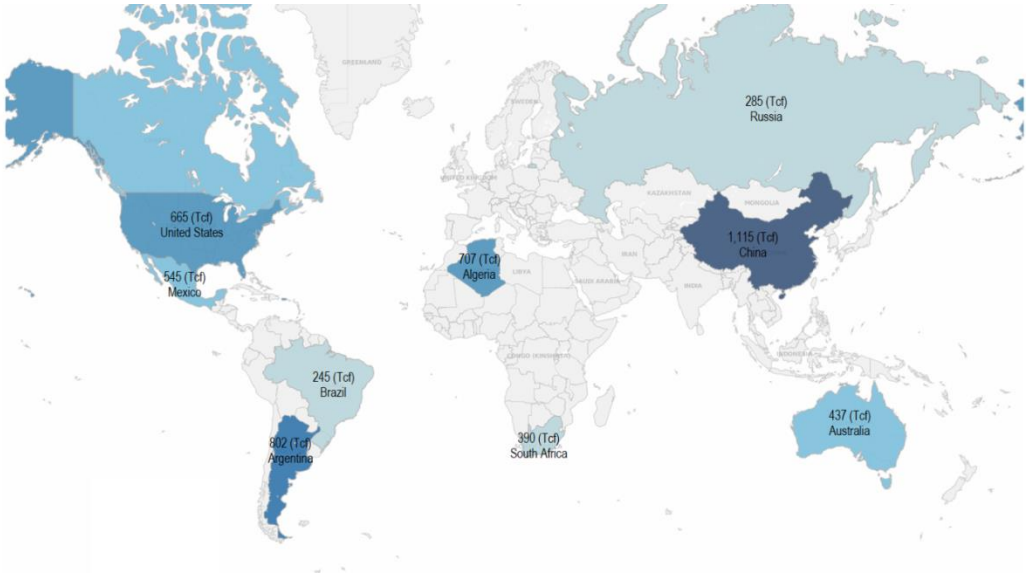


**Figure 1-2.** Technically recoverable shale gas for the ten countries with the biggest shale gas resources (reported in Trillion cubic feet) (Adapted from [8]).

Melikoglu [9] reported ratios of *[total estimated natural gas consumption (between 2010 and 2040)]/[natural gas reserves]* and *[total estimated natural gas consumption (between 2010 and 2040)]/[natural gas reserves + shale gas resources)]* for the ten countries with the largest technically recoverable shale gas resources. For China, when only conventional natural gas reserves are considered (no shale gas resources), the ratio is 2.61, when shale gas resources are considered, the ratio decreases to 0.23. Similarly, for the United States the ratio without considering shale gas resources is 2.50, once shale gas resources are added, it decreases to 0.83. These results highlight the importance of shale gas production, and illustrate why shale gas will play a key role in meeting worldwide demand for natural gas.

The widespread availability of natural gas, both worldwide and in the United States, has caused a displacement of other fossil fuels, reshaping the overall energy landscape. In the United States, 34% of natural gas consumption is used for electricity generation, with forecasts showing that by the year 2035, natural gas will displace coal as the major source of electricity generation [10]. While changes in natural gas production are already reshaping electricity generation, these changes will also influence other sectors.

Low natural gas prices coupled with an increased supply of natural gas co-products, such as ethane, propane, butane, and natural gas liquids, will re-shape the chemical manufacturing sector, with natural gas liquids potentially replacing petroleum-derived feedstocks [10]. Production of ammonia, nitrogen based fertilizers, and hydrogen (produced by steam reforming of methane), are other examples of industrial processes that rely on methane from natural gas that will potentially be affected due to the enhanced availability of natural gas co-products and the decrease in price of natural gas.

The magnitude and rate at which shale gas production is transforming the United States, both in economic and industrial terms, makes it important to study, understand, and assess the potential environmental impacts attached to such transformations. In addition, the present state of shale production development in the United States; characterized by

decades of technological development and an advanced stage of production and extraction in many of the shale basins, can provide lessons for other countries where shale production is in an early stage, or will become a reality in the near future.

### 1.2 Environmental Impacts of Natural Gas Production from Shale Formations

There have been a variety of analyses of the environmental implications of shale gas production, which have addressed *(i) ground water contamination, waste water generation and water availability* [11-14], *(ii) greenhouse gas (GHG)* [15 – 18] *criteria pollutants, and air toxics emissions* [19-20], *(iii) increased seismic activity* [21-22], and *(iv) land use/ land change issues*[22, 23].

This work will focus on the air quality implications of the production of natural gas from shale formations, particularly focusing on greenhouse gases, photochemical air pollutants and their precursors, and air toxics.

Estimating the emissions of air pollutants from natural gas production is a challenging task, due to the high density of sources, the regional characteristics of the geological formations, and the wide range of spatial and temporal scales over which emissions occur. For GHGs, the emissions have impacts on national and global scales; for air toxics and criteria pollutants, the spatial scale is local and regional. Temporal scales of air quality impacts range from hours to decades. This thesis describes a set of multi-level, multi-scale analyses that can be applied to characterize air quality impacts of shale gas production.

## 1.3 Research Objectives

The goals of this work are to:

1. Measure and estimate GHG emissions related to shale gas production activities.
2. Measure and estimate emissions of criteria and toxic pollutants related to shale gas production.
3. Identify and analyze the distribution of emissions from shale gas production, focusing on temporal and spatial patterns.
4. Assess causal factors and emission reduction opportunities.
5. Assess the performance of current emission inventories in predicting observed emissions.
6. Develop tools for the reconciliation of measurements, at multiple spatial scales, and emission inventories

Some of the analyses will be national in scope. Others will focus on the Barnett Shale region in North Central Texas.

## 1.4 Dissertation Structure

**Chapter 2** of this work reviews existing literature on air quality implications of natural gas production from shale gas formations. The review covers greenhouse gases, volatile organic compounds (VOC) (photochemical air pollutants), and air toxics; and identifies uncertainties in current estimates. **Chapter 3** and **Chapter 4** describe measurements done on two of the main sources of emissions from natural gas production: *pneumatic controllers* and *liquids unloading*, assessing the spatial and temporal distributions of emissions as well as the role of very high emitting wells and controllers in determining national emissions.

An important consideration when the environmental footprint of natural gas is estimated and compared against other fuels, is to acknowledge that along with natural gas, other co-products such as Natural Gas Liquids and oil are produced by gas wells. **Chapter 5** describes an allocation method for methane (greenhouse gas) emissions from natural gas production among the different co-products.; consequences and implications of the allocation scheme are discussed in the chapter.

**Chapter 6** focuses on criteria pollutants and air toxic emissions. For this particular analysis, attention is shifted from the national scale, to the Barnett Shale production region in North Central Texas. The work uses dispersion modeling tools to predict ambient concentrations (based on an emissions inventory), which are compared to ambient measurements, allowing a reconciliation between top-down (ambient) measurements and bottom-up emission estimates, using VOC emissions from shale gas production as a case study.

As a follow-up to the work presented in Chapter 6; **Chapter 7** develops a methane ethane, and propane emission inventory for the Barnett Shale; based on the VOC inventory and a recently published dataset of direct measurements of methane emissions from natural gas production. The chapter discusses the spatial distribution of emissions and temporal changes in the magnitude of emissions as a consequence of changes in production over time. Based on the combination of tools developed and used for the study of GHG emissions, criteria pollutants, and air toxics, **Chapter 8** proposes a design of a multi-scale system that allows the detection and attribution of methane in natural gas production region.

Finally, **Chapter 9** discusses implications of the results, summarizing major contributions and findings. This last chapter also provides recommendations that could be explored in future work.

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# 2 BACKGROUND

The previous Chapter discussed the importance of natural gas, and how the development of new technologies has enabled an expansion in the production of unconventional resources, such as shale gas. The environmental impacts associated with shale gas production have made it controversial. This Chapter reviews the impacts associated with greenhouse gas emissions, criteria pollutants, and air toxics. The potential carbon footprint of natural gas production is described, with a focus on the assumptions embedded in its calculation. Existing datasets of GHG emissions, criteria pollutants, and air toxics are presented.

The present state of knowledge of the air quality implications of shale gas production is characterized by great uncertainties in emission estimates. This chapter also discusses the uncertainties and describes how recent research efforts have begun the process of improving understanding of these emissions.

## 2.1 Greenhouse Gas Emissions from Shale Gas Production

### *2.1.1 Carbon footprint of Natural Gas*

Greenhouse gas (GHG) emissions from the combustion of natural gas are lower (per unit of energy) than for other fossil fuels used for the production of energy, such as coal and petroleum.

To generate a MJ of energy, 19.9 g of methane, the primary component of natural gas, must be combusted. If complete combustion is assumed, 54.7 g of carbon dioxide would be released. In contrast, 44 g of coal would be needed to generate the same MJ of energy[1], and if the coal has a composition of 85% carbon, its combustion would yield 137 g of carbon dioxide. Thus, if the analysis is based on the emissions released as a

[1] Assuming a heating value of 50.3 MJ/kg for methane and of 22.7 MJ/kg for coal (lower heating values) [1-2].

consequence of the combustion of fossil fuels for the production of energy, natural gas has considerably lower carbon dioxide emissions than coal (and petroleum) (Figure 2-1).

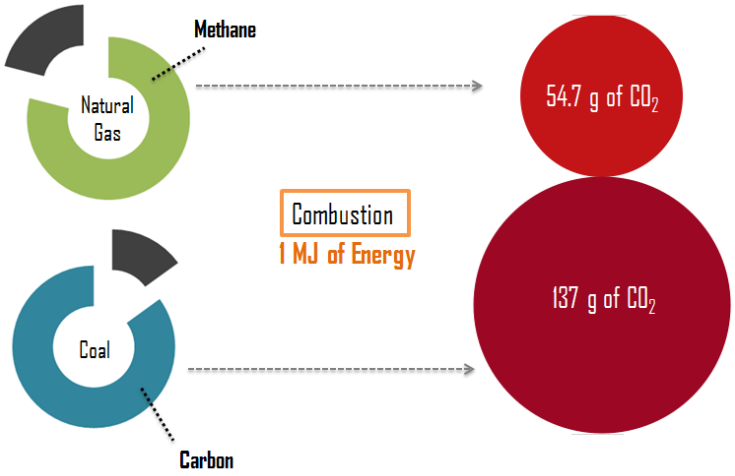



**Figure 2-1.** Comparison of GHG emissions from the generation of 1 MJ of energy from the combustion of methane (natural gas) and coal.

While greenhouse gas emissions from combustion of natural gas are lower than for other fossil fuels, methane, $CH_4$, the principal component of natural gas, is a potent GHG; its emissions along the natural gas supply chain could occur in such an extent that the lower combustion footprint observed when compared against other fossil fuels could be offset. The amount of methane emissions that would alter the GHG footprint of natural gas, relative to other fuels, depends on the potency assumed for methane.

Emissions of greenhouse gases are often expressed on the basis of the radiative forcing that they cause (in units of carbon dioxide equivalents). A number of assumptions are associated with the calculation of carbon dioxide equivalents. One of the primary assumptions is the time over which radiative forcing is integrated. Most assessments (such as those done by the Intergovernmental Panel on Climate Change) have assumed a 100 year time horizon, over which radiative forcing is integrated and averaged. For methane, which is converted to $CO_2$ in the atmosphere, over decadal time scales, the choice of averaging time is important in establishing the importance of the emissions. If a 100 year time horizon is used, methane has a radiative forcing 34 times higher than $CO_2$ on a mass basis (1 kg $CH_4$ is equivalent to 34 kg $CO_2$). If a 20 year time horizon is used,

the radiative forcing is 86 times higher than $CO_2$. The radiative forcing is 102 times the value for $CO_2$ if immediate effects are considered [3]. Figure 2-2 shows how the contributions to radiative forcing from the 2012 U.S. national inventory of greenhouse gas emissions [4] would appear using different time horizons, for the three GHG with most emissions ($CO_2$, $CH_4$, and $N_2O$)[2].

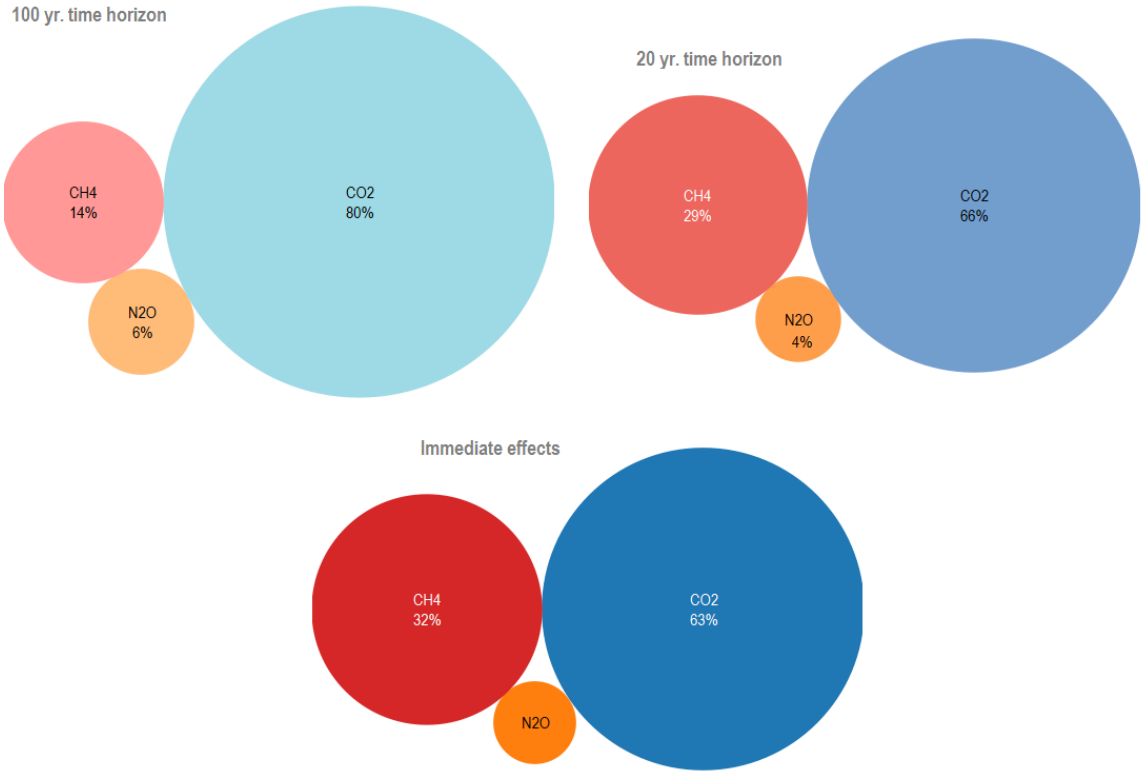



**Figure 2-2.** Total GHG Emissions by species from the EPA GHG National Inventory for 2012 [4]. The circles are sized relative to the percentage of total emissions considering the Global Warming Potentials (GWP) for 100 year, 20 year, and immediate effects time-horizon.

[2] The EPA used a methane radiative forcing of 21 (100-yr time horizon) for the 2012 GHG inventory [4] (consistent with the IPCC fourth assessment report (AR4) [5]). The IPCC AR5 (released in 2013) updates this value to a radiative forcing of 34 [3].

Thus, methane may represent 15% to a third of radiative forcing due to greenhouse gas emissions in the United States, depending on whether the concern is immediate impacts, impacts over a 20 year time horizon or impacts over a century. The climatic implications of transitioning to a higher consumption and usage of natural gas will depend on the selected time horizon, but by any measure, the potential impacts could be large.

Alvarez, *et al* [6], performed a series of analyses comparing greenhouse gas emissions associated with the use of natural gas to other fossil fuels, assuming a variety of GWP. Their study highlighted that, depending on the assumed GWP (and selected time horizon), for some fuel-switching scenarios, net climate benefits would require methane leak rates of less than 1%, while for other scenarios, with long term climate benefits, the leak rate would be set at 4% or more. This work frames the range of potential methane leak rates that would produce positive climate benefits as a result of replacing other fuels with natural gas. However, the study makes clear the need for accurate estimation and measurement of emissions.

### *2.1.2 Methane Emissions along the Natural Gas Supply Chain*

Based on the EPA National GHG inventory for 2012 6,186 Gg of methane were released from natural gas systems [4], This corresponds to 210.3 Tg of $CO_2$ equivalents (Eq.), using a 100-year time horizon (Methane Global Warming Potential (GWP) of 34); However, if the 20-year time horizon is selected (Methane GWP of 86), methane emissions from natural gas systems would result in 532.0 Tg of $CO_2$ Eq. and if the immediate effects scenario (Methane GWP of 102) is used, methane emissions from natural gas systems would be 631.0 Tg of $CO_2$ Eq.

The emissions of methane can be attributed to various parts of the natural gas supply chain, and the supply chain can be divided into four main stages: production, processing, transmission, and distribution (Figure 2-3). During the *production stage*, natural gas, with a mixture of hydrocarbon liquids and water, are extracted from wells. The mixture is typically sent to a separator unit, removing gas from the top of the separator and sending

water and hydrocarbon liquids (condensate) to storage tanks. The production stage, including well operation as well as pre-production activities (e.g., well completion), is estimated to account for 32% of GHG emissions from natural gas systems in the 2012 EPA inventory [4]. The *Processing* stage involves the removal of various constituents in order to produce "pipeline quality" gas. This stage is estimated to account for 14% of natural gas system emissions in the 2012 EPA inventory. *Transmission* involves the flow of gas from the production sites into pipelines and storage reservoirs. The transmission stage is estimated to account for 33% of the GHG emissions in the 2012 inventory for natural gas systems. Finally, the *distribution* stage involves the delivery of natural gas to the final consumer, and is estimated to account for 20% of the 2012 GHG emissions for natural gas systems.

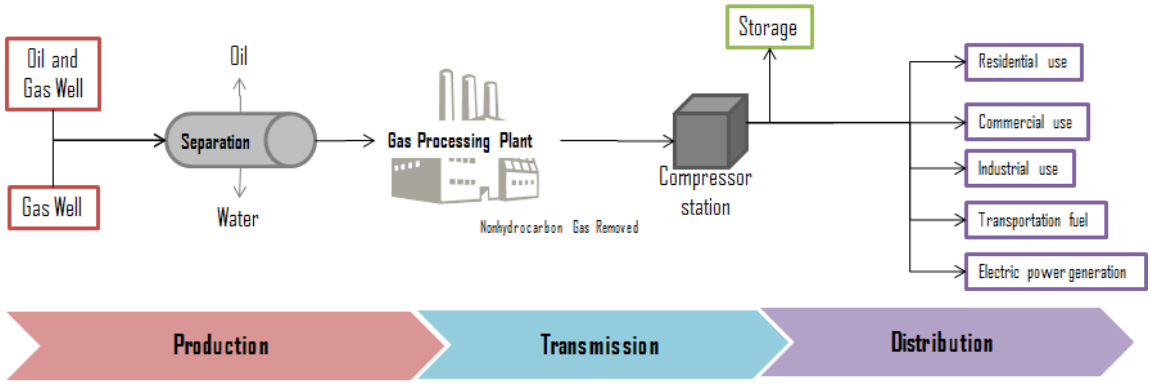
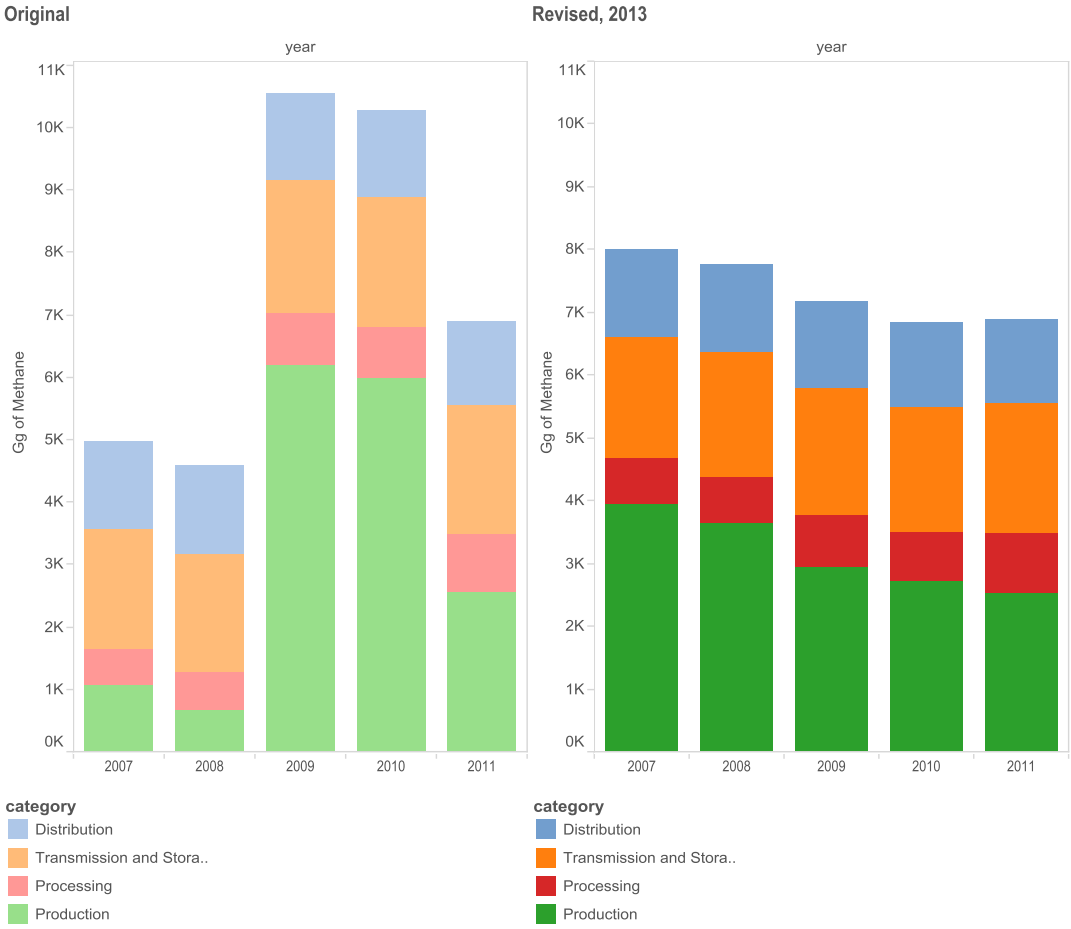



**Figure 2-3.** Simplified diagram illustrating the different stages in the Supply Chain of Natural Gas (Adapted from [7]).

There is considerable uncertainty in the methane emissions reported in EPA national inventories. During the past five years, GHG emissions estimated in the national inventory for natural gas production have varied by an order of magnitude. Figure 2-4 reflects these changes [8]. This variation has been caused mainly by significant modifications in the estimation methods. When the EPA national inventories for the years 2008 and 2009 were originally published, GHG emissions from the production stage were estimated as 674 and 6,205 Gg of methane, respectively. If the emissions are

estimated using a consistent methodology, changes from year to year are much smaller (Figure 2-4, *right*).




**(a)** **(b)**

**Figure 2-4.** CH4 Emissions from Natural Gas Systems category in the EPA National Emission inventory; comparing (a) the year when the inventory was originally published against (b) the values reported in 2013 after revisions made to the estimation methods were applied consistently to previous years [8].

Overall, methane leak rates in the natural gas supply chain (methane as a volume percentage of natural gas production with all methane emissions allocated to natural gas) reported in EPA inventories over the past several years have ranged from less than 1% in

2008 to 2.1% in 2009, with a current estimate of 1.3%. Other researchers have suggested that the leak rates may be much higher than 2%, with some values as high as 8% or more [9]. The Department of Energy and Climate Change in the United Kingdom prepared a review of available estimates of greenhouse gas emissions from shale gas production [10], based exclusively on United States data. Similarly, Caulton, *et al* [11] report ranges of published methane emission estimates; with a range of 0.6 – 7.7% of the lifetime production for the *upstream* and *midstream* sector, and 0.07 to 10% emitted during the downstream stage. These publications document the wide range of published estimates and emphasize the great uncertainty among greenhouse emission estimates.

The production stage represents the sector in which the greatest changes have occurred in the EPA inventory. Table 2-1 summarizes emissions reported in the EPA national emission inventory from 2011. In assembling the national inventory, the EPA estimates potential emissions from source categories, and then reduces the potential emissions by estimated voluntary reductions, as well as reductions required by regulations.

**Table 2-1.** EPA National emission inventory estimates by source category (Adapted from [8]).

| Environmental Protection Agency source activity | Potential emissions (Gg) | Emission reductions (Gg) | Net Emissions (Gg) |
|---|---|---|---|
| Completions with hydraulic fracturing | 1,221 | 567 | 654 |
| Refractures (workovers with hydraulic fracturing) | 266 | 124 | 143 |
| Pneumatic device vents | 1,134 | 779 | 355 |
| Chemical injection pumps | 64 | 30 | 34 |
| Equipment leaks: gas wells | 52 | 24 | |
| Equipment leaks: separators | 107 | 50 | |
| Equipment leaks: meters/piping | 102 | 48 | 172 |
| Equipment leaks: heaters | 33 | 15 | |
| Equipment leaks: dehydrators | 31 | 15 | |
| Workovers without hydraulic fracturing | 0.6 | 0.3 | 0.3 |
| Liquids unloading | 257 | 0 | 257 |
| Kimray pumps | 365 | 180 | |
| Condensate tanks | 313 | 167 | |
| Gas engines | 276 | 49 | |
| Dehydrators vents | 114 | 73 | |
| Reciprocating compressors | 84 | 35 | |
| Pipeline leaks | 170 | 80 | |
| Well drilling | 0.8 | 0.4 | 930 |
| Blowdowns | 6.7 | 2.3 | |
| Compressor starts | 6 | 3 | |
| Pressure relief valves | 0.7 | 0.3 | |
| Mishaps | 2 | 1 | |
| **Emissions from coal bed methane and offshore production** | | | |
| Coal bed methane–produced water | 59 | 27 | |
| Offshore and deepwater platforms | 289 | 136 | |
| **TOTAL** | **4,949** | **2,405** | **2,545** |

The source category with the highest reported emissions in 2011 was completion flowbacks (the 2012 emission inventory, released in 2014, reports a substantial reduction in these emission, largely based on the measurements reported in this work); three other

important source categories are pneumatic devices, equipment leaks and liquid unloadings (detailed description of these categories is provided in *section 2.1.3*).

Part of the reason for emission estimation uncertainty is a lack of measurement data on the methane emissions from natural gas production activities. To address this lack of data, a team led by the University of Texas collected data on a variety of natural gas production activities during 2012. Data were collected on completion flowbacks, wells in routine production, and liquid unloadings. Descriptions of each of these sources and results from the measurements are described in the next section.

### *2.1.3 Direct Measurements of Methane Emissions at Natural Gas Production Sites*

To address the lack of data on methane emissions from natural gas production, a team led by the University of Texas collected data on a variety of natural gas production activities during 2012 [12]. Data were collected on completion flowbacks, wells in routine production, and liquid unloadings.

Allen, *et al*. [12] reported measurements at roughly 478 gas wells; if it is assumed that the measurements are representative of the national population, methane emissions from the source categories on which measurements were made would sum to 957 Gg of methane, which can be compared against the 1,200 Gg of methane reported in the EPA national inventory for comparable source categories [8]. While in total, the emission measurements agreed with the total emissions estimated in the inventory, some source categories had much higher emissions than expected; other source categories had much lower emissions than expected. .

Allen, *et al*. found emissions from well completions to be 97% lower than the 2011 EPA emission estimates (released in 2013) [8]. Pneumatic devices and equipment leaks were found to account for 40% of the methane net emissions from natural gas production, with measured emissions being 70% and 50% higher than the EPA net emission estimates, respectively. Allen, *et al*. acknowledged the need for additional measurements to

characterize and understand the distribution of emissions from pneumatic devices and liquids unloading.

*Well completion flowbacks:* Once a well is drilled and the fracturing has taken place, the well must be cleaned of sand and fluids that were previously injected; the recovery of these fluids is known as flowback. During this stage, natural gas dissolved or entrained in the flowback liquids can be captured, controlled or emitted. The EPA national GHG emissions inventory reported a total of 8,077 completion flowback events during 2011, which accounted for 26% of the emissions related to natural gas production [8].

Well completion flowback emissions reported by Allen, et *al*. were the first measurements from this source to be reported in the scientific literature. From the 27 wells completions that were sampled, flowback durations ranged from 5 hours to 339 hours, with an average emission of 1.7 Mg of methane, a minimum of 0.01 Mg and a maximum of 17 Mg (which corresponds to the completion that lasted 339 hours).

Potential emissions are defined as methane leaving the wellhead; which may or may not be sent to an emissions control device. From the 27 completion events sampled by Allen *et al*, the average potential emissions were 124 Mg, however, 67% of the flowbacks had emission control devices, and 33% had no capture or control Allen, et al [12]. The average control efficiency ((1-(methane emitted to the atmosphere/potential emissions))*100) was 99%. Figure 2-5 summarizes data from the 27 completion events that were directly measured. The 9 events where no emission control devices were in place are represented by the darker green bars; where the measured emissions equal potential emissions. The highest emitting events had actual measured emissions representing 1% of potential emissions for those wells.

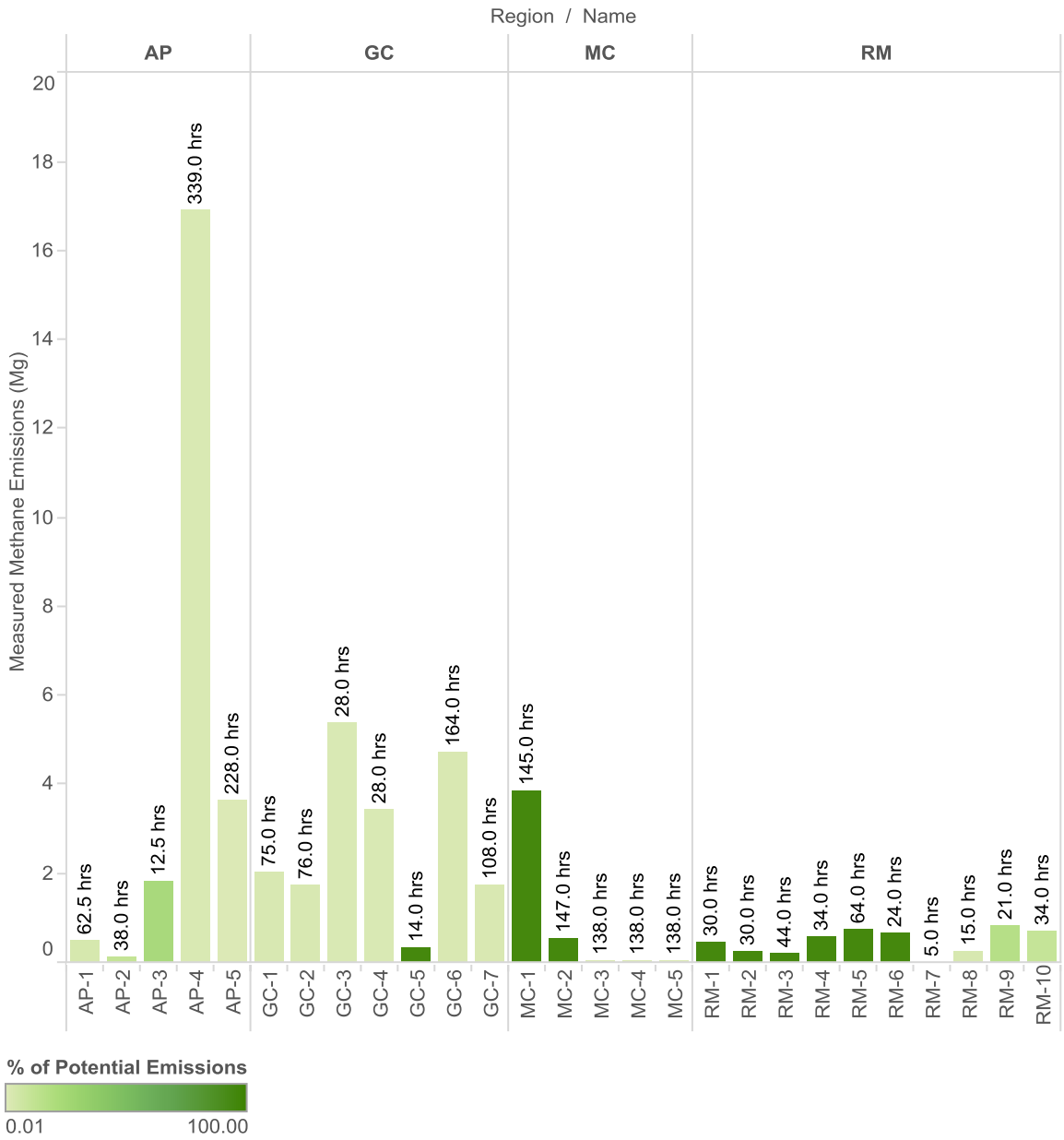



**Figure 2-5.** Well completion events sampled by Allen et al. The height of the bars represents the total methane emissions measured in each event. The color represents the percentage of potential emissions that actual measured emissions represent. The duration of the event is shown at the top of each bar. Regions are designated as AP= Appalachians, GC= Gulf Coast, MC= Midcontinent, RM= Rocky Mountains.

*Wells in routine production:* Once wells go into routine production, the operation of pneumatic controllers, chemical injection pumps, tanks, and compressors, along with equipment leaks, lead to methane emissions. These sources account for 32% of the emissions reported in the EPA national inventory for the natural gas production sector [8]. Among the sources related to routine production, pneumatic controllers stand out due to high equipment counts and heterogeneity of design and operation.

*Pneumatic controllers:* In the work reported by Allen, *et al*.[12], a total of 305 pneumatic controllers were sampled with an average emission rate of 10.5 scf/h of methane (11.2 scf.h of whole gas), a median value of 3.68 scf/h, and a maximum value of 126.9 scf/h. The emissions from pneumatic controllers were the largest single contributor to methane emissions from natural gas production. The data showed significant geographical variability and variability by equipment type. The importance of this source category, and the high degree of variability, led to the decision to collect additional data. Figure 2-6 shows the distribution of pneumatic controllers by region and by host company, and also highlights the impact of outliers on the emission average. Chapter 3 discusses the findings of a second stage of measurements that specifically targeted pneumatic controllers.

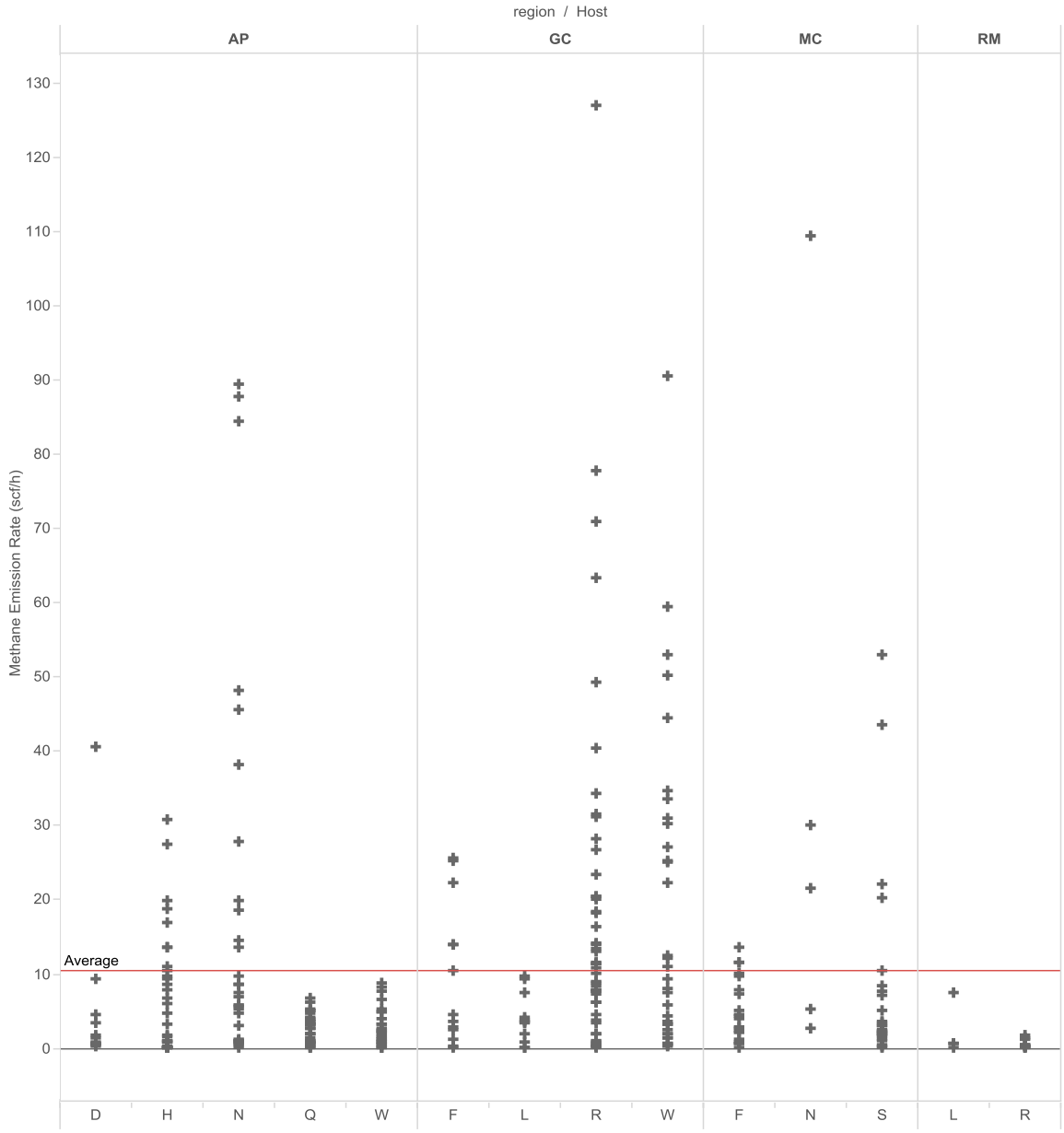



**Figure 2-6.** Distribution of methane emission rates from pneumatic controllers sampled by Allen, et al. The devices are categorized by region (AP= Appalachians, GC= Gulf Coast, MC= Mid Continent, and RM= Rocky Mountains) and host company.

*Liquids unloadings*: When the velocity of natural gas up the subsurface tubing in a well declines and is not enough to lift liquids that are co-produced with the gas, liquids accumulate in the wellbore, restricting the flow of gas, and the accumulated liquids must

be removed. When a *liquids unloading* takes place, flow is diverted into an atmospheric pressure tank, causing a pressure gradient that increases the velocity of the fluid. If there is no emissions control system in place, gas is emitted to the atmosphere. In the 2011 national inventory, EPA estimated that unloading events accounting for 10% of methane emissions from natural gas production [8].

Direct methane measurements conducted by Allen *et al*. [12] took place in four different production regions throughout the United States: Appalachia, Gulf Coast, Midcontinent, and Rocky Mountains. Direct measurements were made at 150 production sites (489 wells), 27 well completion flowbacks, and 9 well unloadings. The nine unloadings measurements represented the first measurements of liquid unloading emissions reported in the scientific literature. These measurements are the starting point for the work presented in Chapter 4, which analyses in detail a second stage of direct measurements that target liquids unloading events.

The nature of the unloading events sampled by Allen *et al*. [12] was diverse, with episodes lasting from 10-15 minutes of uninterrupted flow to two hours of uninterrupted flow. The average measured methane emission was 1.1 Mg per event; with a minimum value of 0.02 Mg and a maximum value of 3.67 Mg of methane. Figure 2-7 shows the measured methane emissions of each measured event and the frequency of liquid unloadings per year for that particular well.

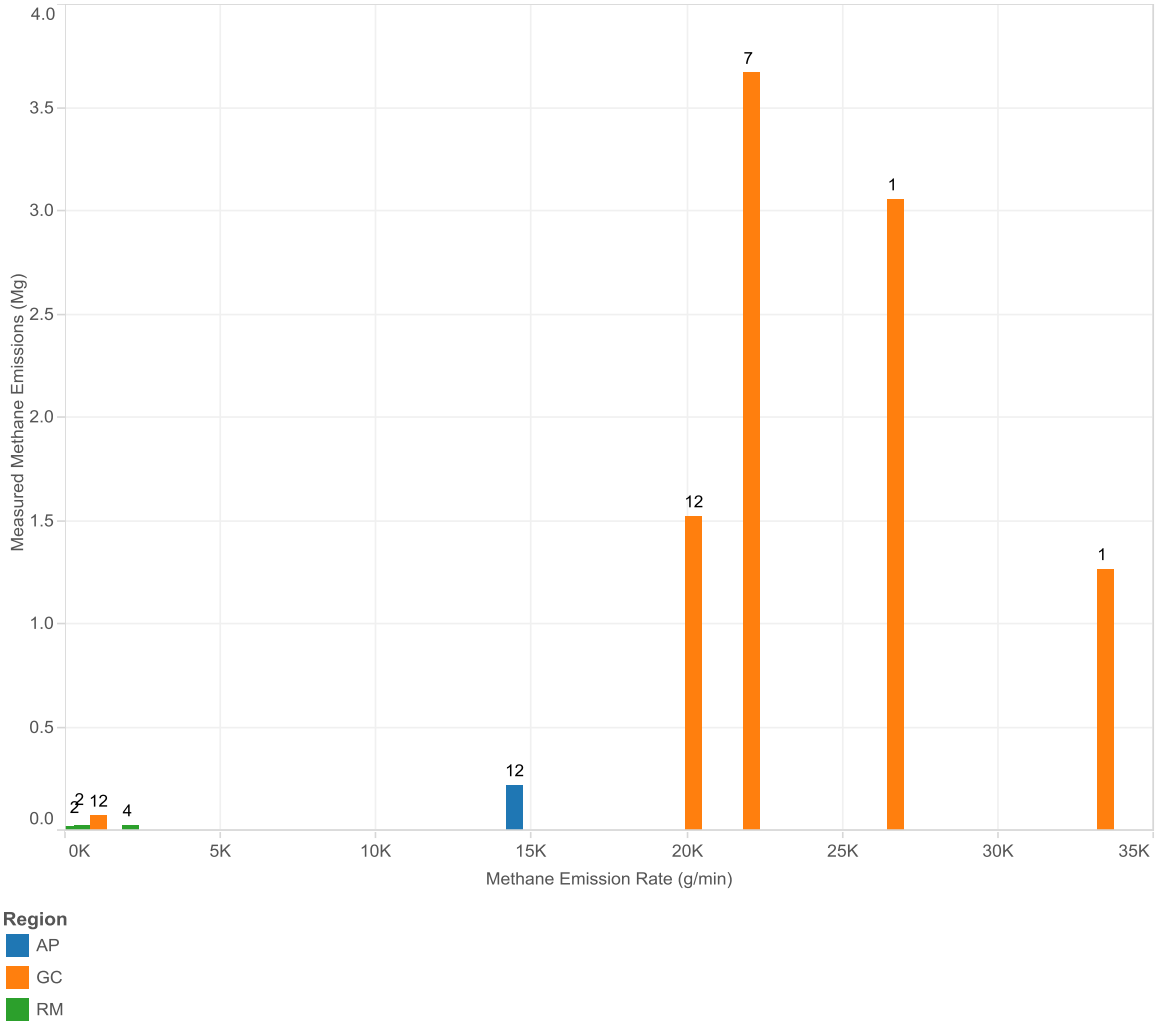



**Figure 2-7.** Methane emissions from the 9 liquid unloadings directly measured by Allen et al. The plot shows the methane emission rate for each event, as well as the number of events per year per well at the top of each bar, and the region where the event took place (AP= Appalachians, GC= Gulf Coast, RM= Rocky Mountains).

The diversity of these events and the small sample size makes it difficult to extrapolate and compare to national inventories

### *2.1.4 Comparison among measurements and emission estimates*

Ambient measurements made at ground level and aloft using aircraft can also be used to improve understanding of emissions from natural gas production.

Ground level measurements, made downwind of natural gas sites, have made use of a variety of techniques designed to infer emission rates from ambient concentrations. One of the most precise methods involves the release of tracer compounds (e.g., $SF_6$, $N_2O$, and $C_2H_2$) at a known rate at or near the methane emission source [12, 13-17]. Downwind measurements of methane (minus background) and the tracers (minus background) are equal to the ratio of emission rates if the dispersions of the methane and the tracer are identical. Consequently, methane emissions can be estimated by multiplying the known emission rate of the tracer by the background corrected downwind concentration ratio of methane to the tracer. Several of these studies have pointed to a skewed distribution of emissions among sites, with a small number of sites accounting for a large fraction of emissions. The existence of high emitting sources (e.g., a pneumatic controller valve that emits much more than the average pneumatic controller, or a liquid unloading event) may explain some of this variability, [12,18].

However, a careful interpretation of these skewed distributions is needed. For example, in a study conducted for the City of Fort Worth [19], emissions from 375 well sites in the Barnett Shale production region were reported (sites were randomly selected from the well sites that were within the City of Fort Worth); 30% of the sites had one well, 63% had between 2 and 6 wells, and one site had 13 wells. Similarly, whereas 78% of the sites had between 1 and 4 tanks, 16% had more than 4 tanks, and one site had 20 tanks. The potential sources of fugitive emissions, such as valves and flanges, varied by an order of magnitude or more between sites. Ten percent of the sites had less than 62 valves, but 10% had more than 446 valves. Ten percent of the sites had 390 or less connectors (such as flanges), but 10% had more than 3,571. Because of this heterogeneity in the equipment among sites, simple comparisons of methane emissions among sites, without adjustments for equipment counts, should be viewed with caution.

Ambient measurements made by aircraft have also been used to assess emissions from the natural gas supply chain. In these studies, average aloft concentrations, upwind and downwind of a natural gas production region, are determined. To estimate total emissions for a region, the difference between upwind and downwind concentration is multiplied by the advection rate of air over the basin (mixing height multiplied by the average wind velocity and the horizontal dimension of the basin). In order to estimate emissions related to natural gas operations, emission from the rest of the sources (e.g emissions from livestock and landfills) must be estimated and subtracted from the total emissions from the area. The accuracy and assumptions made to estimate emissions of non-natural gas sources impacts the uncertainty of aircraft based measurements.

In some regions, aircraft based emission estimates have been a very high percentage of the region's natural gas production or use. Aircraft measurements were reported for a natural gas and oil field in Utah, with an estimated emission rate in the range of 6.2 – 11.7% of natural gas production. In aircraft-based analyses of methane emissions in Los Angeles, fugitive losses from natural gas pipelines and the urban distribution system, along with geological seeps, were identified as the dominant emission sources (47% of total emissions) [20-22] and accounted for 2% of the natural gas delivered to customers, and 1% of the gas flowing into the basin [21]. These analyses suggest emissions sources that are not accurately accounted for in current emission inventories for both natural gas production and natural gas delivery systems. Again, however, these data must be interpreted with care. The attribution of methane emissions to the natural gas supply chain from regions that have both oil and gas production should be done carefully. Gas production operations, and their emissions, also vary over the life of a gas field. Emissions from wells in routine operation may stay roughly constant through the life time of the well; episodic emissions such as new well completions and liquid unloadings are dependent upon the age of the well or the gas field. Early in a field's life, drilling and well-completion activities will be more common than later in a field's life. Late in a field's life, wells may accumulate liquids, and methane venting may occur through

liquids unloading, which removes liquids from the well bore. Consider a detailed example of how liquids unloadings may skew instantaneous measurements. Allen *et al*. [12] have observed emission rates for single liquids unloading events that ranged from roughly 100 g per min to more than 30,000 g per min. These rates are much higher than emission rates for production sites (typically tens of g of methane per minute per well) or from completions (typically a few hundred g per event per min). At these emission rates, a single unloading event could, during the period that it is occurring, result in emissions that are the equivalent of just a few wells in routine production to the equivalent of up to several thousand wells in routine production. Because not all gas fields have wells that unload, and because gas wells may unload for only part of their production life cycle, emissions from different gas fields would be expected to vary, and an individual gas field would be expected to vary in its emissions over time. Overall, reconciliations between instantaneous ambient measurements should carefully account for the status of the wells in a gas field.

Collectively, recent measurements suggest that both ambient and direct source measurements will be important in examining emissions along the natural gas supply chain. *Chapter 6* and *Chapter 7* demonstrate methods for reconciliation between top-down and bottom-up measurements.

## 2.2 Criteria Pollutants and Toxic Emissions from Natural Gas Production

Measurements of photochemically generated air pollutants, such as ozone, in rural production regions, have motivated the collection of data on ozone precursors [23-25] from natural gas production activities. Both ozone and air toxics represent health risks, and as natural gas production increases, determining the magnitude and effect of ozone precursors and air toxics on air quality has become increasingly important.

Armendariz [23] estimated criteria pollutant and air toxics emissions from oil and natural gas sources in the Barnett Shale, estimating that emissions from VOC and $NO_x$ related to

oil and gas production were 36% greater than emissions from motor vehicles in the region. Annual average VOC emissions for 2009 were estimated at 139 tons/day; with a 2009 natural gas production of 4.9 Bcf/day [26]; or 28.4 tons per Bcf of natural gas production. For the case of air toxic compounds, the study found that sources such as condensate tanks and engines could emit a significant amount of benzene and formaldehyde.

Similar studies have been published for other production regions in the U.S., Roy, *et al.* [25] developed a criteria pollutant emission inventory for the development, production, and processing stages of natural gas production in the Marcellus Shale (North East U.S.). The results were extrapolated to 2020, after accounting for the effects of existing and potential regulations. Estimated VOC emissions from gas production activities were 345 tons/year for 2009 and 100 tons/day for 2020, which would account for 12% of the total VOC emissions in the region.

Gilman, *et al*. [27] measured VOC emissions related to natural gas and oil operations in northeastern Colorado, establishing that light alkanes dominate among the VOC species, and that the source signature is clearly differentiated from urban sources. Their results also showed that reactivity of VOC is driven by large abundance of relatively low reactive species (light alkanes). Also in the Rocky Mountain region, Edwards, *et al*. [28] focused on the Uintah Basin in Utah, a region with increasing oil and gas production, where unusual wintertime ozone episodes (where ozone concentrations were above levels harmful to human health) have been present. The authors examine the chemical and physical processes that would lead to elevated ozone concentrations during wintertime, as a result of increased emissions from the natural gas and oil production activities in the basin.

In this thesis, the emissions of Volatile Organic Compounds (VOC) (ozone precursors) from shale gas production are examined using emission inventories and air quality monitoring data from the Barnett Shale production region in north central Texas. What

distinguishes this work from previous studies is the use of a long time series (20 month) of measurements, in contrast to short term, episodic studies. Chapter 6 presents the analyses done to VOC and air toxics emissions related to shale production activities.

## 2.3 Summary

The present state of knowledge of the air quality implications of shale gas production is characterized by a great uncertainty in emission estimates. Recently published data sets of direct measurements have reduced the uncertainty of the emissions and have identified the main sources from natural gas production. Nonetheless, additional measurements and analysis efforts are needed to continue to improve understanding of emission sources.

The following chapters describe how the research presented in this thesis contributes to reducing the uncertainty of emission estimates, characterizing emissions from the different sources, and reconciling different measurement and estimation schemes.

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# 3 METHANE EMISSIONS FROM PNEUMATIC CONTROLLERS

## 3.1 Introduction

As mentioned in the previous chapter, Methane emissions in the natural gas supply chain have been estimated using two basic approaches, commonly referred to as top-down and bottom-up approaches. Top-down approaches for estimating methane emissions from the natural gas supply chain involve measuring ambient concentrations of methane near emission sources. These concentrations can be measured using fixed ground monitors [1, 2], mobile and vehicle mounted ground monitors [3, 4], aircraft based instruments [5-7] or satellite instruments [8]. Brandt *et al*. [9] and Miller, *et al*. [10] have summarized recent top-down estimates of methane emissions and conclude that top-down emission estimates are generally higher than current bottom-up inventories of methane emissions, and some of this difference may be due to methane emissions from the natural gas supply chain. However, these analyses do not reveal which of the many potential sources of methane emissions along the natural gas supply chain might be incorrectly estimated.

Complementing top-down measurements, bottom-up measurements of methane emissions are made directly at the emission sources. In this approach, emission measurements are made at a representative sample of sources; the measurements from the sample population are then extrapolated to larger regional or national populations. The advantage of "bottom-up" approaches is that they can gather much more detail about the emission sources, and therefore can identify which source categories, among many, are responsible for emissions. For example, Allen, *et al* [11] concluded that emissions from well completion flowbacks are over-estimated, while emissions from pneumatic controllers may be under-estimated, in current inventories of emissions. Both top-down and bottom-up approaches can contribute to an improved understanding of methane emissions from the natural gas supply chain.

The work reported in the present chapter uses bottom-up measurements to improve understanding of emissions from pneumatic controllers on natural gas production sites.

Similarly, *Chapter 4* uses bottom-up measurements to improve understanding of emissions from liquid unloadings of natural gas wells.

Pneumatic controllers use gas pressure to control the operation of mechanical devices, such as valves. The valves, in turn, control process conditions such as levels, temperatures and pressures. When a pneumatic controller identifies the need to change liquid level, pressure, temperature or flow, it will open or close a control valve in order to return to a desired set point. The opening and closing of the valve can occur either through discrete (on/off) changes, or through changes that are proportional in magnitude to the deviation from the set point (throttling). Controllers can deliver this type of service (on/off and throttling) through either continuously venting or intermittent venting of gas. Thus, controllers can be grouped into four categories, depending on the type of service (on/off or throttling) and the type of venting (continuous or intermittent). In estimating emissions, the U.S. EPA uses the categories of low continuous bleed (<6 scf/h of gas vented), high continuous bleed (>6 standard cubic feet per hour (scf/h) of gas vented) and intermittent controllers [12]. Finally, controllers can also be categorized based on equipment manufacturer, model number, and the type of application (e.g., separator level control) in which they are used. In this work, the primary categorization of controllers will be as either continuous vent or intermittent vent; data on applications, service types, and EPA categorization for the controllers sampled in this work are provided in the Appendices (Section A.4).

The U.S. EPA [12] reports 447,600 pneumatic controllers are in use at natural gas production sites in the United States. These controllers are estimated to emit 334 Gg/yr of methane (17.4 billion cubic feet (bcf) methane), for an average of 0.7 Mg methane device$^{-1}$ yr$^{-1}$ or 4.2 scf/h methane device$^{-1}$. These estimated emissions from pneumatic controllers have been based on relatively limited measurements [13]; recent field measurements have suggested that these emissions may be understated.

Allen *et al*. [11] made measurements of emissions from 305 pneumatic controllers on well sites in the United States where the wells had been hydraulically fractured. Average emissions were 10.5 scf/h of methane, approximately double the average emission rate per device in the current EPA national emission inventory. Measurements of emissions from 581 pneumatic controllers, made in British Columbia and Alberta, averaged 9.2 scf/h of whole gas [14], an emission rate similar to that reported by Allen, *et al*. [11]. In both of these studies, emissions from controllers exhibited wide ranges. In both sets of measurements, a small subset of controllers accounted for most of the emissions.

While the measurements at hydraulically fractured gas wells in the United States [11] and the measurements in British Columbia and Alberta [14] recorded emissions higher than the average emissions per device in the EPA national emission inventory, the sample sets for these two sets of measurements were not necessarily broadly representative of U.S. national populations of pneumatic controllers. The measurements reported by Allen, *et al*. [11] were made exclusively in shale gas production regions, and at sites where the wells had been hydraulically fractured. Many of the sites were recently completed wells, which initially tend to have higher liquid production rates, and therefore may have more frequent actuation of certain types of pneumatic devices than the average for the entire population of gas wells in the United States, leading to potentially higher emissions. The Canadian measurements [14] were made exclusively in one production region and on devices with manufacturer specified emission rates in excess of 4.2 scf/h.

The goals of the work presented in this chapter were (i) to measure emissions from pneumatic controllers at a wider population of wells, geographically distributed across the United States, including conventional gas wells, shale gas wells and a limited number of oil wells, and (ii) to characterize the features of the controllers with high emissions, which previous work [11, 14] has found to be the major contributor to the emissions.

## 3.2 Methods

### *3.2.1 Sampled Population*

A total of 377 pneumatic controllers were sampled at 65 sites (some with multiple wells) throughout the United States (an average of 5.8 pneumatic controllers per site, 2.7 controllers per well). Measurements were made primarily at natural gas production sites (351 of 377 controllers), and at a limited number of oil sites (26 controllers). Because the definitions of oil and gas wells vary, largely depending on gas to oil production ratios, the data will be treated as a single set. Sampling sites were selected randomly from well sites owned by companies participating in the study (see Appendices, Section A.1). For each well site that was visited, all controllers on the site were sampled, unless operating conditions or safety issues prevented sampling. The applications that the controllers were used in (e.g., separator level control, compressor, pressure control) are shown in Table 3-1. Details of the regions, device types, associated well types, operating methods and other characteristics of each of the 377 controllers sampled in this work are provided in Appendices, Section A.4.

**Table 3-1.** Sample population, categorized by region and controller application

| | Application | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Region** | **Sep.** | **Proc. Heater** | **Comp.** | **Wellhead** | **Plunger Lift** | **Dehyd. Syst.** | **Flare** | **Sales** | **Total** |
| **AP** | 14 | 13 | 0 | 24 | 1 | 0 | 0 | 0 | 52 |
| **GC** | 73 | 0 | 13 | 11 | 7 | 16 | 1 | 1 | 122 |
| **MC** | 48 | 11 | 7 | 0 | 11 | 1 | 0 | 0 | 78 |
| **RM** | 51 | 21 | 0 | 32 | 11 | 8 | 2 | 0 | 125 |
| **Total** | 186 | 45 | 20 | 67 | 30 | 25 | 3 | 1 | 377 |

### *3.2.2 Emission measurement methods*

Emissions from pneumatic controllers can be determined either by measuring the supply of gas entering the controller or by measuring the gas discharged from the controller. Both approaches were used in this work, and since there is no accumulation of gas in the

controller, both measurement approaches should lead, in the absence of emissions from the control valve, to equivalent measurements.

Measurements of the gas entering the controller were made by one of three Fox flow meters (Model #FT2A); flow meters were inserted into the supply gas line for the controller. This supply gas measurement was the primary measurement method used in this work, and was used to measure emission rates on 333 of the 377 controllers in the sample population (the remainder were sampled by measuring gas emitted by the controller, see Appendices, section A.3). The flow meters reported flows at a sampling frequency of 10 Hz. Two of the Fox Model #FT2A instruments (labeled A and C in this study) had a range of operation of 0-300 scf/h, with a precision of ±1% of flow, and the third Fox Model #FT2A (labeled B in this study) had a range of operation of 0-1200 scf/h, with a precision of ±1% of flow. The Fox model #FT2A instruments A and C were used whenever possible because of their greater absolute precision, however, if any instantaneous reading on the A or C Fox Model #FT2A was greater than 300 scf/h, the measurement on the pneumatic device was repeated with the B meter to ensure that high leak rates were measured accurately. This happened only once during the measurement campaign, and for this single controller, the flow exceeded 300 scf/h only during a few seconds when the flow from an actuation was peaking (average whole gas flow rate over fifteen minutes of sampling was 3.06 scf/h). A repeat test with the B instrument did not detect any actuations.

For each controller measurement using the supply gas flow meter, a site operator depressurized and disconnected the controller supply gas line; the flow meter was inserted and the system was reconnected, re-pressurized, and allowed to stabilize for several minutes before measurements began. Once the system had stabilized, measurements were made for approximately 15 minutes. Longer sampling times may have allowed a more complete measurement of emission rates from devices with relatively fewer controller actuations, but would have limited the number of controllers

that could be sampled. Figure 3-2 shows representative 15 minute emission time series for pneumatic controllers measured using the supply gas measurement.

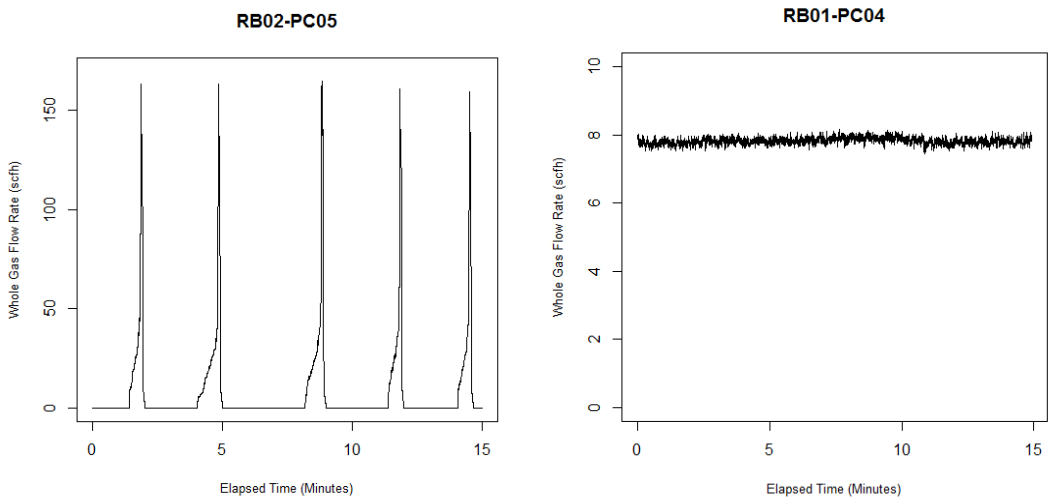


**Figure 3-1.** Representative time series for supply gas measurements for intermittent vent and continuous vent controllers; the actuating controller (RB02-PC05) had a total of 5 actuations during the sampling period and an average emission rate, over the 15 minute period of 7.9 scf/h; the throttling controller (RB01-PC04) had nearly constant emissions of 8.0 scf/h.

All three Fox flow meters were calibrated by the instrument manufacturer and tested in the laboratory, using methane. The instruments measure flow based on a thermal conductivity measurement. In this work, since gas composition information was available for each site where measurements were made, site specific correction factors were employed to estimate methane and whole gas emission rates. The method is described in the Appendices (see Section A.2). Results in this work are reported as both methane and whole gas emission rates, based on site specific gas composition data.

For some pneumatic controllers, it was not possible or safe to disrupt the supply gas to insert the supply gas flow meter, so exhaust gas measurements were used as the primary measurement on that subset of devices. Exhaust gas flow rate was measured using a Hi Flow® instrument similar to that described by Allen *et al*. [11]. Briefly, the Hi Flow® Sampler is a portable, intrinsically safe, battery-powered instrument that has been used

for several decades in measuring emissions of methane in the natural gas supply chain [15-17]. An emission source is enclosed, using attachments that come with the instrument; leak rate is measured by drawing air from the enclosure, through the sampler, at a high flow rate (up to 8-10 cfm) to capture all the gas emitted by the component, along with a certain amount of entrained surrounding air. By accurately measuring the flow rate of the sampled stream and the background corrected natural gas concentration within the sampled stream, the gas leak rate is calculated. Methane is measured, at concentrations less than approximately 5%, by a catalytic oxidizer unit coupled with a thermal conductivity detector. At methane concentrations greater than approximately 5%, concentrations are measured directly using a thermal conductivity detector. The instrument was calibrated in the field using pure methane and a mixture containing 2.5% methane. The instrument reading based on the methane calibration was corrected for gas composition using site specific gas composition data and laboratory data, as described in Appendices (A.2). The commercial Hi Flow® instrument is designed primarily to measure methane leaks that have a relatively steady flow and flow rates are not normally automatically recorded at high frequency. For this work, the instrument software was modified by the manufacturer to output data every 2-3 seconds. A 0.3-0.5 Hz reporting frequency was selected based on residence times expected in the leak enclosures at the maximum flow rate of the Hi Flow® device (at a 10 cubic feet per minute sample flow, gas in a 1 $ft^3$ sample enclosure has a residence time of 6 seconds). As with the in-line supply gas measurement, Hi Flow® data were collected for approximately 15 minutes for each controller.

A time series from the Hi Flow® device, along with a parallel measurement made using a supply gas meter, is shown in Figure 3-3. The Hi Flow® device, because it entrains ambient air in a long sample loop, dampens some of the peak rate. Therefore, the Hi Flow® is not able to resolve high frequency actuations as well as the in-line supply measurement. For 24 controller measurements, both supply gas and Hi Flow® measurements were made. The detailed results are provided in Appendices (Section

A.3). To summarize, 11 of the 24 simultaneous measurements had emissions of less than 0.005 scfh (46%). For 5 devices which had an average emission rate greater than 6 scfh (measured by the supply gas meter) the supply gas meter to Hi Flow® measurement ratio was between 0.7 and 1.1.

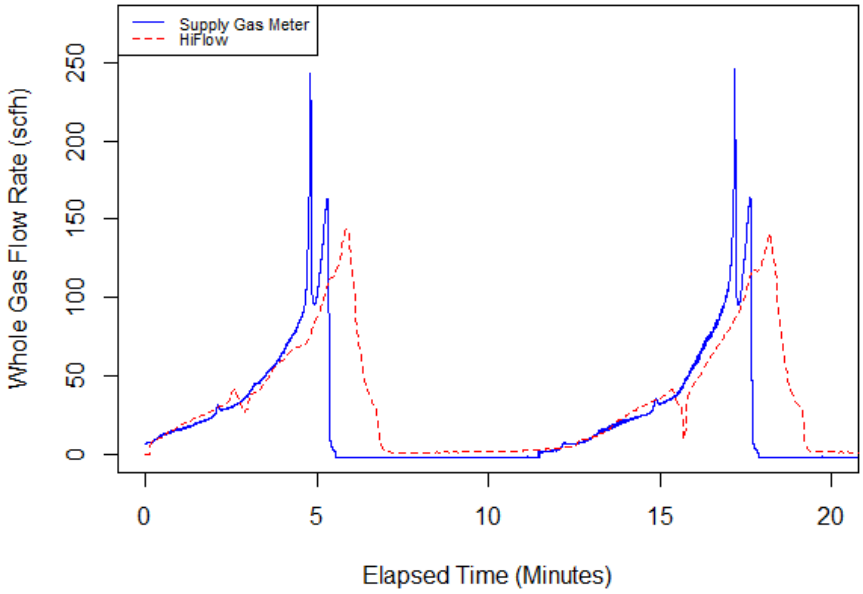


**Figure 3-2.** Comparison of supply gas meter (blue line) and Hi Flow® measurements (red line) for device LB07-PC04, which was a water level control on a separator. The average emission rate measured by the supply gas meter was 27.0 scf/h as compared to 33.9 scf/h measured by the Hi Flow®. Note that the time lag, longer period of emission detection, and the reduced maximum flow rate associated with the Hi Flow® measurement is expected because of the dilution that occurs with ambient air in the exhaust enclosure and the flow through the instrument.

### 3.3 Results and Discussion

Methane emissions from 377 controllers were measured in this work and details of each of the individual measurements are available in Appendices (Section A.4). A relatively small subset of devices accounts for a majority of the emissions. At the high end of the emission rate distribution, twenty percent of devices accounted for 96% of whole gas and methane emissions. The 19% of devices that had emissions in excess of 6 standard cubic

feet whole gas per hour (scf/h) accounted for 95% of all whole gas and methane emissions. At the low emission rate end of the distribution, more than half (51%) of the controllers had an emissions rate less than 0.001 scf/h over the 15 minute sampling period; 62% had an emissions rate less than 0.01 scf/h over the 15 minute sampling period.

The average emission rate for the 377 devices is 5.5 scf/h of whole gas (4.9 scf/h of methane), however, this average emission may be influenced by the estimated emission rates for devices that had no emissions over the 15 minute sampling period. If the devices with no emissions detected over 15 minutes are assigned the lowest emission rate detected (0.001-0.01 scf/h), there is no change in the average emission rate. However, using this minimum detection limit approach may under-estimate potential emissions for devices that had little to no detectable emissions over 15 minutes. Some of these devices may have actuations with relatively large volumes, but that are relatively infrequent. For example, the device that generated the data shown in Figure 3-3 had emissions of more than 2 cubic feet of gas associated with a single actuation, and in principle, a device could actuate up to four times per hour and not be detected over a 15 minute sampling period. Therefore, to estimate the emissions from devices with no emissions detected over a 15 minute sampling period, the average emission per actuation was calculated for controllers in each application. The average emissions per actuation were multiplied by an estimated frequency of actuation. For example, for separator level controllers, the average volume per actuation was estimated by averaging observed volumes per actuation for separator level controllers; the average frequency of actuation for devices, for which no actuations were observed, was estimated by extrapolating observed actuation frequency data for controllers in separator level control service. Details are available in Appendices (Section A.5). Using this approach, the estimated average emissions associated with devices with no emissions recorded over a 15 minute sampling increases the population average emissions by 2-6%. Because this increase is relatively small, for clarity, all of

the data reported in this work are based on actual measurements, not including additions to the emissions for devices with low (0.001-0.01 scf/h) observed emissions.

To estimate an uncertainty bound on the overall average, a bootstrapping process was used [18]. In the bootstrapping procedure, the original data set of 377 devices was recreated by making 377 random device selections, with replacement, from the data set. A total of 1000 of these re-sampled data sets were created and the mean value of the emissions for each re-sampled data set was determined. The 95% confidence interval for the whole gas emission estimate of 5.5 scf/h is 4.0-7.2 scf/h, where the bounds represent the 2.5% and 97.5% percentiles of the means in the 1000 re-sampled datasets. Similarly, the 95% confidence interval for the methane emissions estimate of 4.9 scf/h is 3.6-6.5 scf/h.

The measurements showed significant variations among regions, the controller application, and whether the device was continuous vent or intermittent vent. Table 3-2 summarizes the distribution of emission rates among controllers in various applications, and shows the regional distribution of controller emissions. Measurements made on pneumatics in service on compressors had average emission rates of 14.0 scf/h (12.4 scf/h methane), compared to an average whole gas emission rate of 5.5 scf/h (4.9 scf/h methane) for all devices. Devices in use for level control on separators averaged 8.1 scf whole gas/h (7.1 scf methane/h). Overall, 76% of devices measured with whole gas emission rates greater than 6 scf/h were in service on compressors or as level controllers on separators. Emission rates for continuous vent controllers (57 devices, average emissions of 24.1 scf/h whole gas, 21.8 scf/h methane) were higher than for intermittent devices (2.2 scf/h whole gas, 1.9 scf/h methane).

**Table 3-2.** Whole gas emissions from controllers (scf/h), categorized by region and application.*

| | Average whole gas emission rates from controllers (scf/h), categorized by the application | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | All | Process | | | Plunger | Dehydration | | | | Avg. w/o |
| Region | Devices | Separator | Heater | Compressor | Wellhead | Lift | System | Flare | Sales | Compressors |
| **AP** | 1.7 | 0.3 | 1.3 | - | 2.8 | 0.0 | - | - | - | 1.7 |
| **GC** | 11.9 | 16.3 | - | 10.6 | 0.0 | 7.3 | 4.4 | 0.0 | 0.0 | 12.0 |
| **MC** | 5.8 | 4.9 | 0.0 | 20.2 | - | 6.5 | 4.2 | - | - | 4.4 |
| **RM** | 0.8 | 1.5 | 0.2 | - | 0.4 | 0.1 | 0.0 | 0.0 | - | 0.8 |
| **Total** | 5.5 | 8.1 | 0.5 | 14.0 | 1.2 | 4.1 | 3.0 | 0.0 | 0.0 | 5.0 |

*Numbers of devices sampled in each category are reported in Table 3-1.

In addition to varying by application and controller type (continuous vent or intermittent vent), emissions also varied by region. Emissions were highest in the Gulf Coast and Mid-Continent regions and were lowest in the Rocky Mountain and Appalachian regions (see Appendices, Section A.4, for geographical boundaries of regions). Controllers on compressors, with high average emissions, were only observed on sampling sites in the Gulf Coast and Mid-Continent regions, so some of the regional differences can be attributed to the presence of compressors. As shown in Table 3-2, however, if average emissions by region are recalculated without including controllers associated with compressors, the Gulf Coast and Mid-Continent regions still had average emissions greater than those observed in the Rocky Mountain and Appalachian regions.

Another factor that may account for regional differences in emission rates is frequency of actuation. For example, controllers on separators in the Gulf Coast could actuate more frequently due to higher liquid production rates, which could explain higher emission rates in that region. However, the frequencies of actuation for the devices in Gulf Coast were similar to those in most other regions, indicating a larger emission per actuation for the devices in the Gulf Coast, rather than more frequent actuation. In contrast, the Appalachians showed a considerably higher frequency of actuations and a smaller

emission rate, indicating a smaller emission per actuation for those devices (Table 3-3). Thus, regional differences in pneumatic controller emission rates cannot be completely explained by frequency of actuation of controllers, or by controllers associated with compressors and separator level control (Table 3-2); much of the difference may be due to differences in controller type (continuous vent vs. intermittent vent) among regions. Continuous vent devices, with average whole gas emissions of 24.1 scf/h, were 21% of the controllers in the Gulf Coast and Mid-Continent regions, but only 9% in the Appalachian and Rocky Mountain regions.

**Table 3-3.** Frequency of actuations and emissions from on-off controllers where actuations were observed, categorized by region

| Region | Count of Devices | Frequency of Actuation (#/min) | Avg. Whole Gas Emission rate (scf/h) |
|---|---|---|---|
| **AP** | 8 | 2.42 | 4.85 |
| **GC** | 29 | 0.39 | 21.02 |
| **MC** | 18 | 0.94 | 4.97 |
| **RM** | 25 | 0.43 | 1.72 |
| **Total** | 80 | Average: 0.73 | Average: 9.76 |

This data set of emissions from pneumatic devices has elements that are similar to and different from the previous data sets reported for the United States [11], and for British Columbia and Alberta [14]. The primary similarity is that all three data sets indicate that a small population of devices dominates total emissions. In this work, 19% of devices with emissions greater than 6 scf/h of whole gas account for 95% of the whole gas and methane emissions. In the previous measurements reported by Allen, *et al*. [11], 20% of devices account for 80% of the whole gas emissions and 41% of devices with emissions greater than 6 scf/h of whole gas, account for 90% of the whole gas emissions (88% of the methane emissions). In the measurements for British Columbia and Alberta [14] (referred to here as the British Columbia data), which were restricted to pneumatic devices with manufacturer reported bleed rates greater than 4.2 scf/h, 44% of devices with emissions greater than 6 scf/h accounted for 91% of emissions. Both the British Columbia data and the measurements reported in this work had large numbers of devices for which no emissions were detected during the sampling period. For the British Columbia data (again, focused on devices with manufacturer reported bleed rates in excess of 4.2 cfh), 31% of measurements had no detectable emissions over a 30 minute sampling period; in this work 62% of devices had emissions less than 0.01 scf/h over the 15 minute sampling period.

The overall average emission rates reported in this work are lower than the previous data sets reported for the United States [11], and for British Columbia and Alberta [14]. For

the British Columbia data this can be attributed to the sampling design for that data set, which selected devices with manufacturer reported bleed rates in excess of 4.2 scf/h. These controller types tend to be found in particular applications. When the emissions from the British Columbia data set are compared to the emissions reported in this work, for devices in similar applications, the results are in reasonable agreement. For example, for the separator controllers that were the most frequent application observed in this work, the British Columbia data report an average emissions rate of approximately 7.8 scf/h (level control) while the average for this work was 8.1 scf/h (separator application).

The lower average emission rates reported in this work, compared to those reported by Allen, *et al*. [11] is primarily due to the number of controllers with no emissions detected over the sampling period. Figure 3-4 compares emission rates for controllers sampled in this work, with emissions rates reported by Allen, *et al*. [11]. The results show reasonable agreement between the two studies for controllers with emissions above 6 scf/h. These controllers accounted for 95% of the emissions in this work and 90% of the emissions in the sample reported by Allen, *et al*. [21].

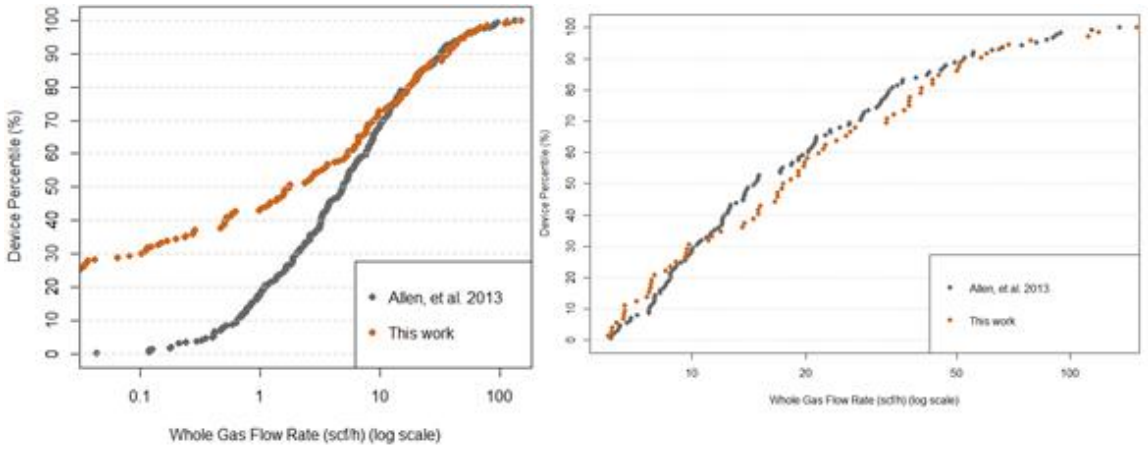


**Figure 3-3.** Distributions of emissions for subsets of controllers venting greater than 0.01 (left) and subsets of controllers venting greater than 6 scf/h of whole gas as reported in this work and Allen, *et al*. [11].

The primary reason for the differences in the average emission rates reported in this work and in Allen, *et al*. [11] is the higher percentage of low emission devices (<0.01 scf/h) observed in this work. This could be due to multiple factors. In this work, all controllers on-site were sampled, regardless of whether they would be reported through emission inventories. For example, Emergency Shut-Down (ESD) controllers represented 12% of the sampled population in this work. These controllers do not have planned actuations, so they would not have been sampled in the work of Allen, *et al*. [11], and they may or may not be included in controller counts in national emission inventories. In addition, in the work of Allen, *et al*. [11] about 40% of the inventoried controllers on sites were sampled; while these were intended to be selected randomly from inventoried controllers, there may have been an unintentional bias toward devices that were observed, with an infrared camera, to have emissions.

### 3.4 Implications for national emission estimates

As shown in Table 3-4, if regional average emission rates determined in this work are multiplied by regional controller counts reported in the 2012 EPA national greenhouse gas emission inventory (2012 GHG NEI, released in 2014 [12]), the national methane emission estimate for pneumatic controllers in natural gas service is 313 Gg/yr (within 10% of the 2012 GHG NEI estimate of 334 Gg). If the national average of the emission rates measured in this work (5.5 scf/h of whole gas, or 4.9 scf/h of methane) is multiplied by the total national equipment count (447,606 controllers) the national methane emission estimate is 369 Gg/yr, 10% higher than the 2012 GHG NEI estimate of 334 Gg [12]. Adding an additional 2-6% to the estimated emission totals to account for potential emissions from controllers that had less than 0.01 scf/hr of emissions over 15 minutes, would only slightly change these comparisons with the 2012 GHG NEI. This estimate may represent a lower bound on national emissions, however, since the average emissions per controller observed in this work includes some low emitting devices, such as ESD controllers, that may not be included in the count of national controllers. If the

average emissions per controller from this work were recalculated with ESD controllers excluded, the average emissions would increase by approximately 15% (see Appendices, Section A.7).

The inclusion or exclusion of ESD controllers in national pneumatic controller counts is just one part of the uncertainty associated with the total count of controllers. The average number of controllers per well observed in this work (2.7 controllers per well) was higher than the average number of controllers per well (1.0 controllers per well) reported in the 2012 GHG NEI, potentially indicating an under-count of controllers in the GHG NEI. Some of the difference between the controllers per well observed in this work and the average pneumatic controllers per well in the GHG NEI is due to wells that use mechanical or other non-pneumatic controllers, as an example of how an alternative controller count could influence national emission estimates, if 75% of wells in the United States have an average of 2.7 pneumatic controllers per well (the remainder having non-pneumatic controllers), the total count of pneumatic controllers would double the level in the current inventory, roughly doubling emissions. It was beyond the scope of this work to develop new national pneumatic controller counts, but the data reported here indicate that this is a topic that merits attention.

**Table 3-4.** National emission estimates, based on regional device counts for pneumatic controllers and regional average emissions measured in this work.

| Region | Count of Devices | Avg. Emission rate whole gas(scfh) | Avg. Emission rate methane (scfh) | Regional emissions (Gg/yr) |
|---|---|---|---|---|
| **AP** | 77,261 | 1.70 | 1.65 | 21.5 |
| **GC*** | 53,436 | 11.86 | 10.67 | 95.9 |
| **MC** | 222,684 | 5.78 | 4.85 | 181.8 |
| **RM**** | 124,225 | 0.75 | 0.67 | 14.0 |
| **Total** | 447,606 | | | 313.2 |

*MC totals include equipment counts for Mid-Continent and Southwest regions reported in the 2012 EPA GHG NEI

** RM totals include equipment counts for Rocky Mountain and West Coast regions reported in the 2012 EPA GHG NEI

### 3.5 Characteristics of high emitting devices

Because average emissions are strongly influenced by the highest emitting devices, the characteristics of the 40 controllers with highest emissions rates were examined in detail by experts in pneumatic device operation. These characterizations included the service type, region of use, device type, number of actuations, and other temporal features of the emission time series. Based on these analyses, many of the devices in the high emitting group were behaving in a manner inconsistent with the manufacturer's design. For example, some devices not designed to bleed continuously had continuous emissions. This could be the result of a defect in the system, such as a crack or hole in the end-device's (control valve's) diaphragm actuator, or a defect in the controller itself, such as fouling or wear. No additional troubleshooting analysis was performed on these high emitters, so the actual root causes are not known with certainty. The results, however, do indicate that some of the high emissions were caused by repairable issues. Details are provided in the Appendices (A.8).

### 3.6 Conclusions

Emissions from 377 gas actuated (pneumatic) controllers were measured at natural gas production sites and a small number of oil production sites, throughout the United States. A small subset of the devices (19%), with whole gas emission rates in excess of 6 standard cubic feet per hour (scf/h), accounted for 95% of emissions. More than half of the controllers recorded emissions of 0.001 scf/h or less during 15 minutes of measurement. Pneumatic controllers in level control applications on separators and in compressor applications had higher emission rates than controllers in other types of applications. Regional differences in emissions were observed, with the lowest emissions measured in the Rocky Mountains and the highest emissions in the Gulf Coast. Average emissions per controller reported in this work are 17% higher than the average emissions per controller in the 2012 EPA greenhouse gas national emission inventory (2012 GHG

NEI, released in 2014); the average of 2.7 controllers per well observed in this work is higher than the 1.0 controllers per well reported in the 2012 GHG NEI.

### 3.7 References

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# 4 METHANE EMISSIONS FROM LIQUIDS UNLOADINGS

## 4.1 Introduction

Measurements of emissions from pneumatic controllers have been described in the previous chapter. This work reports on emissions from gas well liquid unloadings.

A liquid unloading may be necessary when a gas well that also produces oil or water accumulates liquids in the well bore. The liquids accumulation may be due to a variety of causes, including decreases in gas velocity in the well, decreases in reservoir pressure, or changing gas to liquid ratios. As liquids accumulate, well production can decline and an operator may choose to unload the liquids from the well to restore production. Liquids can be unloaded in a variety of ways. For example, the well tubing can be modified to increase gas velocity or a pump may be installed to remove downhole liquids. Neither of these methods lead to venting emissions. Other unloading methods, such as temporarily diverting the flow from the well to an atmospheric vent, do lead to emissions. This work focuses on unloadings that result in emissions.

In the most recent national inventory of greenhouse gas emissions (for calendar year 2012, released in 2014, referred to here as the EPA 2012 GHG NEI) [1], the EPA estimates that 60,810 natural gas wells, out of an estimated 470,913 natural gas wells in the United States (not including oil wells with associated gas production), have liquid unloadings that result in methane emissions. This represents 13% of gas wells in the EPA 2012 GHG NEI. Collectively, liquid unloadings from these wells are estimated to emit 273.6 Gg of methane per year (14.2 billion standard cubic feet, bcf), or approximately 14% of the estimated 1,992 Gg of methane emissions from the natural gas production portion of the natural gas supply chain.

The estimates of methane emissions from liquid unloadings in EPA 2012 GHG NEI are generally consistent with more recent information collected through the EPA's Greenhouse Gas Reporting Program (for calendar year 2012, released in 2013, referred to here as the EPA 2012 GHGRP) [2]. The GHGRP reports approximately 276 Gg of

methane emissions from liquid unloadings at facilities that meet threshold reporting requirements. Information for 58,663 wells that have unloading emissions was reported in 2012. The liquid unloading emission estimates from the EPA GHGRP can be disaggregated by production region and these data are shown in Appendices (*Section B.1*).

Emissions from liquid unloadings of natural gas wells are not uniformly distributed in time or space. Estimated emissions from liquid unloadings are spatially concentrated in Rocky Mountain production regions. Wells in the western United States account for more than half of estimated emissions from liquid unloadings in the 2012 GHGRP. Temporal distributions also vary. Some wells release unloading emissions several times per day while others may release unloading emissions only once per year or once during the well's production life cycle. Wells may only release unloading emissions for a portion of their production lifetime, leading to a dependence of unloading emissions on well age. In addition to spatial and temporal variability in emissions of wells that vent, both estimates and measurements indicate that a small fraction of wells that vent account for a majority of emissions. For example, for one type of well with unloading emissions (wells without plunger lifts – see definition later in text), emission estimates reported by the American Petroleum Institute/America's Natural Gas Alliance (API/ANGA), indicate that three percent of wells accounted for half of emissions from this type of well and half of the wells accounted for more than 90% of emissions [3]. In a limited number of measurements of methane emissions from a single type of well with unloading emissions (wells without plunger lifts – see definition later in text), Allen, *et al*. [4] found that 95% of the emissions came from less than half of the wells.

Emission estimates, and a limited number of measurements of methane emissions from liquid unloadings, both suggest that a small fraction of wells, in particular geographical regions, and at particular times in the well's life cycle, account for a large fraction of liquid unloading emissions. These characterizations of unloadings emissions are primarily based on emission estimates, however, and there are few data in the scientific

literature to test the reliability of emission estimates. This leads to potentially large uncertainties in the emissions from this source category. More measurement data are needed, along with a better understanding of the relationships between well characteristics and unloading emissions.

This work reports measurements of methane emissions from 107 natural gas wells with emissions associated with liquid unloading. These data represent the most extensive set of measurements of emissions from liquid unloadings in the scientific literature. The relationships between emissions magnitude, unloading event frequency and other well characteristics are explored.

## 4.2 Methods

### *4.2.1 Emission Measurements*

The liquid unloadings reported in this work are grouped as plunger-lift unloadings and unloadings of wells without plunger lifts.

In a manually triggered unloading of a well without a plunger lift, an operator manually diverts the well's flow from a production separator, which typically operates at pressures of multiple atmospheres, to an atmospheric pressure tank. This allows the well to flow to a lower pressure destination (the atmospheric pressure tank or vent, rather than the pressurized separator). The resulting higher pressure gradient allows more gas to flow, increasing velocity in the production tubing and entraining and lifting liquids out of the well. Gas is discharged through the tank vent to the atmosphere. In a small number of wells (~0.1% of wells reported by companies participating in this work), this process is automated, resulting in two sub-categories of unloadings for wells without plunger lifts, manual and automatic. All of the measurements reported in this work for wells without plunger lifts are for wells that had unloadings that were manually triggered; no wells without plunger lifts were observed in the sampling that had automated unloadings.

Emissions from unloadings of wells without plunger lifts were measured in this work by directing flow through a temporary stack installed on top of the vent. Figure 4-1 shows a conceptual diagram of a tank layout on a well site and the positioning of the temporary stack. Grounded metal or metal lined tubing was used to construct the temporary stack, to prevent static discharge. Flow rate through the temporary stack was measured continuously, near the centerline of the temporary stack, using a thermal gas mass flow meter. The thermal meter was extended into the middle of the temporary stack, which was between two and eight inches in diameter, with the diameter depending on the anticipated flow rate. Since the width of the meter's probe was approximately 3.5 cm (1.4 in.), the thermal meter recorded a centerline velocity. Total volumetric flow was calculated by multiplying the product of the measured gas velocity and the cross-sectional area of each stack by a correction factor to convert the centerline velocity in the stack to an estimated average velocity in the stack, accounting for the change in velocity profile from friction near the stack walls and accounting for the cross sectional area of the stack obstructed by the flow meter (see Appendices Section B.2). In some well configurations (31 of the 107 wells on which measurements were made), measurement through a temporary stack on the atmospheric tank was not technically feasible. In these cases, measurements were made by inserting a segment of pipe (with the thermal gas mass flow meter in the pipe) into the process line between the well and the atmospheric tank in order to measure the flow into the tank.

The methane fraction of the vented gas was assumed to be equal to the methane fraction in the normally produced gas. This was presumed to be a more accurate indicator of total methane emissions than measurements of the gas composition made through the temporary stack. The gas exiting through the temporary stack during the unloading period is a combination of the unloaded gas from the well and the gas initially in the vapor space of the tank (typically much lower in methane than the site's produced gas). At the end of the unloading, the tank will contain more methane, from the unloading, than was in the tank at the start of the unloading. This methane, which is associated with the

unloading event, will eventually be released as part of normal tank operations. Multiplying the measured vented gas volume by the methane fraction of the produced gas captures these emissions that occur because of the unloading but that are not released during the period when the tank is actively venting.

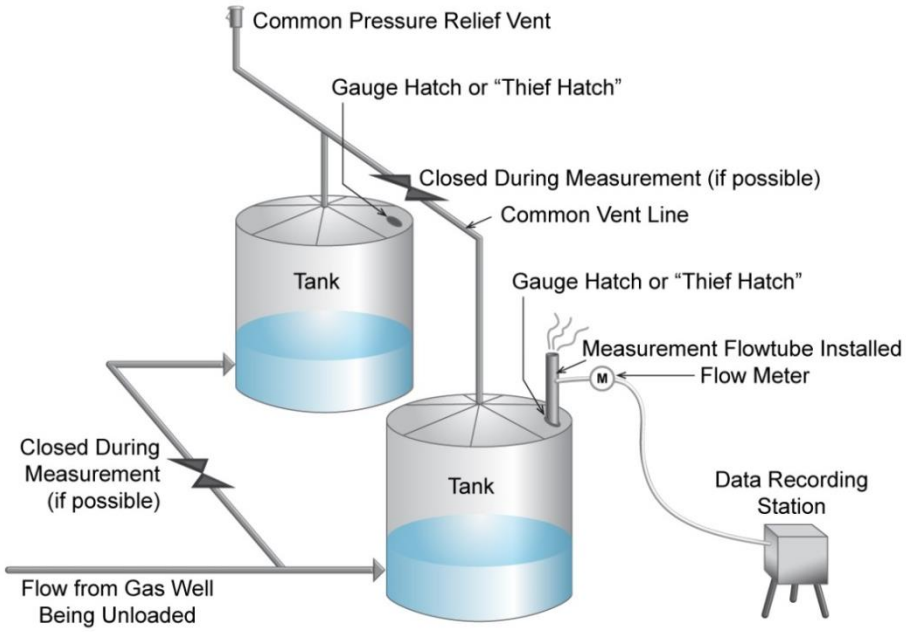


**Figure 4-1.** Conceptual diagram of a tank layout on a well site and the positioning of the temporary stack used to measure volume of gas vented during a liquid unloading

Uncertainty in these measurement methods is estimated at 10-20% of the measured emissions and this estimate is dominated by the assumed uncertainty in the flow, which includes both uncertainties in the stack gas volumetric flow measurement, and determining when flows return to zero. Variability in the gas composition from the well is expected to be much less than 10%. As described in the Results section, these measurement uncertainties are small compared to the combined sampling and measurement uncertainty, which are 50% or more of measured emissions.

Liquids can also be unloaded from a well using a plunger lift system. This liquid recovery operation holds a plunger at the top of the well, and either manually or by

automation occasionally closes (shuts-in) the well and releases the plunger, allowing it to fall down the well bore below the accumulated liquids. The well is then reopened, allowing the gas to push the plunger and the liquid back up the well bore as a slug of liquid. If the plunger returns to the top and the liquid and gas flow to the separator, there is no venting and all gas from the separator is routed to sales. In some cases, if the plunger does not return to the surface as expected, the plunger controller may bypass the separator and direct the flow to an atmospheric pressure vent, such as a vented tank. Directing flow to the lower pressure vent causes the plunger to return to the surface but also allows gas to vent. Plunger cycles may be initiated manually, on a timed interval, or based on certain well parameters such a reduced gas flow. In this work, measurements were made on both wells in which the unloading was automated through use of a controller (automatically triggered), and wells in which the plunger lift cycle was manually initiated by an operator (manually triggered).

In both the manually triggered plunger lift unloadings and the automatically triggered plunger lift unloadings, the volume of vented gas was measured using the same procedures as used for the wells without plunger lifts. For the automatically triggered unloadings, the measurement equipment was typically left in place for one to several days, making measurements continuously. This allowed automated plunger unloading events to be measured only when and if they occurred in routine operation, without artificially triggering the events. For all the plunger lift unloading events, the composition of the vented gas was assumed to be the same as the composition of the gas produced by that well. Produced gas composition was provided by site operators.

### *4.2.2 Sampling Strategies*

Emission estimates reported through the EPA 2012 GHGRP [2] indicate that a small fraction of wells, in particular geographical regions, account for a large fraction of emissions from liquid unloadings. The sampling strategy employed in this work was to

sample most extensively in regions that were likely to dominate emissions (Appendices, Section B.1). Details of the sampling approach are provided in the Appendices. Briefly, the sampling team would visit a region for one or multiple weeks and sample a randomly selected subset of those wells that were unloading during that period. Consequently, more samples were collected on wells that unloaded more frequently. The features of these sample collection methods (preferential sampling in regions with high estimated emissions from unloadings and sampling of wells that tended to have high unloading frequencies) are important to consider when the data presented in this work are used to establish national emission estimates.

### 4.3 Results and Discussion

Methane emissions from liquid unloadings were measured at 107 natural gas wells. A summary of the geographical locations of the wells sampled is provided in Table 4-1.

For the 32 wells without plunger lifts (manually unloaded) sampled in this work, one event was typically sampled for each well; a few wells had more than one event sampled and for these wells, average values are reported. The unloadings of wells without plunger lifts sampled in this work had durations that lasted between 0.17 and 4.5 hr, and vented methane volumes that ranged between 550 and 135,000 standard cubic feet (scf) of methane per event (0.011 – 2.6 Mg). Representative time series for the methane emissions from wells without plunger lifts are shown in Figure 4-2. These three events shown had durations that ranged from 2.72 to 3.75 hr. Vented volumes for these three events shown ranged between 21,000 and 135,000 scf methane (0.40 – 2.6 Mg). As illustrated by these representative time series, some manual unloadings without plunger lift rapidly rose to a high flow rate, then maintained a steady flow throughout the event; others rose more slowly to a peak flow, then had variable flow during the event; still others rapidly rose to a peak flow, then had declining flows throughout the event. This

complex flow behavior makes it difficult to generalize about the flow characteristics for manually triggered unloadings of wells without plunger lifts.

**Table 4-1.** Unloading events measured in this work. Wells with manual unloadings typically had one event per well, while automated plunger lift unloadings had multiple events per well, a mapping of region boundaries is provided in the Appendices.

| Type of Well | Initiation System | Wells with Unloadings sampled | | | | |
|---|---|---|---|---|---|---|
| | | **US Total** | Appalachian | Rocky Mountain | Gulf Coast | Mid-Continent |
| **Plunger** | Auto | 25 | 0 | 20 | 1 | 4 |
| | Manual | 50 | 7 | 29 | 1 | 13 |
| **Non-Plunger** | Manual | 32 | 4 | 2 | 14 | 12 |
| **Total** | | 107 | 10 | 51 | 16 | 29 |

For the 50 plunger lift wells with manually triggered unloadings, one event was typically sampled for each well. The manual unloadings of wells with plunger lifts sampled in this work had durations that lasted between 0.03 hr and more than 3 hr, and had vented methane volumes that ranged between approximately 200 and 49,000 scf methane per event (0.004 – 0.94 Mg). Representative time series for the methane emissions from a manual unloading are shown in Figure 4-3. These three events shown had durations that ranged from 1.2 to 40 min. Vented volumes ranged between 1,220 and 27,000 scf methane for the three events shown (0.02 - 0.52 Mg). As illustrated by these representative time series, some manually triggered unloadings with plunger lift rapidly rose to a high flow rate, then almost immediately fell rapidly, leading to a relatively short duration event; others rose rapidly to a peak flow that was maintained for 5-10 minutes or more; still others had complex flow patterns over an event lasting 10 minutes or more. As was the case for manually triggered unloadings without plunger lifts, this complex flow behavior makes it difficult to generalize about the flow characteristics.

For automated plunger lift wells, the sampling equipment was left in place for one to several days at each well, and typically more than one event was sampled for each well.

The automatically triggered unloadings (with plunger lift) sampled in this work had durations that lasted between <1 minute and more than 20 minutes, and vented methane volumes that ranged between 50 scf methane and more than 8,000 scf methane per event) (0.001 – 0.15 Mg). The numbers of events sampled per well ranged from 2 to more than 70; average values of emissions per event were used when multiple events were recorded. Representative time series for the methane emissions from automated plunger lift unloadings are shown in Figure 4-4. Individual unloading events for these three wells had durations that ranged from 2 to 20 min. Vented volumes per event ranged between 60 and 8600 scf methane for the three wells shown (0.001 – 0.15 Mg). As illustrated by these representative time series, some plunger lift wells with automated unloadings had emissions per event that were quite similar, and that occurred with a regular frequency. In contrast, however, some automated plunger lift wells had events that had qualitatively different emissions and/or variable event frequencies.

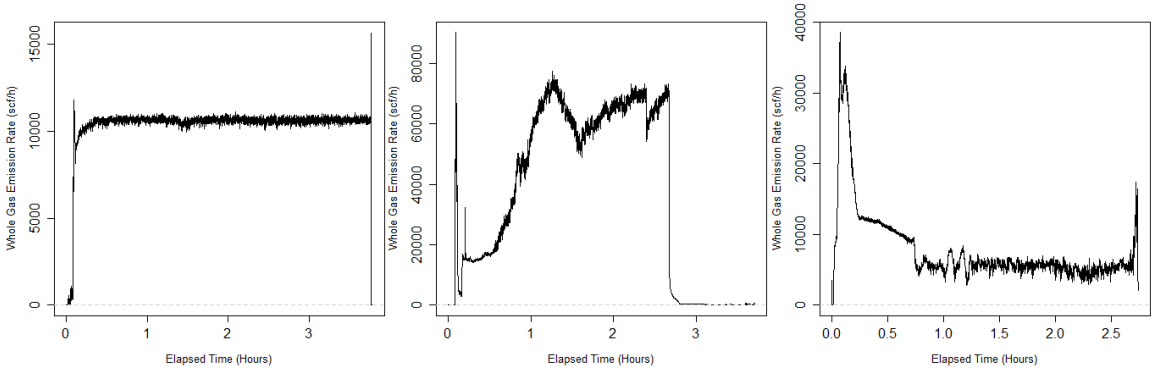


**Figure 4-2.** Representative time series of methane flow rates during manually triggered liquid unloadings from wells without plunger lifts (USH-47-0201 *left*; USH-47-0701 *middle*; UCG-03-0301 *right*); Note differences in horizontal and vertical scales.

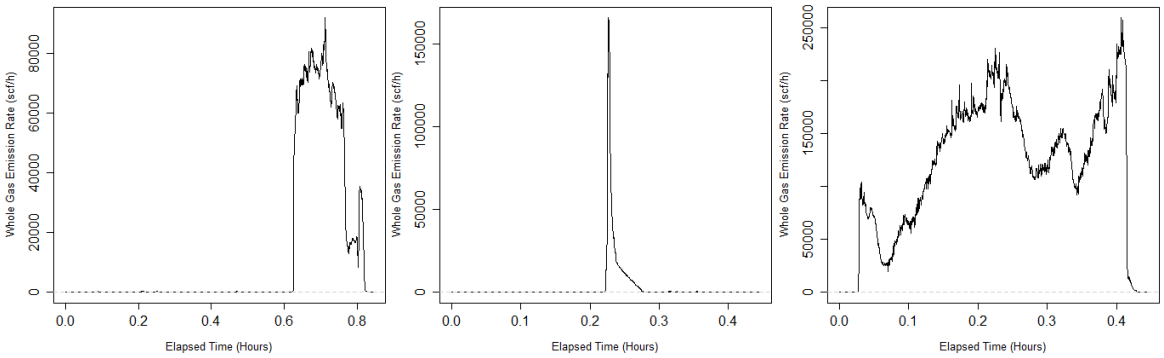


**Figure 4-3**. Representative time series of methane flow rates during manually triggered liquid unloadings from wells with plunger lifts (UBB-45-0101 *left*; UJR-46-0601 *middle*; USH-45-0202 *right*); Note differences in horizontal and vertical scales.

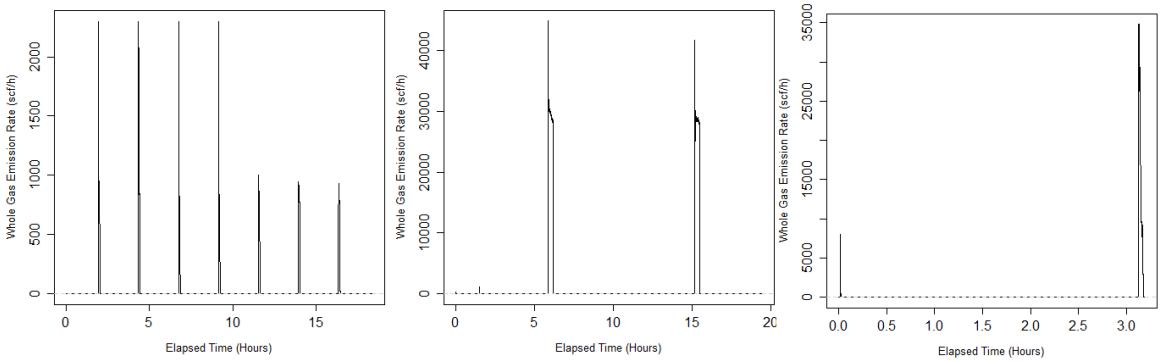


**Figure 4-4.** Representative time series of methane flow rates during automatically triggered liquid unloadings from wells with plunger lifts (UBB-42-0401 *top*; UBB-42-0201 *middle*; UEF-49-0501 *bottom*); Note differences in horizontal and vertical scales.

The Appendices (Section B.3) provides details of the unloading emissions and well characteristics for each of the 107 wells sampled in this work. A summary is provided in Figure 4-5. A relatively small number of wells have high emissions and most wells have much lower emissions. For example, 20% (6 of 32) of the wells account for 83% of the annual emissions for wells without plunger lifts, where annual emissions are estimated by multiplying the emission for an unloading event, measured in this work, by the number of times that well unloaded during calendar year 2012 or 2013 (whichever was the most recent report available), as reported by the well operator. The 6 wells that account for 83% of the annual emissions of wells without plunger lifts vent 6% of their collective

annual production. For manually and automatically triggered plunger lift wells, 20% of the wells account for 65% and 72% of the annual emissions, respectively. These wells vent 2% and 20% of their collective annual production, for manually and automatically triggered wells, respectively.

Because the sample distributions are not normally distributed about a mean, uncertainties in the average values are reported based on the results of a bootstrapping method, rather than as a simple standard deviation of the dataset. In the bootstrapping procedure, the original data set of each type of well was recreated by making random event selections, with replacement, from the data set. A total of 1000 of these re-sampled data sets were created and the mean value of the emissions for each re-sampled data set was determined. The 95% confidence intervals for the emission estimates represent the 2.5% and 97.5% percentiles of the means in the 1000 re-sampled datasets. So, for example, for the 25 automatically triggered plunger lift wells, a mean value for emissions per event, for each well, was calculated by selecting 25 emission measurements, at random and with replacement. This mean was tabulated and the process was repeated 1000 times to generate 1000 mean values. The 2.5% and 97.5% percentiles were determined to be 538 and 2,085 scf methane per event, and these values are the 95% confidence bounds for the mean value of the measurements (in this case 1,210 scf methane/event). The bootstrapping procedure leads to a combined sampling and measurement uncertainty. This uncertainty has a much larger range (typically 50% or more of the mean value, see Figure 4-5) than would be estimated from the uncertainty associated with the measurement alone (approximately 10-20% of the measured value) and is a reflection of the heterogeneity of well characteristics in the data sets and the underlying population of wells with unloading emissions.

Statistical analyses were conducted to identify well and unloading event characteristics that could explain the variability in the measured emission data. Variables that were considered included well pressures, well bore volumes, well ages, unloading event durations and unloading frequencies. The variable that explained the largest amount of

variability in the observed annual well emissions was unloading frequency, although there was also a positive correlation of event frequencies with well age (older wells had more unloading events per year than younger wells) and a negative correlation of annual emissions with well depth (deeper wells, which were generally newer, had lower annual emissions than shallower, generally older, wells). Correlations with emissions per event were generally weaker than for annual emissions. Additional details are provided in the Appendices (Section B.4). As shown in Figure 4-5, for wells without plunger lifts, average emissions for individual unloading events range between 21,000 and 35,000 scf methane per event, if the events are binned into wells that have less than 10 events per year, between 11 and 50 events per year, and between 51 and 200 events per year. The differences in annual emissions from manually unloaded wells without plunger lifts are largely due to the frequency of events, rather than the volume of gas emitted per event. For wells with plunger lifts, Figure 4-5 reports average emissions in two frequency bins. Manually triggered plunger lift wells were binned as a single group; all had less than 100 events per year (maximum observed value of 52 events per year). Automatically triggered plunger lift wells were also considered as a single category since all of these wells had more than 180 unloadings per year (average of 1,870 unloadings per year in the sampled population). Plunger lift wells that were manually triggered had average emissions per event of 9,450 scf methane. Plunger lift wells with automated triggering of the unloading had average emissions of 1210 scf methane per event.

The measured emissions per event were compared to predictions made using emission estimation methods commonly used in EPA GHGRP reporting. For wells with plunger lifts, for which the data required to make the estimates were available (66 wells), the emission estimates averaged 20,200 scf/event as compared to an average of 7,100 scf/event for measurements. The difference is statistically significant ($p = 0.0001$). In contrast, for wells without plunger lifts, the observations were higher (statistically significant difference) than the estimates. See Appendices (Section B.4) for more details.

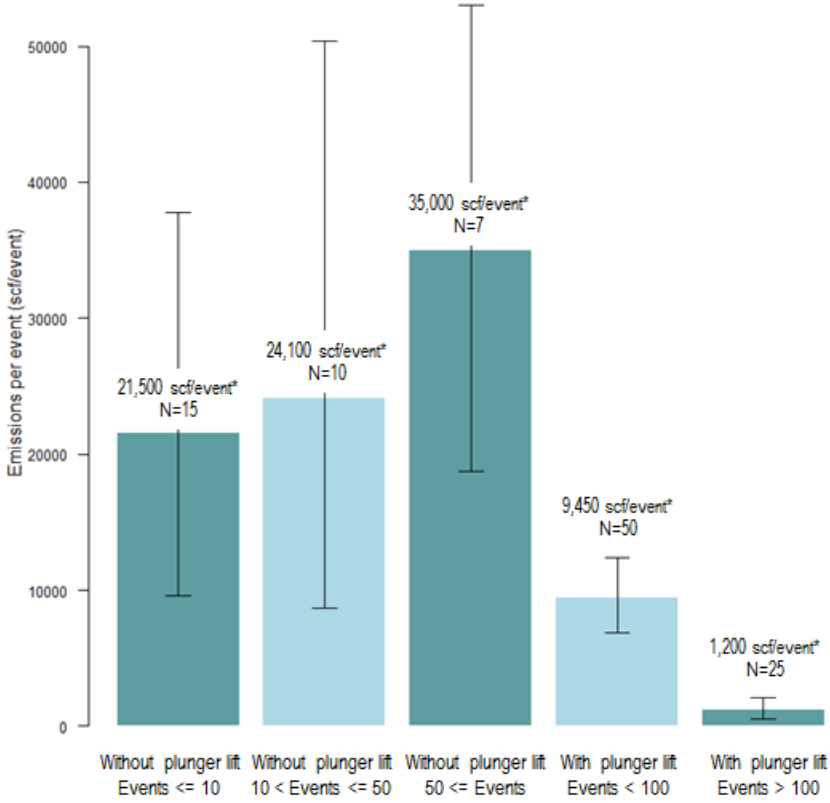


**Figure 4-5.** Average emissions per event for wells with and without plunger lifts, sorted by frequency of events (events per year per well)[3].

## 4.4 Implications for National Emission Estimates

National emissions, based on the measurements made in this work, are estimated by multiplying an emission factor, based on the measurements, by an activity factor. Emission event counts, stratified into categories based on emission events per year per well, were chosen for the activity factor because of the process used for selecting wells to

[3] *95% confidence bounds are:

| | mean (scf methane/vent) | 95% confidence bounds |
|---|---|---|
| Wells without plunger lifts ≤10 events per year: | 21,500 | 9,600-37,800 |
| Wells without plunger lifts 10<events≤50 per year: | 24,100 | 8700-50,400 |
| Wells without plunger lifts 50<events≤150 per year: | 35,000 | 18,700-53,000 |
| Wells with plunger lifts ≤100 events per year: | 9,450 | 6,900-12,400 |
| Wells with plunger lifts >100 events per year: | 1,200 | 500-2,100 |

be sampled and because annual emission estimates for wells with unloadings depended most strongly on event frequency.

As documented in the Appendices (Section B.1), the measurement team typically visited production Basins for approximately a week, and sampled randomly selected wells that had scheduled (for manually triggered wells) or anticipated (for automatically triggered wells) unloading events for that week of sampling. This meant that the study team was far more likely to sample wells that unloaded weekly or more frequently, rather than wells that unloaded just a few times per year. This sampling approach resulted in a representative distribution of events, but not a representative distribution of wells. For example, 85% of the wells, without plunger lift, that have unloading emissions and that are operated by the companies that provided sampling sites in this work, had fewer than 10 emission events per year (See Appendices, Section B.5). In the measurements performed for this work, 15 of the 32 wells without plunger lift (47%) had 10 or less events per year. These wells are therefore under-represented in the measurement data, relative to their presence in the participating companies' overall well population. Because of differences in the distributions of event frequency between the sampled wells and the national population of wells, it would not be appropriate to choose an emission factor of emissions per well per year and an activity factor of number of wells, without adjusting for this difference in event frequency distribution.

An additional reason for stratifying wells by frequency of events in the activity factor is the data shown in Figure 4-5, which indicate a reasonable degree of consistency in per event emissions. Wells without plunger lifts had mean values of 21,000-35,000 scf methane/event. Wells with plunger lifts had mean values of 1,000-10,000 scf methane/event, but much larger ranges of event frequencies. For the calculations reported in this work, national, rather than regional averages of emissions per event will be used, due to the limited number of observations in individual regions.

In this work, national estimates of numbers of unloading events were based on a survey of the participating companies (see Appendices, Section B.5). Data on event counts from EPA GHGRP were not used since event counts for plunger and non-plunger wells are either partially reported or of uncertain quality. The national event counts were assumed to have the same proportion as reported by in the participant survey. Based on this survey, it was estimated that the 32,225 wells with plunger lifts (based on data from the 2012 GHGRP) have a total of 6.8 million events per year. Only 206,500 of these 6.8 million events are associated with wells that vent less than 100 times per year. Total annual emissions from plunger lift wells are estimated at 9.9 billion cubic feet of methane per year (bcf/yr) (190 Gg/yr), with 80% of those emissions associated with wells that vent more than 100 times per year (additional details in Appendices, Section B.5). For wells that vent more than 100 times per year, the average emissions per well per year are 1,400,000 scf per well per year (27 Mg/yr) with 95% confidence bounds of 600,000 – 2,500,000 scf (10 - 50 Mg, based on the confidence bounds in the emissions per event).

For wells without plunger lifts, it was estimated that 26,438 wells (based on data from the 2012 GHGRP) vent a total of 177,000 times per year, with total emissions of 4.4 bcf/yr (84 Gg/yr). Again, the wells that vent with highest frequency have the highest emissions per well. The 1.1% of wells that vent more than 50 times per year have average emissions of 3.2 million scf/yr. For wells without plunger lifts, however, these wells account for only 1.1% of the wells with unloading emissions, so the emissions from these wells venting at high frequency account for only 25% of emissions from wells without plunger lifts. Additional details are provided in Appendices, Section B.5).

The overall emission estimate for liquid unloadings (plunger and non-plunger wells) is 270 Gg (14 bcf/y), which is within a few percent of the national emissions estimated in either the 2012 GHG NEI (273 Gg/yr) or the 2012 GHGRP (276 Gg/yr). The 95% confidence range for this estimate is 190 – 400 Gg/yr, based on the reported confidence ranges in the per event emission factors, but not accounting for uncertainties in event counts. Appendices (Section B.5) reports sensitivity analyses that suggest uncertainties in

event count estimates may be large, which could have a significant impact on national emission estimates. Regardless of the exact national total of emissions, however, wells with high frequencies of unloadings have annual emissions that are a factor of 10 or more greater than the annual emissions of wells with low frequencies of unloadings.

## 4.5 Conclusions

Methane emissions from liquid unloadings were measured at 107 wells in natural gas production regions throughout the United States. Liquid unloadings clear wells of accumulated liquids to increase production, employing a variety of liquid lifting mechanisms. In this work, wells with and without plunger lifts were sampled. Most wells without plunger lifts unload less than 10 times per year with emissions averaging 21,000-35,000 scf methane (0.4-0.7 Mg) per event (95% confidence limits of 10,000-50,000 scf/event). For wells with plunger lifts, emissions averaged 1,000-10,000 scf methane (0.02-0.2 Mg) per event (95% confidence limits of 500-12,000 scf/event). Some wells with plunger lifts are automatically triggered and unload thousands of times per year and these wells account for the majority of the emissions from all wells with liquid unloadings. If the data collected in this work are assumed to be representative of national populations, the data suggest that the central estimate of emissions from unloadings (270 Gg/yr, 95% confidence range of 190-400 Gg/yr) are within a few percent of the emissions estimated in the EPA 2012 Greenhouse Gas National Emission Inventory (released in 2014), with emissions dominated by wells with high frequencies of unloadings.

## 4.6 References

(1) U.S. Environmental Protection Agency (EPA). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012, April 2014.

(2) U.S. Environmental Protection Agency (EPA). Greenhouse Gas Reporting Program, Data for Reporting Year 2012, 2013.

(3) American Petroleum Institute and America's Natural Gas Alliance (API/ANGA) Characterizing Pivotal Sources of Methane Emissions from Natural Gas Production,: Summary and Analyses of API and ANGA Survey Responses, Final Report, updated September, 2012, available at: http://www.api.org/news-and-media/news/newsitems/2012/oct-2012/~/media/Files/News/2012/12-October/API-ANGA-Survey-Report.pdf

(4) Allen, D.T., Torres, V.M., Thomas, J., Sullivan, D., Harrison, M., Hendler, A., Herndon, S.C., Kolb, C.E., Fraser, M., Hill, A.D., Lamb, B.K., Miskimins, J., Sawyer, R.F., and Seinfeld, J.H. Measurements of Methane Emissions at Natural Gas Production Sites in the United States, *Proceedings of the National Academy of Sciences,* 110, 17768-17773, doi: 10.1073/pnas.1304880110 (2013).

# 5 ANALYSIS OF METHANE EMISSIONS ATTRIBUTABLE TO NATURAL GAS PRODUCTION

## 5.1 Introduction

A number of studies have examined greenhouse gas footprints of natural gas supply and use chains, and many of these studies have compared natural gas footprints to the greenhouse gas footprints for the production and use of other fuels [1-6]. In performing comparisons between natural gas and other fuel systems, it is important to recognize that parts of the natural gas supply chain, particularly production operations, produce both natural gas and liquid products. Co-production of natural gas and liquid products is particularly common in some of the most rapidly growing shale gas production regions, such as the Eagle Ford region in Texas [7]. When both gas and liquid products are generated by gas wells, the emissions of greenhouse gases from this part of the supply chain should be allocated to both gas and liquids production.

Recently Allen, *et al*.[8-9] have reported measurements of methane emissions from natural gas production sites, including wells that produced only gas and wells that produced both gas and liquids. All of these wells were classified as gas wells, all were in shale formations, and all were hydraulically fractured. Methane was the focus of these measurements because emissions of methane, a potent greenhouse gas, can significantly impact the supply chain greenhouse gas footprints of natural gas, relative to other fuels. Activities sampled included well completion flowbacks, liquid unloadings, pneumatic device operation, and equipment leaks from wells in routine operation. These data can be used to develop methane emission footprints of the production portion of the natural gas supply chain, with emissions allocated to the multiple products from the wells. For each of the wells sampled by Allen, *et al*. [8-9], gas composition, gas production and liquid production data are available [9]. This work reports allocations of methane emissions to natural gas and other gas and liquid products.

## 5.2 Methods

Allocation methods are commonly used in the analysis of emissions from supply chains when processes produce multiple products. For the case of a well that produces hydrocarbons that will eventually be separated into pipeline quality natural gas, natural gas liquids, and liquid hydrocarbon products, emissions from devices that handle all the products (e.g., a separator), should be allocated among multiple products. The most commonly used allocation methods are based on energy, mass and value [10-12].

In an energy based allocation, a well that produces 6000 standard cubic feet (scf) of gas for every barrel (bbl) of hydrocarbon liquid would generate equal amounts of energy as gas and liquid products, assuming a heating value of 1000 BTU/scf for gas and 6 million BTU/bbl for hydrocarbon liquid. For this simple example, if an emission allocation is based on energy, half of the emissions from the well would be assigned to the gas and half to the liquid product. In contrast, a mass based allocation, for the same simple example, would allocate 60% of the emissions to the gas and 40% to the oil, based on a gas density of 25 g/scf and an oil density of 100 kg/bbl, A value based allocation, based on prices of $3.50 per thousand scf (Mscf) for gas and $90 per bbl for hydrocarbon liquid, would assign 19% of the emissions to gas and 81% to the liquid.

The gas leaving a well site will typically contain quantities of ethane, propane, butane, and heavier hydrocarbons that are largely removed from the methane in the gas before the product is marketed as natural gas. In this work, emissions from well sites will initially be allocated to liquid products and to specific gas phase molecular species (methane, ethane, propane, butanes and pentane and heavier hydrocarbons). The emissions allocated to the gases will then be attributed to three main products: (1) *salable natural gas* (also known as dry natural gas, referring to the remaining gas once the liquefiable hydrocarbon portion has been removed)[13]; the composition of salable gas is based on commonly used life cycle analysis datasets for natural gas: 92.8% methane, and up to 5.54% non-methane hydrocarbon gases (the rest is $N_2$, $CO_2$, $H_2S$, and $H_2O$)[14] (% mass)), (2) *natural gas liquids,* which will be assumed to be the remainder of the

hydrocarbon gas leaving the well, and (3) *Hydrocarbon liquids* (*oil*) for which methane emissions will be assigned as a mixture.

Based on the assumed composition for *salable natural gas*, if the gas produced at each site has a non-methane hydrocarbon content that would produce a *salable natural gas* of up to 5.54% non-methane hydrocarbon (mass), all non-methane hydrocarbons are considered as part of salable natural gas (for that site there would be no natural gas liquids production). On the other hand, if the gas produced at each site is wetter (>5.54% non-methane hydrocarbon gases), non-methane hydrocarbon gases are assigned to *salable natural gas*, starting with ethane and then adding subsequent heavier hydrocarbons, until the 5.54% threshold is reached, the remaining portion of the gas leaving the well is considered *natural gas liquids*.

Properties and assumed economic values for each of these materials are provided in Appendices (Section C.1), Appendices also includes an expanded explanation of how non-methane hydrocarbon gases are split between salable natural gas and natural gas liquids (Appendices, Section C.4). Calculated across all sites, the weighted average composition (% mass) of salable natural gas is 97.3% methane, 2.61% ethane, 0.120% propane, 0.007 butanes, and 0.003% pentane and heavier hydrocarbons. For Natural Gas Liquids, the weighted average composition is 38.6% ethane, 27.8% propane, 18.8% butanes, and 14.8% pentane and heavier hydrocarbons (% mass).

For the case of the energy based allocation, a single heating value of 1,027 BTU/scf (higher heating value) was assigned to salable natural gas (Appendices, Section C.1), this heating value is commonly assumed in life cycle datasets [5, 14]. Nonetheless, a similar value is obtained when the mass weighted average heating value of salable natural gas across all sites is calculated (1,022 BTU/scf), based on the gas composition. For Natural Gas Liquids, an average heating value is derived for each site, based on its particular Natural Gas Liquids composition. (Mass weighted average heating value of natural gas

liquids across all sites is 2,349 BTU/scf (higher heating value)) (See Appendices, Section C.5).

Emissions for each product were allocated based on mass, energy and value, for each product (salable natural gas, natural gas liquids, and oil), for each of the individual sampling sites that were reported by Allen, *et al*. [8-9]. Average normalized emissions for each product are reported as the sum of emissions over all sites attributed to a particular product, divided by the sum of production of that product, over all sites. So, for example, the emissions attributed to natural gas liquids would be summed over all sites then divided by the production of natural gas liquids, summed over all sites.

Production for the sites can be reported either as instantaneous production rate at the time of the measurement or as ultimate production. In this work, the production rate will be reported as an estimated ultimate recovery, over 30 years, for each well. The ultimate recovery is estimated for each well using the age of the well at the time of the measurement, the instantaneous production at the time of the measurement, and an assumed production decay rate over 30 years of production, as described in the Appendices (Section C.2). Sensitivity analyses, using instantaneous production rates and shorter well life, are also reported.

Results in this work are reported as a ratio. For emissions from wells in routine production, the numerator in the ratio is total estimated emissions, over 30 years, based on a measured instantaneous emission rate and an assumption that emissions (except for well completions) remain constant over 30 years. The denominator is the estimated ultimate recovery from the well, over 30 years. For completion events, which are assumed to only occur once over the life of a well, the numerator is the emissions from the single event. The denominator is the estimated ultimate recovery from the well, over 30 years.

## 5.3 Results and Discussion

### *5.3.1 Emissions from wells in routine production*

Table 5-1 reports emissions from pneumatic controllers, pneumatic pumps, and leaks from equipment sampled by Allen, *et al*. [8-9]. Allocated emissions for individual sites are shown in Appendices, Sections C.3-C.6. To arrive at total emissions for each site, emissions from leaks, pneumatic controllers and pneumatic pumps are summed. All leaks at sites were sampled, but not all controllers or pumps. For controllers and pumps, the average emission rate for each site was multiplied by the total number of devices reported for that site. Averages over multiple sites are taken on a production weighted basis, as described in the Methods section. Emissions assigned to each product are summed over all sites and divided by the production rate of that product, summed over all sites.

**Table 5-1.** Ratio of methane emissions allocated to each product (Natural Gas, Natural Gas Liquids, and Oil) divided by its respective production, based on a **mass** allocation, **energy** allocation, and **price** allocation. The values represent the ratio of the sum of emissions divided by the sum of production across all sites where each specific product is produced. From a total of 150 production sites, 144 sites reported natural gas production (for 3 sites production data was reported as "not available"; three sites reported zero gas production), 39 sites reported oil production, and 51 reported Natural Gas Liquids production.

| | **Pneumatic Controllers** | **Pneumatic Pumps** | **Equipment Leaks** | **Total** |
|---|---|---|---|---|
| **MASS ALLOCATION** | | | | |
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)*** | 0.0008 | 0.0002 | 0.0002 | 0.0011 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)**** | 0.0014 | 2.2E-05 | 0.0001 | 0.0016 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 0.0011 | 1.9E-06 | 0.0001 | 0.0012 |
| **ENERGY ALLOCATION** | | | | |
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)*** | 0.0008 | 0.0002 | 0.0002 | 0.0012 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)**** | 0.0013 | 2.0E-05 | 0.0001 | 0.0015 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 0.0010 | 1.7E-06 | 0.0001 | 0.0012 |
| **PRICE ALLOCATION** | | | | |
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)*** | 0.0007 | 0.0002 | 0.0002 | 0.0011 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)**** | 0.0017 | 4.6E-05 | 0.0002 | 0.0019 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 0.0016 | 3.9E-06 | 0.0002 | 0.0017 |

**Produced Natural Gas* refers to *salable natural gas* (also known as dry natural gas, referring to the remaining gas once the liquefiable hydrocarbon portion , propane and heavier, has been removed [13], with the remaining non-methane hydrocarbon gases [14], being allocated to Natural Gas Liquids.

*** Produced Natural Gas Liquids*, *NGL* refers to the remaining non-methane hydrocarbon gases that are not part of salable natural gas. (For expanded explanation of how non-methane hydrocarbon gases are split between salable natural gas and natural gas liquids see *Appendices, Section C.4*).

If the instantaneous emission rate is normalized by instantaneous production rate at the time of the measurement, emissions from pneumatics and leaks from wells in routine production are 0.0003 scf of methane per scf of produced natural gas, compared to the 0.0011 – 0.0012 scf of methane per scf of produced natural gas reported in Table 5-1, when emissions over 30 years and an ultimate production based on a well lifetime of 30 years is assumed (see Appendices, Section C.8). The difference is due to the relatively young age of the wells in the data set (average age of wells, weighted by gas production is 1.3 years), and the assumption that emissions stay constant over the life of the well. If the assumed well life is reduced to 15 years, emissions are reduced by half but production is only reduced by, on average, 22% (see Appendices, Section C.7). This leads to an estimated natural gas emission rate of 0.0007 scf of methane per scf of produced natural gas.

### *5.3.2 Emissions from Completion Flowback Events*

Allen, *et al*. [8-9] also made direct measurements from 27 well completion events. Production data are reported for 19 of these 27 wells; 12 report both gas and oil production, and 7 report production of gas only. Table 5-2 shows the average ratio of methane emissions from the 19 completions, divided by the total estimated ultimate recovery of each component, over 30 years, from the 19 wells. This average represents the sum of emissions divided by the sum of production across the 19 measured events. (Ratios and allocated emissions for each separate event are shown in the Appendices, Section *C.9*). Table 5-3 shows the sum of the average completion, pneumatic device and leak measurements. The contribution of completion events is small compared to the emissions from wells in routine production.

**Table 5-2.** Ratio of methane emissions from completion flowbacks allocated to specific gas phase molecular species (methane, ethane, propane, butanes and pentane and heavier hydrocarbons) and to each product (Natural Gas, Natural Gas Liquids, and Oil) ) divided by its respective production. Results are shown in mass, energy, and price basis.

| | **Mass Basis** | **Energy Basis** | **Price Basis** |
|---|---|---|---|
| **Emitted Methane (scf)** / Produced **Natural Gas (scf)*** | 1.8E-05 | 1.8E-05 | 1.1E-05 |
| **Emitted Methane (Mg)** / Produced **Natural Gas Liquids (Mg)**** | 3.5E-05 | 3.4E-05 | 4.2E-05 |
| **Emitted Methane (Mg)** / Produced **Oil (Mg)** | 1.8E-05 | 1.7E-05 | 2.6E-05 |

**Table 5-3.** Ratio of TOTAL methane emissions from completion flowbacks, pneumatic devices and leaks and routine emissions) allocated to each component (Natural Gas, Natural Gas Liquids, and Oil) divided by its respective production. Results are shown on mass, energy, and price bases.

| | **Mass Basis** | **Energy Basis** | **Price Basis** |
|---|---|---|---|
| **Emitted Methane (scf)** / Produced **Natural Gas (scf)*** | 0.0012 | 0.0012 | 0.0011 |
| **Emitted Methane (Mg)** / Produced **Natural Gas Liquids (Mg)**** | 0.0016 | 0.0015 | 0.0020 |
| **Emitted Methane (Mg)** / Produced **Oil (Mg)** | 0.0012 | 0.0012 | 0.0018 |

Emissions from pneumatic controllers, pneumatic pumps, leaks from equipment and well completion flowback events (categories that were directly measured by Allen, *et al* [8-9]., represent 0.11% - 0.12% (vol.) of the total natural gas production when emissions are allocated among natural gas, natural gas liquids and oil; For those same categories, the current EPA national greenhouse gas inventory (data for calendar year 2012, released in 2014) reports a total of 792 Gg of methane/yr or 0.14%, on a volume basis of total natural gas production (29.5 trillion cubic feet of natural gas produced in the US in 2012 [16].) when allocation to co-products is not considered.

Table 5-4 lists additional sources of methane emissions from natural gas production that are quantified in the EPA national greenhouse gas inventory, but were not measured or were measured in very small sample sizes by Allen, *et al*. [8-9]. Table 5-4 disaggregates these emissions, based on whether the equipment handles natural gas (NG) and natural gas liquids (NGL) alone (NG+NGL), oil alone, or all products from the well (NG + NGL + OIL)[4]. The rationale for the disaggregation of each source into the three products is shown in Section C.10 of the Appendices. For categories that allocate emissions to all three final products (NG + NGL + oil), 85.1% of the emissions from each category will be allocated to Natural Gas. This 85.1% is based on the ratio of the average mass content in natural gas to the mass in all well products, over all wells on which measurements were made. For source categories that allocate emissions to Natural Gas and Natural Gas Liquids only (NG + NGL), 94.1% of the emissions are allocated to natural gas. This value is based on the ratio of the average mass content in natural gas to the combined mass NG and NGL products, over all wells on which measurements were made. Combined, these mass based allocations for natural gas production sources not directly estimated by Allen, *et al*. [8-9] allocate an estimated 1055 Gg of methane emissions to natural gas product, which is 0.19% (volume) of the 28.5 trillion cubic feet of natural gas produced in the US in 2011. Since these national estimates capture a population of wells of all ages, it is assumed that the percentage of natural gas emitted (0.19%) would be the same for current emissions from all wells of all ages divided by current production of all wells of all ages or well lifetime emissions divided by EUR.

If these additional emissions are added to the allocated emissions from pneumatics, equipment leaks, and completion flowbacks described in this work (0.12% of natural gas production), the total methane emissions would represent 0.31% (vol.) of total natural gas

[4]For categories that allocate emissions to all three final products (NG + NGL + oil), 85.1% of the emissions from each category are allocated to Natural Gas (percentage based on the previously described energy basis allocation).
For categories that allocate emissions to Natural Gas and Natural Gas Liquids only (NG + NGL), 94.1% (percentage based on the previously described energy basis allocation) of the emissions from each category are allocated to natural gas.

production, a value that is roughly 26% lower than the 0.42% reported by Allen, *et al*. [8], not accounting for co-product allocation.

**Table 5-4.** Description of emission sources not directly measured by Allen et al. [8] that are considered in the EPA GHG national inventory, showing how the emissions are allocated to the products considered in this work. (NG = Natural Gas, NGL = Natural Gas Liquids). The column showing net emissions refers to total emissions from each category before the allocation to the corresponding products. Last row shows total emissions after allocation. (Rationale for the disaggregation of each category is provided in the Appendices, Section C.10.)

| | | Allocate emissions to | | |
|---|---|---|---|---|
| **EPA GHG Inventory Activity** | **Net Emissions (Gg methane/yr)** | **NG + NGL + Oil** | **NG + NGL** | **Oil only** |
| Refractures | 143 | ✓ | | |
| Gas wells without HF | 13 | ✓ | | |
| Gas wells with HF | 15 | ✓ | | |
| Separators | 57 | ✓ | | |
| Meters/Piping | 54 | ✓ | | |
| Heaters | 18 | ✓ | | |
| Dehydrators | 16 | | ✓ | |
| Workovers without HF | 0.3 | ✓ | | |
| Liquids Unloading (without plunger lifts) | 149 | ✓ | | |
| Liquids Unloading (with plunger lifts) | 108 | ✓ | | |
| Kimray Pumps | 185 | | ✓ | |
| Condensate Tanks without Controls | 94 | | | ✓ |
| Condensate Tanks with Controls | 52 | | | ✓ |
| Gas Engines | 227 | | ✓ | |
| Dehydrators Vents | 41 | | ✓ | |
| Small Reciprocating Compressors | 49 | | ✓ | |
| Large Reciprocating Compressors | | | ✓ | |
| Large Reciprocating Stations | | | ✓ | |
| Pipeline Leaks | 90 | | ✓ | |
| Well Drilling | 0.4 | ✓ | | |
| Vessel Blowdowns | 0.4 | | ✓ | |
| Pipeline Blowdowns | 2 | | ✓ | |
| Compressor Blowdowns | 2 | | ✓ | |
| Compressor Starts | 3 | | ✓ | |
| Pressure Relief Valves | 0.4 | | ✓ | |
| Mishaps | 1 | ✓ | | |
| **Total Emissions allocated to NG** | | **475 Gg** | **580 Gg** | |

### *5.3.3 Regional analysis*

Allen, *et al*. [8-9] reported measured emissions from natural gas production sites from four different regions in the United States: Appalachian (45 sites), Gulf Coast (58 sites), Mid Continent (23 sites), and Rocky Mountains (18 sites). Methane emissions (sum of emissions from pneumatics and equipment leaks) are also allocated on a regional basis (mass based allocation), with the intention of highlighting regional differences in emission rates as well as in total production, and the effects that the proposed co-allocation scheme would have on each region's emissions. Table 5-5 shows allocated methane emissions for each region.

**Table 5-5.** Methane emissions allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil), total estimated ultimate recovery for each product and ratio of emissions to production, based on a **mass** allocation. The values represent the ratio of the sum of emissions divided by the sum of production across all sites where each specific product is produced, considering a 30 year well lifetime and for each region. For each region, the number of sampled wells (within the sampled sites) is shown.

| | **Appalachian (164 wells)** | **Gulf Coast (146 wells)** | **Mid Continent (76 wells)** | **Rocky Mountains (78 wells)** |
|---|---|---|---|---|
| Total Methane Emissions (Mg) | 15,801 | 28,143 | 15,975 | 4,272 |
| Methane emissions allocated to **Natural Gas** (Mg) | 15,736 | 21,288 | 13,994 | 2,175 |
| Methane emissions allocated to **Natural Gas Liquids** (Mg) | 64 | 1,928 | 1,201 | 1,394 |
| Methane emissions allocated to **Oil** (Mg) | 2 | 4,927 | 780 | 703 |
| EUR **Natural Gas** (Mg) | 23,770,765 | 20,371,250 | 2,729,781 | 363,904 |
| EUR **Natural Gas Liquids** (Mg) | 38,492 | 2,505,534 | 138,572 | 265,674 |
| EUR **Oil** (Mg) | 1,037 | 5,014,564 | 114,540 | 210,754 |
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)** | 0.0007 | 0.0010 | 0.0051 | 0.0060 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)** | 0.0017 | 0.0008 | 0.0087 | 0.0052 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 0.0019 | 0.0010 | 0.0068 | 0.0033 |

The Appalachians region shows the biggest difference between gas and oil production; where combined production for Natural Gas and Natural Gas Liquids is four orders of magnitude larger than the Oil production (for the measured wells). In the case of the Gulf Coast region and the Mid Continent region, combined NG and NGL production is just one order of magnitude larger than oil production, while for the Rocky Mountains, gas and oil production are of the same order of magnitude.

When the (measured) wells of all regions are considered (as analyzed in the previous section) (national average) combined production of Natural Gas (47,235,700 Mg) and Natural Gas Liquids (2,948,272 Mg) is one order of magnitude larger than the oil production (5,340,895 Mg); with a higher production of oil relative to Natural Gas Liquids. Consequently, a majority of the emissions (85%) are allocated to Natural Gas while 10% are allocated to Oil, and 5% to Natural Gas Liquids.

For the Appalachian region over 99% of the emissions are allocated to Natural Gas, with almost all the remaining emissions being allocated to natural gas liquids. In the case of the Gulf Coast region, 70% of the emissions are allocated to Natural Gas; from the remaining emissions, 18 percent is allocated to oil and 12% to Natural Gas Liquids. For the Mid Continent, 92% of the emissions are allocated to Natural Gas, with remaining emissions being allocated in similar amounts to Natural Gas Liquids and oil. The Rocky Mountains represent the region where the smallest fraction of emissions is allocated to Natural Gas (43%), with 32% of the emissions allocated to Natural Gas Liquids, and 25% to oil. This is driven by the similar mass content of the three products.

The ratios of methane emissions allocated to natural gas production divided by its production are 5 to 6 times higher for the Mid Continent (0.0051) and Rocky Mountains (0.0060) than for the other two regions (Appalachian: 0.0007, Gulf Coast: 0.0010).

Wells in the Appalachian and Gulf Coast regions have a similar EUR for natural gas; 148,000 Mg per well and 141,500 Mg per well, respectively. These values are considerably higher than for the Mid Continent, where per well  For the Rocky Mountain region EUR for natural gas is 5,000 Mg per well. The higher ratios observed in the Mid Continent and Rocky Mountains are driven by a similar order of magnitudes of emissions across all regions but a significantly lower production per well

### *5.3.4 Comparison to other databases:*

The National Energy Technology Laboratory (NETL) prepared a life cycle assessment (LCA) for natural gas [5], both for conventional and unconventional sources. Under the life cycle stage called "Raw Material Acquisition", the source categories include emissions from well construction, well completions, liquid unloading, workovers, other point source emissions (gas released from wellhead and gathering equipment), other fugitive emissions, and valve fugitive emissions. Data for the LCA comes primarily from EPA emission factors and inventories, which have been subject to uncertainty due to the lack of direct measurements. Estimates are based on the EPA GHG inventory released in 2011, which were higher than the most recent EPA estimates, released in 2014 [16].

NETL reports 0.366 kg of methane emitted per Million BTU of natural gas extracted or 0.0196 scf methane/ scf of extracted natural gas (NETL uses a natural gas energy content of 1,027 BTU per cubic feet of natural gas, the same value used in the present work (Appendices, Section C.1)), from the raw material acquisition stage from shale gas wells. This emission rate is an order of magnitude higher than the value presented in this work (0.0031 scf of methane emissions over the life of a well allocated to natural gas/scf of produced natural gas over a well lifetime) and higher than the value reported by Allen, et al. (0.0042 scf current emissions of methane/scf of current natural gas production) for unallocated emissions.

Argonne National Laboratory prepared a LCA comparing shale gas to conventional natural gas [15]. The report is based on EPA estimates and emission factors, and acknowledges the uncertainty in EPA's estimates and modifications and revisions. Estimates are based on the EPA GHG inventory released in 2011 which were higher than the most recent EPA estimates, released in 2013 [16]. Based on EPA's revisions to the inventory, as well as recently released reports of measurements of methane emissions, such as Allen, *et al*.[8], Argonne updated their inventories [17].

Argonne's GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model is used for the analysis, developing a specific pathway for shale gas. The production stage includes emissions from well completions, workovers, liquid unloading, and well equipment (field separation equipment, gathering compressors, normal operations, condensate collection, compressors venting and upsets). The current inventory estimates a total of 120.7 g of methane per million BTU of natural gas, or a total of 0.0064 scf of methane/scf of natural gas produced, for the production stage, which represents roughly 50% of the emissions estimated with the previous version of the GREET model, and which is a factor of three higher than the value reported in this work.

## 5.4 Conclusions

Mass, energy, and price basis allocation methods have been used to assign methane emissions from natural gas production to the three main products of production activity: salable natural gas, oil, and natural gas liquids. On a national scale, approximately 85% of the emissions from the well site are assigned to natural gas, but regional variability is observed. Methane emissions allocated to salable natural gas reported in this work are lower than those reported in commonly used LCA data sets.

## 5.5 References

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# 6 CRITERIA AND AIR TOXIC EMISSIONS FROM SHALE GAS PRODUCTION

## 6.1 Introduction

The analysis for criteria pollutants and air toxic emissions from shale gas production focuses on the Barnett Shale region in Texas, which has shown a significant growth in gas production activity during the last ten years, with production of 0.11 billion cubic feet per day in 2000, increasing to 5 billion cubic feet per day by 2011 [1,2]. Total natural gas withdrawals in the US in mid-2011 were approximately 70 billion scf/d (bcf/d); with approximately 22 bcf/d in Texas [3]. At 5 bcf/d of production, the Barnett Shale is one of the largest natural gas production regions in the US. The region includes 24 counties to the north and west of Fort Worth, with a total of more than 14,000 producing wells [4].

Since 2010, the Texas Commission on Environmental Quality (TCEQ) has deployed automated gas chromatographs that have recorded hourly averaged atmospheric concentrations of hydrocarbons in the Barnett Shale production region and neighboring areas. The TCEQ has also developed estimates of emissions from over 10,000 production sites in the Barnett Shale region. Figure 6-1 illustrates the locations of the monitoring sites that will be examined in this work, along with the inventoried VOC emissions from the production sites.

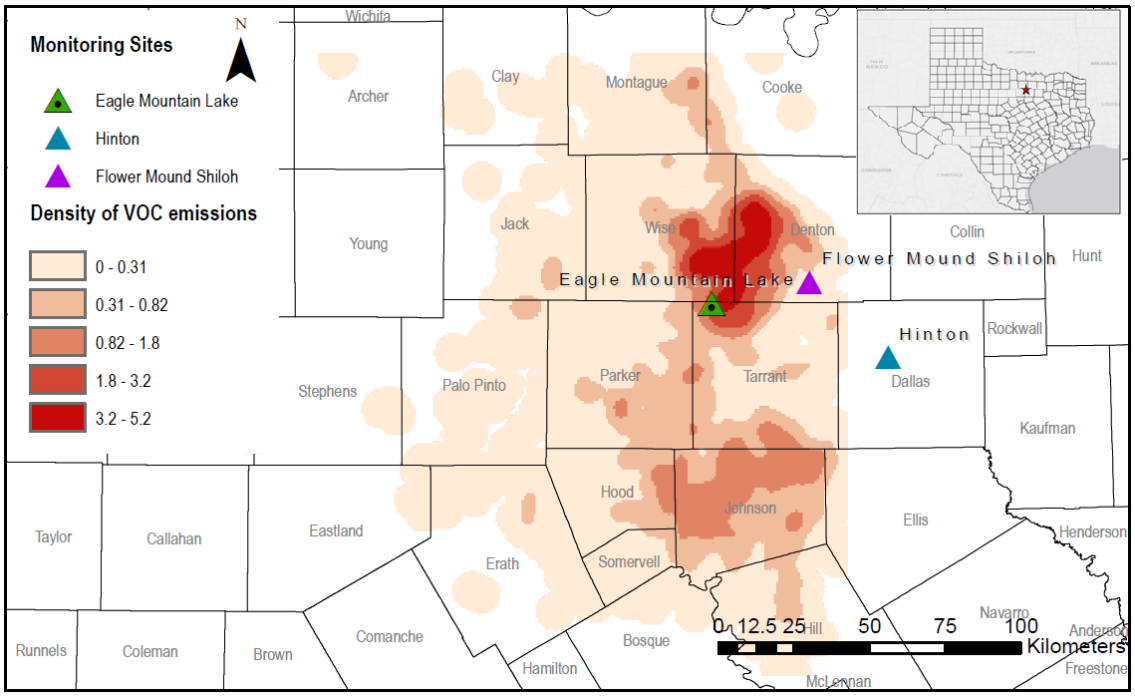



**Figure 6-1.** Density of total VOC emissions (tons per year per square kilometer) based on the locations of natural gas production sites. The map also shows the air monitoring sites (Eagle Mountain Lake (EML), Flower Mound Shiloh and Hinton). The density of emissions is calculated from roughly 8,000 sites which report 19,050 tpy of VOC emissions for the TCEQ Barnett Shale Area Special Inventory.

The goals of the analyses to be presented in this chapter are (1) to report diurnal, monthly and seasonal trends in VOC composition and magnitude; (2) to compare the magnitudes of observed concentrations to concentrations predicted based on the emission inventory using a Lagrangian air quality model; (3) to evaluate the effect that episodic emissions have on the overall predicted concentrations and (4) to assess the overall contributions of the shale gas emissions to benzene concentrations in the region.

## 6.2 Methods

### *6.2.1 Ambient measurements of VOC*

Hourly concentrations for 46 non-methane volatile organic compounds at three sites will be examined in this work. These three sites were selected since they represent a site in the middle of the Barnett Shale (Eagle Mountain Lake, EML), a site at the periphery of the Barnett Shale (Flower Mound-Shiloh) and an urban site, relatively far from the Barnett Shale (Hinton). Eagle Mountain Lake (EML (32.9879º, -97.4772º)), is located in Tarrant County northwest of the Fort Worth urban area. As shown in Figure 6-1, it is located in approximately the geographical center of the Barnett Shale natural gas production region, so EML will serve as the core site for characterizing ambient VOC composition in the shale gas production region. The Flower Mound Shiloh site (33.0459º, -97.1300º) is located northwest of the Dallas urban area and north east of the EML site. Under typical wind conditions, with flow from the south, it is not as strongly influenced by natural gas production activities as the EML site. The Hinton site (32.8201º, -96.8601º), located in the Dallas downtown area, is used to contrast urban sites in the region to the sites influenced by natural gas production emissions. More details about these sites are available from the TCEQ [5].

Hydrocarbon measurements were made using automated gas chromatographs (auto-GCs), which measure concentrations of 46 hydrocarbons on an hourly basis using flame ionization detectors. The auto-GC instrument utilizes two capillary columns that separate light hydrocarbons and heavy hydrocarbons. Samples are collected for a 40 minute period by adsorbing hydrocarbons onto an automated thermal desorber; after the collection period, a 20 minute gas chromatography analysis is performed. Species concentrations determined by the auto-GC are reported as hourly averages based on average concentrations during the 40 minute sampling time. Concentrations are based on FID responses for propane and benzene. Propane is used to calibrate the column for lighter hydrocarbons, while benzene is used to calibrate the column for heavier hydrocarbons[24]. Hydrocarbon concentration and wind data from the period of April 19, 2010 through

December 31, 2011 were examined; the starting date for the analyses is when the auto-GC measurements were initiated at EML.

### *6.2.2 VOC Emission inventory*

The TCEQ reports VOC emissions from individual production sites in the Barnett Shale special inventory [6]. The Barnett Shale Area Special Inventory contains information on a total of 8,025 sites which report a total of 19,050 tons per year (tpy) of VOC emissions. Emissions are disaggregated into 18,466 point sources classified by type of source (92% of the VOC emissions report source type, the other 8% is site specific only). All sites have latitude and longitude reported. The TCEQ provided an emission calculator to assist companies with the emissions estimates [7]. The TCEQ requested emissions estimated with site-specific data. On-site measurements were preferred to emissions-factor based methods but were not required [4].

Table 6-1 shows the total VOC emissions by source type from the TCEQ inventory. Condensate tanks are the largest source of VOC emissions followed by fugitives, water tanks, and engines. VOC emissions from sites that did not report disaggregated sources are listed as without source type (8.1% of the total reported emissions).

**Table 6-1.** Total VOC emissions by source type in the Barnett Shale Special Inventory

| Type of source | Total VOC emissions (tpy) | % of total VOC emissions |
|---|---|---|
| **Amine unit** | 2.47 | 0.013% |
| **Boiler** | 0.30 | 0.002% |
| **Condensate tank** | 10,464 | 54.9% |
| **Engine** | 749 | 3.93% |
| **Flare** | 19.5 | 0.103% |
| **Frac Tank** | 3.46 | 0.018% |
| **Fugitives** | 3,935 | 20.7% |
| **Glycol Dehydrator** | 65.8 | 0.345% |
| **Heater** | 1.68 | 0.009% |
| **Loading** | 511 | 2.68% |
| **Oil Tank** | 221 | 1.16% |
| **Other** | 9.47 | 0.050% |
| **Separator** | 161 | 0.846% |
| **Vent** | 84.3 | 0.442% |
| **Water tank** | 1,286 | 6.75% |
| **Without source type** | 1,535 | 8.06 |
| **Total** | 19,050 | 100% |

As shown in Table 6-1, the TCEQ inventory predicts that VOC emissions will be dominated by tanks and that fugitives account for about 21% of VOC emissions. A recent field measurement campaign[17] has found, however, that current emission factors may underestimate equipment leaks and emissions from pneumatic devices in the Barnett Shale. So, for a series of sensitivity analyses, modified emission factors for equipment leaks and emissions from pneumatic devices (which are both considered fugitives in the TCEQ inventory) will be used.

In addition, the inventory does not contain estimates of emissions from events such as well completions and liquids unloading. The potential impacts of these intermittent, short duration, and potentially large emission sources (episodic emissions) will be examined in a series of sensitivity studies, based source data recently collected on these types of events. [8]

### *6.2.3 Lagrangian air quality modeling*

The AERMOD dispersion model was used to predict VOC concentrations at EML. AERMOD is a steady-state plume dispersion model that can be used to predict concentration distributions under a wide variety of conditions and in moderate to complex topography [9]. It uses a Gaussian distribution in the horizontal direction in the stable boundary layer. The AERMOD modeling system consists of one main program (AERMOD) and three pre-processors (AERSURFACE, AERMAP, and AERMET).

For input to the AERSURFACE pre-processor, National Land Cover data was obtained from the USGS. For AERMOD's meteorological preprocessor (AERMET), near surface characteristics as well as upper-air conditions are needed; these data were obtained from National Weather Service data and NOAA. Additionally, AERMET requires onsite meteorological data, which in this case was obtained from the measurements from the EML monitoring site. With these three datasets AERMET estimates planetary boundary layer parameters[29]. The locations of point sources with known latitude and longitude were extracted from the Barnett Shale Area Special Inventory and were used as input for AERMAP, as well as the USGS 30 m National Elevation Dataset covering the studied region.

Four discrete AERMOD modeling domains were used to evaluate scenarios incorporating sources within 100, 50, 25, and 10 km radii from the EML monitoring site. Emissions from point sources within these distances, obtained from the Barnett Shale Area Special Inventory, their location and reported total VOC emissions (total VOC emissions with

known latitude and longitude), were used as inputs to the dispersion model, along with hourly meteorological data for the 20 month sampling period.

The model was run with just one receptor, corresponding to the location of the EML monitoring site; the various plumes generated at each of the thousands of sources are combined at this receptor point. Hourly total VOC concentrations were predicted for the EML site for the 20 month period.

## 6.3 Results and Discussion

### *6.3.1 Hydrocarbon concentration measurements*

Figures 6-2a and 6-3a show measured diurnal and monthly average concentrations of hydrocarbons at the EML site. Light alkanes dominate, with ethane, propane and n-butane accounting for approximately 70% of the identified hydrocarbon concentrations, expressed as ppbC. This composition is consistent with the expected composition of emissions from natural gas production activities.

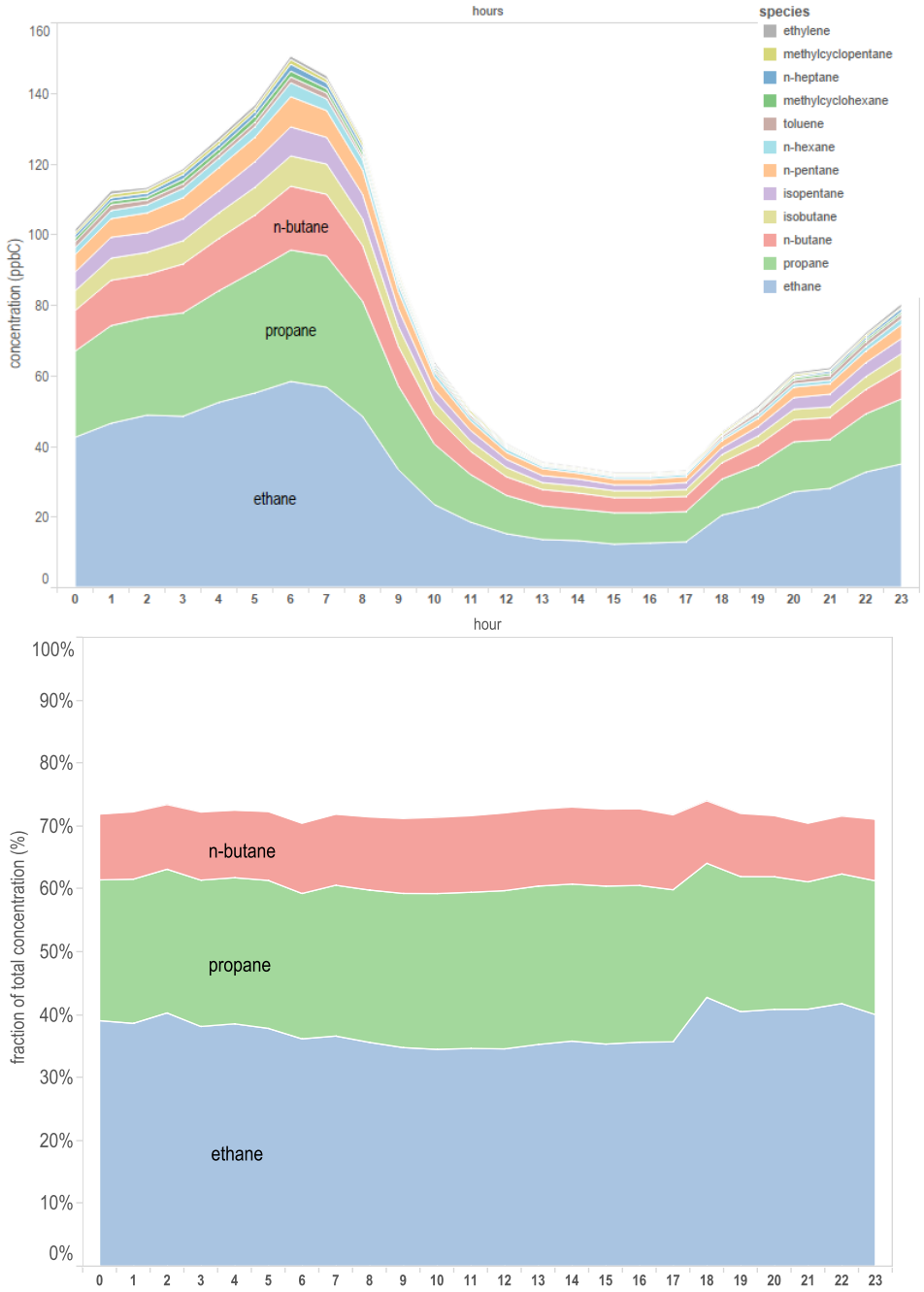



**Figure 6-2.** . (a) Average diurnal pattern of hydrocarbon concentrations (ppbC) at EML; data for each hour are averaged over 20 months of sampling. (b) Percentage of ppbC accounted for by ethane, propane and n-butane, at EML.

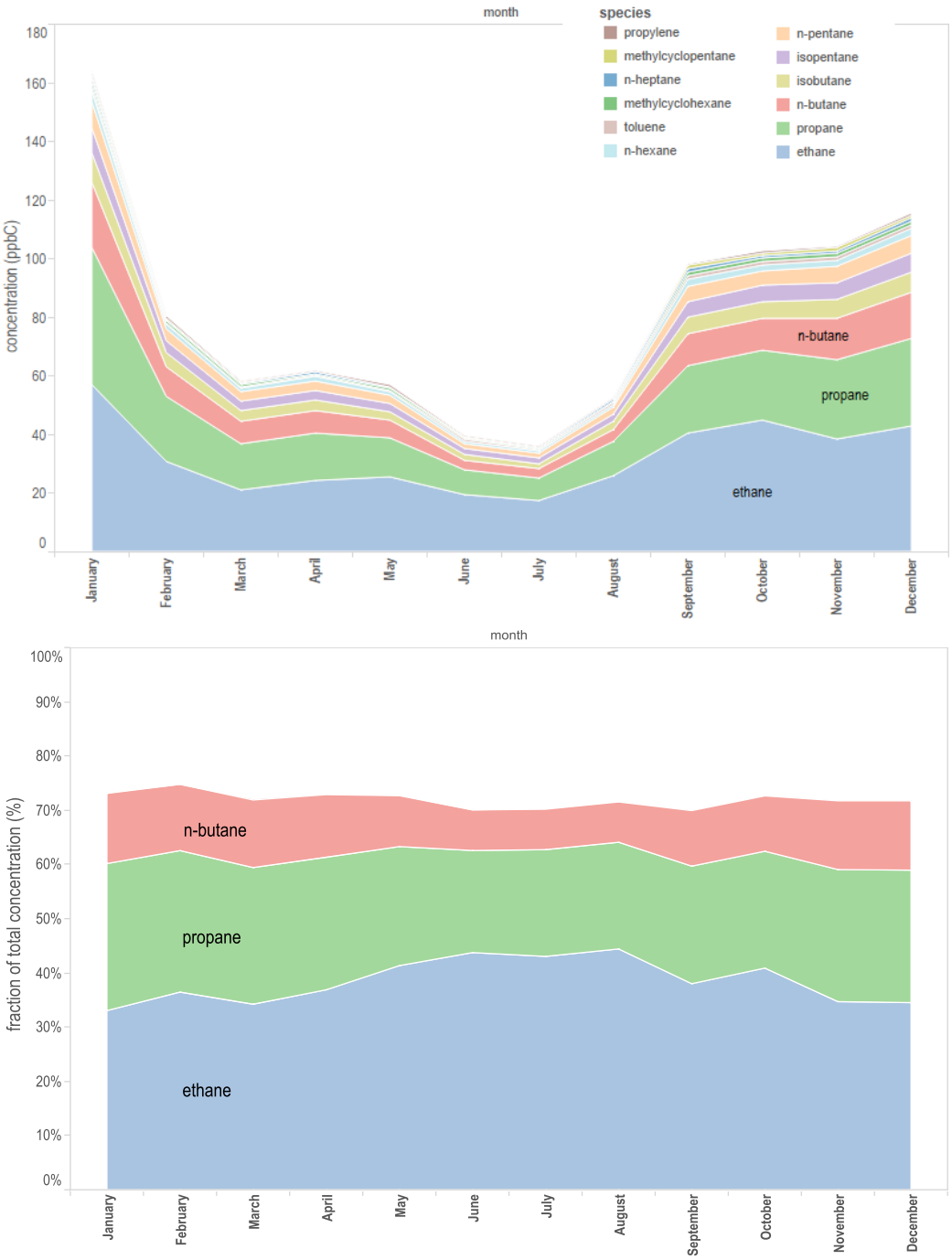



**Figure 6-3.** (a) Monthly average hydrocarbon concentrations at EML (ppbC); data are averaged over all hours and over 20 months of sampling. (b) Percentage of ppbC accounted for by ethane, propane and n-butane at EML

The concentrations show diurnal and monthly patterns, however, as shown in Figures 6-2b and 6-3b, the relative concentrations of the hydrocarbons are constant at all times of day and during all months, suggesting little seasonal or diurnal variability in emissions. The concentrations of light alkanes at EML are higher than at the other two sites. At EML the average morning maximum concentrations of ethane, propane, and butane total close to 100 ppbC, while at Flower Mound Shiloh and Hinton, the morning totals are 60 ppbC and 40 ppbC respectively. Summed over all days and hours in the 20 month sampling period, the average concentrations at EML for ethane, propane, and butane are 31.3, 19.4, and 9.2 ppbC, respectively. For Flower Mound Shiloh those averages are 18.4, 13.0, and 7.8, respectively. In the case of Hinton, the averages are 15.5 for ethane, 11.0 for propane, and 6.5 for butane.

The ethane to isopentane ratio, a measure of the relative importance of natural gas and gasoline related sources, is 7.54 at EML, while at Flower Mound Shiloh and Hinton, the ratio is 4.57, and 3.53, respectively. The difference in these ratios across the three sites highlights the predominant natural gas signal in the case of EML, and the higher impact of vehicle (gasoline) emissions in the urban (Hinton) and suburban (Flower Mound Shiloh) sites. The diurnal concentration patterns at the Flower Mound Shiloh and Hinton sites are shown in *Appendices, Section D.1*).

### *6.3.2 Background Corrected Alkane Concentrations at EML*

In order to compare the observed hydrocarbon concentrations at EML to concentrations predicted from the Barnett Shale special inventory and a Lagrangian air quality model, it is necessary to correct the observed concentrations at EML for regional background concentrations. The ideal background site would exactly duplicate the distribution of natural emissions (e.g., geological seeps) and anthropogenic emissions not associated with natural gas production in the region surrounding the EML site. This hypothetical, ideal background site would also have meteorological conditions identical to the EML

site. Recognizing that all background sites will have limitations, two different background sites were used in this work. Data from both the Flower Mound Shiloh site and the Hinton site were used to estimate regional background concentrations, producing two sets of background corrected hydrocarbon concentrations.

The Flower Mound Shiloh site is only suitable as a background site when winds at the site are not from the Barnett Shale production region. Consequently, in estimating background concentrations using Flower Mound Shiloh observations, data were filtered for wind directions between 135º and 225º (53.4% of the total number of hours). This subset represents observations at Flower Mound Shiloh with the least influence from natural gas sources, mapped in Figure 6-1. Average diurnal hydrocarbon concentrations at Flower Mound Shiloh for observations with winds between 135º and 225º are provided in Appendices, Section D.3. For this data set, during the morning maximum, ethane, propane, and butane concentrations sum to less than 40 ppbC (similar to the observations at the Hinton site), compared to the 60 ppbC when all wind directions were considered. Taking this subset of observations, the average concentrations for ethane, propane, and butane are 13.3, 8.4, and 5.0, respectively, which are similar to the observations at the Hinton site.

No wind direction filtering was required when the Hinton site was used to establish background concentrations, since the location of the Hinton site is relatively far from the Barnett Shale production region. However, natural gas emission sources important in urban regions, such as leaks from natural gas distribution systems, may influence the Hinton data. The similarity of the alkane concentration data for the wind direction corrected Flower Mound Shiloh data set and the Hinton data set suggests that these urban sources are relatively small.

### *6.3.3 Comparisons of measurements and model predictions*

Four different AERMOD scenarios were initially used to generate predicted VOC concentrations at EML. The scenarios considered sources included within different distances of the EML site (radii of 10, 25, 50, and 100 km) to assess whether predicted concentrations were dominated by sites near the measurement location. Table 6-2 shows the number of sources considered in each case, the total VOC emissions and the percentage relative to the total VOC reported in the Barnett Shale special inventory.

**Table 6-2.** Sources considered for each of the scenarios. The percentage shows the relationship between the input emissions for each case relative to the total emissions from all sources in the TCEQ inventory with known latitude and longitude.

| Radius considered | Number of sites | Total VOC emissions (tpy) | Percentage of total VOC emissions |
|---|---|---|---|
| **100 km** | 7,902 | 18,789 | 98.6% |
| **50 km** | 5,168 | 11,221 | 58.9% |
| **25 km** | 2,828 | 3,978 | 20.9% |
| **10 km** | 670 | 430 | 2.26% |

To be compared to AERMOD predictions, observations of hydrocarbon concentrations at the EML site were adjusted as follows.

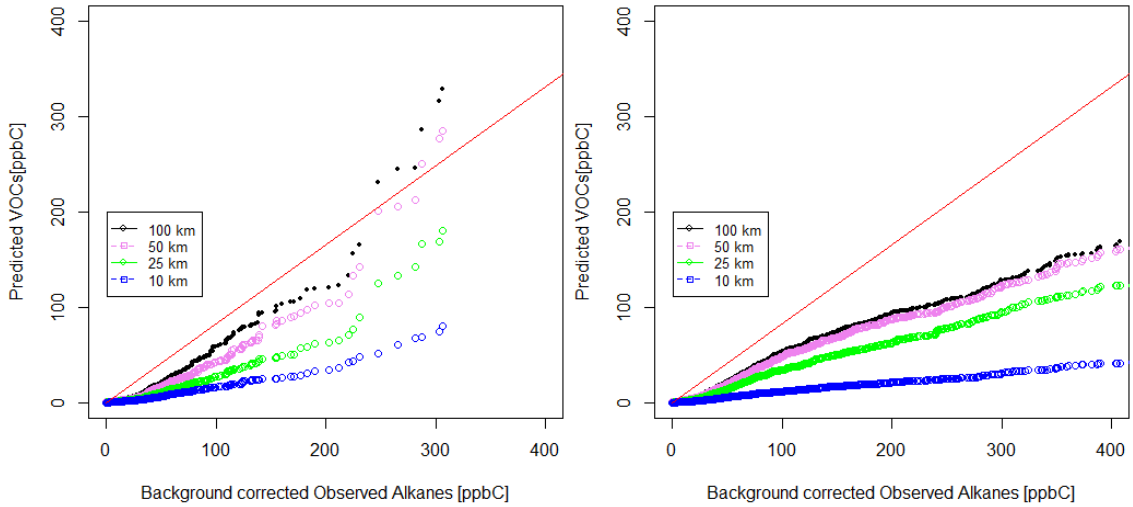
1.) When Flower Mound Shiloh was used to determine background concentrations, data were filtered to consider only wind directions between 135º and 225º (53.4% of the original dataset, this subset represents observations at Flower Mound Shiloh with the least influence from natural gas sources). When Hinton was used as the background site, all wind directions were considered. Data from both Hinton and Flower Mound Shiloh were filtered to eliminate observations when wind speeds measured at EML were less than 0.2 m/s (hours with wind speeds equal or less than 0.2 m/s represent 0.3% of the original dataset). Dispersion models do not perform well at low wind speeds [10].

2.) All alkane concentrations in each hourly data record were summed, except for ethane (methane was not measured). The Barnett Shale special inventory included VOC estimates and the speciation profiles assign 83% of the emissions to alkanes, so it is expected that the reported VOC emissions are largely alkanes. Ethane was excluded because VOC emission inventories do not include ethane.

3.) Day and hour specific background concentrations for summed alkanes at the Flower Mound Shiloh site or the Hinton site were subtracted from the EML concentrations for the same day and hour; the cases where this difference was less than zero were filtered out for the analysis (2,552 hours, 26.5% of the original

dataset when Flower Mound Shiloh was used as a background site; 4,313 hours, 48.4% of the original dataset when Hinton was used as a background site). Cases where the concentration at EML is less than the concentration at the background are almost exclusively at the lower end of concentration distributions. The observations that are finally compared to AERMOD predictions represent 27.3% of the original dataset when Flower Mound Shiloh was used as a background site and 51.3% of the original dataset when Hinton is used as the background site.

Figure 6-4 shows a comparison between predicted VOC concentrations calculated using the AERMOD dispersion model and the observed, background corrected alkane concentrations as they were measured at the EML monitoring site.




(a) (b)

**Figure 6-4.** (a): Predicted total VOC concentrations vs. background corrected observed summed alkane concentrations at EML, when Flower Mound Shiloh was used as background site, for four sets of dispersion calculations, within 10, 25, 50, and 100 km radii of the observation site **(b):** Predicted total VOC concentrations vs. background corrected observed summed alkane concentrations at EML, when *Hinton was used as background site*, for four sets of dispersion calculations, within 10, 25, 50, and 100 km radii of the observation site. The red lines have a slope of 0.83 since 83% of the total VOC are speciated as alkanes.

Figure 6-4 shows that sources both close to and far from the EML site contribute to observed alkane concentrations at the site. The remainder of the analyses presented here will focus on analyses including all sources within a 100 km radius. The observations of total alkane concentrations are compared to 83% of the predicted concentrations of total VOC, since the speciation indicates that 83% of the emissions are paraffinic. As the radius of included sources is increased, the number of sources and the total emissions associated with the sources increase significantly (Table 6-2). Figure 6-4 shows considerable differences between the results as the radius is expanded, indicating that alkane concentrations at the EML site are not just reflecting emissions from sources in the near proximity of the EML monitoring station.

Differences between Figure 6-4a and 6-4b are driven by differences in the background data and in the sub-set of data that were used. For Figure 6-4a, the Flower Mound Shiloh site was used as a background and only data associated with predominantly southerly winds were used. As shown in Figure 6-1, the densest regions of natural gas production emissions are found north of the EML site; the subset of sources to the south of the site may not be representative of the sites to the north. In addition, the Flower Mound Shiloh site may be more heavily influenced by natural gas than the Hinton site, even when winds are from the south.

When using Flower Mound Shiloh as the background site, the regression of predicted vs. observed concentrations has a slope of 0.66 (standard error 0.013), for observations over 50 ppbC (background corrected), compared to an expected value of 0.83 (corresponding to an under-prediction bias of 21%). If the predicted values are increased by 10% to account for reported increases in natural gas production activity between 2009 and the 2010-2011 measurement period [22], the agreement between predicted and observed alkane concentrations shows even less difference.

When Hinton is used as background site, the agreement is not as good as the case of Flower Mound (Figure 6-5b); with a regression of predicted vs. observed concentrations

having a slope of 0.40 (standard error 0.005), for observations over 50 ppbC (background corrected) (corresponding to an under-prediction bias of 52%). If the predicted values are increased by 10% to account for reported increases in natural gas production activity between 2009 and the 2010-2011 measurement period, the slope of predicted versus observed concentrations is still only 0.43, relative to an expected value of 0.83. An additional analysis is included in Appendices (section D.3), where Hinton is used as background site, but data are filtered for the same hours that were considered in the final Flower Mound Shiloh dataset (which was filtered for wind directions). In this sensitivity analysis, the agreement with background corrected observations had a slope of 0.55, intermediate between the result considering all wind directions and the result using Flower Mound Shiloh, suggesting that some of the better performance of the inventory using Flower Mound Shiloh as a background is due to only considering sources to the south of EML.

Two additional sensitivity analyses were conducted to assess the potential contribution of under-estimated continuous emissions and episodic emissions to the predicted concentrations. For continuous emissions, results from a recent study of methane emissions from pneumatic controllers, chemical injection pumps, and equipment leaks in the Barnett Shale were used [8]. This study found that measured emissions from equipment leaks and pneumatic pumps and controllers were 159% higher in the Barnett Shale, compared to emissions estimated using current emission factors. Table 6-3 summarizes emissions per well derived from the measurements and compares these to emissions estimated based on a recent EPA greenhouse gas national inventory [11]. For estimated emissions of propane and higher alkanes, a weighted average gas composition for the Barnett Shale was used; 89.16% (vol.) methane, 4.24% ethane, and 2.67% $C_3$+ alkanes [12].

**Table 6-3.** Routine emissions from production sites in standard cubic feet (scf) of gas per minute per well.

| | Pneumatic devices* | Chemical Injection Pumps* | Equipment Leaks* | Total | Total from EPA estimates** |
|---|---|---|---|---|---|
| **Whole gas** | 0.569 | 0.152 | 0.071 | 0.792 | 0.202 |
| **Methane** | 0.507 | 0.136 | 0.064 | 0.707 | 0.180 |
| **Propane and higher alkanes** | 0.015 | 0.004 | 0.002 | 0.021 | 0.005 |

*Emission factors were obtained from supporting information of Allen, *et al*, and were based on activity counts from the same study[8].

**EPA estimates are based on values shown in Table 2 of Allen, *et al*.[8] Emissions from chemical pumps, pneumatic controllers, and equipment leaks, are 811 Gg of methane per year, or 80,365 scf/min of methane. Using the national gas well count (from the EPA national inventory) mentioned in Allen, *et al* of 447,000 wells; total methane emissions are 0.180 scf/min per well. Using the average gas composition for the Barnett Shale, the whole gas and $C_3$+ emission rate estimates are derived (See Appendices, Section D.3).

Emissions of propane and higher alkanes, per well, from pneumatic devices, chemical injection pumps, and equipment leaks, are 0.021 scf/min, or 0.687 Mg/yr per well. Using the count of 14,886 producing wells[2], total propane and higher alkane emissions (VOC) from production sites would be anticipated to be roughly 10,200 tons per year. This is 159% higher than the corresponding estimate for similar categories in the TCEQ inventory of 3,935 tons per year (Table 6-1), and raises total VOC emissions by approximately 6,265 tons per year (33%). This change would eliminate the bias in the predicted concentrations when Flower Mound is used as a background site (causing an over-prediction bias of roughly 5%) and would reduce the bias to 37% if Hinton is used as a background site (all wind directions).

Episodic emissions due to events such as well unloadings are also not accounted for in the Barnett Shale emission inventory. Well unloadings are events that clear operating

wells from accumulated liquids that restrict the flow of natural gas. During the life of a well, as production declines, the velocity of natural gas in the well tubing might start to decrease, causing an accumulation of fluids in the wellbore. To remove the accumulated liquids, flow from the well is diverted into an atmospheric pressure tank, causing a large pressure drop that increases the velocity of the fluid. When there are no emission control systems in place, gas is vented to the atmosphere. Allen, *et al*. [8,12], report a total of 422 unloadings with venting per year for companies that operate a total of 2,791 wells in the Barnett Shale, a frequency of unloadings of 0.15 unloadings/well per year. Using the total number of wells reported by the TCEQ for the Barnett Shale in 2011 (14,886), the expected frequency of unloadings would be 2,251 events in a year.

To simulate the unloading events, 2,251 point sources from the TCEQ special inventory (within a 100 km radius from EML, from a total of the 8,025 inventoried sites) were randomly selected. Two unloadings scenarios are analyzed: (i) a frequency of unloadings resulting in 2,251 (random) point sources with 1 event with an emission per event of 1.1 Mg of methane (0.105 Mg propane and higher alkanes), and (ii) a frequency of unloadings resulting in 2,251 (random) point sources with 1 event with an emission per event of 3.7 Mg of methane (0.353 Mg propane and higher alkanes). Scenario (i) uses the average of emissions for an unloading event reported by Allen, *et al.*[8], while scenario (ii) uses the maximum observed emissions from an unloading event. Allen, *et al.* note that the unloading events sampled in their work may represent higher than average emissions, so the results reported here may overstate the impact of unloadings.

The time and date when each of the unloading events was simulated was randomly selected. Each event was assumed to last for one hour, and events were assumed to occur between 8 am and 5 pm, when operators would be onsite to perform manual unloading.

Figure 6-5 shows the propane and higher alkanes concentration at EML as a result of predicted unloadings The plot shows the 1,597 distinct hours when the episodes occur (from the total 2,251 unloading events simulated, with a random date and time, some

events occur in the same day and hour, resulting in a total of 1,597 distinct hours where at least one event occurs).

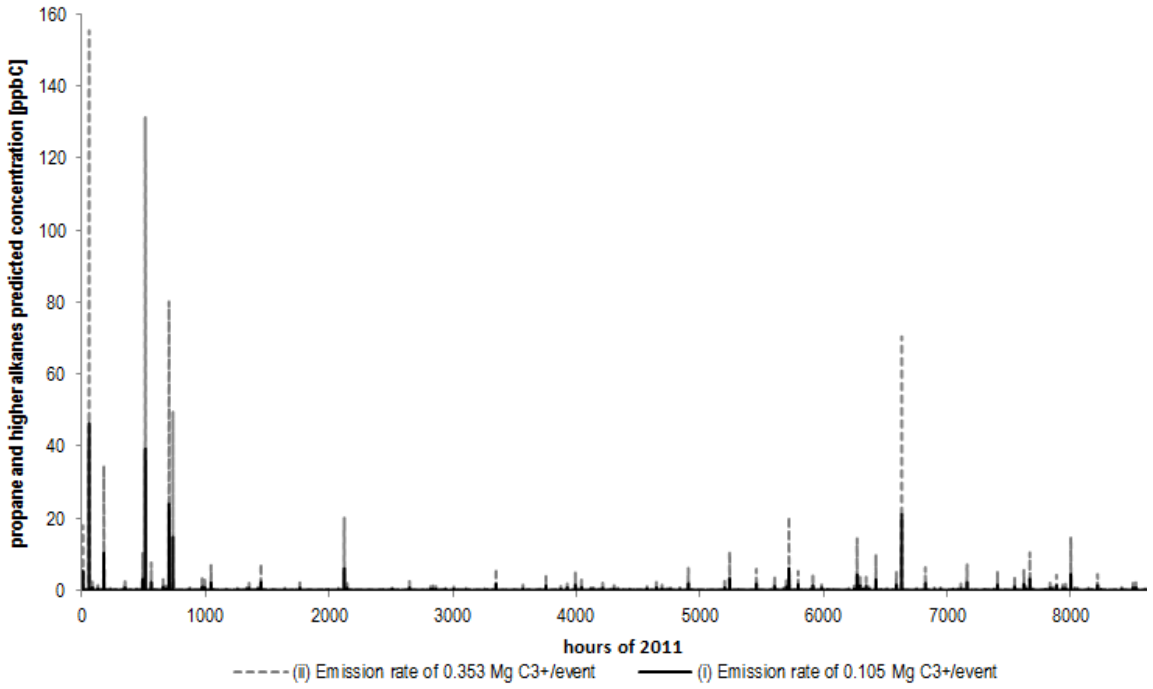



**Figure 6-5.** Time series showing the hours when an unloading event was simulated to occur and the resulting propane and higher alkanes predicted concentration at EML.

When the unloadings are simulated with the average emission rate of 0.105 Mg of propane and higher alkanes/event; the average $C_3$+ predicted concentration at EML due to these events is 0.183 ppbC, with a median value of 0.007 ppbC and a maximum value of 46.4 ppbC, considering just the hours when an event is occurring (non-zero values only). When the maximum emission rate of 0.353 Mg propane and higher alkanes/event is used to simulate the unloadings, the average, median and maximum methane predicted concentration at EML is 0.613, 0.024, and 155 ppbC; respectively.

To compare these emissions to observations, the 4 largest simulated events are selected, with concentrations for scenario (i) of 21, 24, 39, and 46 ppbC, respectively. All the

events occurred under southeasterly/southwesterly winds (154º - 200º), with the exception of the second highest event which is related to northeasterly winds (4º). In all of these events, there are two sources with an unloading event during the same hour related to the predicted concentration at EML, with the exception of the event with a concentration of 39 ppbC; where there is just one source. All of the unloading were within a 30 km to 52 km radius of EML with the exception of one of the two sources related to the highest event (46 ppbC), which is 83 km away from EML. This analysis suggests that, given the assumptions stated above, if unloading events occur at the national average emission rate observed by Allen, *et al*, that several observations of increases in alkane concentrations greater than 20 ppbC should be evident in the dataset.

Close examination of Figure 6-4 shows that there are no episodic, anomalously low predictions from the dispersion models. In fact, when Flower Mound Shiloh is used as the background site, the dispersion model shows over-prediction at high concentration as opposed to the under-prediction at high concentration that would be expected if episodic events were important. If unloading events were occurring with an average emission of 0.105 Mg of propane and higher alkanes per event (scenario i) there should have been 4 events with 20 ppbC or larger enhancement of emissions. If scenario (ii) (higher emissions per event, 0.353 Mg of propane and higher alkanes per event) is considered, the number of events with a 20 ppbC or larger enhancement would be 8 over the sampling period. No such episodic anomalies are observed, indicating that unloadings or other episodic events are not significantly impacting ambient concentrations in the Barnett Shale. This result is specific to the Barnett Shale. In other regions, with higher frequencies of episodic events, events could play a role in the temporal distribution of ambient concentrations.

### *6.3.4 Benzene emissions*

In addition to characterizing VOC emissions from natural gas production, the Barnett Shale Area Special Inventory reports emissions of benzene. A total of 54.5 tpy of benzene emissions (0.29% of the VOC emissions) are reported. Condensate tanks (44%),

water tanks (28%), and fugitives (20%) account for 92% of the benzene emissions. This distribution of sources by type is similar to VOC, where these source types were also among the top VOC emitters.

For the period of April 2010 to December 2011, benzene is not one of dominant species measured at EML. Table 6-4 shows the average, median, 90$^{th}$ percentile, 99$^{th}$ percentile, and maximum value from concentrations measured at EML and Flower Mound Shiloh and Hinton. Average, 90$^{th}$ and 99$^{th}$ percentile concentrations at Flower Mound Shiloh and Hinton are higher than at EML. When observed benzene concentrations at EML are compared to the predicted benzene concentrations (based on the AERMOD modeling) the estimated contribution from natural gas production ranges from a few percent of median total observed benzene concentrations to 30% of the total (99$^{th}$ percentile). This suggests that sources not directly associated with natural gas production determine benzene concentrations observed at EML. Some of these sources may be indirectly related to natural gas production, however, such as truck traffic servicing the production sites.

**Table 6-4.** Summary of benzene measured and predicted concentrations (ppbC) at the three sites.

| Site | Average | Median | 90th percentile | 99th percentile | Maximum value |
|---|---|---|---|---|---|
| **Eagle Mountain Lake** | 0.51 | 0.44 | 1.10 | 2.02 | 24.53 |
| **Eagle Mountain Lake PREDICTED from natural gas production** | 0.04 | 0.01 | 0.11 | 0.59 | 1.67 |
| **Flower Mound Shiloh** | 0.79 | 0.68 | 1.39 | 2.53 | 51.78 |
| **Hinton** | 0.94 | 0.71 | 1.79 | 4.64 | 13.84 |

## 6.4 Conclusions

In summary, hourly hydrocarbon concentrations from the Barnett Shale Natural Gas Production region indicate relatively little temporal variability in emissions from natural gas production. Hourly and daily variations in observed, background corrected concentrations were primarily explained by variability in meteorology, suggesting that episodic emission events, such as well unloadings, had little impact on hourly averaged concentrations. Total emissions for VOC are estimated to be approximately 25,300 tons/yr, when accounting for potential under-estimation of certain emission categories. This region produced, in 2011, approximately 5 bcf/d of natural gas (100 Gg/d or 40,000,000 tons/yr) for a VOC to natural gas production ratio (mass basis) of 0.00063. The dominant species are light alkanes.

## 6.5 References

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# 7 DEVELOPING A METHANE, ETHANE, AND PROPANE EMISSION INVENTORY FOR THE BARNETT SHALE PRODUCTION REGION

## 7.1 Introduction

The natural gas supply chain is one of the largest anthropogenic sources of methane emissions in the United States, second only to enteric fermentation [1]. Due to the availability of new production technologies, such as horizontal drilling and hydraulic fracturing, U.S. natural gas production is increasing, making accurate estimates of methane emissions from natural gas production increasingly important.

Significant uncertainties exist in methane emission estimates; regional emission estimates based on ambient measurements are generally larger than regional emission estimates based on counts of emission sources and data on average, source specific, emission rates. Brandt, *et al.*[2] and Miller, *et al.* [3] have summarized recent emission estimates based on ambient measurements (top-down analyses) and conclude that emissions are generally higher than current inventories based on equipment counts and average emission factors (bottom-up estimates).

A challenge in reconciling top-down and bottom-up emission estimates is to identify which of many potential sources might be contributing to methane emissions inferred from top-down measurements. Since top-down measurements determine a regional total of methane emissions, contributions from a single source sector, such as the natural gas supply chain, are generally estimated by subtracting the contributions from all other sources (e.g., landfills, enteric fermentation) from the total regional estimate of emissions. This can introduce large uncertainties in emission estimates. An alternative is to use source specific tracers to estimate emissions from particular sources. Because natural gas is the only significant source of ethane and propane in the US, methane to ethane and methane to propane ratios have been used to attribute ambient methane emission observations to the natural gas industry [4-5]. Unfortunately, methane to ethane

and methane to propane ratios can vary spatially, even within a single natural gas field, making quantitative use of ratios difficult. Spatially resolved methane to ethane and methane to propane ratio data are needed to enable tracer analyses of natural gas emissions. [6-8].

This work provides spatially resolved methane, ethane, and propane emissions estimates as well as methane to ethane and methane to propane ratios for the Barnett Shale production region (North, Central Texas), scaled to the region's 2013 natural gas production levels. Development of spatially resolved methane, ethane and propane data for the Barnett Shale could improve source attribution based on airborne or ambient methane emissions measurements and inform comparisons between ambient measurements and bottom-up inventories.

This work estimates methane, ethane and propane emissions using a detailed inventory of VOC emissions prepared by the Texas Commission on Environmental Quality (TCEQ) and an extensive dataset of gas production data compiled as part of the direct measurement campaign conducted by Allen, *et al*. [9].

The Barnett Shale Special Inventory, prepared by the TCEQ, is a comprehensive inventory of Volatile Organic Compounds (VOC). It provides latitude, longitude, and magnitude of source – specific VOC emissions for over 8,000 sites [10]. By combining the 2009 Barnet Shale Special Inventory source locations, gas composition, and VOC emissions data with gas well composition data from a national dataset of methane emissions [9] from natural gas production, and scaling to 2013 production levels; this work develops estimates of methane, ethane, and propane emissions from over 18,000 individual sources in the Barnett Shale, spatially resolved on a 4km x 4km grid.

## 7.2 Methods

The Texas Commission on Environmental Quality (TCEQ) reported emissions from production sites in the Barnett Shale special inventory [10, 11] for the year 2009. This inventory compiles production data, source profiles, and emissions of volatile organic compounds (VOC). VOCs include propane and heavier hydrocarbons (methane, ethane are not inventoried because by regulatory definition, they are not VOCs). VOC data were collected for 18,466 sources; accounting for a total of 19,050 tons per year (tpy) (92% of the emissions are source-specific, with the remaining 8% being site-specific only). The source specific data are aggregated onto 8,025 upstream sites (with geospatial information).

Emissions are divided into 16 source categories, with condensate tanks, fugitives, water tanks, and engines dominating the VOC emissions. Figure 7-1 shows the distribution of VOC emissions by source category as reported in the special inventory.

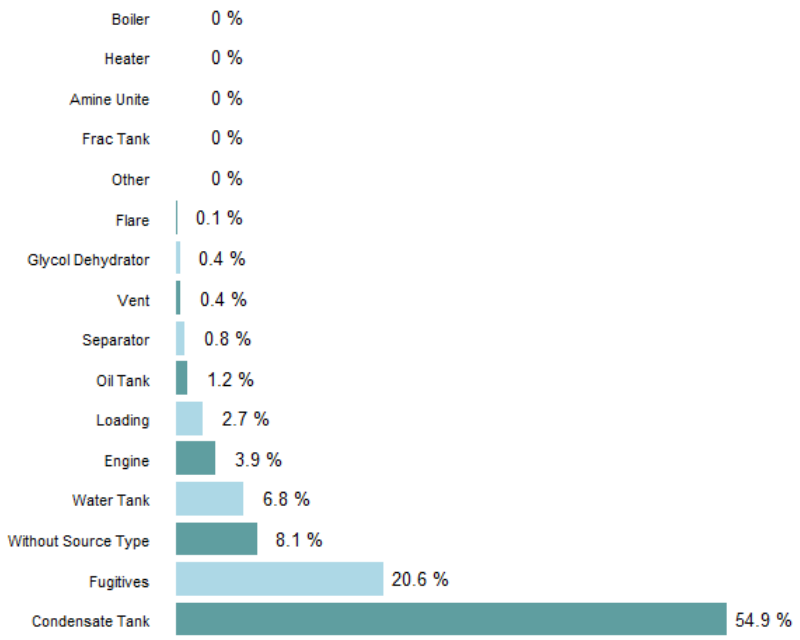


**Figure 7-1.** VOC emissions by source type, as reported in the TCEQ special inventory. Total emissions add up to 19,050 tpy.

For the development of the inventory, the TCEQ provided an emission calculator, allowing for estimates of emissions using site-specific data (summing up emissions from sources contained within each site) [12]. On-site direct measurements were preferred to indirect measurements or emission-factor based methods but they were not required [13].The inventory of methane, ethane and propane emissions developed in this work uses the TCEQ special inventory (for VOC emissions) together with natural gas composition data to estimate methane, ethane and propane emissions.

Allen, *et al*. [9,14] reported gas composition for 150 wells in 4 different production regions across the U.S. Figure 7-2 shows the linear regression of percent of methane in the produced gas (% C1) as a function of percent VOC in the produced gas (% VOC, for propane and heavier hydrocarbons), (*slope* = -1.978, *intercept* = 96.149, $R^2$ = 0.962).

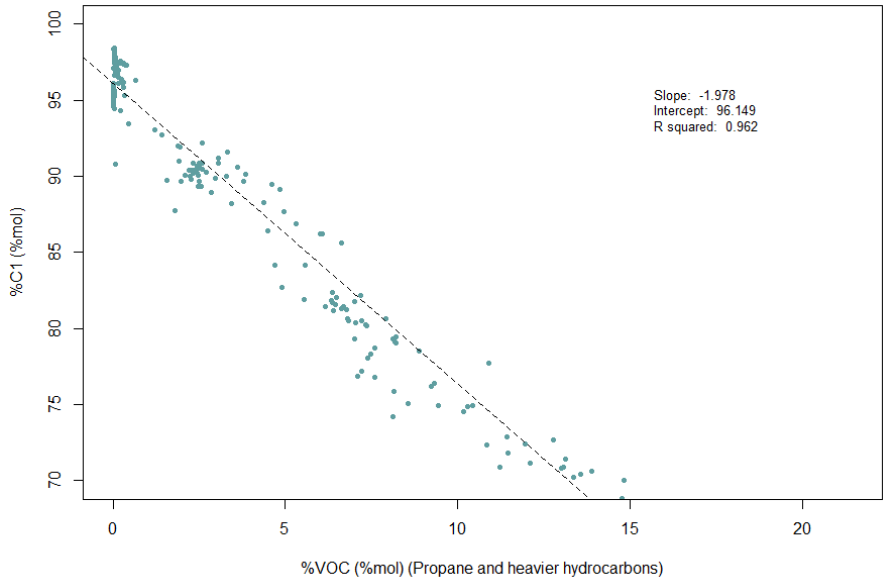


**Figure 7-2.** Linear regression of %C1 as a function of %VOC for 150 wells across the U.S. where direct measurements were made by Allen, *et al*. [14].

The linear relationship observed for wells in different regions allows the estimation of the percent of methane in vented gas if the percent of VOC is known, regardless of the wet or dry nature of the well and the specific regional characteristics. Similarly, the linear

regression of percent propane in gas (%C3) as a function of %VOC shows that roughly 60% of the VOC is propane (*slope* = 0.588, *intercept* = -0.046, $R^2$ = 0.983). Thus, if the %VOC for a site is known, it is possible to estimate %C1 and %C3 from the regressions presented in this work, and consequently estimate %C2 from the difference (100% - [%C1 + %VOC]).

As part of the data requested for the TCEQ special inventory %VOC values were collected for sites that reported fugitive emissions. Only 30% of the roughly 8,000 sites report %VOC value; nonetheless, the sites with known %VOC have a characteristic spatial distribution throughout the Barnett Shale region, therefore, missing %VOC values were spatially interpolated using an inverse distance weight method (IDW). (See Appendices, *Section E.1* for more details on the interpolation of percent VOC values).

Using the interpolated %VOC values, and the correlations presented in this work, %C1, %C2, %C3 were estimated to determine the composition of the gas at each site. Table 7-1 summarizes how gas composition, source-specific VOC emissions, and site-specific production data were used to estimate methane, ethane, and propane emissions, following a specific rationale based on the specific characteristics of each specific emission source category. Appendices (Section E.2) describes in detail how each separate source category was treated). All emissions were estimated for the baseline year, 2009, and then projected to 2013.

**Table 7-1.** Source-specific rationale for the estimation of methane, ethane, and propane, emissions from each source category. Section E.2 from the Appendices explains each calculation in detail.

| Source Category | Reported VOC Emissions (tpy) | Rationale for the estimation of Methane emissions |
|---|---|---|
| Condensate Tank | 10,465 | Estimated the solubility of gas in oil (Vasquez-Beggs equation [14, 15] and used site-specific production data to determine the volume of gas that flashes. It was assumed that all methane, ethane and propane flash, and that their relative composition is similar to their relative composition in the produced gas. |
| Fugitives | 3,935 | Corrected emissions for the underestimation of equipment leaks and pneumatic devices [16], and then methane emissions were scaled based on % VOC. |
| Water Tank | 1,286 | Estimated the solubility of methane, ethane, and propane in water (Henry's law [14]), and used site-specific information production data to determine the volume of gas vented from water tanks. |
| Engine | 749 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions. |
| Loading | 511 | Assumed no methane emissions are released from these source category. |
| Oil Tank | 221 | Estimated the solubility of gas in oil (Vasquez-Beggs equation [14, 15]) and used site-specific production data to determine the volume of gas that flashes. It was assumed that only methane, ethane and propane flash, and that their relative composition is similar to their relative composition in the produced gas. |
| Separator | 161 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions. |
| Vent | 84 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions. |

**Table 7-1.** (continued).

| Source Category | Reported VOC Emissions (tpy) | Rationale for the estimation of Methane emissions |
|---|---|---|
| Glycol Dehydrator | 66 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions. |
| Flare | 20 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions. |
| Other | 9.5 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions. |
| Frac Tank | 3.5 | Emissions were estimated based on the estimated emissions from completion flowback events measured by Allen, *et al*. [9, 15] |
| Amine Unite | 2.5 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions. |
| Heater | 1.7 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions. |
| Boiler | 0.30 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions. |
| Without Source Type | 1,535 | Methane, ethane, and propane emissions were scaled based on %VOC and reported VOC emissions.. |

## 7.3 Results and Discussion

### *7.3.1 Spatially resolved emission inventory*

To facilitate the use of the inventory developed in the present work as a tool to reconcile top-down and bottom-up measurements, emissions were summed up and divided into 4 km by 4 km grid cells that correspond to the grid cells used in TCEQ air quality modeling applications, which were developed for the State Implementation Plan (SIP) in the Dallas-Fort Worth ozone nonattainment area [17].

Total methane emissions for the Barnett Shale production region were estimated to be 5,741 kg/h (2,619 MMscf/yr) for 2009. Roughly 60% of the emissions are attributed to fugitives, with 12% from engines, 7% from condensate tanks, 6% from water tanks and 13% without source type. Figure 7-3 illustrates the spatial distribution of methane emissions; plotted as density of emissions (kg/h per square kilometer) (Tables with estimated emissions for each grid cell are provided in Appendices, Section E.3).

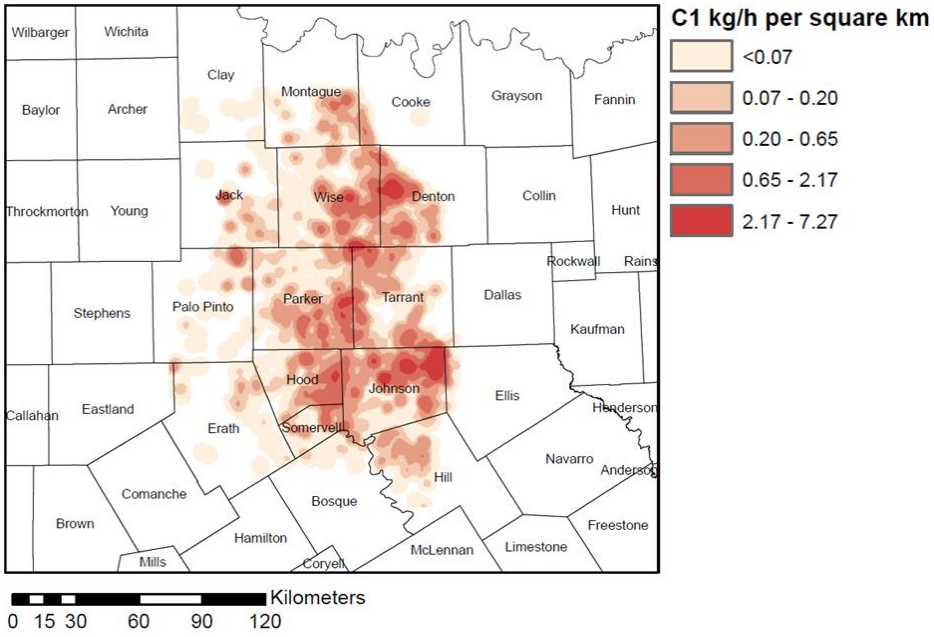


**Figure 7-3.** Density of estimated methane emissions (2009) (kg/h per square kilometer).

The spatial distribution of the estimated methane emissions indicates two hotspots: one on the Wise\Denton county border, and the other in the northeast corner of Johnson County. The hotspot in Wise and Denton counties located in the region of the Barnett Shale with the highest well density and with the highest VOC emissions [12]. On the other hand, Johnson County has a lower density of wells, hence the methane hotspot is explained by the combination of significant fugitive emissions combined with a dry gas composition. Figure 7-4 shows the distribution of VOC fugitive emissions and %VOC by county. The distribution of VOC emissions for Johnson County is similar to other counties, but the distribution of %VOC for sites in Johnson county is characterized by lower values than the rest of the region (gas in Johnson is drier). Thus for a given amount of VOC emissions, whole gas emissions would be higher in Johnson County and consequently, methane emissions would also be scaled towards higher values.

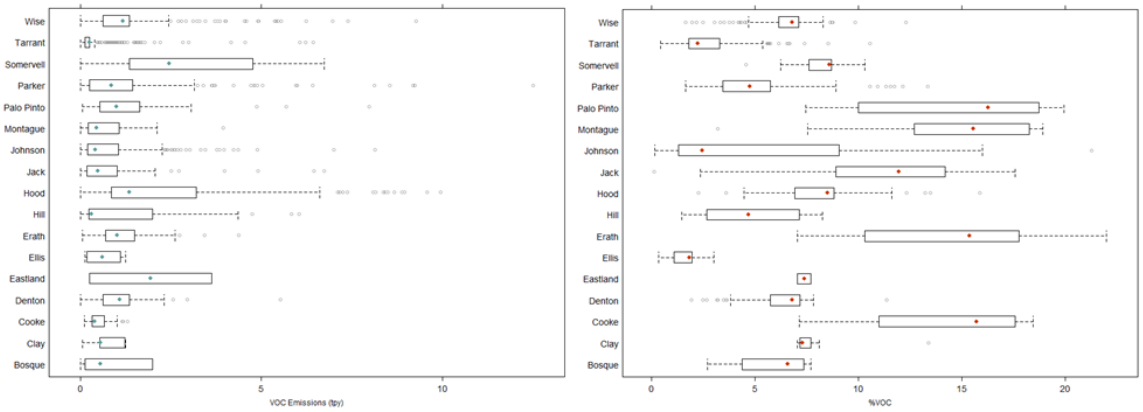


**Figure 7-4.** Distribution of VOC emissions (*left*) and %VOC (*right*) by county. The distributions are represented by boxplots, with the central dot representing the median value, and the range of the rectangle representing the interquartile range (25$^{th}$ and 75$^{th}$ percentile).

### *7.3.2 Scaling emissions*

To scale emissions from the baseline year (2009) to 2013, it was assumed that, since emissions are associated with wells in routine operation, emissions can be scaled based on natural gas production. Natural gas production for the Barnett Shale in 2009 was 4,921

MMcf/d, while for 2013, production was 5,309 MMcf/d [11], an 8% increase in production relative to 2009.

The scaled 2013 methane emissions are equal to the product of an emission factor (EF); defined as the ratio of methane emissions for the baseline year, divided by gas production for the baseline year, and an activity factor (AF), in this case; natural gas production for 2013.

If an average emission factor is calculated as the sum of all estimated methane emissions in the domain (2,619 MMscf/yr), divided by 2009 Natural Gas Production from all the sites in the domain (1,790,655 MMscf/yr), the EF would be 0.0015, which multiplied by the activity factor of 1,937,785 MMscf/yr (Natural Gas Production 2013) would yield total 2013 methane emissions of 2,834.6 MMscf/yr or 6,213 kg/h.

Figure 7-5 shows the distribution of emission factors for each grid cell;. 12% of the grid cells had an emission factor of zero. For non-zero EF grid cells, the median value was 0.0022, the average value was 0.0154, with a $25^{th}$ percentile of 0.0006, a $75^{th}$ percentile of 0.006, and a $95^{th}$ percentile of 0.0522.

57% of the 2013 Natural Gas Production is in cells with an emission factor less than 0.001. For the remaining Natural Gas Production, 35% is in cells with an emission factor between 0.001 and 0.01, and 8% has an emission factor greater than 0.01. Although more than half of the production falls into cells with an emission factor that is below the median, the skewed distribution of emission factors causes the estimated emissions to depend strongly on the production in the cells with the highest EFs. (See Section E.3 of Appendices for tables reporting EF and AF values for each grid cell).

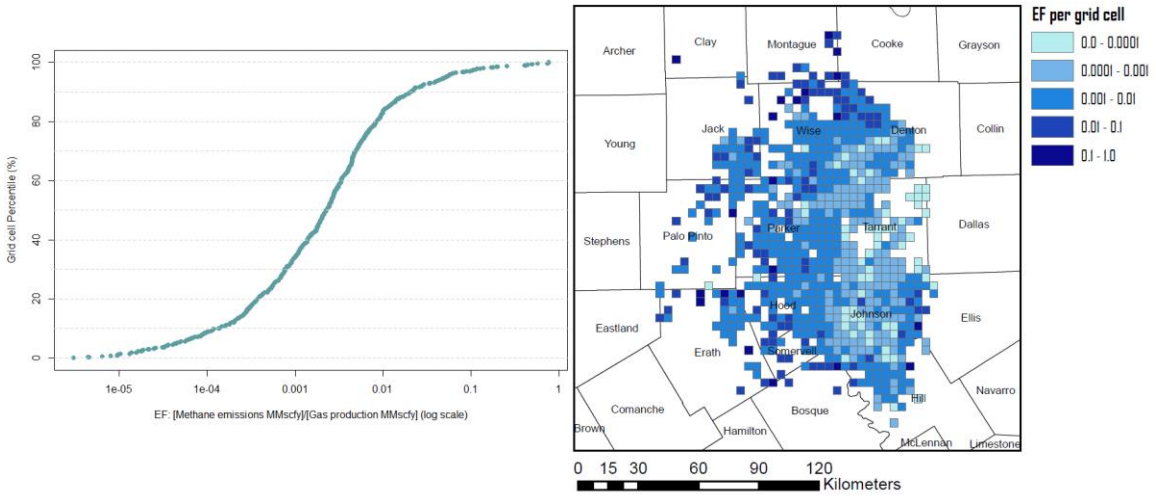


**Figure 7-5.** Cumulative distribution plot for non-zero emission factors for each grid cell (log scale) (*left*), and map showing the spatial distribution of emission factors in the Barnett Shale (*right*).

Since estimated emissions have a strong correlation with natural gas production, and the skewed distribution of emission factor evidences important regional differences, the relationship of EF and AF for each grid cell is important. Therefore, another way to estimate the scaled emissions, is to obtain the product of EF and AF for each individual grid cell and then sum all the emissions. Following this method, estimated methane emissions for 2013 are 46,745 kg/h (compared to 6,213 kg/h when regional averages were used).

In summary, the Barnett Shale exhibits a heterogeneous distribution of methane emissions. The region's heterogeneity is driven by both the skewed spatial distribution of emission factors among grid cells and the heterogeneous distribution of the temporal changes in production from 2009 to 2013. Appendices, Section E.4 analyses the spatial distribution of both emission factors and activity factors. These significant differences within the Barnett Shale production region should be taken into account when top-down and bottom-up measurements are compared.

Using methods similar to those used for methane, emissions for ethane and propane were estimated. 2009 emissions for ethane were 778 kg/h and for propane were 599 kg/h. 2013 projected emissions were 2,848 kg/h for ethane and 2,301 kg/h for propane (if emissions are scaled for each individual grid cell). As mentioned previously, methane to ethane and methane to propane ratios have been used extensively to attribute ambient methane emission observations to the natural gas industry. Figure 7-6 and Figure 7-7 show the spatially resolved methane to ethane and methane to propane ratios for the Barnett Shale, respectively. (Data set with ethane and propane emissions, as well as ratios is provided in Appendices, Section E.3).

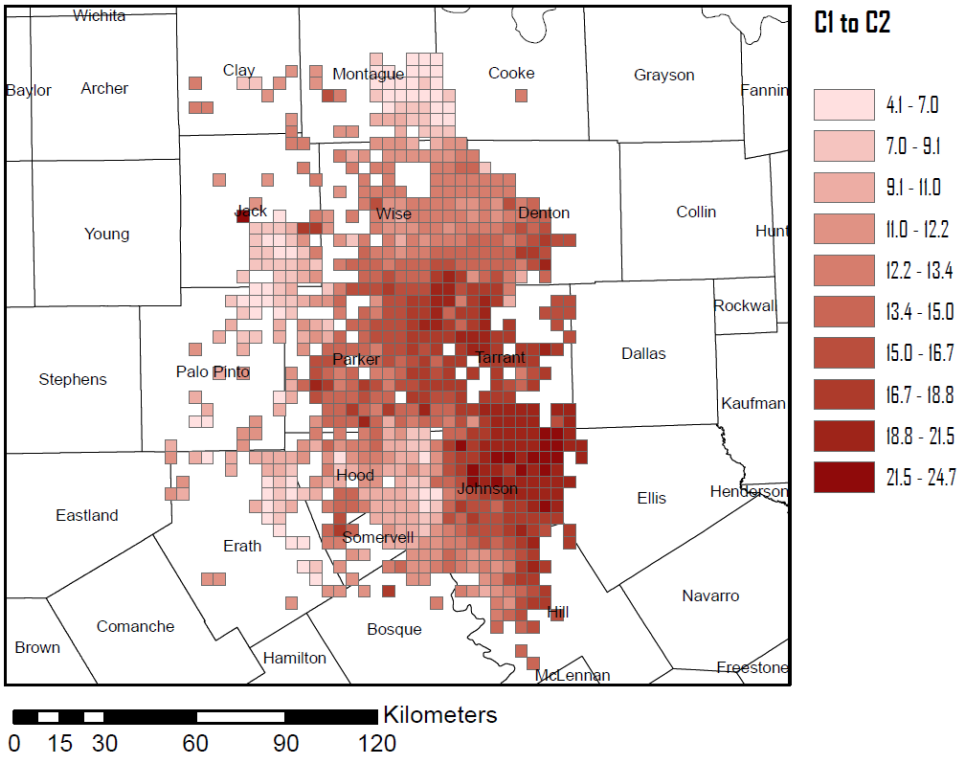


**Figure 7-6.** Methane to ethane ratio of emissions.

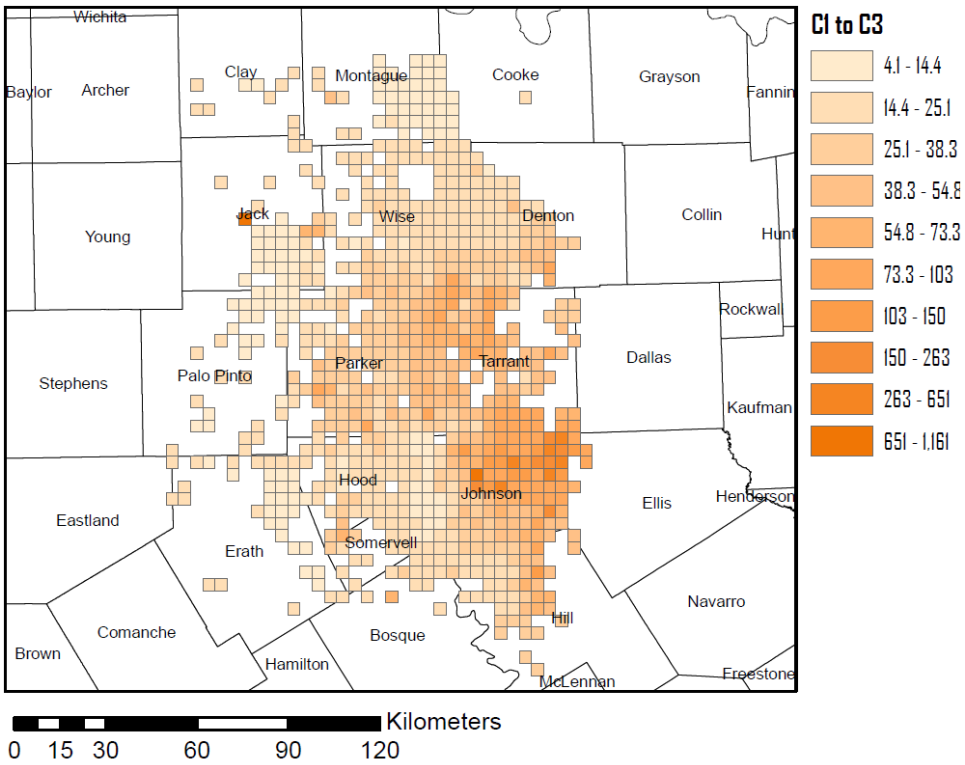


**Figure 7-7.** Methane to propane ratio of emissions.

## 7.4 Conclusions

Methane, ethane, and propane emission inventories can be used for the reconciliation of bottom-up and top-down measurements in the Barnett Shale Production Region. Significant shifts in the spatial distributions of production should be taken into account when direct and indirect measurements are compared against estimates from emission inventories.

The development of spatially resolved methane, ethane and propane data for the Barnett Shale could have particular relevance to a diverse group of research teams that are utilizing airborne, vehicle, and ground-based measurements to estimate emissions in the Barnett Shale.

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# 8 DESIGN OF A MULTI-SCALE METHANE EMISSION DETECTION AND ATTRIBUTION IN NATURAL GAS PRODUCTION REGIONS

## 8.1 Introduction

As regulations are promulgated to reduce methane emissions from natural gas production sites [1-4], it becomes important to track the effectiveness of the emission reduction programs. As documented in previous chapters, methane emissions from natural gas production occur on a variety of spatial and temporal scales [5, 6], and so systems designed to monitor emission reductions must be capable of detecting changes in both emissions from routine operations (e.g. equipment leaks, pneumatic devices) and from episodic events (e.g. well completions, liquids unloading). Figure 8-1 simulates a representative emission signal from a natural gas production well pad where: (i) there is an equipment leak with an average whole gas emission rate of 10scf/h, (ii) an intermittent-vent controller with an average whole gas emission rate of 28 scf/h, and (iii) a manual liquid unloading event takes place with a duration of roughly 1.2 hours, and a total vented volume of gas of 120,000 scf. Figure 8-2 highlights, on different scales, the equipment leak signal (*left*), and the liquid unloading event signal (*right*)).

This chapter describes a potential monitoring system, with three spatial tiers, for identifying methane emission sources in natural gas production regions, such as those illustrated in Figures 8-1 and 8-2. The design of a possible methane monitoring network for the Barnett Shale region will be used as an illustrative case study. A network of high sensitivity, high time resolution fixed ground monitors could be used to identify large intermittent emissions, and could be coupled with a mobile unit that will allow a high sensitivity identification and quantification of specific emission sources.

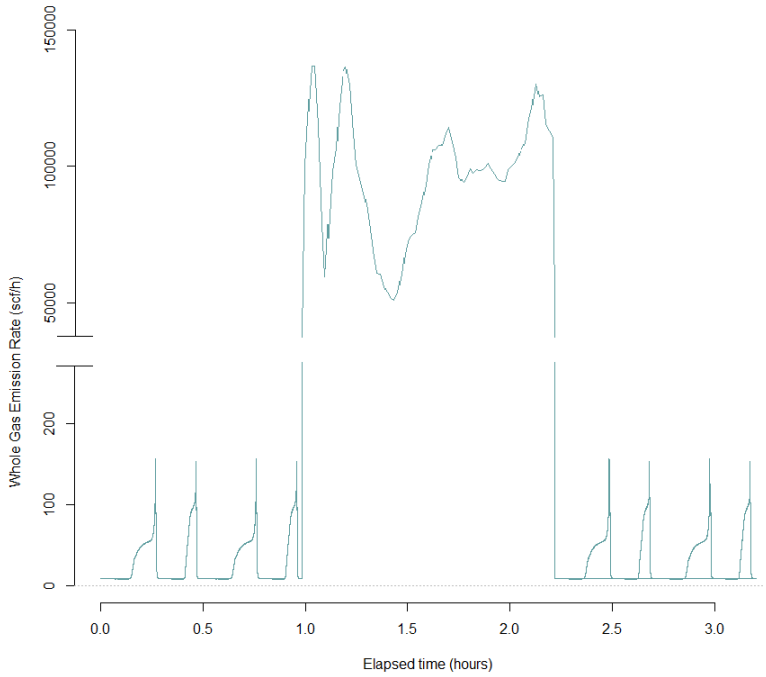


**Figure 8-1.** Simulated emission signal from a natural gas well pad. Methane emissions caused by different sources are illustrated. Actuations from an intermittent-vent pneumatic controller occur as part of the routine operation of the well. The offset between the actuations of the pneumatic controller and the zero emissions baseline is caused by the existence of an equipment leak on the site. At 1.0 hours (elapsed time) a manual liquid unloading event takes place, with duration of 1.2 hours and a 120,000 scf of whole gas emitted. After the event ends, the well goes back to routine operation, the equipment leak and the emissions from the pneumatic device and leak are apparent again.

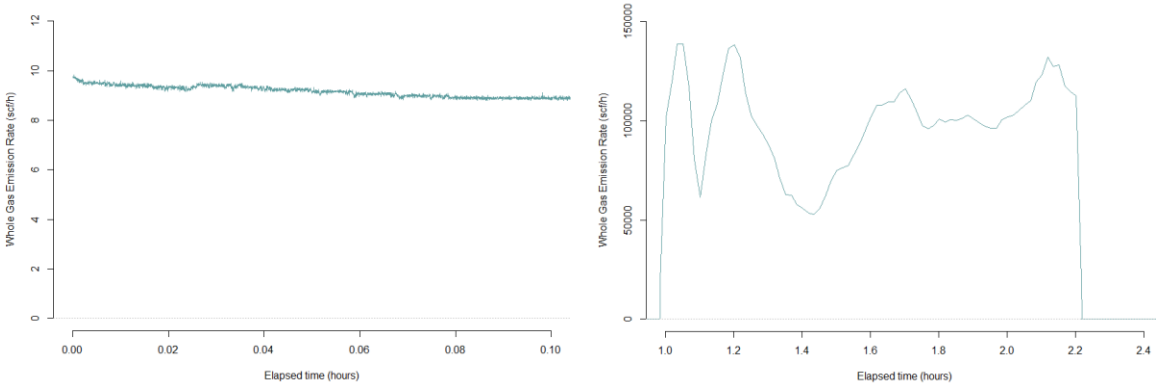


**Figure 8-2.** Leak with an average whole gas emission rate of 10 scf/h (left), and liquid unloading event, with total emissions of 120,000 scf for the event.

## 8.2 Design of the monitoring system

### *8.2.1 Study Region*

The Barnett Shale production region has shown a significant growth in gas production activity during the last ten years; with production of 0.11 billion cubic feet per day in 2000, increasing to 5 billion cubic feet per day by 2011 [7, 8]. Total natural gas withdrawals in the US in mid-2011 were approximately 70 billion scf/d (bcf/d). With over 10,000 well sites in a mature production region, the Barnett Shale was selected as a potential location for a proof of concept regional methane monitoring network. *Chapter 6* of this thesis presented analyses on VOC emissions from this region, and *Chapter 7* expanded those analyses by developing a methane inventory; which is used in the this chapter to select the specific section of the Barnett Shale where a proof of concept network could be placed.

Figure 8-3 shows well density and methane emissions density for the Barnett Shale region. Based on the locations of methane emission hotspots, a study region covering 1,000 – 2,000 wells was selected (black circle in Figure 8-3, expanded in Figure 8-4). The characteristics of the monitoring network shown in Figure 8-4 are described in the next section.

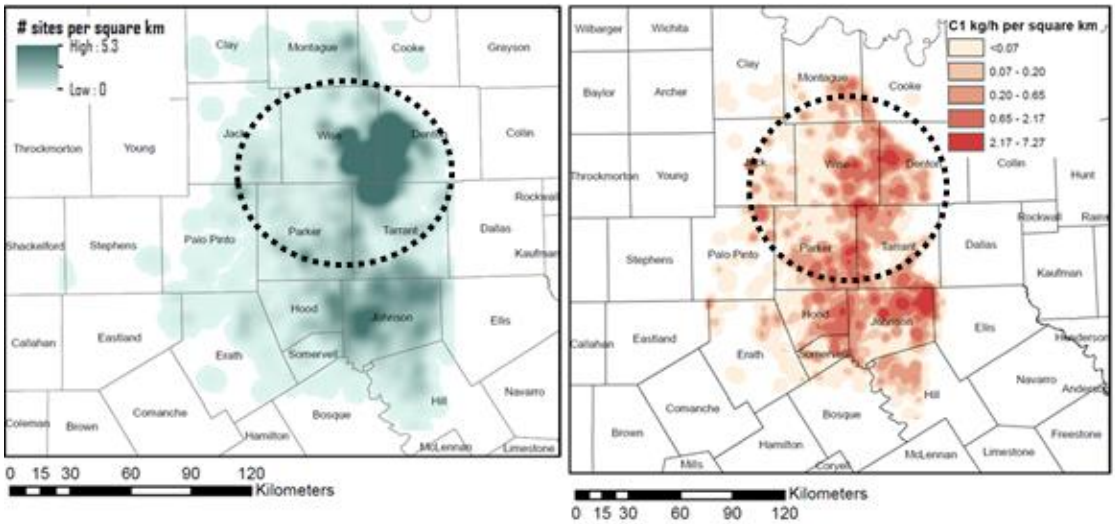


**Figure 8-3.** Well density (*left*) and Methane emissions density (*right*) for the Barnett Shale production region. Methane emissions were estimated following the procedure described in *Chapter 7* of the present work. The black circle shows the study region (1,000 – 2,000 wells).

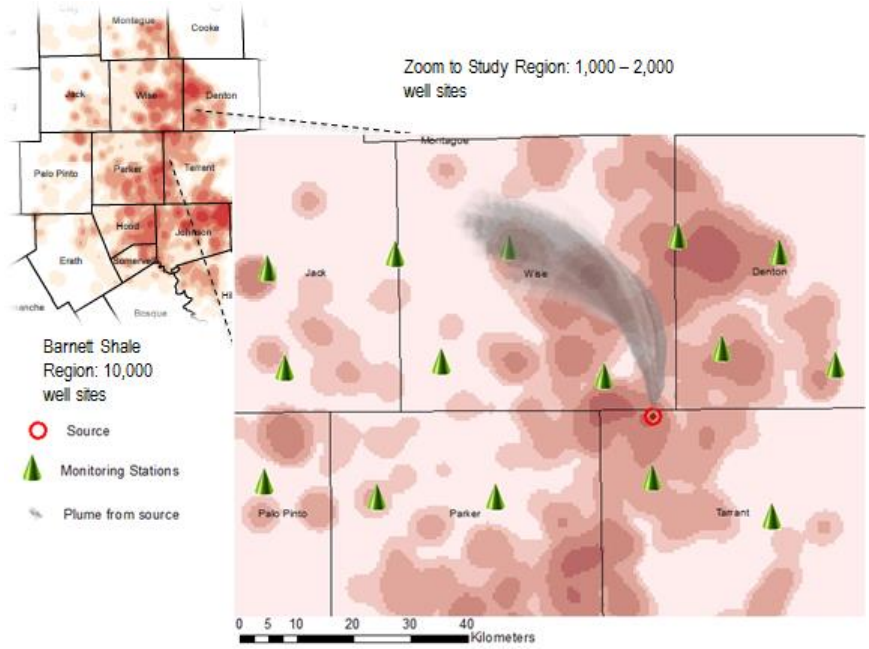


**Figure 8-4.** Spatial location of the study region, with monitoring network that detects methane hotspots (density of methane emissions in the Barnett Shale region is shown in red shading).

### *8.2.2 First level: Monitoring network*

At the largest spatial scale, fixed ground monitors could be deployed at multiple sites in production basins, as shown in Figure 8-4, to identify changes in emissions. Methane and ethane could be measured at 1 Hz, using Quantum Cascade Tunable Infrared Laser Differential Absorption Spectroscopy (QC-TILDAS); wind speed, wind direction, and carbon dioxide could also be measured using current measurement technologies.

The QC-TILDAS system is an atmospheric trace gas detector based on mid-infrared absorption spectroscopy that uses pulsed quantum cascade lasers. Tunable infrared laser differential absorption spectroscopy systems (TILDAS) are characterized by a high sensitivity, high specificity and fast response time in the mid-infrared spectral region. By incorporating the use of quantum cascade lasers, it is possible to operate the system at near room temperature. The system has been used for detection of nitric oxide [9], carbon monoxide, and methane [10], among other atmospheric trace species.

These instruments employ continuous, quantitative spectroscopic ethane and methane measurements in the fingerprint mid-IR with extreme precision and speed; the 1-second detection sensitivities are 400 and 150 parts per trillion for methane and ethane respectively [11].

### *8.2.3 Second level: Mobile Unit*

At intermediate spatial scales, vehicle mounted measurements could be used to quantify emissions at specific sites; the site emission total could then be compared to detailed, site specific emission inventories as described in *Chapter 7*. The vehicle mounted monitors could include QC-TILDAS system for methane and ethane, as well as wind speed and wind direction data, operating at 1 Hz.

Figure 8-5 illustrates the role of the mobile unit in detecting emissions from specific well sites.

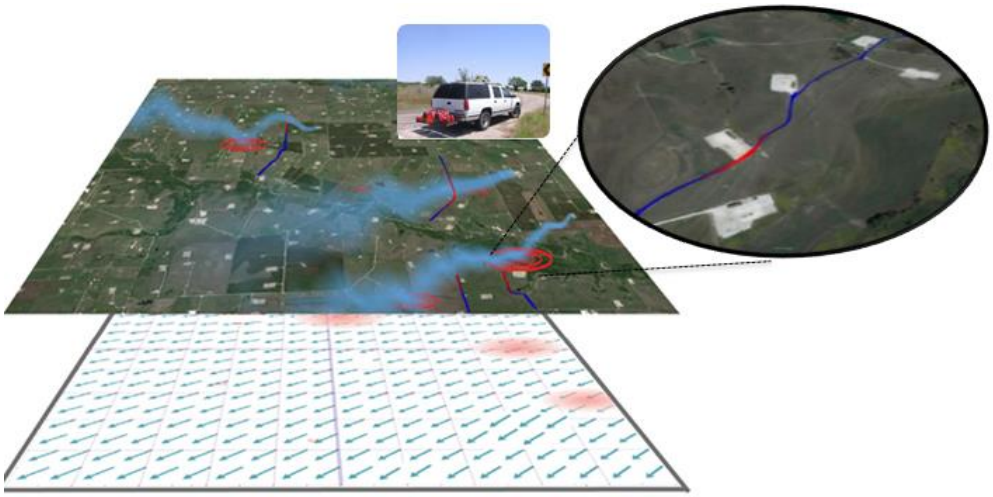

**Figure 8-5.** Mobile unit detects emissions at specific sites. Driving path shaded accordingly to the magnitude of emissions.

### *8.2.4 Third level: IR Camera and conventional leak measurement methods*

At the finest spatial scales, two approaches could be used. For sites where a vehicle mounted system has quantified emissions higher than expected for a site, infrared camera systems could be used to identify the precise location of the leak; where possible, conventional leak measurement methods (e.g., HiFlow © measurements) will be used to confirm the emission rate determined by the vehicle mounted system.

As described in Chapter 3 of this thesis and in Allen, *et al*. [5], the Hi Flow® Sampler is a portable, intrinsically safe, battery-powered instrument that has been used for several decades in measuring emissions of methane in the natural gas supply chain [12-14].

Figure 8-6 shows examples of the IR camera detecting specific emission sources at a well site.

**Figure 8-6.** IR camera pinpoints specific emission source. Examples show equipment leak (*left*), venting from tank (center), and emissions from pneumatic controller (*right*).

### *8.2.5 Coupling the different monitoring levels*

Instantaneous measurements of methane and ethane concentrations at fixed sites could be continuously compared to predicted concentrations. Predicted concentrations generated by lagrangian models could use, as input, site specific emission data for thousands of well sites in a production region and instantaneous wind field measurements generated by the network of fixed ground sites. *Chapter 6* of the present work describes a similar approach, where VOC concentrations at fixed receptor site were compared against predicted concentrations generated by a langrangian dispersion model. In this case, the methodology could be applied to the network of sites and in a continuous manner. Each hour, back trajectories could be calculated for each fixed ground site based on the local wind fields measured at the sites. Methane and ethane concentrations, as well as concentrations of key tracer species such as $CO_2$ (for combustion sources), could be predicted every minute, based on the hourly back trajectories and detailed emission inventories, and compared to observations. Daily routes for the vehicle mounted sensors could be mapped based on these daily identifications of source regions yielding higher than expected concentrations.

## 8.3 Conclusions

Monitoring methane emissions from natural gas production is a complex task due to the heterogeneous spatial and temporal patterns of the emission sources. This Chapter has described a set of monitoring and attribution systems at different scales, allowing the interpretation, characterization, and accurate detection of the emission signals. Previous chapters in this thesis have defined the spatial and temporal emission patterns of emissions from natural gas production regions and the use of langrangian models and analysis of ambient concentrations measured at monitoring sites. The present chapter proposes coupling all of these elements into an innovative and effective solution to the attribution and monitoring of methane emissions.

## 8.4 References

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# 9 SUMMARY OF CONTRIBUTIONS AND FINDINGS

The appearance of new extraction technologies such as horizontal drilling and hydraulic fracturing have propelled the development of natural gas production, and driven a need for accurate characterizations of air pollutant emissions from natural gas production. Previous emission estimates have been characterized by large uncertainties. This work has addressed emissions of greenhouse gases (GHG, specifically methane), criteria pollutants, and toxic emissions from natural gas production. Both direct and indirect measurements of emissions have been reported, and the spatial and temporal distributions of emissions as well as the role of very high emitting wells and high emitting sources in determining national emissions have been assessed. The major findings from this work are summarized below:

- For virtually all of the sources for which direct measurements were made (e.g. equipment leaks, pneumatic devices, liquids unloading events) a small subset of the sampled devices or wells account for the majority of the emissions.

- For pneumatic devices the subset of high emitters is characterized by devices that behave in a manner inconsistent with the manufacturer's design. Due to the high and relatively continuous emissions, this subset of devices should be readily detectable in leak detection programs; repair or replacement would have a high impact as an emission reduction strategy. Reducing the emissions of the highest emitting devices from their current level to less than 6 scf/h would reduce total emissions from these pneumatic controllers by an average of 160,000 standard cubic feet per year per device.

- For liquids unloading events, emissions depended most strongly on event frequency. Identification of high emitting wells is therefore relatively straight-forward. Emission reduction strategies should focus on the small subset of wells that have a high frequency of unloadings and account for the majority of the emissions from all wells with liquid unloadings. Based on the analyses of different unloading methods (plunger-lift, non-plunger lift), selection of an unloading method for a particular well should take into

consideration the age of the well and potential frequency of unloadings not just in terms of its effectiveness in clearing the well from liquids, but also in the potential reduction of emissions.

- Reconciliation between direct source measurements (bottom-up measurements) and ambient measurements (top-down analyses) was demonstrated by comparing a 20-month time series of hydrocarbon concentration data from a monitoring station in the center of a shale production region (Barnett Shale), with a site by site inventory of emissions for the region. The inventory, adjusted based on recent direct source measurements, was consistent with observations. Hourly and daily variations in the concentrations were explained by variations in meteorology. Evidence of large episodic emissions was not observed in the data set.

- Based on the analyses of hydrocarbon emissions in the Barnett Shale production region, a spatially resolved methane, ethane, and propane emission inventory was developed. This spatially resolved inventory will be used in comparisons with a variety of measurements schemes in the Barnett Shale, including airborne, vehicle, and ground-based measurements.

- Based on all of these analyses, a multi-scale system was designed that would detect and attribute sources of methane emissions in natural gas production regions.

This work has focused on national and regional scale analyses of emissions. Natural gas production from shale gas formations is already in an advanced stage of development in the U.S; with some basins already reaching their peak of production. An area of further research opportunities lies in the application of the array of concepts and tools described in the present work to other countries and regions in the world, where the technological development for the production of natural gas from shale formations is in an early stage.

Collectively, the direct source measurements, and analyses of ambient air pollutant measurements in natural gas production regions reported in this work improve the

estimation, characterization, and methods for monitoring air quality implications of shale gas production.

# APPENDICES

## A Methane Emissions from Pneumatic Controllers

### *A.1 Methods for site selection*

*Goals and overall sampling strategy.* Sampling of pneumatic controllers was conducted in four major regions (Appalachian, Gulf Coast, Mid-continent, Rocky Mountain); based on current characterizations of pneumatic controller design types (continuous vent or intermittent vent, on/off or throttling), it was anticipated that several types of controller designs would need to be sampled; it was also anticipated that there would be multiple types of controller service (e.g., separator level control service) that would influence actuation frequency and other parameters that affect emissions. To sample regions, controller design types and controller service types, it was anticipated that approximately 400 devices would need to be sampled.

*Selection of Basins* Data from EPA's Greenhouse Gas Reporting Program (GHGRP, Reporting Year 2012) were used to identify the Basins where the ten participant companies had reported pneumatic emissions. Based on this distribution of available Basins in which to sample, the study team selected at least two companies to sample in each region (Appalachian, Gulf Coast, Mid-continent, Rocky Mountain), such that all ten participant companies were sampled. Where possible, the study team selected Basins that produced a mix of device design and service types, rather than visiting sites that reported only one device type. The Study Team was solely responsible for the selection of regions and Basins in which to sample.

Once basins and companies to be sampled in each basin were selected, 2-3 day site visits were planned. In each of these site visits, the focus was on sampling well pads for a single company in a single basin. Thirteen of these 2-3 day visits were conducted.

*Selection of well pads.* Local contacts for participant companies provided descriptions or lists of the well pad sites or central facilities (e.g. sites with separators for multiple wells),

with pneumatic controllers, in the area to be sampled. The study team selected the sites; all sites identified by the local contacts were available for sampling; depending on the distances between sites, the study team either randomly selected sites or selected sites that were relatively proximate to the starting location, so that a relatively large number of samples could be made without losing efficiency due to long travel times between pad locations. The goal was to sample a cross section of typical facilities. If a company had a mix of old and new facilities, or acquired and company built facilities, the study team selected pad types in proportion to the population in the area.

*Sampling of devices on well pads or central facilities.* Once at a site, the Study Team measured emissions from all pneumatic devices at the site, unless safety or operational issues or lack of access prohibited sampling. This was done to achieve a sample population that would represent controller service and design types currently in use.

### *A.2 Corrections to Instrument Flow Measurements based on Gas Composition*

The supply gas flow meter was calibrated by the manufacturer (Fox Thermal Instruments) using pure methane; instrument flow rates were corrected to account for natural gas compositions, which varied from site to site. Because the flow meter measurement is based on thermal conductivity, the composition correction was based on the relative thermal conductivities of the gas used by pneumatic devices at each site and the pure methane used as a calibration gas.

$$scf/h_{corrected} = scf/h_{inst}\left(\frac{k_{CH4}}{k_{gas}}\right) \quad \text{(A2.1)}$$

where $scf/h_{inst}$ is the raw instrument flow rate reading in standard cubic feet per hour, $k_{CH4}$ is the pure component thermal conductivity (W/m*K) for methane at standard conditions (70ºF and 14.7 psia), and $k_{gas}$ is the thermal conductivity of the gas sampled at standard conditions as determined from the company-provided gas analysis for the site. The

thermal conductivity of the sampled gas ($k_{gas}$) was calculated as a molar weighted average:

$$k_{gas} = \sum_{i=1}^{6} k_i n_i \quad \text{(A2.2)}$$

where $n_i$ is the mole fraction of species $i$ in the gas sample for the site and $k_i$ is the pure component thermal conductivity of the species (http://webbook.nist.gov/chemistry/fluid/) under standard conditions. For this work, the pure component species considered were methane, ethane, propane, nitrogen, and carbon dioxide. All higher hydrocarbons with a carbon count of four or greater were lumped with butane for purposes of the gas composition correction. The pure component properties used in the calculations are shown in Table A-1. For the range of natural gas compositions from sites visited in this project, the composition correction factor ranged between 1.009 (0.9% increase from raw instrument data) and 1.215 (21.5% increase from raw instrument flow data).

**Table A-1**. Thermal conductivity (http://webbook.nist.gov/chemistry/fluid/) of natural gas components at standard conditions (14.7 psia and 70ºF)

| Species | Thermal Conductivity (W/m*K) |
|---|---|
| **Methane** | 0.033759 |
| **Ethane** | 0.020491 |
| **Propane** | 0.017884 |
| **Butane +** | 0.016181 |
| **Nitrogen** | 0.025473 |
| **Carbon Dioxide** | 0.016331 |

## *A.3 Field and laboratory comparisons of supply gas and Hi Flow ® measurements*

### *Laboratory measurements*

The measurement instruments were laboratory tested using gas flows generated with a mass flow controller. The test flows were designed to mimic the patterns of time varying flow expected from intermittent vent controllers. The flow out of the mass flow

controller was routed through the in-line supply gas meter then fed directly into the feed for the Hi Flow® system (the supply gas meter had a sample frequency of 10 Hz, while the Hi Flow® had a sampling frequency of 0.3 – 0.5 Hz). Tests for the High Flow instrument were completed both with the emissions point bagged and with the emissions being directly fed into the Hi Flow® inlet. In selected experiments, the mass flow controller output was compared to the results of a dry test meter.

Multiple tests were conducted. Figure A-1 shows the results of one test scenario with a pure methane gas stream. The initial flow pattern consisted of three step up-step down flows with a maximum flow of 100 scf/h (a simulated controller actuation). The duration of each step was 30 seconds, and the period between simulated actuations was 2.5 minutes. The second part of the test consisted of three step up-step down flows that also had a maximum flow of 100 scf/h. Each step had a duration of 3 seconds, and the period between simulated actuations was 2.5 minutes.

The time integrated flow per simulated actuation from the mass flow controller was compared to the time integrated flow for the supply gas meter and the Hi Flow® device. The ratio of the integrated supply gas meter flow to the integrated mass flow controller flow averaged 1.07 for this test; the ratio of the integrated Hi Flow® device flow to the integrated mass flow controller flow averaged 0.983.

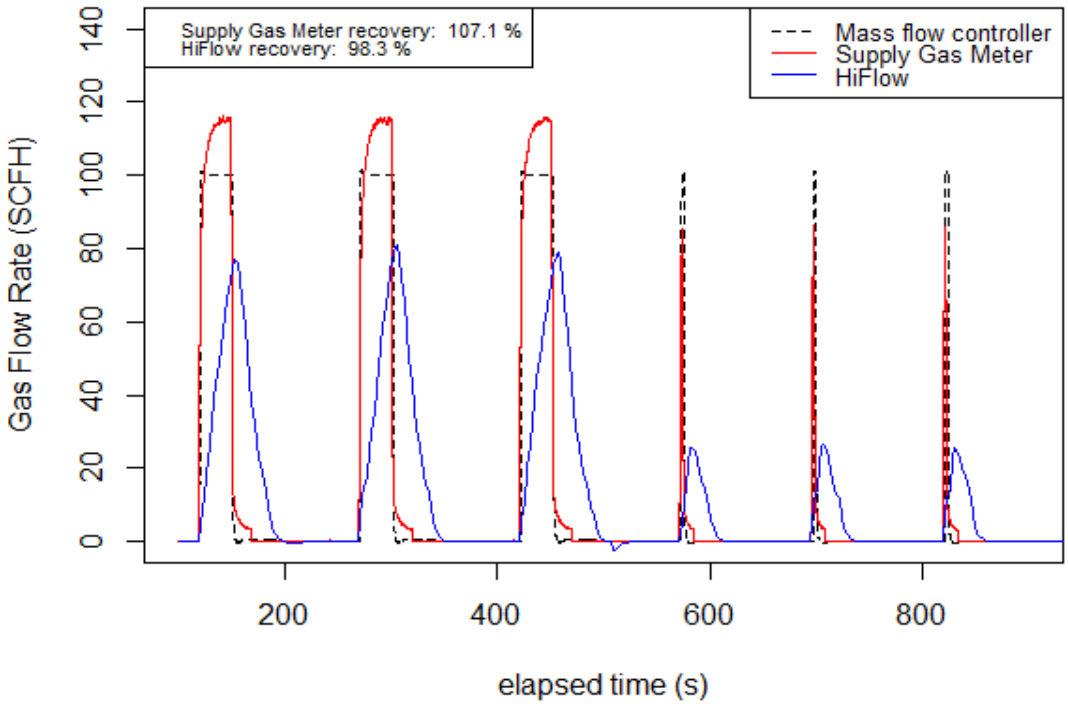



**Figure A-1.** Laboratory test comparing supply gas meter to Hi Flow® and mass flow controller. The test consisted of two sets of three 100 scf/h simulated actuations; the first set of actuations had a duration of 30 seconds while the second set of actuations had durations of 3 seconds.

For another test (with pure methane test gas), four simulated actuations were performed (30 seconds between actuations), with an increasing maximum flow rate (10, 30, 50, and 100 scf/h, respectively); each simulated actuation had a duration of 20 seconds (Figure A-2). In this test, the ratio of the integrated supply gas meter flow to the integrated mass flow controller flow averaged 1.035; the ratio of the integrated Hi Flow® device flow to the integrated mass flow controller flow averaged 0.952.

Table A-2 summarizes the laboratory tests that were conducted, showing the relative ratio of integrated flows for each case (with pure methane test gas).

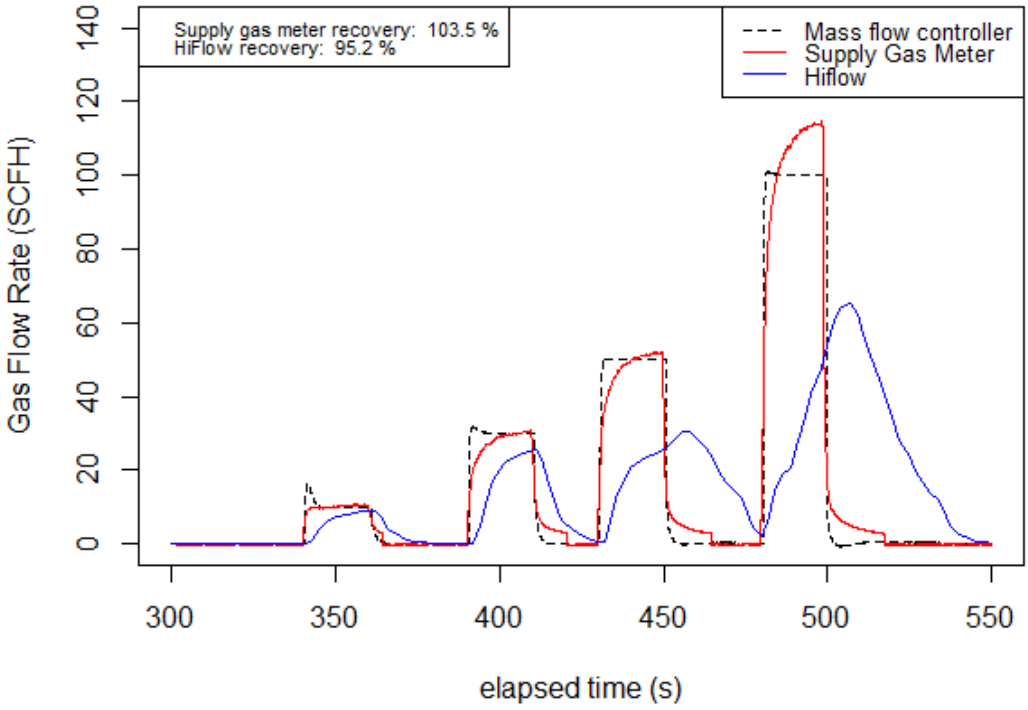



**Figure A-2.** Laboratory test comparing Supply Gas Meter to Hi Flow® and Mass Flow Controller. The test consisted of four actuations with maximum flows of 10 scf/h, 30 scf/h, 50 scf/h, and 100 scf/h, with a duration of 20 seconds and an interval between actuations of 30 seconds.

**Table A-2.** Laboratory tests simulating controller actuations, using pure methane, comparing the Supply Gas Meter to the Hi Flow® device.

| Test Description | Ratio of integrated supply gas meter flow to integrated mass flow controller flow | Ratio of integrated Hi Flow® device flow to integrated mass flow controller flow |
|---|---|---|
| *Step up-step down flow. Maximum flow was 100 scf/h, duration of each step was 30 seconds and the period between simulated actuations was 2.5 minutes.* | 1.07 | 0.983 |
| *Set of actuations with maximum flow of 10 scf/h, 30 scf/h, 50 scf/h, and 100 scf/h with a duration of 20 seconds per actuation, and an interval of 30 seconds between actuations.* | 1.03 | 0.952 |
| *Set of actuations with a maximum flow of 100 scf/h, 30 scf/h and 10 scf/h, with a duration of 1 second per actuation and an interval of 1 second between actuations.* | 0.856 | 0.959 |
| *Set of three actuations with a maximum flow of 100 scf/h with a duration of 30 seconds per actuation. Interval of 2.5 minutes between actuations.* | 1.10 | 0.922 |
| *Set of three actuations with a maximum flow of 100 scf/h with a duration of 3 seconds per actuation. Interval of 2.5 minutes between actuations.* | 0.829 | 1.58 |

Additional tests with a wet gas surrogate (70.5% methane by volume) were completed in the lab before field sampling (Table A-3). For the tests listed in Table A-3, the average ratio of instrument reported mass flow rate to the controller mass flow rate (uncorrected for composition) is 0.878 for the supply gas meter and 0.608 for the Hi Flow®.

**Table A-3.** Laboratory tests simulating controller actuations, comparing the supply gas meter to the Hi Flow® device with a wet gas surrogate (70.5% methane by volume). Each test consisted of three 30 second bursts at 3 scf/h and at 50 scf/h.

| Test Number | Ratio of integrated supply gas meter flow to integrated mass flow controller flow | Ratio of integrated Hi Flow® device flow to integrated mass flow controller flow |
|---|---|---|
| ***1*** | Not Tested | 0.663 |
| ***2*** | 0.857 | 0.552 |
| ***3*** | 0.898 | Not Tested |

If the supply gas meter is corrected for composition, the average ratio of instrument reported mass flow rate to the controller mass flow rate is 1.034 for the wet gas tests. The Hi Flow® instrument reading is difficult to correct for composition for non-steady flows. At low emission rates, the composition correction would be based on a molar flow rate of carbon, since the sampled gas is catalytically oxidized before it is sent to a thermal conductivity detector. In contrast, at high flow rates, the sample is sent directly to a thermal conductivity detector and the gas composition adjustment would be based on a molar weighted thermal conductivity (see Section A.2). These two adjustments would require precise identification of the transitions between sampling regimes, making the interpretation of field data difficult. Therefore, to adjust Hi Flow® measurements for gas composition in field measurements, the following procedure was used:

1. Determine whether a wet gas or dry gas adjustment will be used; if the percentage methane in the produced gas at a site was greater than 85%, a dry gas correction was used; otherwise a wet gas correction was used
2. For dry gas sites, the Hi Flow® measurement, uncorrected for gas composition, was converted to a supply gas measurement, uncorrected for gas composition. This conversion is based on the laboratory data collected on pure methane reported in Table A-3 (ratio of Supply gas flow rate to Hi Flow® flow rate of 1.12). The uncorrected supply gas flow rate was then corrected for composition using the method described in Section A.2.

3. For wet gas sites, the Hi Flow® measurement, uncorrected for gas composition, was converted to a supply gas measurement, uncorrected for gas composition. This conversion is based on the laboratory data collected on a surrogate wet gas reported in Table A-4 (ratio of Supply gas flow rate to Hi Flow® flow rate of 0.878/0.608; 1.44). The uncorrected supply gas flow rate was then corrected for composition using the method described in Section A.2.

*Field Measurements*

In field measurements, for 29 controllers, both supply gas and Hi Flow® measurements were made, simultaneously. Four of those measurements will not be analyzed because they occurred at a site (DL02) where the Hi Flow® was capturing a leak signal from equipment, not associated with the controller, located inside the enclosure where the pneumatic devices were installed. An additional measurement (device XQ01-PC04) will not be analyzed because it was concluded that the controller was not completely bagged.

For the final data set of 24 controllers with coupled measurements, 11 (46%) had emissions of less than 0.005 scf/h of whole gas, as measured by the supply gas meter. The results for the remaining 13 devices are shown in Table A-4. For devices with an average emission rate greater than 6 scf/h (measured by the supply gas meter), the supply gas meter to Hi Flow® measurement ratio is between 0.7 and 1.1. These results suggest that for controllers that account for most of the emissions, the two methods produce similar results. For lower flow rates, the lack of agreement is generally due to higher supply gas measurements, relative to Hi Flow® measurements. This is likely due to leaks in the controller/control valve gas line that were not captured by the Hi Flow® enclosure. For the samples where the Hi Flow® device was measuring higher emissions than the supply gas meter, the Hi Flow® may have been sampling emissions that were not in the controller/control valve gas line.

**Table A-4.** Supply gas meter and Hi Flow® for thirteen controllers where both instruments were used to make measurements.

| Device Name | Supply Gas meter - avg. emission rate Whole Gas (scf/h) | Hi Flow® - avg. emission rate Whole Gas (scf/h) | Supply Gas meter to Hi Flow® measurement ratio |
|---|---|---|---|
| AP04-PC02 | 0.111 | 0 | - |
| AP04-PC03 | 0.036 | 0.007 | 5.4 |
| AP05-PC01 | 0.169 | 0.197 | 0.9 |
| DL02-PC11 | 0.528 | 0.881 | 0.6 |
| DL02-PC15 | 1.360 | 0.696 | 2.0 |
| DL02-PC42 | 0.504 | 0.001 | 553 |
| LB03-PC01 | 50.0 | 55.3 | 0.9 |
| LB06-PC05 | 22.5 | 20.8 | 1.1 |
| LB07-PC01 | 36.3 | 51.3 | 0.7 |
| LB07-PC04 | 27.0 | 33.9 | 0.8 |
| RB01-PC14 | 4.16 | 0.194 | 21.5 |
| RQ05-PC02 | 0.008 | 5.15 | 0.0 |
| RQ07-PC03 | 18.2 | 21.0 | 0.9 |

### *A.4 Pneumatic controller emission data*

Tables A-5 to A-9 contain the data collected for each of the 377 measured devices. The first letter of the device code indicates the host company that operated the site where the measurement was performed. The second letter of the device code indicates the basin where the measurement was performed. Letters for these codes were randomly selected, but are used consistently (i.e., specific letters always represent the same company or basin). Figure A-3 shows the boundaries of the geographical regions into which controllers were grouped. Figure A-4 summarizes the application types, well types, and service types sampled population.

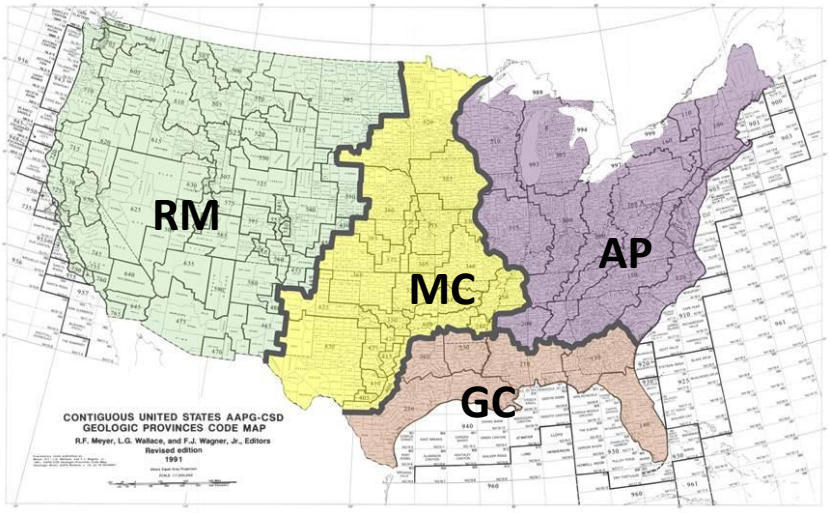



**Figure A-3.** Measurements of emissions from pneumatic controllers were categorized into Appalachian (AP), Gulf Coast (GC), Mid-Continent (MC) and Rocky Mountain (RM) regions.

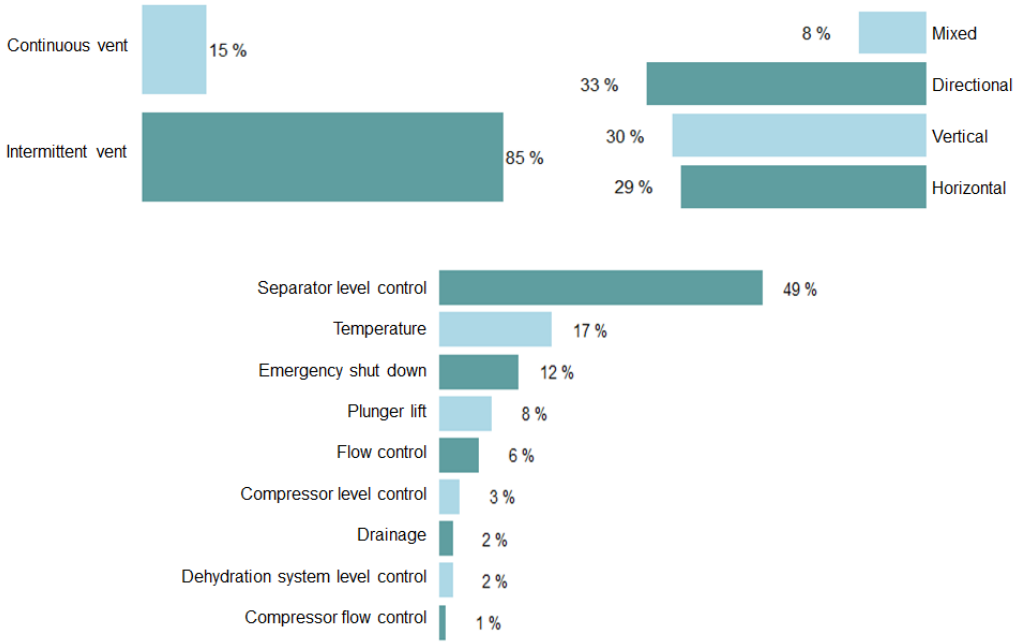



**Figure A-4.** Sample population characterized by the service type (upper left, continuous vent or intermittent vent), well type (upper right, horizontal, vertical, directional or mixed type), and type of application in which the controller is used (lower, e.g., separator level control).

**Table A-5.** Descriptive data of measured devices, showing the pneumatic controller application (level, pressure or temperature), process unit they are servicing, and if they are linked to a single well or multiple wells.

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| AA01-PC04 | MC | Level | Separator | Separator - Level Control | Y |
| AA01-PC05 | MC | Level | Separator | Separator - Level Control | Y |
| AA01-PC06 | MC | Level | Separator | Separator - Level Control | Y |
| AA01-PC07 | MC | Level | Separator | Separator - Level Control | Y |
| AA01-PC08 | MC | Level | Separator | Separator - Level Control | Y |
| AA01-PC09 | MC | Level | Separator | Separator - Level Control | Y |
| AA01-PC11 | MC | Pressure | Compressor | Compressor | Y |
| AA02-PC04 | MC | Level | Compressor | Other | Y |
| AA02-PC05 | MC | Level | Compressor | Compressor | Y |
| AA02-PC06 | MC | Level | Compressor | Compressor | Y |
| AA02-PC07 | MC | Level | Compressor | Compressor | Y |
| AA02-PC08 | MC | Pressure | Compressor | Compressor | Y |
| AA02-PC09 | MC | Level | Compressor | Compressor | Y |
| AP01-PC01 | MC | Level | Separator | Separator - Level Control | N |
| AP01-PC02 | MC | Level | Separator | Separator - Level Control | Y |
| AP01-PC03 | MC | Level | Separator | Separator - Level Control | Y |
| AP01-PC04 | MC | Level | Separator | Separator - Level Control | Y |
| AP01-PC05 | MC | Level | Separator | Separator - Level Control | Y |
| AP01-PC12 | MC | Level | Separator | Separator - Level Control | N |
| AP02-PC01 | MC | Level | Separator | Separator - Level Control | N |
| AP02-PC02 | MC | Level | Separator | Separator - Level Control | N |
| AP02-PC03 | MC | Level | Separator | Separator - Level Control | N |
| AP02-PC04 | MC | Level | Separator | Separator - Level Control | N |
| AP03-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| AP03-PC02 | MC | Level | Separator | Separator - Level Control | N |
| AP04-PC01 | MC | Level | Separator | Separator - Level Control | N |
| AP04-PC02 | MC | Level | Separator | Separator - Level Control | N |
| AP04-PC03 | MC | Level | Separator | Separator - Level Control | N |
| AP04-PC04 | MC | Level | Separator | Separator - Level Control | Y |
| AP05-PC01 | MC | Level | Separator | Separator - Level Control | N |
| AP05-PC02 | MC | Level | Separator | Separator - Level Control | Y |
| CW01-PC01 | RM | Pressure | Wellhead | ESD | Y |
| CW01-PC02 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| CW01-PC03 | RM | Level | Separator | Separator - Level Control | Y |
| CW01-PC04 | RM | Level | Separator | Separator - Level Control | Y |
| CW01-PC05 | RM | Temperature | Process Heater | Process Heater | Y |

**Table A-5** (continued)

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| CW01-PC11 | RM | Pressure | Wellhead | ESD | Y |
| CW01-PC12 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| CW01-PC13 | RM | Level | Separator | Separator - Level Control | Y |
| CW01-PC14 | RM | Level | Separator | Separator - Level Control | Y |
| CW01-PC15 | RM | Temperature | Process Heater | Process Heater | Y |
| CW01-PC21 | RM | Pressure | Wellhead | ESD | Y |
| CW01-PC22 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| CW01-PC23 | RM | Level | Separator | Separator - Level Control | Y |
| CW01-PC24 | RM | Level | Separator | Separator - Level Control | Y |
| CW01-PC25 | RM | Temperature | Process Heater | Process Heater | Y |
| CW01-PC31 | RM | Pressure | Wellhead | ESD | Y |
| CW01-PC32 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| CW01-PC33 | RM | Level | Separator | Separator - Level Control | Y |
| CW01-PC34 | RM | Level | Separator | Separator - Level Control | Y |
| CW01-PC35 | RM | Temperature | Process Heater | Process Heater | Y |
| CW02-PC01 | RM | Pressure | Wellhead | ESD | Y |
| CW02-PC02 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| CW02-PC03 | RM | Level | Separator | Separator - Level Control | Y |
| CW02-PC04 | RM | Level | Separator | Separator - Level Control | Y |
| CW02-PC05 | RM | Temperature | Process Heater | Process Heater | Y |
| CW02-PC11 | RM | Pressure | Wellhead | ESD | Y |
| CW02-PC12 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| CW02-PC13 | RM | Level | Separator | Separator - Level Control | Y |
| CW02-PC14 | RM | Level | Separator | Separator - Level Control | Y |
| CW02-PC15 | RM | Temperature | Process Heater | Process Heater | Y |
| CW02-PC21 | RM | Pressure | Wellhead | ESD | Y |
| CW02-PC22 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| CW02-PC23 | RM | Level | Separator | Separator - Level Control | Y |
| CW02-PC24 | RM | Level | Separator | Separator - Level Control | Y |
| CW02-PC25 | RM | Temperature | Process Heater | Process Heater | Y |
| CW02-PC31 | RM | Pressure | Wellhead | ESD | Y |
| CW02-PC32 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| CW02-PC33 | RM | Level | Separator | Separator - Level Control | Y |
| CW02-PC34 | RM | Level | Separator | Separator - Level Control | Y |
| CW02-PC35 | RM | Temperature | Process Heater | Process Heater | Y |
| CZ01-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| CZ01-PC02 | GC | Pressure | Plunger Lift | Plunger Lift | Y |
| CZ02-PC01 | GC | Level | Separator | Separator - Level Control | Y |

**Table A-5** (continued)

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| CZ02-PC02 | GC | Pressure | Plunger Lift | Plunger Lift | Y |
| CZ03-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| CZ03-PC02 | GC | Pressure | Plunger Lift | Plunger Lift | Y |
| CZ04-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| CZ04-PC02 | GC | Pressure | Plunger Lift | Plunger Lift | Y |
| CZ05-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| CZ05-PC02 | GC | Pressure | Plunger Lift | Plunger Lift | Y |
| CZ05-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| CZ06-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| CZ06-PC02 | GC | Pressure | Plunger Lift | Plunger Lift | Y |
| CZ06-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| CZ07-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| CZ07-PC02 | GC | Pressure | Plunger Lift | Plunger Lift | Y |
| CZ08-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| CZ08-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| CZ09-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| CZ09-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| CZ10-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| CZ11-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| DL01-PC01 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC02 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC03 | RM | Temperature | Process Heater | Process Heater | Y |
| DL01-PC04 | RM | Level | Wellhead | ESD | Y |
| DL01-PC05 | RM | Temperature | Process Heater | Process Heater | Y |
| DL01-PC11 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC12 | RM | Level | Wellhead | ESD | Y |
| DL01-PC13 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC14 | RM | Level | Wellhead | ESD | Y |
| DL01-PC15 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC21 | RM | Level | Wellhead | ESD | Y |
| DL01-PC22 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC23 | RM | Level | Wellhead | ESD | Y |
| DL01-PC24 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC25 | RM | Level | Wellhead | ESD | Y |
| DL01-PC31 | RM | Temperature | Process Heater | Process Heater | Y |
| DL01-PC32 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC33 | RM | Level | Wellhead | ESD | Y |
| DL01-PC34 | RM | Level | Separator | Separator - Level Control | Y |

**Table A-5** (continued)

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| DL01-PC35 | RM | Level | Wellhead | ESD | Y |
| DL01-PC41 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC42 | RM | Level | Wellhead | ESD | Y |
| DL01-PC43 | RM | Level | Separator | Separator - Level Control | Y |
| DL01-PC44 | RM | Level | Wellhead | ESD | Y |
| DL01-PC45 | RM | Temperature | Flare | Other | N |
| DL02-PC01 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC02 | RM | Level | Wellhead | ESD | Y |
| DL02-PC03 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC04 | RM | Level | Wellhead | ESD | Y |
| DL02-PC05 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC11 | RM | Level | Wellhead | ESD | Y |
| DL02-PC12 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC13 | RM | Level | Wellhead | ESD | Y |
| DL02-PC14 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC15 | RM | Level | Wellhead | ESD | Y |
| DL02-PC21 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC22 | RM | Level | Wellhead | ESD | Y |
| DL02-PC23 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC24 | RM | Level | Wellhead | ESD | Y |
| DL02-PC25 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC31 | RM | Level | Wellhead | ESD | Y |
| DL02-PC32 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC33 | RM | Level | Wellhead | ESD | Y |
| DL02-PC34 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC35 | RM | Level | Wellhead | ESD | Y |
| DL02-PC41 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC42 | RM | Level | Wellhead | ESD | Y |
| DL02-PC43 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC44 | RM | Level | Wellhead | ESD | Y |
| DL02-PC45 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC51 | RM | Level | Wellhead | ESD | Y |
| DL02-PC52 | RM | Level | Separator | Separator - Level Control | Y |
| DL02-PC53 | RM | Level | Wellhead | ESD | Y |
| DL02-PC54 | RM | Temperature | Process Heater | Separator - Other | Y |
| DL02-PC55 | RM | Temperature | Process Heater | Separator - Other | Y |
| DL02-PC61 | RM | Temperature | Process Heater | Separator - Other | Y |
| DL02-PC62 | RM | Temperature | Flare | Other | Y |

**Table A-5** (continued)

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| GZ01-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| GZ01-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| GZ01-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| GZ01-PC04 | GC | Level | Separator | Separator - Level Control | Y |
| GZ01-PC05 | GC | Level | Separator | Separator - Level Control | Y |
| GZ01-PC11 | GC | Level | Separator | Separator - Level Control | Y |
| GZ01-PC12 | GC | Level | Separator | Separator - Level Control | Y |
| GZ01-PC13 | GC | Level | Separator | Separator - Level Control | Y |
| GZ01-PC14 | GC | Pressure | Wellhead | ESD | Y |
| GZ01-PC15 | GC | Pressure | Wellhead | ESD | Y |
| GZ01-PC21 | GC | Pressure | Wellhead | ESD | Y |
| GZ01-PC22 | GC | Pressure | Wellhead | ESD | Y |
| GZ02-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| GZ02-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| GZ02-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| GZ02-PC04 | GC | Level | Separator | Separator - Level Control | Y |
| GZ02-PC05 | GC | Level | Compressor | Other | N |
| GZ02-PC11 | GC | Level | Compressor | Compressor | N |
| GZ02-PC12 | GC | Level | Compressor | Compressor | N |
| GZ02-PC13 | GC | Level | Compressor | Compressor | N |
| GZ02-PC14 | GC | Pressure | Compressor | Compressor | N |
| GZ02-PC15 | GC | Level | Compressor | Compressor | N |
| GZ02-PC21 | GC | Level | Compressor | Compressor | N |
| GZ02-PC22 | GC | Pressure | Wellhead | ESD | Y |
| GZ02-PC23 | GC | Pressure | Wellhead | ESD | Y |
| GZ02-PC24 | GC | Pressure | Compressor | Compressor | N |
| GZ03-PC01 | GC | Level | Compressor | Compressor | N |
| GZ03-PC02 | GC | Level | Compressor | Compressor | N |
| GZ03-PC03 | GC | Level | Compressor | Compressor | N |
| GZ03-PC04 | GC | Level | Compressor | Other | N |
| GZ03-PC05 | GC | Pressure | Compressor | Compressor | N |
| GZ03-PC11 | GC | Pressure | Wellhead | ESD | Y |
| GZ03-PC12 | GC | Pressure | Wellhead | ESD | Y |
| GZ03-PC13 | GC | Level | Separator | Separator - Level Control | N |
| GZ03-PC14 | GC | Level | Separator | Separator - Level Control | N |
| GZ03-PC15 | GC | Level | Separator | Separator - Level Control | N |
| GZ03-PC21 | GC | Level | Separator | Separator - Level Control | Y |
| GZ03-PC22 | GC | Level | Separator | Separator - Level Control | Y |

**Table A-5** (continued).

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| GZ03-PC23 | GC | Level | Separator | Separator - Level Control | Y |
| GZ03-PC24 | GC | Level | Separator | Separator - Level Control | Y |
| GZ03-PC25 | GC | Pressure | Wellhead | ESD | N |
| GZ03-PC31 | GC | Level | Dehydration System | Separator - Level Control | N |
| GZ03-PC32 | GC | Level | Dehydration System | Dehydration System | N |
| GZ03-PC33 | GC | Level | Dehydration System | Dehydration System | N |
| GZ03-PC34 | GC | Temperature | Dehydration System | Dehydration System | N |
| GZ03-PC35 | GC | Temperature | Dehydration System | Dehydration System | N |
| GZ03-PC41 | GC | Level | Dehydration System | Other | N |
| GZ03-PC42 | GC | Pressure | Sales | Other | N |
| GZ04-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| GZ04-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| GZ04-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| GZ04-PC04 | GC | Level | Separator | Separator - Level Control | Y |
| GZ04-PC05 | GC | Pressure | Wellhead | ESD | Y |
| GZ04-PC11 | GC | Pressure | Wellhead | ESD | Y |
| LB01-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| LB01-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| LB02-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| LB02-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| LB02-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| LB02-PC04 | GC | Level | Separator | Separator - Level Control | Y |
| LB03-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| LB03-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| LB04-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| LB04-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| LB04-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| LB04-PC04 | GC | Level | Separator | Separator - Level Control | Y |
| LB05-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| LB05-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| LB05-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| LB05-PC04 | GC | Level | Separator | Separator - Level Control | Y |
| LB06-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| LB06-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| LB06-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| LB06-PC04 | GC | Level | Separator | Separator - Level Control | Y |
| LB06-PC05 | GC | Level | Separator | Separator - Level Control | Y |
| LB06-PC11 | GC | Level | Separator | Separator - Level Control | Y |

**Table A-5** (continued).

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| LB07-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| LB07-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| LB07-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| LB07-PC04 | GC | Level | Separator | Separator - Level Control | Y |
| OF01-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF02-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF03-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF04-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF05-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF06-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF07-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF08-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF08-PC02 | AP | Pressure | Plunger Lift | Plunger Lift | Y |
| OF09-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF10-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF11-PC01 | AP | Pressure | Wellhead | Separator - Other | Y |
| OF11-PC02 | AP | Level | Separator | Separator - Level Control | Y |
| OF11-PC03 | AP | Level | Separator | Separator - Level Control | Y |
| OF11-PC04 | AP | Pressure | Wellhead | Separator - Other | Y |
| RB01-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| RB01-PC02 | GC | Level | Separator | Separator - Level Control | Y |
| RB01-PC03 | GC | Level | Separator | Separator - Level Control | Y |
| RB01-PC04 | GC | Pressure | Separator | Separator - Other | N |
| RB01-PC05 | GC | Level | Separator | Separator - Level Control | N |
| RB01-PC11 | GC | Level | Separator | Separator - Level Control | N |
| RB01-PC12 | GC | Level | Separator | Separator - Level Control | N |
| RB01-PC13 | GC | Level | Dehydration System | Dehydration System | N |
| RB01-PC14 | MC | Level | Dehydration System | Dehydration System | N |
| RB01-PC15 | GC | Level | Dehydration System | Dehydration System | N |
| RB01-PC21 | GC | Temperature | Dehydration System | Dehydration System | N |
| RB01-PC23 | GC | Pressure | Dehydration System | Other | N |
| RB01-PC24 | GC | Level | Dehydration System | Separator - Level Control | N |
| RB01-PC25 | GC | Level | Flare | Other | N |
| RB01-PC34 | GC | Level | Separator | Separator - Level Control | Y |
| RB02-PC01 | GC | Level | Separator | Separator - Level Control | Y |
| RB02-PC02 | GC | Level | Dehydration System | Dehydration System | Y |
| RB02-PC03 | GC | Temperature | Dehydration System | Dehydration System | Y |
| RB02-PC05 | GC | Level | Dehydration System | Dehydration System | Y |

**Table A-5** (continued).

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| RB02-PC11 | GC | Level | Dehydration System | Dehydration System | Y |
| RB02-PC12 | GC | Level | Dehydration System | Other | Y |
| RQ01-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| RQ02-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| RQ02-PC02 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| RQ03-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| RQ04-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| RQ05-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| RQ05-PC02 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| RQ05-PC03 | MC | Level | Separator | Separator - Level Control | Y |
| RQ05-PC04 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| RQ06-PC01 | MC | Temperature | Process Heater | Process Heater | Y |
| RQ06-PC02 | MC | Temperature | Process Heater | Process Heater | Y |
| RQ06-PC03 | MC | Level | Separator | Separator - Level Control | Y |
| RQ06-PC04 | MC | Level | Separator | Separator - Level Control | Y |
| RQ07-PC01 | MC | Temperature | Process Heater | Process Heater | Y |
| RQ07-PC02 | MC | Temperature | Process Heater | Process Heater | Y |
| RQ07-PC03 | MC | Level | Separator | Separator - Level Control | Y |
| RQ07-PC04 | MC | Level | Separator | Separator - Level Control | Y |
| RQ07-PC05 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| VF01-PC01 | AP | Level | Wellhead | ESD | Y |
| VF01-PC02 | AP | Level | Separator | Separator - Level Control | Y |
| VF01-PC03 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC04 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC05 | AP | Level | Wellhead | ESD | Y |
| VF01-PC11 | AP | Level | Separator | Separator - Level Control | Y |
| VF01-PC12 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC13 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC14 | AP | Level | Wellhead | ESD | Y |
| VF01-PC15 | AP | Level | Separator | Separator - Level Control | Y |
| VF01-PC21 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC22 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC23 | AP | Level | Wellhead | ESD | Y |
| VF01-PC24 | AP | Level | Separator | Separator - Level Control | Y |
| VF01-PC25 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC31 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC32 | AP | Level | Wellhead | ESD | Y |
| VF01-PC33 | AP | Level | Separator | Separator - Level Control | Y |

**Table A-5** (continued).

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| VF01-PC34 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC35 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC41 | AP | Level | Wellhead | ESD | Y |
| VF01-PC42 | AP | Level | Separator | Separator - Level Control | Y |
| VF01-PC43 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC44 | AP | Temperature | Process Heater | Process Heater | Y |
| VF01-PC45 | AP | Pressure | Wellhead | Other | Y |
| VF01-PC51 | AP | Pressure | Wellhead | Other | Y |
| VF01-PC52 | AP | Pressure | Wellhead | Other | Y |
| VF01-PC53 | AP | Pressure | Wellhead | Other | Y |
| VF01-PC54 | AP | Pressure | Wellhead | Other | Y |
| VF01-PC55 | AP | Pressure | Wellhead | Other | Y |
| VF02-PC01 | AP | Level | Separator | Separator - Level Control | Y |
| VF02-PC02 | AP | Level | Separator | Separator - Level Control | Y |
| VF02-PC03 | AP | Level | Separator | Separator - Level Control | Y |
| VF02-PC04 | AP | Level | Separator | Separator - Level Control | Y |
| VF02-PC05 | AP | Level | Separator | Separator - Level Control | Y |
| VF02-PC11 | AP | Level | Separator | Separator - Level Control | Y |
| VF02-PC12 | AP | Temperature | Process Heater | Process Heater | Y |
| XQ01-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| XQ01-PC02 | MC | Level | Separator | Separator - Level Control | Y |
| XQ01-PC03 | MC | Temperature | Process Heater | Process Heater | Y |
| XQ01-PC04 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| XQ02-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| XQ02-PC02 | MC | Level | Separator | Separator - Level Control | Y |
| XQ02-PC03 | MC | Temperature | Process Heater | Process Heater | Y |
| XQ02-PC04 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| XQ03-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| XQ03-PC02 | MC | Level | Separator | Separator - Level Control | Y |
| XQ03-PC03 | MC | Temperature | Process Heater | Process Heater | Y |
| XQ03-PC04 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| XQ04-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| XQ04-PC02 | MC | Level | Separator | Separator - Level Control | Y |
| XQ04-PC03 | MC | Temperature | Process Heater | Process Heater | Y |
| XQ04-PC04 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| XQ05-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| XQ05-PC02 | MC | Level | Separator | Separator - Level Control | Y |
| XQ05-PC03 | MC | Temperature | Process Heater | Process Heater | Y |

**Table A-5** (continued).

| Device Identifier | Region | Controller application | Basic application | Detailed application | Single Well (Y/N) |
|---|---|---|---|---|---|
| XQ05-PC04 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| XQ06-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| XQ06-PC02 | MC | Level | Separator | Separator - Level Control | Y |
| XQ06-PC03 | MC | Temperature | Process Heater | Process Heater | Y |
| XQ06-PC04 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| XQ07-PC01 | MC | Level | Separator | Separator - Level Control | Y |
| XQ07-PC02 | MC | Level | Separator | Separator - Level Control | Y |
| XQ07-PC03 | MC | Temperature | Process Heater | Process Heater | Y |
| XQ07-PC04 | MC | Pressure | Plunger Lift | Plunger Lift | Y |
| ZW01-PC01 | RM | Level | Separator | Separator - Level Control | Y |
| ZW01-PC02 | RM | Level | Separator | Separator - Level Control | Y |
| ZW01-PC03 | RM | Temperature | Dehydration System | Dehydration System | Y |
| ZW01-PC04 | RM | Temperature | Dehydration System | Dehydration System | Y |
| ZW01-PC05 | RM | Temperature | Process Heater | Process Heater | Y |
| ZW01-PC11 | RM | Temperature | Process Heater | Process Heater | Y |
| ZW01-PC12 | RM | Level | Separator | Separator - Level Control | Y |
| ZW01-PC13 | RM | Level | Separator | Separator - Level Control | Y |
| ZW01-PC14 | RM | Level | Separator | Separator - Level Control | Y |
| ZW01-PC15 | RM | Level | Separator | Separator - Level Control | Y |
| ZW01-PC21 | RM | Level | Process Heater | Process Heater | Y |
| ZW01-PC22 | RM | Temperature | Dehydration System | Dehydration System | Y |
| ZW01-PC23 | RM | Temperature | Dehydration System | Dehydration System | Y |
| ZW01-PC24 | RM | Temperature | Process Heater | Process Heater | Y |
| ZW01-PC25 | RM | Temperature | Process Heater | Process Heater | Y |
| ZW01-PC31 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| ZW01-PC32 | RM | Temperature | Dehydration System | Dehydration System | Y |
| ZW01-PC33 | RM | Temperature | Dehydration System | Dehydration System | Y |
| ZW01-PC34 | RM | Temperature | Process Heater | Process Heater | Y |
| ZW01-PC35 | RM | Temperature | Process Heater | Process Heater | Y |
| ZW02-PC01 | RM | Level | Separator | Separator - Level Control | Y |
| ZW02-PC02 | RM | Level | Separator | Separator - Level Control | Y |
| ZW02-PC03 | RM | Temperature | Dehydration System | Dehydration System | Y |
| ZW02-PC04 | RM | Temperature | Dehydration System | Dehydration System | Y |
| ZW02-PC12 | RM | Pressure | Plunger Lift | Plunger Lift | Y |
| ZW03-PC01 | RM | Level | Separator | Separator - Level Control | Y |
| ZW03-PC02 | RM | Level | Separator | Separator - Level Control | Y |
| ZW03-PC03 | RM | Pressure | Plunger Lift | Plunger Lift | Y |

**Table A-6.** Device classification, based on field characterization by site operator (On/OFF or throttle), time series characterization (Intermittent-vent, Continuous bleed, Intermittent-vent*, or Continuous bleed*, and EPA classification provided by the companies.

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| AA01-PC04 | On/Off | intermittent-vent | intermittent |
| AA01-PC05 | Throttle | intermittent-vent | intermittent |
| AA01-PC06 | On/Off | intermittent-vent | intermittent |
| AA01-PC07 | Throttle | intermittent-vent | intermittent |
| AA01-PC08 | On/Off | intermittent-vent | intermittent |
| AA01-PC09 | Throttle | intermittent-vent | intermittent |
| AA01-PC11 | Throttle | intermittent-vent | intermittent |
| AA02-PC04 | On/Off | continuous bleed | intermittent |
| AA02-PC05 | On/Off | intermittent-vent | intermittent |
| AA02-PC06 | On/Off | continuous bleed * | intermittent |
| AA02-PC07 | On/Off | continuous bleed * | intermittent |
| AA02-PC08 | Throttle | continuous bleed | intermittent |
| AA02-PC09 | On/Off | continuous bleed | intermittent |
| AP01-PC01 | On/Off | intermittent-vent | intermittent |
| AP01-PC02 | On/Off | intermittent-vent | intermittent |
| AP01-PC03 | On/Off | intermittent-vent | intermittent |
| AP01-PC04 | On/Off | intermittent-vent | intermittent |
| AP01-PC05 | On/Off | intermittent-vent | intermittent |
| AP01-PC12 | On/Off | intermittent-vent * | intermittent |
| AP02-PC01 | On/Off | intermittent-vent | intermittent |
| AP02-PC02 | On/Off | intermittent-vent | intermittent |
| AP02-PC03 | On/Off | intermittent-vent | intermittent |
| AP02-PC04 | On/Off | intermittent-vent | intermittent |
| AP03-PC01 | On/Off | intermittent-vent | intermittent |
| AP03-PC02 | On/Off | intermittent-vent | intermittent |
| AP04-PC01 | On/Off | intermittent-vent | intermittent |
| AP04-PC02 | On/Off | intermittent-vent | intermittent |
| AP04-PC03 | On/Off | intermittent-vent | intermittent |
| AP04-PC04 | On/Off | intermittent-vent | intermittent |
| AP05-PC01 | On/Off | intermittent-vent | intermittent |
| AP05-PC02 | On/Off | intermittent-vent | intermittent |
| CW01-PC01 | On/Off | intermittent-vent | low bleed |
| CW01-PC02 | On/Off | intermittent-vent | low bleed |
| CW01-PC03 | On/Off | intermittent-vent | low bleed |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| CW01-PC04 | On/Off | intermittent-vent | low bleed |
| CW01-PC05 | On/Off | intermittent-vent | low bleed |
| CW01-PC11 | On/Off | intermittent-vent | low bleed |
| CW01-PC12 | On/Off | intermittent-vent | low bleed |
| CW01-PC13 | On/Off | intermittent-vent | low bleed |
| CW01-PC14 | On/Off | intermittent-vent | low bleed |
| CW01-PC15 | On/Off | intermittent-vent | low bleed |
| CW01-PC21 | On/Off | intermittent-vent | low bleed |
| CW01-PC22 | On/Off | intermittent-vent | low bleed |
| CW01-PC23 | On/Off | intermittent-vent | low bleed |
| CW01-PC24 | On/Off | intermittent-vent | low bleed |
| CW01-PC25 | On/Off | intermittent-vent | low bleed |
| CW01-PC31 | On/Off | intermittent-vent | low bleed |
| CW01-PC32 | On/Off | intermittent-vent | low bleed |
| CW01-PC33 | On/Off | intermittent-vent | low bleed |
| CW01-PC34 | On/Off | intermittent-vent | low bleed |
| CW01-PC35 | On/Off | intermittent-vent | low bleed |
| CW02-PC01 | On/Off | intermittent-vent | intermittent |
| CW02-PC02 | On/Off | intermittent-vent | intermittent |
| CW02-PC03 | On/Off | intermittent-vent | intermittent |
| CW02-PC04 | On/Off | intermittent-vent | intermittent |
| CW02-PC05 | On/Off | intermittent-vent | intermittent |
| CW02-PC11 | On/Off | intermittent-vent | intermittent |
| CW02-PC12 | On/Off | intermittent-vent | intermittent |
| CW02-PC13 | On/Off | intermittent-vent | intermittent |
| CW02-PC14 | On/Off | intermittent-vent | intermittent |
| CW02-PC15 | On/Off | intermittent-vent | intermittent |
| CW02-PC21 | On/Off | intermittent-vent | intermittent |
| CW02-PC22 | On/Off | intermittent-vent | intermittent |
| CW02-PC23 | On/Off | intermittent-vent | intermittent |
| CW02-PC24 | On/Off | intermittent-vent | intermittent |
| CW02-PC25 | On/Off | intermittent-vent | intermittent |
| CW02-PC31 | On/Off | intermittent-vent | intermittent |
| CW02-PC32 | On/Off | intermittent-vent | intermittent |
| CW02-PC33 | On/Off | continuous bleed * | intermittent |
| CW02-PC34 | On/Off | intermittent-vent | intermittent |
| CW02-PC35 | On/Off | intermittent-vent | intermittent |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| CZ01-PC01 | On/Off | intermittent-vent | not classified |
| CZ01-PC02 | On/Off | intermittent-vent | not classified |
| CZ02-PC01 | On/Off | continuous bleed * | not classified |
| CZ02-PC02 | On/Off | intermittent-vent | not classified |
| CZ03-PC01 | Throttle | intermittent-vent | not classified |
| CZ03-PC02 | On/Off | intermittent-vent | not classified |
| CZ04-PC01 | On/Off | intermittent-vent | not classified |
| CZ04-PC02 | On/Off | intermittent-vent | not classified |
| CZ05-PC01 | On/Off | continuous bleed | not classified |
| CZ05-PC02 | On/Off | intermittent-vent | not classified |
| CZ05-PC03 | On/Off | intermittent-vent | not classified |
| CZ06-PC01 | Throttle | continuous bleed | not classified |
| CZ06-PC02 | On/Off | continuous bleed | not classified |
| CZ06-PC03 | Throttle | intermittent-vent | not classified |
| CZ07-PC01 | On/Off | intermittent-vent | not classified |
| CZ07-PC02 | On/Off | intermittent-vent | not classified |
| CZ08-PC01 | Throttle | continuous bleed | low bleed |
| CZ08-PC02 | Throttle | intermittent-vent * | low bleed |
| CZ09-PC01 | On/Off | continuous bleed | low bleed |
| CZ09-PC02 | Throttle | continuous bleed | low bleed |
| CZ10-PC01 | On/Off | intermittent-vent * | low bleed |
| CZ11-PC01 | Throttle | intermittent-vent * | low bleed |
| DL01-PC01 | On/Off | intermittent-vent | not classified |
| DL01-PC02 | On/Off | intermittent-vent | not classified |
| DL01-PC03 | On/Off | intermittent-vent | not classified |
| DL01-PC04 | On/Off | continuous bleed * | not classified |
| DL01-PC05 | On/Off | intermittent-vent | not classified |
| DL01-PC11 | On/Off | intermittent-vent | not classified |
| DL01-PC12 | On/Off | intermittent-vent | not classified |
| DL01-PC13 | On/Off | intermittent-vent | not classified |
| DL01-PC14 | On/Off | intermittent-vent | not classified |
| DL01-PC15 | On/Off | intermittent-vent | not classified |
| DL01-PC21 | On/Off | intermittent-vent | not classified |
| DL01-PC22 | On/Off | intermittent-vent | not classified |
| DL01-PC23 | On/Off | intermittent-vent * | not classified |
| DL01-PC24 | On/Off | continuous bleed | not classified |
| DL01-PC25 | On/Off | intermittent-vent | not classified |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| DL01-PC31 | On/Off | intermittent-vent | not classified |
| DL01-PC32 | On/Off | intermittent-vent | not classified |
| DL01-PC33 | On/Off | intermittent-vent | not classified |
| DL01-PC34 | On/Off | intermittent-vent | not classified |
| DL01-PC35 | On/Off | intermittent-vent | not classified |
| DL01-PC41 | On/Off | intermittent-vent | not classified |
| DL01-PC42 | On/Off | intermittent-vent | not classified |
| DL01-PC43 | On/Off | intermittent-vent | not classified |
| DL01-PC44 | On/Off | intermittent-vent | not classified |
| DL01-PC45 | On/Off | intermittent-vent | not classified |
| DL02-PC01 | On/Off | intermittent-vent | not classified |
| DL02-PC02 | On/Off | intermittent-vent | not classified |
| DL02-PC03 | On/Off | intermittent-vent | not classified |
| DL02-PC04 | On/Off | intermittent-vent | not classified |
| DL02-PC05 | On/Off | intermittent-vent | not classified |
| DL02-PC11 | On/Off | intermittent-vent | not classified |
| DL02-PC12 | On/Off | intermittent-vent | not classified |
| DL02-PC13 | On/Off | intermittent-vent | not classified |
| DL02-PC14 | On/Off | intermittent-vent * | not classified |
| DL02-PC15 | On/Off | intermittent-vent * | not classified |
| DL02-PC21 | On/Off | intermittent-vent | not classified |
| DL02-PC22 | On/Off | intermittent-vent | not classified |
| DL02-PC23 | On/Off | intermittent-vent | not classified |
| DL02-PC24 | On/Off | intermittent-vent | not classified |
| DL02-PC25 | On/Off | continuous bleed * | not classified |
| DL02-PC31 | On/Off | intermittent-vent | not classified |
| DL02-PC32 | On/Off | intermittent-vent | not classified |
| DL02-PC33 | On/Off | intermittent-vent * | not classified |
| DL02-PC34 | On/Off | intermittent-vent | not classified |
| DL02-PC35 | On/Off | intermittent-vent | not classified |
| DL02-PC41 | On/Off | intermittent-vent | not classified |
| DL02-PC42 | On/Off | intermittent-vent | not classified |
| DL02-PC43 | On/Off | intermittent-vent | not classified |
| DL02-PC44 | On/Off | intermittent-vent | not classified |
| DL02-PC45 | On/Off | intermittent-vent | not classified |
| DL02-PC51 | On/Off | intermittent-vent | not classified |
| DL02-PC52 | On/Off | intermittent-vent | not classified |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| DL02-PC53 | On/Off | intermittent-vent | not classified |
| DL02-PC54 | On/Off | intermittent-vent | not classified |
| DL02-PC55 | On/Off | intermittent-vent | not classified |
| DL02-PC61 | On/Off | intermittent-vent | not classified |
| DL02-PC62 | On/Off | intermittent-vent | not classified |
| GZ01-PC01 | On/Off | intermittent-vent | intermittent |
| GZ01-PC02 | On/Off | intermittent-vent | intermittent |
| GZ01-PC03 | On/Off | intermittent-vent | intermittent |
| GZ01-PC04 | On/Off | intermittent-vent | intermittent |
| GZ01-PC05 | On/Off | intermittent-vent | intermittent |
| GZ01-PC11 | On/Off | intermittent-vent | intermittent |
| GZ01-PC12 | On/Off | intermittent-vent | intermittent |
| GZ01-PC13 | On/Off | intermittent-vent | intermittent |
| GZ01-PC14 | On/Off | intermittent-vent | intermittent |
| GZ01-PC15 | On/Off | intermittent-vent | intermittent |
| GZ01-PC21 | On/Off | intermittent-vent | intermittent |
| GZ01-PC22 | On/Off | intermittent-vent | intermittent |
| GZ02-PC01 | Throttle | intermittent-vent | intermittent |
| GZ02-PC02 | Throttle | intermittent-vent | intermittent |
| GZ02-PC03 | Throttle | intermittent-vent | intermittent |
| GZ02-PC04 | Throttle | intermittent-vent | intermittent |
| GZ02-PC05 | On/Off | intermittent-vent | intermittent |
| GZ02-PC11 | On/Off | intermittent-vent | intermittent |
| GZ02-PC12 | On/Off | continuous bleed | intermittent |
| GZ02-PC13 | On/Off | intermittent-vent | intermittent |
| GZ02-PC14 | Throttle | continuous bleed | intermittent |
| GZ02-PC15 | On/Off | intermittent-vent | intermittent |
| GZ02-PC21 | Throttle | intermittent-vent | intermittent |
| GZ02-PC22 | On/Off | intermittent-vent | intermittent |
| GZ02-PC23 | On/Off | intermittent-vent | intermittent |
| GZ02-PC24 | On/Off | intermittent-vent | intermittent |
| GZ03-PC01 | On/Off | continuous bleed * | intermittent |
| GZ03-PC02 | On/Off | intermittent-vent * | intermittent |
| GZ03-PC03 | On/Off | intermittent-vent | intermittent |
| GZ03-PC04 | On/Off | intermittent-vent | intermittent |
| GZ03-PC05 | Throttle | intermittent-vent * | intermittent |
| GZ03-PC11 | On/Off | intermittent-vent | intermittent |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| GZ03-PC12 | On/Off | intermittent-vent | intermittent |
| GZ03-PC13 | Throttle | continuous bleed | intermittent |
| GZ03-PC14 | On/Off | intermittent-vent * | intermittent |
| GZ03-PC15 | On/Off | intermittent-vent | intermittent |
| GZ03-PC21 | On/Off | intermittent-vent | intermittent |
| GZ03-PC22 | On/Off | continuous bleed | intermittent |
| GZ03-PC23 | On/Off | intermittent-vent | intermittent |
| GZ03-PC24 | On/Off | continuous bleed | intermittent |
| GZ03-PC25 | On/Off | intermittent-vent | intermittent |
| GZ03-PC31 | On/Off | intermittent-vent | intermittent |
| GZ03-PC32 | Throttle | intermittent-vent | intermittent |
| GZ03-PC33 | Throttle | intermittent-vent | intermittent |
| GZ03-PC34 | On/Off | intermittent-vent | intermittent |
| GZ03-PC35 | On/Off | intermittent-vent | intermittent |
| GZ03-PC41 | On/Off | intermittent-vent | intermittent |
| GZ03-PC42 | Throttle | intermittent-vent | intermittent |
| GZ04-PC01 | On/Off | intermittent-vent | intermittent |
| GZ04-PC02 | Throttle | continuous bleed * | intermittent |
| GZ04-PC03 | On/Off | intermittent-vent * | intermittent |
| GZ04-PC04 | Throttle | intermittent-vent | intermittent |
| GZ04-PC05 | On/Off | intermittent-vent | intermittent |
| GZ04-PC11 | On/Off | intermittent-vent | intermittent |
| LB01-PC01 | On/Off | intermittent-vent | not classified |
| LB01-PC02 | On/Off | intermittent-vent | not classified |
| LB02-PC01 | On/Off | intermittent-vent | not classified |
| LB02-PC02 | On/Off | intermittent-vent | not classified |
| LB02-PC03 | On/Off | intermittent-vent | not classified |
| LB02-PC04 | On/Off | intermittent-vent | not classified |
| LB03-PC01 | On/Off | intermittent-vent * | not classified |
| LB03-PC02 | On/Off | intermittent-vent | not classified |
| LB04-PC01 | On/Off | intermittent-vent | not classified |
| LB04-PC02 | On/Off | intermittent-vent * | not classified |
| LB04-PC03 | On/Off | intermittent-vent | not classified |
| LB04-PC04 | On/Off | intermittent-vent | not classified |
| LB05-PC01 | On/Off | intermittent-vent * | not classified |
| LB05-PC02 | On/Off | intermittent-vent | not classified |
| LB05-PC03 | On/Off | intermittent-vent * | not classified |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| LB05-PC04 | On/Off | intermittent-vent | not classified |
| LB06-PC01 | On/Off | intermittent-vent | not classified |
| LB06-PC02 | On/Off | intermittent-vent | not classified |
| LB06-PC03 | On/Off | intermittent-vent | not classified |
| LB06-PC04 | On/Off | intermittent-vent | not classified |
| LB06-PC05 | On/Off | intermittent-vent | not classified |
| LB06-PC11 | On/Off | intermittent-vent | not classified |
| LB07-PC01 | On/Off | intermittent-vent | not classified |
| LB07-PC02 | On/Off | continuous bleed * | not classified |
| LB07-PC03 | On/Off | intermittent-vent | not classified |
| LB07-PC04 | On/Off | intermittent-vent | not classified |
| OF01-PC01 | On/Off | intermittent-vent * | not classified |
| OF02-PC01 | On/Off | intermittent-vent | not classified |
| OF03-PC01 | On/Off | intermittent-vent | not classified |
| OF04-PC01 | On/Off | intermittent-vent | not classified |
| OF05-PC01 | On/Off | intermittent-vent | not classified |
| OF06-PC01 | On/Off | intermittent-vent | not classified |
| OF07-PC01 | On/Off | continuous bleed * | not classified |
| OF08-PC01 | On/Off | intermittent-vent | not classified |
| OF08-PC02 | On/Off | intermittent-vent | not classified |
| OF09-PC01 | On/Off | intermittent-vent | not classified |
| OF10-PC01 | On/Off | continuous bleed | not classified |
| OF11-PC01 | On/Off | intermittent-vent * | not classified |
| OF11-PC02 | Throttle | continuous bleed * | not classified |
| OF11-PC03 | Throttle | intermittent-vent | not classified |
| OF11-PC04 | Throttle | intermittent-vent | not classified |
| RB01-PC01 | On/Off | intermittent-vent | not classified |
| RB01-PC02 | On/Off | intermittent-vent | not classified |
| RB01-PC03 | On/Off | intermittent-vent | not classified |
| RB01-PC04 | Throttle | continuous bleed | not classified |
| RB01-PC05 | On/Off | intermittent-vent | not classified |
| RB01-PC11 | On/Off | intermittent-vent | not classified |
| RB01-PC12 | On/Off | intermittent-vent | not classified |
| RB01-PC13 | On/Off | continuous bleed | not classified |
| RB01-PC14 | On/Off | intermittent-vent * | not classified |
| RB01-PC15 | On/Off | intermittent-vent | not classified |
| RB01-PC21 | Throttle | continuous bleed | not classified |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| RB01-PC23 | Throttle | continuous bleed | not classified |
| RB01-PC24 | On/Off | intermittent-vent | not classified |
| RB01-PC25 | On/Off | intermittent-vent | not classified |
| RB01-PC34 | On/Off | continuous bleed | not classified |
| RB02-PC01 | On/Off | intermittent-vent | not classified |
| RB02-PC02 | On/Off | intermittent-vent | not classified |
| RB02-PC03 | Throttle | continuous bleed * | not classified |
| RB02-PC05 | On/Off | intermittent-vent | not classified |
| RB02-PC11 | On/Off | intermittent-vent | not classified |
| RB02-PC12 | On/Off | intermittent-vent | not classified |
| RQ01-PC01 | Throttle | intermittent-vent | not classified |
| RQ02-PC01 | Throttle | continuous bleed | not classified |
| RQ02-PC02 | On/Off | intermittent-vent | not classified |
| RQ03-PC01 | Throttle | continuous bleed | not classified |
| RQ04-PC01 | Throttle | intermittent-vent | not classified |
| RQ05-PC01 | Throttle | intermittent-vent | not classified |
| RQ05-PC02 | On/Off | intermittent-vent | not classified |
| RQ05-PC03 | Throttle | continuous bleed | not classified |
| RQ05-PC04 | On/Off | intermittent-vent | not classified |
| RQ06-PC01 | On/Off | intermittent-vent | not classified |
| RQ06-PC02 | On/Off | intermittent-vent | not classified |
| RQ06-PC03 | Throttle | intermittent-vent | not classified |
| RQ06-PC04 | Throttle | intermittent-vent | not classified |
| RQ07-PC01 | On/Off | intermittent-vent | not classified |
| RQ07-PC02 | On/Off | intermittent-vent | not classified |
| RQ07-PC03 | Throttle | continuous bleed | not classified |
| RQ07-PC04 | Throttle | continuous bleed | not classified |
| RQ07-PC05 | On/Off | intermittent-vent | not classified |
| VF01-PC01 | On/Off | continuous bleed | not classified |
| VF01-PC02 | On/Off | intermittent-vent | not classified |
| VF01-PC03 | On/Off | intermittent-vent | not classified |
| VF01-PC04 | On/Off | intermittent-vent | not classified |
| VF01-PC05 | On/Off | continuous bleed | not classified |
| VF01-PC11 | On/Off | intermittent-vent | not classified |
| VF01-PC12 | On/Off | intermittent-vent | not classified |
| VF01-PC13 | On/Off | intermittent-vent | not classified |
| VF01-PC14 | On/Off | intermittent-vent | not classified |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| VF01-PC15 | On/Off | intermittent-vent | not classified |
| VF01-PC21 | On/Off | intermittent-vent | not classified |
| VF01-PC22 | On/Off | continuous bleed | not classified |
| VF01-PC23 | On/Off | intermittent-vent | not classified |
| VF01-PC24 | On/Off | intermittent-vent | not classified |
| VF01-PC25 | On/Off | intermittent-vent | not classified |
| VF01-PC31 | On/Off | intermittent-vent | not classified |
| VF01-PC32 | On/Off | intermittent-vent | not classified |
| VF01-PC33 | On/Off | intermittent-vent | not classified |
| VF01-PC34 | On/Off | intermittent-vent | not classified |
| VF01-PC35 | On/Off | intermittent-vent | not classified |
| VF01-PC41 | On/Off | intermittent-vent | not classified |
| VF01-PC42 | On/Off | intermittent-vent | not classified |
| VF01-PC43 | On/Off | intermittent-vent | not classified |
| VF01-PC44 | On/Off | intermittent-vent | not classified |
| VF01-PC45 | On/Off | continuous bleed | not classified |
| VF01-PC51 | On/Off | continuous bleed | not classified |
| VF01-PC52 | On/Off | intermittent-vent | not classified |
| VF01-PC53 | On/Off | intermittent-vent * | not classified |
| VF01-PC54 | On/Off | intermittent-vent * | not classified |
| VF01-PC55 | On/Off | intermittent-vent | not classified |
| VF02-PC01 | On/Off | intermittent-vent | not classified |
| VF02-PC02 | On/Off | intermittent-vent | low bleed |
| VF02-PC03 | On/Off | intermittent-vent | low bleed |
| VF02-PC04 | On/Off | intermittent-vent | low bleed |
| VF02-PC05 | On/Off | intermittent-vent | low bleed |
| VF02-PC11 | On/Off | intermittent-vent | low bleed |
| VF02-PC12 | On/Off | intermittent-vent | low bleed |
| XQ01-PC01 | On/Off | intermittent-vent | intermittent |
| XQ01-PC02 | On/Off | intermittent-vent | intermittent |
| XQ01-PC03 | Throttle | intermittent-vent | intermittent |
| XQ01-PC04 | On/Off | continuous bleed * | high bleed |
| XQ02-PC01 | On/Off | intermittent-vent | intermittent |
| XQ02-PC02 | On/Off | intermittent-vent | intermittent |
| XQ02-PC03 | Throttle | intermittent-vent | intermittent |
| XQ02-PC04 | On/Off | continuous bleed | high bleed |
| XQ03-PC01 | On/Off | continuous bleed | high bleed |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| XQ03-PC02 | On/Off | continuous bleed | high bleed |
| XQ03-PC03 | Throttle | intermittent-vent | intermittent |
| XQ03-PC04 | On/Off | continuous bleed | high bleed |
| XQ04-PC01 | On/Off | intermittent-vent | intermittent |
| XQ04-PC02 | On/Off | continuous bleed | high bleed |
| XQ04-PC03 | Throttle | intermittent-vent | intermittent |
| XQ04-PC04 | On/Off | continuous bleed * | intermittent |
| XQ05-PC01 | On/Off | intermittent-vent | intermittent |
| XQ05-PC02 | On/Off | continuous bleed | high bleed |
| XQ05-PC03 | Throttle | intermittent-vent | intermittent |
| XQ05-PC04 | On/Off | intermittent-vent | intermittent |
| XQ06-PC01 | On/Off | continuous bleed | intermittent |
| XQ06-PC02 | On/Off | continuous bleed | intermittent |
| XQ06-PC03 | Throttle | intermittent-vent | intermittent |
| XQ06-PC04 | On/Off | intermittent-vent | intermittent |
| XQ07-PC01 | On/Off | intermittent-vent | intermittent |
| XQ07-PC02 | On/Off | intermittent-vent | intermittent |
| XQ07-PC03 | Throttle | intermittent-vent | intermittent |
| XQ07-PC04 | On/Off | intermittent-vent | intermittent |
| ZW01-PC01 | On/Off | continuous bleed * | not classified |
| ZW01-PC02 | On/Off | intermittent-vent | not classified |
| ZW01-PC03 | On/Off | intermittent-vent | not classified |
| ZW01-PC04 | On/Off | intermittent-vent | not classified |
| ZW01-PC05 | On/Off | intermittent-vent | not classified |
| ZW01-PC11 | On/Off | intermittent-vent | not classified |
| ZW01-PC12 | On/Off | intermittent-vent | not classified |
| ZW01-PC13 | On/Off | continuous bleed * | not classified |
| ZW01-PC14 | On/Off | intermittent-vent | not classified |
| ZW01-PC15 | On/Off | intermittent-vent | not classified |
| ZW01-PC21 | On/Off | intermittent-vent | not classified |
| ZW01-PC22 | On/Off | intermittent-vent | not classified |
| ZW01-PC23 | On/Off | intermittent-vent | not classified |
| ZW01-PC24 | On/Off | intermittent-vent | not classified |
| ZW01-PC25 | On/Off | intermittent-vent | not classified |
| ZW01-PC31 | On/Off | intermittent-vent | not classified |
| ZW01-PC32 | On/Off | intermittent-vent | not classified |
| ZW01-PC33 | On/Off | intermittent-vent | not classified |

**Table A-6** (continued).

| Device Identifier | Field Characterization of Device service | Classification based on time series[1] | Company classification into EPA categories[2] |
|---|---|---|---|
| ZW01-PC34 | On/Off | intermittent-vent | not classified |
| ZW01-PC35 | On/Off | intermittent-vent | not classified |
| ZW02-PC01 | On/Off | continuous bleed | not classified |
| ZW02-PC02 | On/Off | intermittent-vent | not classified |
| ZW02-PC03 | On/Off | intermittent-vent | not classified |
| ZW02-PC04 | On/Off | intermittent-vent | not classified |
| ZW02-PC12 | On/Off | intermittent-vent | not classified |
| ZW03-PC01 | On/Off | intermittent-vent | not classified |
| ZW03-PC02 | On/Off | continuous bleed * | not classified |
| ZW03-PC03 | On/Off | intermittent-vent | not classified |

(1) Classification based on time series: *Intermittent-vent*: Clear actuation pattern, returning to zero between actuations. *Continuous bleed*: Non-zero, no temporal variability. A (*) Indicates that the study team made classification based on best judgment due to ambiguity from the time series.
(2) *Intermittent High bleed*, or *Low bleed*, for sites where all devices had the same classification (non-ambiguous). *Not classified* for sites where companies reported more than one device type,

**Table A-7.** For each device, the manufacturer and model are classified into blinded bins. The table shows measured tubing diameter and tubing length (from the controller to the valve it controls), supply gas pressure, as well as gas hydrocarbon composition for the well each device is servicing.

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| AA01-PC04 | Q01 | 29 | 0.25 | 94 | 81.85 | 8.72 | 3.86 | 2.47 |
| AA01-PC05 | Q01 | 30 | 0.25 | 94 | 81.85 | 8.72 | 3.86 | 2.47 |
| AA01-PC06 | Q01 | 0 | 0.25 | 94 | 81.42 | 8.79 | 4.02 | 2.69 |
| AA01-PC07 | Q01 | 0 | 0.25 | 94 | 81.42 | 8.79 | 4.02 | 2.69 |
| AA01-PC08 | Q01 | 28 | 0.25 | 94 | 78.32 | 8.87 | 4.44 | 3.05 |
| AA01-PC09 | Q01 | 30 | 0.25 | 94 | 78.32 | 8.87 | 4.44 | 3.05 |
| AA01-PC11 | I01 | 34 | 0.25 | 15 | 81.85 | 8.72 | 3.86 | 2.47 |
| AA02-PC04 | H01 | 11 | 0.25 | 6 | 80.53 | 8.79 | 4.10 | 2.74 |
| AA02-PC05 | L01 | 29 | 0.25 | 32 | 80.53 | 8.79 | 4.10 | 2.74 |
| AA02-PC06 | L01 | 29 | 0.25 | 39 | 80.53 | 8.79 | 4.10 | 2.74 |
| AA02-PC07 | L01 | 29 | 0.25 | 41 | 80.53 | 8.79 | 4.10 | 2.74 |
| AA02-PC08 | I01 | 60 | 0.375 | 23 | 80.53 | 8.79 | 4.10 | 2.74 |
| AA02-PC09 | L01 | 29 | 0.25 | 19 | 80.53 | 8.79 | 4.10 | 2.74 |
| AP01-PC01 | N01 | 30 | 0.375 | 180 | 66.43 | 14.72 | 10.54 | 5.88 |
| AP01-PC02 | N01 | 30 | 0.375 | 50 | 66.43 | 14.72 | 10.54 | 5.88 |
| AP01-PC03 | N01 | 30 | 0.375 | 50 | 66.43 | 14.72 | 10.54 | 5.88 |
| AP01-PC04 | N01 | 30 | 0.375 | 60 | 66.43 | 14.72 | 10.54 | 5.88 |
| AP01-PC05 | N01 | 30 | 0.375 | 60 | 66.43 | 14.72 | 10.54 | 5.88 |
| AP01-PC12 | I02 | 11 | 0.375 | 25 | 66.43 | 14.72 | 10.54 | 5.88 |
| AP02-PC01 | I02 | 22 | 0.375 | 90 | 68.85 | 14.18 | 9.90 | 4.86 |
| AP02-PC02 | I02 | 20 | 0.375 | 90 | 70.63 | 13.28 | 9.05 | 4.85 |
| AP02-PC03 | I02 | 24 | 0.375 | 75 | 72.66 | 12.24 | 8.36 | 4.40 |

**Table A-7** (continued)

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| AP02-PC04 | I02 | 55 | 0.375 | 45 | 70.05 | 12.41 | 9.96 | 4.87 |
| AP03-PC01 | I02 | 30 | 0.375 | 55 | 64.46 | 15.11 | 11.39 | 6.86 |
| AP03-PC02 | I02 | 30 | 0.375 | 50 | 68.26 | 13.28 | 10.21 | 6.25 |
| AP04-PC01 | I02 | 32 | 0.375 | 25 | 65.35 | 13.15 | 11.62 | 7.04 |
| AP04-PC02 | I02 | 23 | 0.375 | 40 | 66.28 | 14.46 | 9.79 | 6.61 |
| AP04-PC03 | I02 | 32 | 0.375 | 65 | 62.75 | 13.93 | 12.76 | 7.82 |
| AP04-PC04 | I02 | 30 | 0.375 | 55 | 59.63 | 16.87 | 14.22 | 7.25 |
| AP05-PC01 | I02 | 34 | 0.375 | 25 | 70.86 | 14.03 | 7.87 | 5.14 |
| AP05-PC02 | I02 | 32 | 0.375 | 70 | 70.86 | 14.03 | 7.87 | 5.14 |
| CW01-PC01 | F01 | 20 | 0.375 | 45 | 81.26 | 7.76 | 3.90 | 2.87 |
| CW01-PC02 | B01 | 20 | 0.375 | 130 | 81.26 | 7.76 | 3.90 | 2.87 |
| CW01-PC03 | Q02 | 22 | 0.375 | 30 | 81.26 | 7.76 | 3.90 | 2.87 |
| CW01-PC04 | Q02 | 18 | 0.375 | 30 | 81.26 | 7.76 | 3.90 | 2.87 |
| CW01-PC05 | I05 | 20 | 0.375 | 28 | 81.26 | 7.76 | 3.90 | 2.87 |
| CW01-PC11 | F01 | 25 | 0.375 | 45 | 81.58 | 8.25 | 3.75 | 2.71 |
| CW01-PC12 | B01 | 25 | 0.375 | 130 | 81.58 | 8.25 | 3.75 | 2.71 |
| CW01-PC13 | Q02 | 25 | 0.375 | 30 | 81.58 | 8.25 | 3.75 | 2.71 |
| CW01-PC14 | Q02 | 30 | 0.375 | 30 | 81.58 | 8.25 | 3.75 | 2.71 |
| CW01-PC15 | I05 | 25 | 0.375 | 28 | 81.58 | 8.25 | 3.75 | 2.71 |
| CW01-PC21 | F01 | 18 | 0.375 | 45 | 84.18 | 7.69 | 2.84 | 1.85 |
| CW01-PC22 | B01 | 18 | 0.375 | 130 | 84.18 | 7.69 | 2.84 | 1.85 |
| CW01-PC23 | Q02 | 18 | 0.375 | 30 | 84.18 | 7.69 | 2.84 | 1.85 |
| CW01-PC24 | Q02 | 18 | 0.375 | 30 | 84.18 | 7.69 | 2.84 | 1.85 |
| CW01-PC25 | I05 | 18 | 0.375 | 28 | 84.18 | 7.69 | 2.84 | 1.85 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| CW01-PC31 | F01 | 20 | 0.375 | 45 | 81.69 | 7.79 | 3.77 | 2.60 |
| CW01-PC32 | B01 | 20 | 0.375 | 130 | 81.69 | 7.79 | 3.77 | 2.60 |
| CW01-PC33 | Q02 | 22 | 0.375 | 30 | 81.69 | 7.79 | 3.77 | 2.60 |
| CW01-PC34 | Q02 | 22 | 0.375 | 30 | 81.69 | 7.79 | 3.77 | 2.60 |
| CW01-PC35 | I05 | 22 | 0.375 | 28 | 81.69 | 7.79 | 3.77 | 2.60 |
| CW02-PC01 | F01 | 20 | 0.375 | 45 | 81.80 | 8.12 | 4.39 | 2.63 |
| CW02-PC02 | B01 | 20 | 0.375 | 130 | 81.80 | 8.12 | 4.39 | 2.63 |
| CW02-PC03 | Q02 | 20 | 0.375 | 30 | 81.80 | 8.12 | 4.39 | 2.63 |
| CW02-PC04 | Q02 | 19 | 0.375 | 30 | 81.80 | 8.12 | 4.39 | 2.63 |
| CW02-PC05 | I05 | 20 | 0.375 | 28 | 81.80 | 8.12 | 4.39 | 2.63 |
| CW02-PC11 | F01 | 15 | 0.375 | 45 | 80.64 | 7.81 | 4.41 | 3.51 |
| CW02-PC12 | B01 | 15 | 0.375 | 130 | 80.64 | 7.81 | 4.41 | 3.51 |
| CW02-PC13 | Q02 | 16 | 0.375 | 30 | 80.64 | 7.81 | 4.41 | 3.51 |
| CW02-PC14 | Q02 | 16 | 0.375 | 30 | 80.64 | 7.81 | 4.41 | 3.51 |
| CW02-PC15 | I05 | 16 | 0.375 | 28 | 80.64 | 7.81 | 4.41 | 3.51 |
| CW02-PC21 | F01 | 20 | 0.375 | 45 | 82.36 | 7.66 | 3.78 | 2.60 |
| CW02-PC22 | B01 | 20 | 0.375 | 130 | 82.36 | 7.66 | 3.78 | 2.60 |
| CW02-PC23 | Q02 | 22 | 0.375 | 30 | 82.36 | 7.66 | 3.78 | 2.60 |
| CW02-PC24 | Q02 | 22 | 0.375 | 30 | 82.36 | 7.66 | 3.78 | 2.60 |
| CW02-PC25 | I05 | 22 | 0.375 | 28 | 82.36 | 7.66 | 3.78 | 2.60 |
| CW02-PC31 | F01 | 19 | 0.375 | 30 | 82.02 | 7.89 | 4.01 | 2.48 |
| CW02-PC32 | B01 | 19 | 0.375 | 130 | 82.02 | 7.89 | 4.01 | 2.48 |
| CW02-PC33 | Q02 | 19 | 0.375 | 30 | 82.02 | 7.89 | 4.01 | 2.48 |
| CW02-PC34 | Q02 | 20 | 0.375 | 30 | 82.02 | 7.89 | 4.01 | 2.48 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| CW02-PC35 | I05 | 19 | 0.375 | 28 | 82.02 | 7.89 | 4.01 | 2.48 |
| CZ01-PC01 | M01 | 32.5 | 0.375 | 40 | 90.81 | 3.25 | 0.99 | 2.26 |
| CZ01-PC02 | E01 | 20 | 0.375 | 11 | 90.81 | 3.25 | 0.99 | 2.26 |
| CZ02-PC01 | J01 | 17 | 0.25 | 54 | 91.13 | 2.89 | 0.91 | 2.26 |
| CZ02-PC02 | E01 | 20 | 0.25 | 32 | 91.13 | 2.89 | 0.91 | 2.26 |
| CZ03-PC01 | A01 | 27 | 0.5 | 37 | 93.33 | 2.04 | 0.51 | 1.26 |
| CZ03-PC02 | E01 | 20 | 0.375 | 13 | 93.33 | 2.04 | 0.51 | 1.26 |
| CZ04-PC01 | M01 | 11 | 0.375 | 43 | 91.72 | 2.82 | 0.79 | 1.89 |
| CZ04-PC02 | E01 | 20 | 0.375 | 10 | 91.72 | 2.82 | 0.79 | 1.89 |
| CZ05-PC01 | A01 | 29 | 0.375 | 45 | 93.76 | 1.87 | 0.46 | 1.14 |
| CZ05-PC02 | E01 | 20 | 0.375 | 19 | 93.76 | 1.87 | 0.46 | 1.14 |
| CZ05-PC03 | A01 | 29 | 0.375 | 18 | 93.76 | 1.87 | 0.46 | 1.14 |
| CZ06-PC01 | G01 | 6 | 0.25 | 73 | 94.07 | 1.84 | 0.42 | 0.92 |
| CZ06-PC02 | E01 | 20 | 0.375 | 17 | 94.07 | 1.84 | 0.42 | 0.92 |
| CZ06-PC03 | G01 | 6 | 0.25 | 39 | 94.07 | 1.84 | 0.42 | 0.92 |
| CZ07-PC01 | A01 | 20 | 0.375 | 38 | 93.29 | 2.10 | 0.54 | 1.20 |
| CZ07-PC02 | E01 | 27.5 | 0.375 | 27 | 93.29 | 2.10 | 0.54 | 1.20 |
| CZ08-PC01 | M01 | 11 | 0.375 | 77 | 96.14 | 0.76 | 0.11 | 0.20 |
| CZ08-PC02 | M01 | 19 | 0.375 | 77 | 97.58 | 0.78 | 0.08 | 0.15 |
| CZ09-PC01 | M01 | 19 | 0.375 | 52 | 96.07 | 0.70 | 0.06 | 0.10 |
| CZ09-PC02 | M01 | 9 | 0.375 | 40 | 96.07 | 0.70 | 0.06 | 0.10 |
| CZ10-PC01 | M01 | 13 | 0.375 | 40 | 96.10 | 0.69 | 0.09 | 0.19 |
| CZ11-PC01 | M01 | 23 | 0.375 | 43 | 95.81 | 0.86 | 0.11 | 0.20 |
| DL01-PC01 | Q02 | 15 | 0.375 | 40 | 90.57 | 4.93 | 1.37 | 1.14 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| DL01-PC02 | Q02 | 12 | 0.375 | 40 | 90.57 | 4.93 | 1.37 | 1.14 |
| DL01-PC03 | I05 | 30 | 0.375 | 90 | 90.57 | 4.93 | 1.37 | 1.14 |
| DL01-PC04 | F01 | 27 | 0.375 | 90 | 90.57 | 4.93 | 1.37 | 1.14 |
| DL01-PC05 | I05 | 25 | 0.375 | 90 | 90.84 | 4.92 | 1.43 | 1.16 |
| DL01-PC11 | M01 | 30 | 0.375 | 25 | 90.84 | 4.92 | 1.43 | 1.16 |
| DL01-PC12 | F01 | 27 | 0.375 | 160 | 90.84 | 4.92 | 1.43 | 1.16 |
| DL01-PC13 | M01 | 35 | 0.375 | 25 | 90.10 | 5.08 | 1.39 | 1.08 |
| DL01-PC14 | F01 | 30 | 0.375 | 160 | 90.10 | 5.08 | 1.39 | 1.08 |
| DL01-PC15 | M01 | 35 | 0.375 | 25 | 91.00 | 4.16 | 1.04 | 0.88 |
| DL01-PC21 | F01 | 35 | 0.375 | 160 | 91.00 | 4.16 | 1.04 | 0.88 |
| DL01-PC22 | M01 | 30 | 0.375 | 25 | 90.65 | 4.82 | 1.32 | 1.12 |
| DL01-PC23 | F01 | 30 | 0.375 | 160 | 90.65 | 4.82 | 1.32 | 1.12 |
| DL01-PC24 | M01 | 38 | 0.375 | 25 | 89.35 | 5.19 | 1.39 | 1.18 |
| DL01-PC25 | F01 | 28 | 0.375 | 160 | 89.35 | 5.19 | 1.39 | 1.18 |
| DL01-PC31 | I05 | 25 | 0.375 | 90 | 90.84 | 4.92 | 1.43 | 1.16 |
| DL01-PC32 | M01 | 28 | 0.375 | 25 | 90.84 | 4.92 | 1.43 | 1.16 |
| DL01-PC33 | F01 | 28 | 0.375 | 160 | 90.84 | 4.92 | 1.43 | 1.16 |
| DL01-PC34 | M01 | 26 | 0.375 | 25 | 90.88 | 4.82 | 1.35 | 1.16 |
| DL01-PC35 | F01 | 25 | 0.375 | 160 | 90.88 | 4.82 | 1.35 | 1.16 |
| DL01-PC41 | M01 | 28 | 0.375 | 25 | 89.68 | 5.11 | 1.38 | 1.11 |
| DL01-PC42 | F01 | 28 | 0.375 | 160 | 89.68 | 5.11 | 1.38 | 1.11 |
| DL01-PC43 | M01 | 29 | 0.375 | 25 | 89.35 | 5.30 | 1.44 | 1.03 |
| DL01-PC44 | F01 | 28 | 0.375 | 160 | 89.35 | 5.30 | 1.44 | 1.03 |
| DL01-PC45 | I05 | 25 | 0.375 | 45 | 89.35 | 5.30 | 1.44 | 1.03 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| DL02-PC01 | M03 | 28 | 0.375 | 25 | 90.36 | 4.93 | 1.30 | 1.03 |
| DL02-PC02 | F01 | 28 | 0.375 | 160 | 90.36 | 4.93 | 1.30 | 1.03 |
| DL02-PC03 | M03 | 22 | 0.375 | 25 | 90.51 | 5.03 | 1.37 | 1.09 |
| DL02-PC04 | F01 | 25 | 0.375 | 160 | 90.51 | 5.03 | 1.37 | 1.09 |
| DL02-PC05 | M03 | 26 | 0.375 | 25 | 90.51 | 5.03 | 1.37 | 1.09 |
| DL02-PC11 | F01 | 25 | 0.375 | 160 | 90.51 | 5.03 | 1.37 | 1.09 |
| DL02-PC12 | M03 | 24 | 0.375 | 25 | 90.39 | 4.99 | 1.34 | 1.03 |
| DL02-PC13 | F01 | 25 | 0.375 | 160 | 90.39 | 4.99 | 1.34 | 1.03 |
| DL02-PC14 | M03 | 26 | 0.375 | 25 | 90.47 | 5.19 | 1.47 | 1.11 |
| DL02-PC15 | F01 | 25 | 0.375 | 160 | 90.47 | 5.19 | 1.47 | 1.11 |
| DL02-PC21 | M03 | 26 | 0.375 | 25 | 90.20 | 4.98 | 1.30 | 1.04 |
| DL02-PC22 | F01 | 27 | 0.375 | 160 | 90.20 | 4.98 | 1.30 | 1.04 |
| DL02-PC23 | M03 | 26 | 0.375 | 25 | 90.00 | 5.03 | 1.35 | 0.88 |
| DL02-PC24 | F01 | 26 | 0.375 | 160 | 90.00 | 5.03 | 1.35 | 0.88 |
| DL02-PC25 | M03 | 26 | 0.375 | 25 | 90.21 | 5.10 | 1.40 | 1.04 |
| DL02-PC31 | F01 | 27 | 0.375 | 160 | 90.21 | 5.10 | 1.40 | 1.04 |
| DL02-PC32 | M03 | 26 | 0.375 | 25 | 89.80 | 5.15 | 1.31 | 0.97 |
| DL02-PC33 | F01 | 26 | 0.375 | 160 | 89.80 | 5.15 | 1.31 | 0.97 |
| DL02-PC34 | M03 | 28 | 0.375 | 25 | 90.38 | 5.08 | 1.38 | 0.84 |
| DL02-PC35 | F01 | 28 | 0.375 | 160 | 90.38 | 5.08 | 1.38 | 0.84 |
| DL02-PC41 | M03 | 30 | 0.375 | 25 | 90.06 | 4.97 | 1.28 | 0.82 |
| DL02-PC42 | F01 | 28 | 0.375 | 160 | 90.06 | 4.97 | 1.28 | 0.82 |
| DL02-PC43 | M03 | 28 | 0.375 | 25 | 90.27 | 4.78 | 1.20 | 1.50 |
| DL02-PC44 | F01 | 28 | 0.375 | 160 | 90.27 | 4.78 | 1.20 | 1.50 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| DL02-PC45 | M03 | 28 | 0.375 | 25 | 90.38 | 4.96 | 1.32 | 0.97 |
| DL02-PC51 | F01 | 26 | 0.375 | 160 | 90.38 | 4.96 | 1.32 | 0.97 |
| DL02-PC52 | M03 | 28 | 0.375 | 25 | 89.67 | 5.07 | 1.17 | 0.81 |
| DL02-PC53 | F01 | 28 | 0.375 | 160 | 89.67 | 5.07 | 1.17 | 0.81 |
| DL02-PC54 | I05 | 25 | 0.375 | 90 | 90.20 | 4.98 | 1.30 | 1.04 |
| DL02-PC55 | I05 | 28 | 0.375 | 90 | 90.20 | 4.98 | 1.30 | 1.04 |
| DL02-PC61 | I05 | 25 | 0.375 | 90 | 90.20 | 4.98 | 1.30 | 1.04 |
| DL02-PC62 | I05 | 25 | 0.375 | 45 | 90.20 | 4.98 | 1.30 | 1.04 |
| GZ01-PC01 | J01 | 23 | 0.375 | 47 | 97.40 | 0.52 | 0.11 | 0.21 |
| GZ01-PC02 | J01 | 22 | 0.375 | 47 | 97.40 | 0.52 | 0.11 | 0.21 |
| GZ01-PC03 | J01 | 26 | 0.375 | 184 | 97.42 | 0.52 | 0.11 | 0.15 |
| GZ01-PC04 | J01 | 26 | 0.375 | 47 | 97.42 | 0.52 | 0.11 | 0.15 |
| GZ01-PC05 | J01 | 20 | 0.375 | 184 | 97.32 | 0.52 | 0.11 | 0.25 |
| GZ01-PC11 | J01 | 23 | 0.375 | 47 | 97.32 | 0.52 | 0.11 | 0.25 |
| GZ01-PC12 | J01 | 25 | 0.375 | 184 | 97.29 | 0.55 | 0.12 | 0.28 |
| GZ01-PC13 | J01 | 23 | 0.375 | 47 | 97.29 | 0.55 | 0.12 | 0.28 |
| GZ01-PC14 | K01 | 30 | 0.375 | NA | 97.40 | 0.52 | 0.11 | 0.21 |
| GZ01-PC15 | K01 | 30 | 0.375 | NA | 97.42 | 0.52 | 0.11 | 0.15 |
| GZ01-PC21 | K01 | 30 | 0.375 | NA | 97.32 | 0.52 | 0.11 | 0.25 |
| GZ01-PC22 | K01 | 30 | 0.375 | NA | 97.29 | 0.55 | 0.12 | 0.28 |
| GZ02-PC01 | M01 | 29 | 0.375 | 127 | 97.35 | 0.51 | 0.10 | 0.21 |
| GZ02-PC02 | M01 | 28 | 0.375 | 35 | 97.35 | 0.51 | 0.10 | 0.21 |
| GZ02-PC03 | M01 | 30 | 0.375 | 127 | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ02-PC04 | M01 | 31 | 0.375 | 35 | 97.42 | 0.51 | 0.09 | 0.12 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| GZ02-PC05 | H01 | NA | 0.375 | NA | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ02-PC11 | J01 | 30 | 0.375 | 110 | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ02-PC12 | J01 | 28 | 0.375 | 120 | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ02-PC13 | J01 | 30 | 0.375 | 135 | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ02-PC14 | I01 | 42 | 0.375 | 36 | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ02-PC15 | M01 | NA | 0.375 | 20 | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ02-PC21 | M01 | 20 | 0.25 | 120 | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ02-PC22 | K01 | 3 | 0.375 | 3600 | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ02-PC23 | K01 | 3 | 0.375 | 3600 | 97.35 | 0.51 | 0.10 | 0.21 |
| GZ02-PC24 | I01 | 300 | 0.375 | 25 | 97.42 | 0.51 | 0.09 | 0.12 |
| GZ03-PC01 | L01 | 30 | 0.25 | 26 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC02 | L01 | 30 | 0.25 | 26 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC03 | L01 | 30 | 0.25 | 26 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC04 | H01 | NA | 0.25 | 8 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC05 | I01 | 32 | 0.375 | 36 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC11 | K01 | 37 | 0.375 | 5400 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC12 | K01 | 37 | 0.375 | 5400 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC13 | M01 | 26 | 0.375 | 93 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC14 | M01 | 27 | 0.375 | 70 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC15 | M01 | 25 | 0.375 | 55 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC21 | M01 | 27 | 0.375 | 84 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC22 | M01 | 7 | 0.375 | 47 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC23 | M01 | 32 | 0.375 | 29 | 97.36 | 0.30 | 0.03 | 0.04 |
| GZ03-PC24 | M01 | 1 | 0.375 | 47 | 97.36 | 0.30 | 0.03 | 0.04 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| GZ03-PC25 | K01 | 31 | 0.375 | 66 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC31 | M04 | 25 | 0.375 | 95 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC32 | M03 | 26 | 0.25 | 28 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC33 | M03 | 29 | 0.25 | 86 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC34 | I05 | NA | 0.375 | 40 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC35 | I05 | 29 | 0.375 | 31 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC41 | H01 | 32 | 0.25 | 8 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ03-PC42 | I01 | 36 | 0.375 | 20 | 97.16 | 0.33 | 0.03 | 0.08 |
| GZ04-PC01 | M01 | 27 | 0.375 | 94 | 90.83 | 0.22 | 0.01 | 0.07 |
| GZ04-PC02 | M01 | 25 | 0.6 | 32 | 90.83 | 0.22 | 0.01 | 0.07 |
| GZ04-PC03 | M01 | 30 | 0.375 | 25 | 97.44 | 0.23 | 0.02 | 0.02 |
| GZ04-PC04 | M01 | 30 | 0.375 | 94 | 97.44 | 0.23 | 0.02 | 0.02 |
| GZ04-PC05 | K01 | 30 | 0.375 | 5400 | 90.83 | 0.22 | 0.01 | 0.07 |
| GZ04-PC11 | K01 | 32 | 0.375 | 3600 | 97.44 | 0.23 | 0.02 | 0.02 |
| LB01-PC01 | M03 | 30 | 0.375 | 400 | 80.52 | 10.62 | 3.62 | 3.61 |
| LB01-PC02 | M03 | 30 | 0.375 | 292 | 80.52 | 10.62 | 3.62 | 3.61 |
| LB02-PC01 | M01 | 30 | 0.375 | 85 | 80.41 | 10.77 | 3.56 | 3.48 |
| LB02-PC02 | M01 | 30 | 0.375 | 80 | 80.41 | 10.77 | 3.56 | 3.48 |
| LB02-PC03 | M01 | 30 | 0.375 | 80 | 80.41 | 10.77 | 3.56 | 3.48 |
| LB02-PC04 | M01 | 30 | 0.375 | 80 | 80.41 | 10.77 | 3.56 | 3.48 |
| LB03-PC01 | M01 | 30 | 0.375 | 73 | 79.46 | 10.95 | 4.15 | 4.05 |
| LB03-PC02 | M01 | 30 | 0.375 | 48 | 79.46 | 10.95 | 4.15 | 4.05 |
| LB04-PC01 | M03 | 30 | 0.375 | 90 | 79.15 | 11.16 | 4.26 | 3.94 |
| LB04-PC02 | M03 | 30 | 0.375 | 85 | 79.15 | 11.16 | 4.26 | 3.94 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| LB04-PC03 | M03 | 30 | 0.375 | 93 | 78.53 | 11.43 | 4.43 | 4.45 |
| LB04-PC04 | M03 | 30 | 0.375 | 83 | 78.53 | 11.43 | 4.43 | 4.45 |
| LB05-PC01 | M03 | 30 | 0.375 | 390 | 87.73 | 3.07 | 0.81 | 0.99 |
| LB05-PC02 | M03 | 30 | 0.375 | 328 | 87.73 | 3.07 | 0.81 | 0.99 |
| LB05-PC03 | M03 | 25 | 0.375 | 387 | 87.73 | 3.07 | 0.81 | 0.99 |
| LB05-PC04 | M03 | 25 | 0.375 | 352 | 87.73 | 3.07 | 0.81 | 0.99 |
| LB06-PC01 | M03 | 32 | 0.375 | 408 | 81.15 | 11.16 | 3.75 | 2.65 |
| LB06-PC02 | M03 | 32 | 0.375 | 301 | 81.15 | 11.16 | 3.75 | 2.65 |
| LB06-PC03 | M03 | 32 | 0.375 | 427 | 80.67 | 11.27 | 3.88 | 2.92 |
| LB06-PC04 | M03 | 28 | 0.375 | 300 | 80.67 | 11.27 | 3.88 | 2.92 |
| LB06-PC05 | M03 | 30 | 0.375 | 427 | 81.44 | 11.10 | 3.66 | 2.50 |
| LB06-PC11 | M03 | 30 | 0.375 | 300 | 81.44 | 11.10 | 3.66 | 2.50 |
| LB07-PC01 | M03 | 24 | 0.375 | 85 | 79.04 | 11.45 | 4.24 | 3.97 |
| LB07-PC02 | M03 | 24 | 0.375 | 85 | 79.04 | 11.45 | 4.24 | 3.97 |
| LB07-PC03 | J01 | 28 | 0.375 | 85 | 79.31 | 11.34 | 4.14 | 3.99 |
| LB07-PC04 | M03 | 28 | 0.375 | 85 | 79.31 | 11.34 | 4.14 | 3.99 |
| OF01-PC01 | I03 | 14 | 0.25 | 34 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF02-PC01 | I03 | 20 | 0.25 | 35 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF03-PC01 | I03 | 30 | 0.25 | 38 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF04-PC01 | I03 | 18 | 0.25 | 50 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF05-PC01 | I03 | 30 | 0.25 | 39 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF06-PC01 | I03 | 16 | 0.25 | 39 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF07-PC01 | I03 | 22 | 0.375 | 88 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF08-PC01 | I03 | 27 | 0.25 | 110 | 96.34 | 2.96 | 0.43 | 0.22 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| OF08-PC02 | E01 | NA | 0.25 | 20 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF09-PC01 | I03 | 14 | 0.25 | 25 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF10-PC01 | I03 | 23 | 0.25 | 20 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF11-PC01 | I03 | 29 | 0.25 | 23 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF11-PC02 | M01 | 40 | 0.375 | 120 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF11-PC03 | M01 | 40 | 0.375 | 92 | 96.34 | 2.96 | 0.43 | 0.22 |
| OF11-PC04 | I01 | 40 | 0.375 | 18 | 96.34 | 2.96 | 0.43 | 0.22 |
| RB01-PC01 | M03 | 10 | 0.25 | 1 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC02 | M03 | 32 | 0.375 | 140 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC03 | M03 | 32 | 0.375 | 140 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC04 | M05 | 30 | 0.375 | 15 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC05 | M01 | 35 | 0.375 | 45 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC11 | M01 | 32 | 0.375 | 70 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC12 | M01 | 32 | 0.375 | 180 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC13 | M01 | 25 | 0.375 | 100 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC14 | M01 | 19 | 0.375 | 60 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC15 | M01 | 32 | 0.375 | NA | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC21 | I05 | 10 | 0.25 | 100 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC23 | M05 | 30 | 0.375 | 30 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC24 | M01 | 32 | 0.375 | 30 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC25 | H01 | 52 | 0.375 | 1 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB01-PC34 | M01 | 32 | 0.375 | 140 | 82.19 | 8.47 | 3.85 | 3.33 |
| RB02-PC01 | M01 | 32 | 0.375 | 75 | 72.35 | 14.60 | 7.40 | 3.44 |
| RB02-PC02 | M01 | 29 | 0.25 | 25 | 72.35 | 14.60 | 7.40 | 3.44 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| RB02-PC03 | I05 | 14 | 0.25 | 35 | 72.35 | 14.60 | 7.40 | 3.44 |
| RB02-PC05 | M01 | 30 | 0.25 | 100 | 72.35 | 14.60 | 7.40 | 3.44 |
| RB02-PC11 | M01 | 30 | 0.25 | 100 | 72.35 | 14.60 | 7.40 | 3.44 |
| RB02-PC12 | M01 | 32 | 0.25 | NA | 72.35 | 14.60 | 7.40 | 3.44 |
| RQ01-PC01 | Q02 | 24 | 0.25 | 70 | 86.88 | 6.48 | 2.83 | 2.48 |
| RQ02-PC01 | Q02 | 23 | 0.25 | 32 | 86.22 | 6.43 | 2.86 | 3.21 |
| RQ02-PC02 | O01 | 30 | 0.375 | 102 | 86.22 | 6.43 | 2.86 | 3.21 |
| RQ03-PC01 | Q02 | 22 | 0.375 | 40 | 85.61 | 6.43 | 2.84 | 3.80 |
| RQ04-PC01 | Q02 | 20 | 0.25 | 28 | 86.24 | 6.45 | 2.84 | 3.16 |
| RQ05-PC01 | Q02 | 21 | 0.375 | 34 | 88.27 | 6.12 | 2.86 | 1.52 |
| RQ05-PC02 | O01 | 30 | 0.375 | 34 | 88.27 | 6.12 | 2.86 | 1.52 |
| RQ05-PC03 | G01 | 22 | 0.375 | 38 | 87.71 | 6.11 | 3.20 | 1.76 |
| RQ05-PC04 | O01 | 30 | 0.375 | 0 | 87.71 | 6.11 | 3.20 | 1.76 |
| RQ06-PC01 | I05 | 8 | 0.25 | 32 | 84.16 | 8.24 | 3.97 | 1.61 |
| RQ06-PC02 | I05 | 8 | 0.25 | 47 | 84.16 | 8.24 | 3.97 | 1.61 |
| RQ06-PC03 | M03 | 27 | 0.25 | 38 | 84.16 | 8.24 | 3.97 | 1.61 |
| RQ06-PC04 | M03 | 29 | 0.25 | 27 | 84.16 | 8.24 | 3.97 | 1.61 |
| RQ07-PC01 | I05 | 18 | 0.25 | 65 | 77.73 | 9.13 | 6.59 | 4.32 |
| RQ07-PC02 | I05 | 18 | 0.25 | 55 | 77.73 | 9.13 | 6.59 | 4.32 |
| RQ07-PC03 | G01 | 22 | 0.25 | 36 | 77.73 | 9.13 | 6.59 | 4.32 |
| RQ07-PC04 | G01 | 21 | 0.25 | 25 | 77.73 | 9.13 | 6.59 | 4.32 |
| RQ07-PC05 | P01 | 25 | 0.375 | 0 | 77.73 | 9.13 | 6.59 | 4.32 |
| VF01-PC01 | F01 | 95 | 0.375 | 140 | 97.49 | 2.02 | 0.06 | 0.00 |
| VF01-PC02 | M02 | 40 | 0.375 | 90 | 97.49 | 2.02 | 0.06 | 0.00 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| VF01-PC03 | I04 | 21 | 0.25 | 27 | 97.49 | 2.02 | 0.06 | 0.00 |
| VF01-PC04 | I04 | 21 | 0.25 | 40 | 97.49 | 2.02 | 0.06 | 0.00 |
| VF01-PC05 | F01 | 61 | 0.25 | 134 | 97.63 | 1.95 | 0.05 | 0.00 |
| VF01-PC11 | M02 | 38 | 0.375 | 90 | 97.63 | 1.95 | 0.05 | 0.00 |
| VF01-PC12 | I04 | 23 | 0.25 | 15 | 97.63 | 1.95 | 0.05 | 0.00 |
| VF01-PC13 | I04 | 22 | 0.25 | 41 | 97.63 | 1.95 | 0.05 | 0.00 |
| VF01-PC14 | F01 | 50 | 0.375 | 95 | 97.61 | 2.01 | 0.06 | 0.00 |
| VF01-PC15 | M02 | 35 | 0.375 | 90 | 97.61 | 2.01 | 0.06 | 0.00 |
| VF01-PC21 | I04 | 7 | 0.25 | 26 | 97.61 | 2.01 | 0.06 | 0.00 |
| VF01-PC22 | I04 | 7 | 0.25 | 45 | 97.61 | 2.01 | 0.06 | 0.00 |
| VF01-PC23 | F01 | 86 | 0.375 | 110 | 97.74 | 1.82 | 0.04 | 0.00 |
| VF01-PC24 | M02 | 34 | 0.375 | 100 | 97.74 | 1.82 | 0.04 | 0.00 |
| VF01-PC25 | I04 | 15 | 0.375 | 32 | 97.74 | 1.82 | 0.04 | 0.00 |
| VF01-PC31 | I04 | 15 | 0.375 | 45 | 97.74 | 1.82 | 0.04 | 0.00 |
| VF01-PC32 | F01 | 25 | 0.375 | 98 | 97.63 | 2.01 | 0.05 | 0.00 |
| VF01-PC33 | M02 | 40 | 0.375 | 90 | 97.63 | 2.01 | 0.05 | 0.00 |
| VF01-PC34 | I04 | 14 | 0.25 | 25 | 97.63 | 2.01 | 0.05 | 0.00 |
| VF01-PC35 | I04 | 14 | 0.25 | 40 | 97.63 | 2.01 | 0.05 | 0.00 |
| VF01-PC41 | F01 | 89 | 0.375 | 84 | 97.68 | 1.89 | 0.05 | 0.00 |
| VF01-PC42 | M02 | 36 | 0.375 | 85 | 97.68 | 1.89 | 0.05 | 0.00 |
| VF01-PC43 | I04 | 17 | 0.25 | 26 | 97.68 | 1.89 | 0.05 | 0.00 |
| VF01-PC44 | I04 | 17 | 0.25 | 40 | 97.68 | 1.89 | 0.05 | 0.00 |
| VF01-PC45 | C01 | 27 | 0.375 | 28 | 97.49 | 2.02 | 0.06 | 0.00 |
| VF01-PC51 | C01 | 18 | 0.375 | 28 | 97.63 | 1.95 | 0.05 | 0.00 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| VF01-PC52 | C01 | 30 | 0.375 | 28 | 97.61 | 2.01 | 0.06 | 0.00 |
| VF01-PC53 | C01 | 25 | 0.375 | 28 | 97.74 | 1.82 | 0.04 | 0.00 |
| VF01-PC54 | C01 | 25 | 0.375 | 28 | 97.63 | 2.01 | 0.05 | 0.00 |
| VF01-PC55 | C01 | 30 | 0.375 | 28 | 97.68 | 1.89 | 0.05 | 0.00 |
| VF02-PC01 | F03 | 25 | 0.375 | 110 | 96.90 | 2.66 | 0.10 | 0.00 |
| VF02-PC02 | F03 | 30 | 0.375 | 110 | 96.94 | 2.59 | 0.09 | 0.00 |
| VF02-PC03 | F03 | 30 | 0.375 | 110 | 96.81 | 2.68 | 0.09 | 0.00 |
| VF02-PC04 | F03 | 30 | 0.375 | 110 | 96.98 | 2.56 | 0.08 | 0.00 |
| VF02-PC05 | F03 | 28 | 0.375 | 110 | 97.02 | 2.66 | 0.09 | 0.00 |
| VF02-PC11 | F03 | 31 | 0.375 | 110 | 96.93 | 2.61 | 0.09 | 0.00 |
| VF02-PC12 | I05 | 31 | 0.375 | 331 | 96.98 | 2.56 | 0.08 | 0.00 |
| XQ01-PC01 | Q02 | 27 | 0.25 | 30 | 88.21 | 6.64 | 1.98 | 1.46 |
| XQ01-PC02 | Q02 | 24 | 0.25 | 30 | 88.21 | 6.64 | 1.98 | 1.46 |
| XQ01-PC03 | I05 | 15 | 0.25 | 40 | 88.21 | 6.64 | 1.98 | 1.46 |
| XQ01-PC04 | F02 | 15 | 0.375 | 25 | 88.21 | 6.64 | 1.98 | 1.46 |
| XQ02-PC01 | G01 | 28 | 0.25 | 35 | 86.45 | 7.49 | 2.61 | 1.90 |
| XQ02-PC02 | G01 | 28 | 0.25 | 35 | 86.45 | 7.49 | 2.61 | 1.90 |
| XQ02-PC03 | I05 | 18 | 0.25 | 45 | 86.45 | 7.49 | 2.61 | 1.90 |
| XQ02-PC04 | F02 | 18 | 0.375 | 15 | 86.45 | 7.49 | 2.61 | 1.90 |
| XQ03-PC01 | Q02 | 23 | 0.25 | 30 | 90.85 | 5.17 | 1.28 | 1.04 |
| XQ03-PC02 | Q02 | 23 | 0.25 | 30 | 90.85 | 5.17 | 1.28 | 1.04 |
| XQ03-PC03 | I05 | 22 | 0.25 | 20 | 90.85 | 5.17 | 1.28 | 1.04 |
| XQ03-PC04 | F02 | 22 | 0.375 | 35 | 90.85 | 5.17 | 1.28 | 1.04 |
| XQ04-PC01 | Q02 | 25 | 0.25 | 38 | 89.49 | 5.33 | 2.32 | 2.27 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| XQ04-PC02 | Q02 | 28 | 0.25 | 38 | 89.49 | 5.33 | 2.32 | 2.27 |
| XQ04-PC03 | I05 | 15 | 0.25 | 15 | 89.49 | 5.33 | 2.32 | 2.27 |
| XQ04-PC04 | D01 | 15 | 0.375 | 10 | 89.49 | 5.33 | 2.32 | 2.27 |
| XQ05-PC01 | Q02 | 25 | 0.25 | 35 | 90.16 | 5.38 | 2.11 | 1.75 |
| XQ05-PC02 | Q02 | 27 | 0.25 | 35 | 90.16 | 5.38 | 2.11 | 1.75 |
| XQ05-PC03 | I05 | 17 | 0.25 | 12 | 90.16 | 5.38 | 2.11 | 1.75 |
| XQ05-PC04 | D01 | 17 | 0.375 | 10 | 90.16 | 5.38 | 2.11 | 1.75 |
| XQ06-PC01 | G01 | 28 | 0.25 | 38 | 89.14 | 5.48 | 2.41 | 2.45 |
| XQ06-PC02 | G01 | 28 | 0.25 | 38 | 89.14 | 5.48 | 2.41 | 2.45 |
| XQ06-PC03 | I05 | 28 | 0.25 | 30 | 89.14 | 5.48 | 2.41 | 2.45 |
| XQ06-PC04 | D01 | 28 | 0.375 | 10 | 89.14 | 5.48 | 2.41 | 2.45 |
| XQ07-PC01 | G01 | 60 | 0.25 | 38 | 91.62 | 4.41 | 1.72 | 1.59 |
| XQ07-PC02 | G01 | 60 | 0.25 | 38 | 91.62 | 4.41 | 1.72 | 1.59 |
| XQ07-PC03 | I05 | 60 | 0.25 | 30 | 91.62 | 4.41 | 1.72 | 1.59 |
| XQ07-PC04 | D01 | 60 | 0.375 | 10 | 91.62 | 4.41 | 1.72 | 1.59 |
| ZW01-PC01 | Q02 | 28 | 0.375 | 42 | 90.61 | 5.09 | 2.00 | 1.62 |
| ZW01-PC02 | Q02 | 27 | 0.375 | 52 | 90.61 | 5.09 | 2.00 | 1.62 |
| ZW01-PC03 | I05 | 14 | 0.375 | NA | 90.61 | 5.09 | 2.00 | 1.62 |
| ZW01-PC04 | I05 | 14 | 0.375 | NA | 90.61 | 5.09 | 2.00 | 1.62 |
| ZW01-PC05 | I05 | 12 | 0.375 | NA | 90.61 | 5.09 | 2.00 | 1.62 |
| ZW01-PC11 | I05 | 12 | 0.375 | NA | 90.61 | 5.09 | 2.00 | 1.62 |
| ZW01-PC12 | Q02 | 25 | 0.375 | 42 | 90.87 | 5.24 | 1.80 | 1.25 |
| ZW01-PC13 | Q02 | 25 | 0.375 | 52 | 90.87 | 5.24 | 1.80 | 1.25 |
| ZW01-PC14 | Q02 | 25 | 0.375 | 42 | 90.87 | 5.24 | 1.80 | 1.25 |

**Table A-7** (continued).

| Device Identifier | Man., Model | Supply gas pressure (psig) | Tubing Diameter (in) | Tubing Length (in) | % of C1 in gas (%mol)[1] | % of C2 in gas (%mol)[1] | % of C3 in gas (%mol)[1] | % of C4+ in gas (%mol)[1] |
|---|---|---|---|---|---|---|---|---|
| ZW01-PC15 | Q02 | 25 | 0.375 | 52 | 90.87 | 5.24 | 1.80 | 1.25 |
| ZW01-PC21 | Q02 | 40 | 0.375 | 22 | 90.87 | 5.24 | 1.80 | 1.25 |
| ZW01-PC22 | I05 | 15 | 0.375 | NA | 90.87 | 5.24 | 1.80 | 1.25 |
| ZW01-PC23 | I05 | 15 | 0.375 | NA | 90.03 | 5.89 | 2.03 | 1.25 |
| ZW01-PC24 | I05 | 15 | 0.375 | NA | 90.03 | 5.89 | 2.03 | 1.25 |
| ZW01-PC25 | I05 | 15 | 0.375 | NA | 90.03 | 5.89 | 2.03 | 1.25 |
| ZW01-PC31 | B01 | 22 | 0.375 | 60 | 90.03 | 5.89 | 2.03 | 1.25 |
| ZW01-PC32 | I05 | 15 | 0.375 | NA | 90.03 | 5.89 | 2.03 | 1.25 |
| ZW01-PC33 | I05 | 15 | 0.375 | NA | 90.03 | 5.89 | 2.03 | 1.25 |
| ZW01-PC34 | I05 | 15 | 0.375 | NA | 90.03 | 5.89 | 2.03 | 1.25 |
| ZW01-PC35 | I05 | 15 | 0.375 | NA | 90.03 | 5.89 | 2.03 | 1.25 |
| ZW02-PC01 | Q02 | 25 | 0.375 | 30 | 89.65 | 5.68 | 2.22 | 1.59 |
| ZW02-PC02 | Q02 | 25 | 0.375 | 35 | 89.65 | 5.68 | 2.22 | 1.59 |
| ZW02-PC03 | I05 | 60 | 0.375 | NA | 89.65 | 5.68 | 2.22 | 1.59 |
| ZW02-PC04 | I05 | 60 | 0.375 | NA | 89.65 | 5.68 | 2.22 | 1.59 |
| ZW02-PC12 | B01 | 25 | 0.375 | 52 | 89.65 | 5.68 | 2.22 | 1.59 |
| ZW03-PC01 | Q02 | 25 | 0.375 | 26 | 91.22 | 4.94 | 1.81 | 1.25 |
| ZW03-PC02 | Q02 | 25 | 0.375 | 40 | 91.22 | 4.94 | 1.81 | 1.25 |
| ZW03-PC03 | F01 | 25 | 0.375 | 50 | 91.22 | 4.94 | 1.81 | 1.20 |

(1) Total may not sum to 100% due to nitrogen, $CO_2$, and other species in the gas.

**Table A-8.** Average measured emission rates for each device (whole gas and methane).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| AA01-PC04 | 7.595 | not measured | 7.595 | 6.216 | c |
| AA01-PC05 | 0 | not measured | 0.000 | 0.000 | |
| AA01-PC06 | 1.602 | not measured | 1.602 | 1.304 | c |
| AA01-PC07 | 0.013 | not measured | 0.013 | 0.011 | |
| AA01-PC08 | 1.741 | not measured | 1.741 | 1.363 | c |
| AA01-PC09 | 0.035 | not measured | 0.035 | 0.027 | c |
| AA01-PC11 | 0.279 | not measured | 0.279 | 0.228 | c |
| AA02-PC04 | 13.597 | not measured | 13.597 | 10.950 | |
| AA02-PC05 | 2.514 | not measured | 2.514 | 2.025 | c |
| AA02-PC06 | 4.926 | not measured | 4.926 | 3.967 | |
| AA02-PC07 | 1.186 | not measured | 1.186 | 0.955 | |
| AA02-PC08 | 111.413 | not measured | 111.413 | 89.718 | |
| AA02-PC09 | 7.766 | not measured | 7.766 | 6.254 | |
| AP01-PC01 | 1.027 | not measured | 1.027 | 0.682 | c |
| AP01-PC02 | 0.001 | not measured | 0.001 | 0.000 | c |
| AP01-PC03 | 0.036 | not measured | 0.036 | 0.024 | |
| AP01-PC04 | 0.003 | not measured | 0.003 | 0.002 | |
| AP01-PC05 | 0.001 | not measured | 0.001 | 0.001 | |
| AP01-PC12 | 25.559 | not measured | 25.559 | 16.980 | |
| AP02-PC01 | 0.028 | not measured | 0.028 | 0.020 | |
| AP02-PC02 | 0.112 | not measured | 0.112 | 0.079 | c |
| AP02-PC03 | 0.002 | 0.000 | 0.002 | 0.002 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| AP02-PC04 | 0.032 | not measured | 0.032 | 0.022 | c |
| AP03-PC01 | 0 | not measured | 0.000 | 0.000 | |
| AP03-PC02 | 0 | not measured | 0.000 | 0.000 | |
| AP04-PC01 | 0.004 | not measured | 0.004 | 0.002 | |
| AP04-PC02 | 0.111 | 0.000 | 0.111 | 0.074 | c |
| AP04-PC03 | 0.036 | 0.007 | 0.036 | 0.023 | c |
| AP04-PC04 | 0.001 | not measured | 0.001 | 0.001 | |
| AP05-PC01 | 0.169 | 0.197 | 0.169 | 0.120 | c |
| AP05-PC02 | 0 | not measured | 0.000 | 0.000 | |
| CW01-PC01 | not measured | 0.000 | 0.000 | 0.000 | |
| CW01-PC02 | 0 | not measured | 0.000 | 0.000 | |
| CW01-PC03 | 0 | not measured | 0.000 | 0.000 | |
| CW01-PC04 | 0 | not measured | 0.000 | 0.000 | a |
| CW01-PC05 | 0.008 | not measured | 0.008 | 0.007 | a |
| CW01-PC11 | 0.022 | not measured | 0.022 | 0.018 | c |
| CW01-PC12 | 0.034 | not measured | 0.034 | 0.028 | a |
| CW01-PC13 | 0.235 | not measured | 0.235 | 0.192 | |
| CW01-PC14 | 0.031 | not measured | 0.031 | 0.025 | a |
| CW01-PC15 | 0 | not measured | 0.000 | 0.000 | |
| CW01-PC21 | 0 | 0.002 | 0.000 | 0.000 | |
| CW01-PC22 | 0 | not measured | 0.000 | 0.000 | |
| CW01-PC23 | 1.377 | not measured | 1.377 | 1.159 | c |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| CW01-PC24 | 0 | not measured | 0.000 | 0.000 | a |
| CW01-PC25 | 0.003 | not measured | 0.003 | 0.003 | a |
| CW01-PC31 | 0 | not measured | 0.000 | 0.000 | a |
| CW01-PC32 | 0.102 | not measured | 0.102 | 0.083 | b, c |
| CW01-PC33 | 0 | not measured | 0.000 | 0.000 | |
| CW01-PC34 | 0 | not measured | 0.000 | 0.000 | a |
| CW01-PC35 | 0.622 | not measured | 0.622 | 0.508 | a, b |
| CW02-PC01 | not measured | 0.082 | 0.082 | 0.067 | |
| CW02-PC02 | 0 | not measured | 0.000 | 0.000 | |
| CW02-PC03 | 0 | not measured | 0.000 | 0.000 | |
| CW02-PC04 | 0 | not measured | 0.000 | 0.000 | a |
| CW02-PC05 | 0.004 | not measured | 0.004 | 0.003 | a |
| CW02-PC11 | not measured | 0.000 | 0.000 | 0.000 | |
| CW02-PC12 | 0 | not measured | 0.000 | 0.000 | |
| CW02-PC13 | 0 | not measured | 0.000 | 0.000 | |
| CW02-PC14 | 0 | not measured | 0.000 | 0.000 | a |
| CW02-PC15 | 0.002 | not measured | 0.002 | 0.002 | a |
| CW02-PC21 | not measured | 0.000 | 0.000 | 0.000 | |
| CW02-PC22 | 0.003 | not measured | 0.003 | 0.003 | a |
| CW02-PC23 | 0 | not measured | 0.000 | 0.000 | a |
| CW02-PC24 | 0 | 0.142 | 0.000 | 0.000 | |
| CW02-PC25 | 0 | not measured | 0.000 | 0.000 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| CW02-PC31 | not measured | 0.000 | 0.000 | 0.000 | |
| CW02-PC32 | 0.529 | not measured | 0.529 | 0.434 | |
| CW02-PC33 | 7.821 | not measured | 7.821 | 6.415 | |
| CW02-PC34 | 0 | not measured | 0.000 | 0.000 | a |
| CW02-PC35 | 0.010 | not measured | 0.010 | 0.008 | a |
| CZ01-PC01 | 0.243 | not measured | 0.243 | 0.221 | a |
| CZ01-PC02 | not measured | 0.000 | 0.000 | 0.000 | |
| CZ02-PC01 | 118.497 | not measured | 118.497 | 107.983 | a |
| CZ02-PC02 | not measured | 0.580 | 0.580 | 0.528 | |
| CZ03-PC01 | 0.006 | not measured | 0.006 | 0.005 | a |
| CZ03-PC02 | not measured | 0.000 | 0.000 | 0.000 | |
| CZ04-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| CZ04-PC02 | not measured | 0.000 | 0.000 | 0.000 | |
| CZ05-PC01 | 40.400 | not measured | 40.400 | 37.880 | a |
| CZ05-PC02 | not measured | 0.000 | 0.000 | 0.000 | |
| CZ05-PC03 | 0 | not measured | 0.000 | 0.000 | |
| CZ06-PC01 | not measured | 51.231 | 51.231 | 48.192 | |
| CZ06-PC02 | not measured | 50.714 | 50.714 | 47.705 | |
| CZ06-PC03 | not measured | 0.000 | 0.000 | 0.000 | |
| CZ07-PC01 | 0.007 | not measured | 0.007 | 0.006 | a |
| CZ07-PC02 | not measured | 0.000 | 0.000 | 0.000 | |
| CZ08-PC01 | 60.099 | not measured | 60.099 | 57.783 | a |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| CZ08-PC02 | 21.578 | not measured | 21.578 | 21.056 | |
| CZ09-PC01 | 149.678 | not measured | 149.678 | 143.801 | a |
| CZ09-PC02 | 44.871 | not measured | 44.871 | 43.109 | |
| CZ10-PC01 | 43.173 | not measured | 43.173 | 41.489 | a |
| CZ11-PC01 | 22.183 | not measured | 22.183 | 21.253 | a |
| DL01-PC01 | 0.065 | not measured | 0.065 | 0.059 | |
| DL01-PC02 | 0 | not measured | 0.000 | 0.000 | a |
| DL01-PC03 | 0 | not measured | 0.000 | 0.000 | a |
| DL01-PC04 | not measured | 1.461 | 1.461 | 1.323 | |
| DL01-PC05 | 0 | not measured | 0.000 | 0.000 | a |
| DL01-PC11 | 0 | not measured | 0.000 | 0.000 | a |
| DL01-PC12 | 0.502 | not measured | 0.502 | 0.456 | |
| DL01-PC13 | 0 | not measured | 0.000 | 0.000 | a |
| DL01-PC14 | 0.595 | not measured | 0.595 | 0.536 | |
| DL01-PC15 | 5.386 | not measured | 5.386 | 4.902 | a |
| DL01-PC21 | 0.980 | not measured | 0.980 | 0.892 | c |
| DL01-PC22 | 0 | not measured | 0.000 | 0.000 | a |
| DL01-PC23 | 1.574 | not measured | 1.574 | 1.427 | c |
| DL01-PC24 | 19.759 | not measured | 19.759 | 17.656 | a |
| DL01-PC25 | 0 | not measured | 0.000 | 0.000 | |
| DL01-PC31 | 0 | not measured | 0.000 | 0.000 | |
| DL01-PC32 | 0 | not measured | 0.000 | 0.000 | a |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| DL01-PC33 | 0.114 | not measured | 0.114 | 0.104 | |
| DL01-PC34 | 0 | not measured | 0.000 | 0.000 | a |
| DL01-PC35 | 0 | not measured | 0.000 | 0.000 | |
| DL01-PC41 | 0 | not measured | 0.000 | 0.000 | a |
| DL01-PC42 | 0.489 | not measured | 0.489 | 0.438 | |
| DL01-PC43 | 0 | not measured | 0.000 | 0.000 | a |
| DL01-PC44 | 0.502 | not measured | 0.502 | 0.449 | |
| DL01-PC45 | not measured | 0.000 | 0.000 | 0.000 | |
| DL02-PC01 | 0.005 | not measured | 0.005 | 0.004 | a |
| DL02-PC02 | 0.465 | not measured | 0.465 | 0.420 | |
| DL02-PC03 | 0.008 | 59.833 | 0.008 | 0.007 | a |
| DL02-PC04 | 0.007 | not measured | 0.007 | 0.006 | |
| DL02-PC05 | 0.007 | not measured | 0.007 | 0.006 | a |
| DL02-PC11 | 0.528 | 0.881 | 0.528 | 0.478 | |
| DL02-PC12 | 0.008 | not measured | 0.008 | 0.007 | a |
| DL02-PC13 | 0 | 3.537 | 0.000 | 0.000 | |
| DL02-PC14 | 13.760 | not measured | 13.760 | 12.449 | a |
| DL02-PC15 | 1.360 | 0.696 | 1.360 | 1.230 | c |
| DL02-PC21 | 0.005 | 13.328 | 0.005 | 0.004 | a |
| DL02-PC22 | 0 | not measured | 0.000 | 0.000 | |
| DL02-PC23 | 0.005 | not measured | 0.005 | 0.004 | a |
| DL02-PC24 | 0 | not measured | 0.000 | 0.000 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| DL02-PC25 | 5.137 | not measured | 5.137 | 4.634 | a |
| DL02-PC31 | 0 | 0.507 | 0.000 | 0.000 | |
| DL02-PC32 | 0.004 | not measured | 0.004 | 0.004 | a |
| DL02-PC33 | 1.783 | not measured | 1.783 | 1.601 | |
| DL02-PC34 | 0.005 | 9.214 | 0.005 | 0.004 | a |
| DL02-PC35 | 1.207 | not measured | 1.207 | 1.091 | c |
| DL02-PC41 | 0.006 | not measured | 0.006 | 0.005 | a |
| DL02-PC42 | 0.504 | 0.001 | 0.504 | 0.454 | |
| DL02-PC43 | 0.007 | not measured | 0.007 | 0.007 | a |
| DL02-PC44 | 0 | 1.244 | 0.000 | 0.000 | |
| DL02-PC45 | 0.005 | 0.007 | 0.005 | 0.005 | a |
| DL02-PC51 | 0 | not measured | 0.000 | 0.000 | |
| DL02-PC52 | 0.004 | not measured | 0.004 | 0.003 | a |
| DL02-PC53 | 0 | not measured | 0.000 | 0.000 | |
| DL02-PC54 | 0.004 | not measured | 0.004 | 0.004 | |
| DL02-PC55 | 0 | not measured | 0.000 | 0.000 | a |
| DL02-PC61 | 0.002 | not measured | 0.002 | 0.002 | a |
| DL02-PC62 | not measured | 0.000 | 0.000 | 0.000 | |
| GZ01-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| GZ01-PC02 | 0 | not measured | 0.000 | 0.000 | |
| GZ01-PC03 | 0 | not measured | 0.000 | 0.000 | a |
| GZ01-PC04 | 0 | not measured | 0.000 | 0.000 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| GZ01-PC05 | 0 | not measured | 0.000 | 0.000 | a |
| GZ01-PC11 | 0 | not measured | 0.000 | 0.000 | |
| GZ01-PC12 | 0 | not measured | 0.000 | 0.000 | a |
| GZ01-PC13 | 0 | not measured | 0.000 | 0.000 | |
| GZ01-PC14 | not measured | 0.042 | 0.042 | 0.041 | |
| GZ01-PC15 | not measured | 0.000 | 0.000 | 0.000 | |
| GZ01-PC21 | not measured | 0.000 | 0.000 | 0.000 | |
| GZ01-PC22 | not measured | 0.000 | 0.000 | 0.000 | |
| GZ02-PC01 | 0 | 0.000 | 0.000 | 0.000 | a |
| GZ02-PC02 | 0 | not measured | 0.000 | 0.000 | |
| GZ02-PC03 | 0 | not measured | 0.000 | 0.000 | a |
| GZ02-PC04 | 0 | not measured | 0.000 | 0.000 | |
| GZ02-PC05 | 0 | not measured | 0.000 | 0.000 | a |
| GZ02-PC11 | 0 | not measured | 0.000 | 0.000 | a |
| GZ02-PC12 | 57.949 | not measured | 57.949 | 56.454 | |
| GZ02-PC13 | 0 | not measured | 0.000 | 0.000 | |
| GZ02-PC14 | not measured | 43.288 | 43.288 | 42.171 | |
| GZ02-PC15 | 0 | not measured | 0.000 | 0.000 | |
| GZ02-PC21 | 0 | not measured | 0.000 | 0.000 | a |
| GZ02-PC22 | not measured | 0.000 | 0.000 | 0.000 | |
| GZ02-PC23 | not measured | 0.000 | 0.000 | 0.000 | |
| GZ02-PC24 | not measured | 0.000 | 0.000 | 0.000 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| GZ03-PC01 | 3.664 | not measured | 3.664 | 3.560 | |
| GZ03-PC02 | 32.606 | not measured | 32.606 | 31.680 | |
| GZ03-PC03 | 0 | not measured | 0.000 | 0.000 | a |
| GZ03-PC04 | 0 | not measured | 0.000 | 0.000 | a |
| GZ03-PC05 | not measured | 0.013 | 0.013 | 0.013 | |
| GZ03-PC11 | not measured | 0.024 | 0.024 | 0.024 | |
| GZ03-PC12 | not measured | 0.000 | 0.000 | 0.000 | |
| GZ03-PC13 | 34.132 | not measured | 34.132 | 33.163 | |
| GZ03-PC14 | 6.122 | not measured | 6.122 | 5.948 | a |
| GZ03-PC15 | 0 | 0.052 | 0.000 | 0.000 | |
| GZ03-PC21 | 0 | not measured | 0.000 | 0.000 | a |
| GZ03-PC22 | 37.673 | not measured | 37.673 | 36.603 | a |
| GZ03-PC23 | 0.024 | not measured | 0.024 | 0.024 | c |
| GZ03-PC24 | 6.647 | not measured | 6.647 | 6.471 | |
| GZ03-PC25 | not measured | 0.000 | 0.000 | 0.000 | |
| GZ03-PC31 | not measured | 0.000 | 0.000 | 0.000 | |
| GZ03-PC32 | 0 | not measured | 0.000 | 0.000 | a |
| GZ03-PC33 | 0.002 | not measured | 0.002 | 0.002 | a |
| GZ03-PC34 | 0 | not measured | 0.000 | 0.000 | a |
| GZ03-PC35 | 0 | not measured | 0.000 | 0.000 | |
| GZ03-PC41 | 0 | not measured | 0.000 | 0.000 | |
| GZ03-PC42 | not measured | 0.000 | 0.000 | 0.000 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| GZ04-PC01 | 5.504 | not measured | 5.504 | 4.999 | c |
| GZ04-PC02 | 6.009 | not measured | 6.009 | 5.458 | a,b |
| GZ04-PC03 | 32.670 | not measured | 32.670 | 31.834 | |
| GZ04-PC04 | 0 | not measured | 0.000 | 0.000 | a |
| GZ04-PC05 | not measured | 0.142 | 0.142 | 0.129 | |
| GZ04-PC11 | not measured | 0.012 | 0.012 | 0.012 | |
| LB01-PC01 | 40.155 | not measured | 40.155 | 32.333 | a, c |
| LB01-PC02 | 8.774 | not measured | 8.774 | 7.065 | c |
| LB02-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| LB02-PC02 | 0 | not measured | 0.000 | 0.000 | |
| LB02-PC03 | 0.001 | not measured | 0.001 | 0.000 | a |
| LB02-PC04 | 0 | not measured | 0.000 | 0.000 | |
| LB03-PC01 | 49.983 | 55.301 | 49.983 | 39.715 | a |
| LB03-PC02 | 0.273 | not measured | 0.273 | 0.217 | |
| LB04-PC01 | 26.212 | not measured | 26.212 | 20.748 | a, c |
| LB04-PC02 | 9.820 | not measured | 9.820 | 7.773 | |
| LB04-PC03 | 19.116 | not measured | 19.116 | 15.012 | a, c |
| LB04-PC04 | 9.701 | not measured | 9.701 | 7.619 | c |
| LB05-PC01 | 68.606 | not measured | 68.606 | 60.188 | a |
| LB05-PC02 | 0 | not measured | 0.000 | 0.000 | |
| LB05-PC03 | 78.556 | not measured | 78.556 | 68.916 | a |
| LB05-PC04 | 0 | not measured | 0.000 | 0.000 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| LB06-PC01 | 3.475 | not measured | 3.475 | 2.820 | a, c |
| LB06-PC02 | 6.630 | not measured | 6.630 | 5.380 | c |
| LB06-PC03 | 7.691 | not measured | 7.691 | 6.204 | a, c |
| LB06-PC04 | 0 | not measured | 0.000 | 0.000 | |
| LB06-PC05 | 22.456 | 20.773 | 22.456 | 18.287 | a, c |
| LB06-PC11 | 0.288 | not measured | 0.288 | 0.235 | c |
| LB07-PC01 | 36.294 | 51.347 | 36.294 | 28.685 | a, c |
| LB07-PC02 | 64.752 | not measured | 64.752 | 51.178 | |
| LB07-PC03 | 3.293 | not measured | 3.293 | 2.612 | a, c |
| LB07-PC04 | 26.980 | 33.879 | 26.980 | 21.399 | |
| OF01-PC01 | 7.125 | not measured | 7.125 | 6.864 | |
| OF02-PC01 | 0 | not measured | 0.000 | 0.000 | |
| OF03-PC01 | 1.556 | not measured | 1.556 | 1.499 | c |
| OF04-PC01 | 0 | not measured | 0.000 | 0.000 | |
| OF05-PC01 | 1.607 | not measured | 1.607 | 1.548 | c |
| OF06-PC01 | 0 | not measured | 0.000 | 0.000 | |
| OF07-PC01 | 6.615 | not measured | 6.615 | 6.373 | |
| OF08-PC01 | 0 | not measured | 0.000 | 0.000 | |
| OF08-PC02 | 0 | not measured | 0.000 | 0.000 | |
| OF09-PC01 | 0 | not measured | 0.000 | 0.000 | |
| OF10-PC01 | 2.696 | not measured | 2.696 | 2.597 | |
| OF11-PC01 | 6.589 | not measured | 6.589 | 6.347 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| OF11-PC02 | 2.821 | not measured | 2.821 | 2.717 | |
| OF11-PC03 | 0 | not measured | 0.000 | 0.000 | |
| OF11-PC04 | 0 | not measured | 0.000 | 0.000 | |
| RB01-PC01 | 0 | not measured | 0.000 | 0.000 | |
| RB01-PC02 | 0 | not measured | 0.000 | 0.000 | |
| RB01-PC03 | 0 | not measured | 0.000 | 0.000 | |
| RB01-PC04 | 7.787 | not measured | 7.787 | 6.400 | |
| RB01-PC05 | 0.123 | not measured | 0.123 | 0.101 | |
| RB01-PC11 | 0.199 | not measured | 0.199 | 0.163 | |
| RB01-PC12 | 0 | not measured | 0.000 | 0.000 | |
| RB01-PC13 | 17.226 | not measured | 17.226 | 14.159 | |
| RB01-PC14 | 4.163 | 0.194 | 4.163 | 3.422 | |
| RB01-PC15 | 0 | not measured | 0.000 | 0.000 | |
| RB01-PC21 | 15.169 | not measured | 15.169 | 12.468 | |
| RB01-PC23 | 19.824 | not measured | 19.824 | 16.294 | |
| RB01-PC24 | 0 | not measured | 0.000 | 0.000 | |
| RB01-PC25 | 0 | not measured | 0.000 | 0.000 | |
| RB01-PC34 | 16.795 | not measured | 16.795 | 13.804 | |
| RB02-PC01 | 0 | 6.664 | 0.000 | 0.000 | |
| RB02-PC02 | 0 | not measured | 0.000 | 0.000 | |
| RB02-PC03 | 9.578 | not measured | 9.578 | 6.930 | |
| RB02-PC05 | 7.949 | not measured | 7.949 | 5.751 | c |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| RB02-PC11 | 0.002 | not measured | 0.002 | 0.001 | |
| RB02-PC12 | 0.004 | not measured | 0.004 | 0.003 | |
| RQ01-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| RQ02-PC01 | 6.316 | not measured | 6.316 | 5.446 | a |
| RQ02-PC02 | 0.001 | not measured | 0.001 | 0.001 | |
| RQ03-PC01 | 19.088 | NA | 19.088 | 16.341 | a |
| RQ04-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| RQ05-PC01 | 0 | not measured | 0.000 | 0.000 | |
| RQ05-PC02 | 0.008 | 0.515 | 0.008 | 0.007 | a |
| RQ05-PC03 | 17.390 | not measured | 17.390 | 15.253 | |
| RQ05-PC04 | 0 | not measured | 0.000 | 0.000 | a |
| RQ06-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| RQ06-PC02 | 0 | not measured | 0.000 | 0.000 | |
| RQ06-PC03 | 0 | 0.000 | 0.000 | 0.000 | a |
| RQ06-PC04 | 0 | not measured | 0.000 | 0.000 | |
| RQ07-PC01 | 0 | not measured | 0.000 | 0.000 | |
| RQ07-PC02 | 0 | not measured | 0.000 | 0.000 | |
| RQ07-PC03 | 18.241 | 20.992 | 18.241 | 14.179 | a |
| RQ07-PC04 | 9.078 | not measured | 9.078 | 7.056 | a |
| RQ07-PC05 | 0 | not measured | 0.000 | 0.000 | a |
| VF01-PC01 | 2.347 | not measured | 2.347 | 2.288 | |
| VF01-PC02 | 0.003 | not measured | 0.003 | 0.003 | a |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| VF01-PC03 | 0 | not measured | 0.000 | 0.000 | |
| VF01-PC04 | 0 | not measured | 0.000 | 0.000 | a |
| VF01-PC05 | 5.387 | not measured | 5.387 | 5.259 | a |
| VF01-PC11 | 0 | not measured | 0.000 | 0.000 | |
| VF01-PC12 | 0.001 | not measured | 0.001 | 0.001 | a |
| VF01-PC13 | 0 | not measured | 0.000 | 0.000 | |
| VF01-PC14 | 0.001 | not measured | 0.001 | 0.001 | a |
| VF01-PC15 | 0 | not measured | 0.000 | 0.000 | |
| VF01-PC21 | 0 | not measured | 0.000 | 0.000 | a |
| VF01-PC22 | 16.807 | not measured | 16.807 | 16.405 | |
| VF01-PC23 | 0 | not measured | 0.000 | 0.000 | a |
| VF01-PC24 | 0 | not measured | 0.000 | 0.000 | |
| VF01-PC25 | 0 | not measured | 0.000 | 0.000 | |
| VF01-PC31 | 0.001 | not measured | 0.001 | 0.001 | a |
| VF01-PC32 | 0.001 | not measured | 0.001 | 0.001 | a |
| VF01-PC33 | 0 | not measured | 0.000 | 0.000 | |
| VF01-PC34 | 0 | not measured | 0.000 | 0.000 | |
| VF01-PC35 | 0.001 | not measured | 0.001 | 0.001 | a |
| VF01-PC41 | 0 | not measured | 0.000 | 0.000 | a |
| VF01-PC42 | 0 | not measured | 0.000 | 0.000 | |
| VF01-PC43 | 0 | not measured | 0.000 | 0.000 | a |
| VF01-PC44 | 0 | not measured | 0.000 | 0.000 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| VF01-PC45 | 8.505 | not measured | 8.505 | 8.291 | |
| VF01-PC51 | 11.023 | not measured | 11.023 | 10.761 | a |
| VF01-PC52 | 0 | not measured | 0.000 | 0.000 | a |
| VF01-PC53 | 9.645 | not measured | 9.645 | 9.427 | |
| VF01-PC54 | 4.544 | not measured | 4.544 | 4.436 | |
| VF01-PC55 | 0.002 | not measured | 0.002 | 0.002 | a |
| VF02-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| VF02-PC02 | 0 | not measured | 0.000 | 0.000 | |
| VF02-PC03 | 1.119 | not measured | 1.119 | 1.083 | a |
| VF02-PC04 | 0 | not measured | 0.000 | 0.000 | |
| VF02-PC05 | 0 | not measured | 0.000 | 0.000 | a |
| VF02-PC11 | 0 | not measured | 0.000 | 0.000 | |
| VF02-PC12 | 0 | not measured | 0.000 | 0.000 | |
| XQ01-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| XQ01-PC02 | 0 | not measured | 0.000 | 0.000 | |
| XQ01-PC03 | not measured | 0.000 | 0.000 | 0.000 | |
| XQ01-PC04 | 37.374 | 0.125 | 37.374 | 32.969 | a |
| XQ02-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| XQ02-PC02 | 0 | 0.000 | 0.000 | 0.000 | |
| XQ02-PC03 | not measured | 0.000 | 0.000 | 0.000 | |
| XQ02-PC04 | 14.982 | not measured | 14.982 | 12.952 | a |
| XQ03-PC01 | 14.955 | not measured | 14.955 | 13.587 | a |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| XQ03-PC02 | 16.531 | not measured | 16.531 | 15.019 | |
| XQ03-PC03 | not measured | 0.000 | 0.000 | 0.000 | |
| XQ03-PC04 | 14.500 | not measured | 14.500 | 13.174 | a |
| XQ04-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| XQ04-PC02 | 37.406 | not measured | 37.406 | 33.473 | |
| XQ04-PC03 | not measured | 0.000 | 0.000 | 0.000 | |
| XQ04-PC04 | not measured | 2.866 | 2.866 | 2.564 | |
| XQ05-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| XQ05-PC02 | 24.085 | not measured | 24.085 | 21.714 | |
| XQ05-PC03 | not measured | 0.000 | 0.000 | 0.000 | |
| XQ05-PC04 | not measured | 0.000 | 0.000 | 0.000 | |
| XQ06-PC01 | 20.160 | not measured | 20.160 | 17.970 | a |
| XQ06-PC02 | 11.918 | not measured | 11.918 | 10.623 | |
| XQ06-PC03 | not measured | 0.000 | 0.000 | 0.000 | |
| XQ06-PC04 | not measured | 0.149 | 0.149 | 0.133 | |
| XQ07-PC01 | 0 | not measured | 0.000 | 0.000 | a |
| XQ07-PC02 | 0 | not measured | 0.000 | 0.000 | |
| XQ07-PC03 | not measured | 0.000 | 0.000 | 0.000 | |
| XQ07-PC04 | not measured | 1.752 | 1.752 | 1.605 | |
| ZW01-PC01 | 6.149 | not measured | 6.149 | 5.572 | |
| ZW01-PC02 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC03 | 0 | not measured | 0.000 | 0.000 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| ZW01-PC04 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC05 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC11 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC12 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC13 | 2.664 | not measured | 2.664 | 2.421 | |
| ZW01-PC14 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC15 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC21 | 3.058 | not measured | 3.058 | 2.779 | c |
| ZW01-PC22 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC23 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC24 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC25 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC31 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC32 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC33 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC34 | 0 | not measured | 0.000 | 0.000 | |
| ZW01-PC35 | 0 | not measured | 0.000 | 0.000 | |
| ZW02-PC01 | 11.284 | not measured | 11.284 | 10.116 | |
| ZW02-PC02 | 0 | not measured | 0.000 | 0.000 | |
| ZW02-PC03 | 0 | not measured | 0.000 | 0.000 | |
| ZW02-PC04 | 0 | not measured | 0.000 | 0.000 | |
| ZW02-PC12 | 0 | not measured | 0.000 | 0.000 | |

**Table A-8** (continued).

| Device Identifier | Supply Gas meter - avg. emission rate whole gas (scf/h) | Hi Flow® - avg. emission rate whole gas (scf/h) | Whole gas flow rate used in data analysis (scf/h) | Methane flow rate used in data analysis (scf/h) | Flags |
|---|---|---|---|---|---|
| ZW03-PC01 | 0 | not measured | 0.000 | 0.000 | |
| ZW03-PC02 | 3.590 | not measured | 3.590 | 3.275 | |
| ZW03-PC03 | 0 | not measured | 0 | 0 | |

Flags: (*a*): Correction factor was applied to account for the condensation of an oily substance on the sensor of the measuring instrument.
(*b*): Rapid peak in time series attributed to voltage surge associated with vehicle, which was the source of power for the supply gas meters used in the study, being turned on/off rather than with a pneumatic controller actuation.
(*c*): Devices used in volume per actuation analysis for the "zero" pattern emissions.

**Table A-9.** Total measurement time, number of actuations, and frequency of actuations.

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| AA01-PC04 | 15.4 | 51 | 3.3 |
| AA01-PC05 | 109.2 | 0 | no actuations |
| AA01-PC06 | 23.0 | 24 | 1.0 |
| AA01-PC07 | 18.7 | 1 | 0.1 |
| AA01-PC08 | 15.2 | 10 | 0.7 |
| AA01-PC09 | 15.7 | 2 | 0.1 |
| AA01-PC11 | 14.3 | 2 | 0.1 |
| AA02-PC04 | 11.0 | 0 | no actuations |
| AA02-PC05 | 14.8 | 2 | 0.1 |
| AA02-PC06 | 15.7 | 1 | 0.1 |
| AA02-PC07 | 18.0 | 4 | 0.2 |
| AA02-PC08 | 10.3 | 0 | no actuations |
| AA02-PC09 | 11.2 | 0 | no actuations |
| AP01-PC01 | 15.7 | 12 | 0.8 |
| AP01-PC02 | 14.3 | 0 | no actuations |
| AP01-PC03 | 53.1 | 0 | no actuations |
| AP01-PC04 | 15.0 | 0 | no actuations |
| AP01-PC05 | 15.0 | 0 | no actuations |
| AP01-PC12 | 15.0 | 78 | 5.2 |
| AP02-PC01 | 15.1 | 4 | 0.3 |
| AP02-PC02 | 15.4 | 10 | 0.6 |
| AP02-PC03 | 16.0 | 0 | no actuations |
| AP02-PC04 | 15.0 | 7 | 0.5 |
| AP03-PC01 | 16.7 | 0 | no actuations |
| AP03-PC02 | 16.1 | 0 | no actuations |
| AP04-PC01 | 16.0 | 0 | no actuations |
| AP04-PC02 | 16.6 | 35 | 2.1 |
| AP04-PC03 | 13.5 | 5 | 0.4 |
| AP04-PC04 | 15.1 | 0 | no actuations |
| AP05-PC01 | 23.9 | 6 | 0.3 |
| AP05-PC02 | 14.0 | 0 | no actuations |
| CW01-PC01 | 15.0 | 0 | no actuations |
| CW01-PC02 | 15.0 | 0 | no actuations |
| CW01-PC03 | 15.7 | 0 | no actuations |
| CW01-PC04 | 15.5 | 0 | no actuations |
| CW01-PC05 | 15.6 | 0 | no actuations |
| CW01-PC11 | 19.5 | 2 | 0.1 |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| CW01-PC12 | 14.8 | 1 | 0.1 |
| CW01-PC13 | 15.5 | 1 | 0.1 |
| CW01-PC14 | 15.7 | 1 | 0.1 |
| CW01-PC15 | 15.0 | 0 | no actuations |
| CW01-PC21 | 14.7 | 0 | no actuations |
| CW01-PC22 | 15.7 | 0 | no actuations |
| CW01-PC23 | 15.7 | 21 | 1.3 |
| CW01-PC24 | 15.8 | 0 | no actuations |
| CW01-PC25 | 15.6 | 0 | no actuations |
| CW01-PC31 | 15.3 | 0 | no actuations |
| CW01-PC32 | 18.5 | 0 | no actuations |
| CW01-PC33 | 15.3 | 0 | no actuations |
| CW01-PC34 | 15.4 | 0 | no actuations |
| CW01-PC35 | 18.5 | 0 | no actuations |
| CW02-PC01 | 15.0 | 0 | no actuations |
| CW02-PC02 | 15.3 | 0 | no actuations |
| CW02-PC03 | 14.6 | 0 | no actuations |
| CW02-PC04 | 14.5 | 0 | no actuations |
| CW02-PC05 | 15.4 | 0 | no actuations |
| CW02-PC11 | 1.50 | 0 | no actuations |
| CW02-PC12 | 15.4 | 0 | no actuations |
| CW02-PC13 | 16.8 | 0 | no actuations |
| CW02-PC14 | 16.9 | 0 | no actuations |
| CW02-PC15 | 15.5 | 0 | no actuations |
| CW02-PC21 | 1.50 | 0 | no actuations |
| CW02-PC22 | 15.3 | 0 | no actuations |
| CW02-PC23 | 15.3 | 0 | no actuations |
| CW02-PC24 | 15.2 | 0 | no actuations |
| CW02-PC25 | 15.2 | 0 | no actuations |
| CW02-PC31 | 15.0 | 0 | no actuations |
| CW02-PC32 | 16.3 | 3 | 0.2 |
| CW02-PC33 | 20.2 | 1 | 0.0 |
| CW02-PC34 | 20.2 | 0 | no actuations |
| CW02-PC35 | 16.3 | 0 | no actuations |
| CZ01-PC01 | 14.9 | 1 | 0.1 |
| CZ01-PC02 | 15.0 | 0 | no actuations |
| CZ02-PC01 | 15.2 | 0 | no actuations |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| CZ02-PC02 | 15.0 | 1 | 0.7 |
| CZ03-PC01 | 16.4 | 0 | no actuations |
| CZ03-PC02 | 15.0 | 0 | no actuations |
| CZ04-PC01 | 16.1 | 0 | no actuations |
| CZ04-PC02 | 15.0 | 0 | no actuations |
| CZ05-PC01 | 15.3 | 0 | no actuations |
| CZ05-PC02 | 15.0 | 0 | no actuations |
| CZ05-PC03 | 15.3 | 0 | no actuations |
| CZ06-PC01 | 15.0 | 0 | no actuations |
| CZ06-PC02 | 15.0 | 0 | no actuations |
| CZ06-PC03 | 15.0 | 0 | no actuations |
| CZ07-PC01 | 16.2 | 0 | no actuations |
| CZ07-PC02 | 15.0 | 0 | no actuations |
| CZ08-PC01 | 15.1 | 0 | no actuations |
| CZ08-PC02 | 16.1 | 3 | 0.2 |
| CZ09-PC01 | 15.1 | 0 | no actuations |
| CZ09-PC02 | 15.2 | 0 | no actuations |
| CZ10-PC01 | 29.5 | 2 | 0.1 |
| CZ11-PC01 | 15.7 | 0 | no actuations |
| DL01-PC01 | 15.0 | 1 | 0.1 |
| DL01-PC02 | 15.0 | 0 | no actuations |
| DL01-PC03 | 14.9 | 0 | no actuations |
| DL01-PC04 | 15.0 | 0 | no actuations |
| DL01-PC05 | 14.4 | 0 | no actuations |
| DL01-PC11 | 14.8 | 0 | no actuations |
| DL01-PC12 | 14.7 | 1 | 0.1 |
| DL01-PC13 | 14.9 | 0 | no actuations |
| DL01-PC14 | 14.8 | 1 | 0.1 |
| DL01-PC15 | 14.9 | 1 | 0.1 |
| DL01-PC21 | 14.8 | 7 | 0.5 |
| DL01-PC22 | 14.7 | 0 | no actuations |
| DL01-PC23 | 14.7 | 7 | 0.5 |
| DL01-PC24 | 15.5 | 0 | no actuations |
| DL01-PC25 | 15.5 | 0 | no actuations |
| DL01-PC31 | 14.5 | 0 | no actuations |
| DL01-PC32 | 15.0 | 0 | no actuations |
| DL01-PC33 | 15.0 | 1 | 0.1 |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| DL01-PC34 | 15.2 | 0 | no actuations |
| DL01-PC35 | 15.2 | 0 | no actuations |
| DL01-PC41 | 15.7 | 0 | no actuations |
| DL01-PC42 | 15.7 | 1 | 0.1 |
| DL01-PC43 | 14.9 | 0 | no actuations |
| DL01-PC44 | 14.9 | 1 | 0.1 |
| DL01-PC45 | 15.0 | 0 | no actuations |
| DL02-PC01 | 14.9 | 0 | no actuations |
| DL02-PC02 | 14.9 | 1 | 0.1 |
| DL02-PC03 | 14.9 | 0 | no actuations |
| DL02-PC04 | 14.9 | 1 | 0.1 |
| DL02-PC05 | 14.9 | 0 | no actuations |
| DL02-PC11 | 14.8 | 1 | 0.1 |
| DL02-PC12 | 15.2 | 0 | no actuations |
| DL02-PC13 | 15.3 | 0 | no actuations |
| DL02-PC14 | 14.8 | 30 | 2.0 |
| DL02-PC15 | 14.9 | 30 | 2.0 |
| DL02-PC21 | 16.1 | 0 | no actuations |
| DL02-PC22 | 16.0 | 0 | no actuations |
| DL02-PC23 | 15.0 | 0 | no actuations |
| DL02-PC24 | 14.7 | 0 | no actuations |
| DL02-PC25 | 15.3 | 0 | no actuations |
| DL02-PC31 | 15.2 | 0 | no actuations |
| DL02-PC32 | 14.9 | 0 | no actuations |
| DL02-PC33 | 14.8 | 33 | 2.2 |
| DL02-PC34 | 15.2 | 0 | no actuations |
| DL02-PC35 | 15.1 | 11 | 0.7 |
| DL02-PC41 | 14.7 | 0 | no actuations |
| DL02-PC42 | 14.7 | 1 | 0.1 |
| DL02-PC43 | 15.0 | 0 | no actuations |
| DL02-PC44 | 15.0 | 0 | no actuations |
| DL02-PC45 | 14.9 | 0 | no actuations |
| DL02-PC51 | 14.9 | 0 | no actuations |
| DL02-PC52 | 15.1 | 0 | no actuations |
| DL02-PC53 | 15.1 | 0 | no actuations |
| DL02-PC54 | 14.6 | 0 | no actuations |
| DL02-PC55 | 14.6 | 0 | no actuations |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| DL02-PC61 | 14.5 | 0 | no actuations |
| DL02-PC62 | 15.0 | 0 | no actuations |
| GZ01-PC01 | 15.3 | 0 | no actuations |
| GZ01-PC02 | 15.7 | 0 | no actuations |
| GZ01-PC03 | 15.2 | 0 | no actuations |
| GZ01-PC04 | 15.1 | 0 | no actuations |
| GZ01-PC05 | 15.4 | 0 | no actuations |
| GZ01-PC11 | 15.3 | 0 | no actuations |
| GZ01-PC12 | 14.6 | 0 | no actuations |
| GZ01-PC13 | 14.4 | 0 | no actuations |
| GZ01-PC14 | 15.0 | 0 | no actuations |
| GZ01-PC15 | 15.0 | 0 | no actuations |
| GZ01-PC21 | 15.0 | 0 | no actuations |
| GZ01-PC22 | 15.0 | 0 | no actuations |
| GZ02-PC01 | 14.6 | 0 | no actuations |
| GZ02-PC02 | 14.5 | 0 | no actuations |
| GZ02-PC03 | 14.8 | 0 | no actuations |
| GZ02-PC04 | 15.6 | 0 | no actuations |
| GZ02-PC05 | 15.0 | 0 | no actuations |
| GZ02-PC11 | 15.2 | 0 | no actuations |
| GZ02-PC12 | 15.2 | 0 | no actuations |
| GZ02-PC13 | 15.0 | 0 | no actuations |
| GZ02-PC14 | 15.0 | 0 | no actuations |
| GZ02-PC15 | 15.1 | 0 | no actuations |
| GZ02-PC21 | 15.3 | 0 | no actuations |
| GZ02-PC22 | 15.0 | 0 | no actuations |
| GZ02-PC23 | 15.0 | 0 | no actuations |
| GZ02-PC24 | 15.0 | 0 | no actuations |
| GZ03-PC01 | 15.2 | 2 | 0.1 |
| GZ03-PC02 | 15.5 | 2 | 0.1 |
| GZ03-PC03 | 15.5 | 0 | no actuations |
| GZ03-PC04 | 15.2 | 0 | no actuations |
| GZ03-PC05 | 15.0 | 0 | no actuations |
| GZ03-PC11 | 15.0 | 0 | no actuations |
| GZ03-PC12 | 15.0 | 0 | no actuations |
| GZ03-PC13 | 17.6 | 0 | no actuations |
| GZ03-PC14 | 17.6 | 0 | no actuations |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| GZ03-PC15 | 14.9 | 0 | no actuations |
| GZ03-PC21 | 90.5 | 0 | no actuations |
| GZ03-PC22 | 15.0 | 0 | no actuations |
| GZ03-PC23 | 90.4 | 14 | 0.2 |
| GZ03-PC24 | 15.2 | 0 | no actuations |
| GZ03-PC25 | 15.0 | 0 | no actuations |
| GZ03-PC31 | 15.0 | 0 | no actuations |
| GZ03-PC32 | 14.9 | 0 | no actuations |
| GZ03-PC33 | 14.9 | 0 | no actuations |
| GZ03-PC34 | 14.9 | 0 | no actuations |
| GZ03-PC35 | 14.9 | 0 | no actuations |
| GZ03-PC41 | 15.1 | 0 | no actuations |
| GZ03-PC42 | 15.0 | 0 | no actuations |
| GZ04-PC01 | 16.0 | 2 | 0.1 |
| GZ04-PC02 | 16.0 | 0 | no actuations |
| GZ04-PC03 | 17.8 | 5 | 0.3 |
| GZ04-PC04 | 17.9 | 0 | no actuations |
| GZ04-PC05 | 15.0 | 0 | no actuations |
| GZ04-PC11 | 15.0 | 0 | no actuations |
| LB01-PC01 | 15.0 | 4 | 0.3 |
| LB01-PC02 | 15.0 | 3 | 0.2 |
| LB02-PC01 | 15.0 | 0 | no actuations |
| LB02-PC02 | 15.0 | 0 | no actuations |
| LB02-PC03 | 15.0 | 0 | no actuations |
| LB02-PC04 | 15.0 | 0 | no actuations |
| LB03-PC01 | 15.2 | 8 | 0.5 |
| LB03-PC02 | 15.2 | 1 | 0.1 |
| LB04-PC01 | 15.0 | 5 | 0.3 |
| LB04-PC02 | 15.0 | 6 | 0.4 |
| LB04-PC03 | 20.2 | 8 | 0.4 |
| LB04-PC04 | 20.2 | 2 | 0.1 |
| LB05-PC01 | 15.1 | 11 | 0.7 |
| LB05-PC02 | 15.1 | 0 | no actuations |
| LB05-PC03 | 15.5 | 15 | 1.0 |
| LB05-PC04 | 15.5 | 0 | no actuations |
| LB06-PC01 | 15.0 | 4 | 0.3 |
| LB06-PC02 | 15.0 | 2 | 0.1 |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| LB06-PC03 | 15.2 | 11 | 0.7 |
| LB06-PC04 | 15.2 | 0 | no actuations |
| LB06-PC05 | 15.7 | 14 | 0.9 |
| LB06-PC11 | 15.7 | 6 | 0.4 |
| LB07-PC01 | 15.0 | 15 | 1.0 |
| LB07-PC02 | 15.0 | 15 | 1.0 |
| LB07-PC03 | 18.1 | 14 | 0.8 |
| LB07-PC04 | 21.1 | 2 | 0.1 |
| OF01-PC01 | 15.0 | 23 | 1.5 |
| OF02-PC01 | 14.9 | 0 | no actuations |
| OF03-PC01 | 15.0 | 154 | 10.3 |
| OF04-PC01 | 15.0 | 0 | no actuations |
| OF05-PC01 | 15.4 | 6 | 0.4 |
| OF06-PC01 | 15.0 | 0 | no actuations |
| OF07-PC01 | 15.0 | 98 | 6.5 |
| OF08-PC01 | 15.2 | 0 | no actuations |
| OF08-PC02 | 15.0 | 0 | no actuations |
| OF09-PC01 | 15.1 | 0 | no actuations |
| OF10-PC01 | 15.1 | 0 | no actuations |
| OF11-PC01 | 22.7 | 10 | 0.4 |
| OF11-PC02 | 14.9 | 0 | no actuations |
| OF11-PC03 | 15.7 | 0 | no actuations |
| OF11-PC04 | 15.3 | 0 | no actuations |
| RB01-PC01 | 15.0 | 0 | no actuations |
| RB01-PC02 | 11.0 | 0 | no actuations |
| RB01-PC03 | 15.0 | 0 | no actuations |
| RB01-PC04 | 14.9 | 0 | no actuations |
| RB01-PC05 | 18.0 | 0 | no actuations |
| RB01-PC11 | 18.0 | 1 | 0.1 |
| RB01-PC12 | 16.0 | 0 | no actuations |
| RB01-PC13 | 14.9 | 0 | no actuations |
| RB01-PC14 | 16.9 | 8 | 0.5 |
| RB01-PC15 | 15.0 | 0 | no actuations |
| RB01-PC21 | 15.0 | 0 | no actuations |
| RB01-PC23 | 15.0 | 0 | no actuations |
| RB01-PC24 | 15.0 | 0 | no actuations |
| RB01-PC25 | 15.0 | 0 | no actuations |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| RB01-PC34 | 15.0 | 0 | no actuations |
| RB02-PC01 | 15.0 | 0 | no actuations |
| RB02-PC02 | 15.8 | 0 | no actuations |
| RB02-PC03 | 15.0 | 0 | no actuations |
| RB02-PC05 | 15.0 | 5 | 0.3 |
| RB02-PC11 | 15.0 | 0 | no actuations |
| RB02-PC12 | 15.0 | 0 | no actuations |
| RQ01-PC01 | 15.1 | 0 | no actuations |
| RQ02-PC01 | 16.2 | 0 | no actuations |
| RQ02-PC02 | 16.1 | 0 | no actuations |
| RQ03-PC01 | 20.4 | 0 | no actuations |
| RQ04-PC01 | 39.9 | 0 | no actuations |
| RQ05-PC01 | 20.2 | 0 | no actuations |
| RQ05-PC02 | 20.3 | 1 | 0.0 |
| RQ05-PC03 | 14.8 | 0 | no actuations |
| RQ05-PC04 | 15.0 | 0 | no actuations |
| RQ06-PC01 | 14.8 | 0 | no actuations |
| RQ06-PC02 | 15.0 | 0 | no actuations |
| RQ06-PC03 | 15.9 | 0 | no actuations |
| RQ06-PC04 | 15.8 | 0 | no actuations |
| RQ07-PC01 | 15.1 | 0 | no actuations |
| RQ07-PC02 | 15.0 | 0 | no actuations |
| RQ07-PC03 | 16.1 | 0 | no actuations |
| RQ07-PC04 | 15.2 | 0 | no actuations |
| RQ07-PC05 | 15.2 | 0 | no actuations |
| VF01-PC01 | 15.7 | 0 | no actuations |
| VF01-PC02 | 15.8 | 0 | no actuations |
| VF01-PC03 | 15.3 | 0 | no actuations |
| VF01-PC04 | 15.4 | 0 | no actuations |
| VF01-PC05 | 15.2 | 0 | no actuations |
| VF01-PC11 | 15.2 | 0 | no actuations |
| VF01-PC12 | 15.8 | 0 | no actuations |
| VF01-PC13 | 15.9 | 0 | no actuations |
| VF01-PC14 | 14.1 | 0 | no actuations |
| VF01-PC15 | 14.1 | 0 | no actuations |
| VF01-PC21 | 15.2 | 0 | no actuations |
| VF01-PC22 | 15.2 | 0 | no actuations |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| VF01-PC23 | 15.2 | 0 | no actuations |
| VF01-PC24 | 15.2 | 0 | no actuations |
| VF01-PC25 | 15.2 | 0 | no actuations |
| VF01-PC31 | 15.2 | 0 | no actuations |
| VF01-PC32 | 15.0 | 0 | no actuations |
| VF01-PC33 | 16.1 | 0 | no actuations |
| VF01-PC34 | 15.1 | 0 | no actuations |
| VF01-PC35 | 15.1 | 0 | no actuations |
| VF01-PC41 | 17.1 | 0 | no actuations |
| VF01-PC42 | 17.1 | 0 | no actuations |
| VF01-PC43 | 14.9 | 0 | no actuations |
| VF01-PC44 | 14.9 | 0 | no actuations |
| VF01-PC45 | 14.5 | 0 | no actuations |
| VF01-PC51 | 14.5 | 0 | no actuations |
| VF01-PC52 | 15.2 | 0 | no actuations |
| VF01-PC53 | 15.2 | 1 | 0.1 |
| VF01-PC54 | 16.0 | 1 | 0.1 |
| VF01-PC55 | 16.0 | 0 | no actuations |
| VF02-PC01 | 15.3 | 0 | no actuations |
| VF02-PC02 | 15.3 | 0 | no actuations |
| VF02-PC03 | 15.0 | 1 | 0.1 |
| VF02-PC04 | 15.0 | 0 | no actuations |
| VF02-PC05 | 14.6 | 0 | no actuations |
| VF02-PC11 | 14.6 | 0 | no actuations |
| VF02-PC12 | 15.0 | 0 | no actuations |
| XQ01-PC01 | 15.0 | 0 | no actuations |
| XQ01-PC02 | 15.0 | 0 | no actuations |
| XQ01-PC03 | 15.0 | 0 | no actuations |
| XQ01-PC04 | 15.3 | 3 | 0.2 |
| XQ02-PC01 | 15.9 | 0 | no actuations |
| XQ02-PC02 | 15.9 | 0 | no actuations |
| XQ02-PC03 | 15.0 | 0 | no actuations |
| XQ02-PC04 | 14.0 | 0 | no actuations |
| XQ03-PC01 | 15.0 | 0 | no actuations |
| XQ03-PC02 | 15.0 | 0 | no actuations |
| XQ03-PC03 | 15.0 | 0 | no actuations |
| XQ03-PC04 | 15.0 | 0 | no actuations |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| XQ04-PC01 | 15.9 | 0 | no actuations |
| XQ04-PC02 | 15.9 | 0 | no actuations |
| XQ04-PC03 | 15.0 | 0 | no actuations |
| XQ04-PC04 | 15.0 | 0 | no actuations |
| XQ05-PC01 | 15.0 | 0 | no actuations |
| XQ05-PC02 | 15.0 | 0 | no actuations |
| XQ05-PC03 | 15.0 | 0 | no actuations |
| XQ05-PC04 | 15.0 | 0 | no actuations |
| XQ06-PC01 | 15.0 | 0 | no actuations |
| XQ06-PC02 | 15.0 | 0 | no actuations |
| XQ06-PC03 | 15.0 | 0 | no actuations |
| XQ06-PC04 | 15.0 | 0 | no actuations |
| XQ07-PC01 | 17.0 | 0 | no actuations |
| XQ07-PC02 | 17.0 | 0 | no actuations |
| XQ07-PC03 | 15.0 | 0 | no actuations |
| XQ07-PC04 | 15.0 | 1 | 0.7 |
| ZW01-PC01 | 15.3 | 0 | no actuations |
| ZW01-PC02 | 15.0 | 0 | no actuations |
| ZW01-PC03 | 15.0 | 0 | no actuations |
| ZW01-PC04 | 15.3 | 0 | no actuations |
| ZW01-PC05 | 15.4 | 0 | no actuations |
| ZW01-PC11 | 14.9 | 0 | no actuations |
| ZW01-PC12 | 22.0 | 0 | no actuations |
| ZW01-PC13 | 15.0 | 0 | no actuations |
| ZW01-PC14 | 15.5 | 0 | no actuations |
| ZW01-PC15 | 14.9 | 0 | no actuations |
| ZW01-PC21 | 15.0 | 4 | 0.3 |
| ZW01-PC22 | 14.8 | 0 | no actuations |
| ZW01-PC23 | 14.9 | 0 | no actuations |
| ZW01-PC24 | 15.0 | 0 | no actuations |
| ZW01-PC25 | 14.9 | 0 | no actuations |
| ZW01-PC31 | 15.0 | 0 | no actuations |
| ZW01-PC32 | 15.0 | 0 | no actuations |
| ZW01-PC33 | 14.9 | 0 | no actuations |
| ZW01-PC34 | 14.9 | 0 | no actuations |
| ZW01-PC35 | 15.1 | 0 | no actuations |
| ZW02-PC01 | 15.0 | 0 | no actuations |

**Table A-9** (continued).

| Device Identifier | Total measured time (min) | # of actuations | frequency of actuations (#/min) |
|---|---|---|---|
| ZW02-PC02 | 14.9 | 0 | no actuations |
| ZW02-PC03 | 15.0 | 0 | no actuations |
| ZW02-PC04 | 15.0 | 0 | no actuations |
| ZW02-PC12 | 15.0 | 0 | no actuations |
| ZW03-PC01 | 15.0 | 0 | no actuations |
| ZW03-PC02 | 15.0 | 0 | no actuations |
| ZW03-PC03 | 15.0 | 0 | no actuations |

### *A.5 Estimates of emissions from devices with no emissions detected during 15 minute sampling period*

The data set includes 241 devices (64%) for which no emissions were detected over a 15 minute sampling period (136 devices) or that had flow below the instrument measurement threshold that was indistinguishable from instrument noise (105 devices). Even though no actuations were detected on these devices during the sampling period, for some of these devices, actuations and the associated emissions per actuation would have been observed if the sampling period had been extended. Estimates of the potential emissions from these devices can be determined by estimating actuation frequency and volume.

$$\textit{Estimated emissions} = \textit{actuation frequency } (min^{-1}) * \textit{actuation volume (scf)} \qquad (A5.1)$$

It is assumed, in these estimates, that all of these devices for which emissions are estimated are intermittent vent controllers, rather than continuous vent controllers, since the measured emission rates included zero values.

The actuation frequencies and emissions per actuation were estimated based on data for controllers with well-defined actuation patterns. A well-defined actuation pattern exhibited intermittent emissions patterns, returned to a zero emissions baseline between actuations, and had two or more actuations during the 15 minute sampling period. Average actuation volumes for controllers in eight types of service are provided in Table A-10.

**Table A-10.** Counts of devices and average emissions per actuation for controllers in eight application categories; note that for ESDs, the emissions measured during the sampling were device leak rates rather than device actuations.

| Application | Devices with no emissions detected during sampling period | Devices with well-defined actuations | Average volume per actuation for "Actuating" Devices (scf) |
|---|---|---|---|
| **Separator - Level Control** | 109 | 26 | 0.349 |
| **ESD** | 31 | 5 | 0.026 |
| **Plunger Lift** | 20 | 1 | 0.048 |
| **Process Heater** | 40 | 1 | 0.191 |
| **Other** | 10 | 0 | Assumed average from all other devices (0.271) |
| **Separator - Other** | 9 | 2 | 0.070 |
| **Compressor** | 7 | 2 | 0.158 |
| **Dehydration System** | 15 | 1 | 0.398 |

Table A-10 provides estimates of actuation volumes, categorized by application. Actuation frequency could be estimated using a variety of approaches. An upper bound on the emission rate could be estimated by assuming that all devices for which no emissions were observed over 15 minutes of sampling actually had actuations that occurred immediately before and immediately after the sampling period (4 actuations per hour, a frequency of 0.067 $min^{-1}$). This scenario is improbable, nevertheless, it does provide an upper bound. Assuming that devices with no measured emissions actuated every 15 minutes, and had the actuation volumes, consistent with application type, reported in Table A-10, increases the overall population average emissions by 11% (from 5.52 scf/h to 6.13 scf/h whole gas). As the assumed actuation frequency decreases, the estimated additional emissions decrease, as shown in Figure A-5. If a 3 hour period between actuations is assumed (0.0055 $min^{-1}$), the study average emissions rate per device increases by less than 1%.

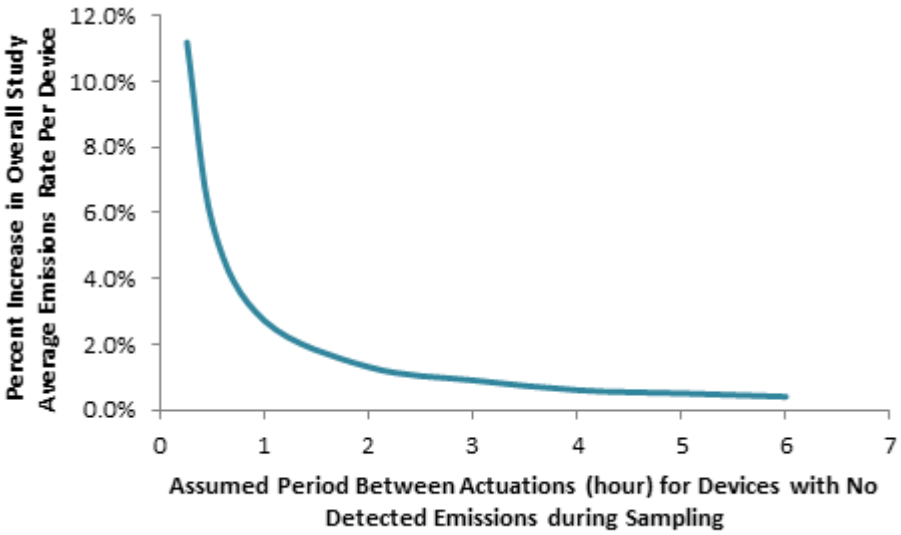



**Figure A-5.** Sensitivity of study-average emissions rate per device to the assumed period between actuations for devices with no detected emissions during the sampling period.

For some application categories, specifically level control of separators, actuation frequencies, for devices with no actuations detected over 15 minutes of sampling, can be estimated based on the data from devices with observed actuations. Separator level controllers were both the largest category of pneumatic devices measured in this study (50% of total devices) and the largest category of devices with no measured emissions over a 15 minute sampling period (45%). For this category of devices, the actuation frequencies for all intermittent vent controllers with a period between actuations of less than 7.5 minutes (at least two actuations in 15 minutes of observation, 21% of the intermittent vent separator level controllers) are shown in Figure A-6. The most conservative estimate of the range of periods between actuations for separator level controllers would be a linear extrapolation of the subset of devices with a periodicity of less than 7.5 minutes (Figure A-6).

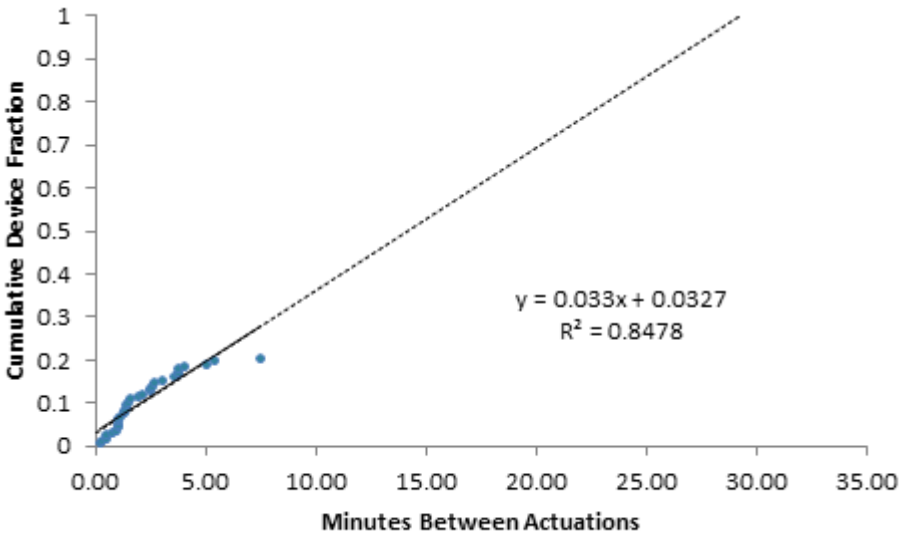



**Figure A-6.** Period between actuations for separator level controllers with intermittent vent emissions patterns.

A linear extrapolation of the actuation frequency for separator level controllers with two or more actuations in the sample period to the overall population of separator level controllers indicated that all separator level controllers would undergo an actuation within 30 minutes. Assuming that the minutes between actuations for the separator level controllers for which no emissions were detected during sampling were evenly spaced between 15 minutes and 30 minutes, the increase in the overall study-average per device emissions rate for all devices in all applications would be between 5.1% (assuming that the actual emissions rate from all non-separator level controllers for which no emissions were detected during sampling were negligible) and 8.9% (assuming that all devices without detected emissions during sampling and that were not in separator level controller applications actuated every 15 minutes). This approach likely under-estimates the time between actuations for separator level controllers (over-estimates the frequency). Based on the linear extrapolation shown in Figure A-6-, 25% of devices in separator level control applications would be expected to have actuations between 7.5 minutes to 15 minutes. For devices sampled in the study, only 6% of level controllers on separators recorded a single actuation during a 15 minute sample time or had a periodicity in this

range due to two actuations during a sample time longer than 15 minutes. Adjusting the slope of the linear interpolation to fit the data collected between 7.5 and 15 minutes changes the slope to 0.008 and would indicate that all devices would actuate within 121 minutes. Separator level controller emissions would be estimated to increase by 2.9% under this assumption. Under this revised linear interpolation, the estimated average emissions per device from the overall study population could increase between 2.1% and 5.9%, again depending on the frequency assumed for controllers not in separator level control service.

Overall, the study average emission rate for controllers would be expected to increase by 2%-6% if the measurement period had been extended indefinitely. This estimate is based on data for controllers in separator level control service, the most common type of service observed in the study, and a type of service that is likely to result in regular actuations.

### *A.6 Numbers of controllers per well*

In this work, a total of 65 sites were visited. The 65 sites had 377 pneumatic controllers on which measurements were performed and 53 for which either time constraints or equipment failure led to no sample being collected. The 65 sites with 430 controllers had 161 wells, for an average of 2.7 devices per well. The median value was 2.0 controllers per well with $25^{th}$ and $75^{th}$ percentile values of 1 and 4 controllers per well. The minimum value was 0.4 devices per well, and the maximum value was 11 devices per well. The distribution is shown in Figure A-7. Table A-11 provides counts of controllers and wells at individual sites.

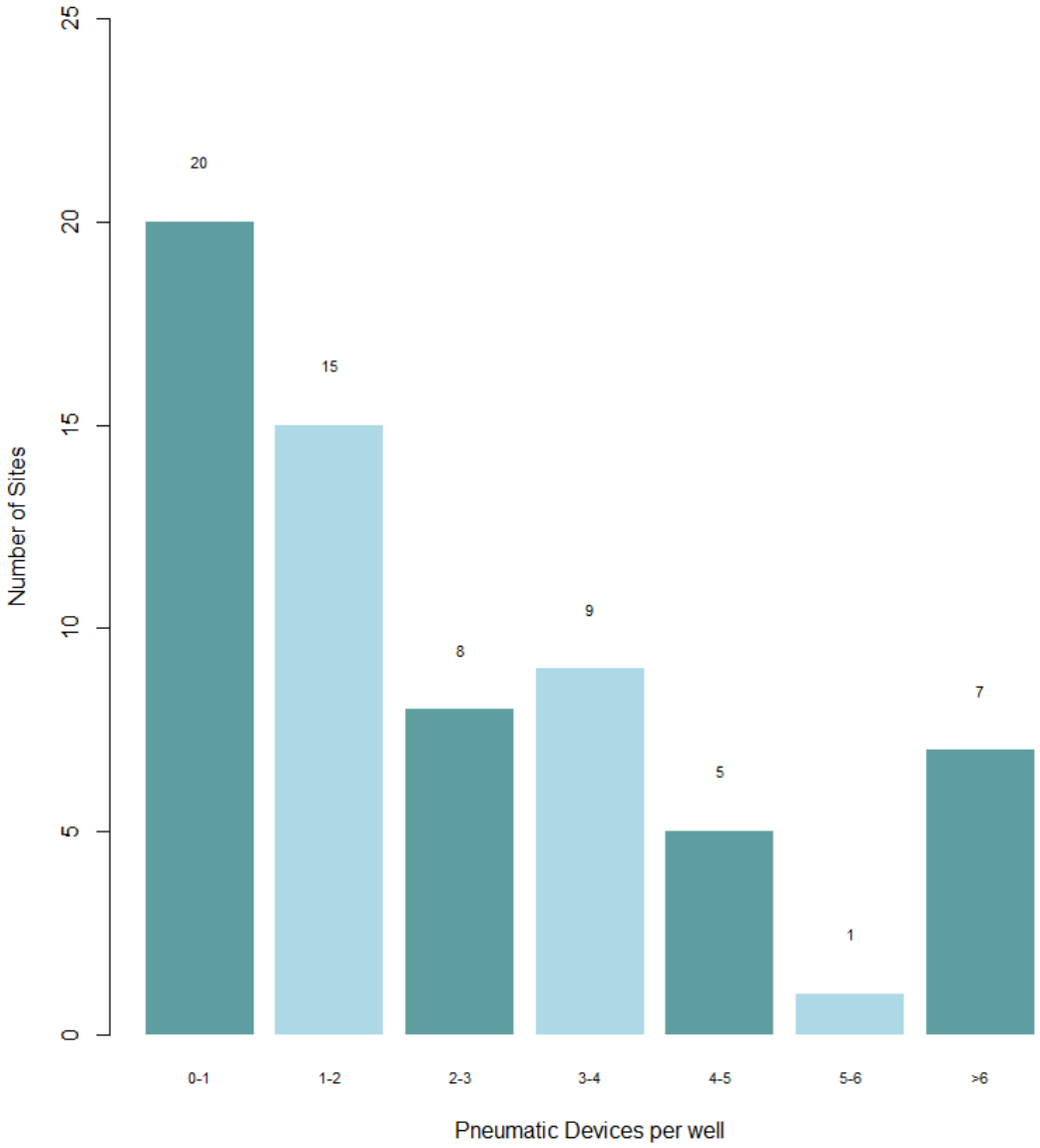



**Figure A-7**. Distribution of number of pneumatic devices per well for production sites sampled by the study team.

**Table A-11.** Number of pneumatic devices and wells for sites sampled in this work.

| Site Identifier | Count of Measured Pneumatic Devices | Count of Not measured Pneumatic Devices: | Total Pneumatic Devices | Count of wells | Devices/ well |
|---|---|---|---|---|---|
| AA01 | 7 | 22 | 29 | 3 | 9.7 |
| AA02 | 6 | 14 | 20 | 2 | 10.0 |
| AP01 | 6 | 0 | 6 | 16 | 0.4 |
| AP02 | 4 | 0 | 4 | 10 | 0.4 |
| AP03 | 2 | 0 | 2 | 3 | 0.7 |
| AP04 | 4 | 0 | 4 | 8 | 0.5 |
| AP05 | 2 | 0 | 2 | 4 | 0.5 |
| CW01 | 20 | 0 | 20 | 4 | 5.0 |
| CW02 | 20 | 0 | 20 | 4 | 5.0 |
| CZ01 | 2 | 0 | 2 | 1 | 2.0 |
| CZ02 | 2 | 0 | 2 | 1 | 2.0 |
| CZ03 | 2 | 0 | 2 | 1 | 2.0 |
| CZ04 | 2 | 0 | 2 | 1 | 2.0 |
| CZ05 | 3 | 0 | 3 | 1 | 3.0 |
| CZ06 | 3 | 0 | 3 | 1 | 3.0 |
| CZ07 | 2 | 0 | 2 | 1 | 2.0 |
| CZ08 | 2 | 1 | 3 | 3 | 1.0 |
| CZ09 | 2 | 0 | 2 | 1 | 2.0 |
| CZ10 | 1 | 0 | 1 | 1 | 1.0 |
| CZ11 | 1 | 0 | 1 | 1 | 1.0 |
| DL01 | 25 | 0 | 25 | 10 | 2.5 |
| DL02 | 32 | 0 | 32 | 14 | 2.3 |
| GZ01 | 12 | 0 | 12 | 4 | 3.0 |
| GZ02 | 14 | 0 | 14 | 2 | 7.0 |
| GZ03 | 22 | 0 | 22 | 2 | 11.0 |
| GZ04 | 6 | 0 | 6 | 2 | 3.0 |
| LB01 | 2 | 0 | 2 | 1 | 2.0 |
| LB02 | 4 | 0 | 4 | 2 | 2.0 |
| LB03 | 2 | 0 | 2 | 1 | 2.0 |
| LB04 | 4 | 0 | 4 | 2 | 2.0 |
| LB05 | 4 | 2 | 6 | 2 | 3.0 |
| LB06 | 6 | 3 | 9 | 3 | 3.0 |
| LB07 | 4 | 0 | 4 | 2 | 2.0 |
| OF01 | 1 | 0 | 1 | 1 | 1.0 |
| OF02 | 1 | 0 | 1 | 1 | 1.0 |
| OF03 | 1 | 0 | 1 | 1 | 1.0 |

**Table A-11** (continued).

| Site Identifier | Count of Measured Pneumatic Devices | Count of Not measured Pneumatic Devices: | Total Pneumatic Devices | Count of wells | Devices/ well |
|---|---|---|---|---|---|
| OF04 | 1 | 0 | 1 | 1 | 1.0 |
| OF05 | 1 | 0 | 1 | 1 | 1.0 |
| OF06 | 1 | 0 | 1 | 1 | 1.0 |
| OF07 | 1 | 0 | 1 | 1 | 1.0 |
| OF08 | 2 | 0 | 2 | 1 | 2.0 |
| OF09 | 1 | 0 | 1 | 1 | 1.0 |
| OF10 | 1 | 0 | 1 | 1 | 1.0 |
| OF11 | 4 | 0 | 4 | 1 | 4.0 |
| RB01 | 15 | 0 | 15 | 3 | 5.0 |
| RB02 | 6 | 1 | 7 | 1 | 7.0 |
| RQ01 | 1 | 0 | 1 | 1 | 1.0 |
| RQ02 | 2 | 0 | 2 | 1 | 2.0 |
| RQ03 | 1 | 0 | 1 | 1 | 1.0 |
| RQ04 | 1 | 0 | 1 | 1 | 1.0 |
| RQ05 | 4 | 0 | 4 | 2 | 2.0 |
| RQ06 | 4 | 0 | 4 | 1 | 4.0 |
| RQ07 | 5 | 0 | 5 | 1 | 5.0 |
| VF01 | 30 | 0 | 30 | 6 | 5.0 |
| VF02 | 7 | 0 | 7 | 6 | 1.2 |
| XQ01 | 4 | 0 | 4 | 1 | 4.0 |
| XQ02 | 4 | 0 | 4 | 1 | 4.0 |
| XQ03 | 4 | 0 | 4 | 1 | 4.0 |
| XQ04 | 4 | 0 | 4 | 1 | 4.0 |
| XQ05 | 4 | 0 | 4 | 1 | 4.0 |
| XQ06 | 4 | 0 | 4 | 1 | 4.0 |
| XQ07 | 4 | 0 | 4 | 1 | 4.0 |
| ZW01 | 20 | 5 | 25 | 3 | 8.3 |
| ZW02 | 5 | 1 | 6 | 1 | 6.0 |
| ZW03 | 3 | 4 | 7 | 1 | 7.0 |

### *A.7 Estimates of emissions from pneumatic controllers in the United States*

National emissions are estimated by multiplying an average emission measurement by the number of times that emission occurs on the national scale. Emission measurements are often referred to as an "emission factor" or EF, and the data used to scale up the emissions is called the activity factor (AF). Emissions are calculated as:

$$EF_i * AF_i = ER_i \quad \text{(A7.1)}$$

*where:*

$EF_i$ = Emission Factor for region i

$AF_i$ = Activity Factor for region i

$ER_i$ = resulting Emission Rate total for region i

For this work, the activity factors are national estimates of the number of pneumatic controllers. Emission factors are based on average emissions per controller measured in this work. Four combinations of activity factors and emission factors are used to calculate national emission estimates (Table A-12); these scenarios illustrate the uncertainty in national emission estimates that arise due to uncertainties in activity factors.

**Table A-12.** National methane emission estimates, assuming various activity factor scenarios

| Activity Factor | Emission Factor | National methane emission estimate |
|---|---|---|
| Number of controllers in EPA 2012 Greenhouse Gas National Emission Inventory, 477,606 controllers | Average emission rate for all controllers measured in this work, 4.9 scf methane/h | 394 Gg/y<br>20.5 bcf/y |
| Number of controllers in EPA 2012 Greenhouse Gas National Emission Inventory, 477,606 controllers | Average emission rate for controllers measured in this work, not including ESD controllers in the average, 5.5 scf methane/h | 442 Gg/y<br>23.0 bcf/y |
| Number of wells in EPA 2012 Greenhouse Gas National Emission Inventory, 470,913 wells, with 75% of the wells assumed to have 2.7 pneumatic controllers per well, as observed in this work | Average emission rate for all controllers measured in this work, 4.9 scf methane/h | 786 Gg/y<br>40.9 bcf/y |
| Number of wells in EPA 2012 Greenhouse Gas National Emission Inventory, 470,913 wells, with all of the wells assumed to have 2.7 pneumatic controllers per well, as observed in this work | Average emission rate for all controllers measured in this work, 4.9 scf methane/h | 1050 Gg/y<br>54.6 bcf/y |

The range of estimates (394-1,050 Gg/y) in Table S7-2 indicates the extent of variability in national emission estimates due to uncertainties in activity data. In the absence of additional activity data, a central estimate will be assumed to be a mid-point between the second and third scenarios, approximately 600 Gg/yr. These scenarios were selected since at least some of the participants in this study have significant numbers of wells with no pneumatic controllers, and because at least some of the participants do not inventory devices, such as Emergency Shut Down controllers, that are not expected to actuate.

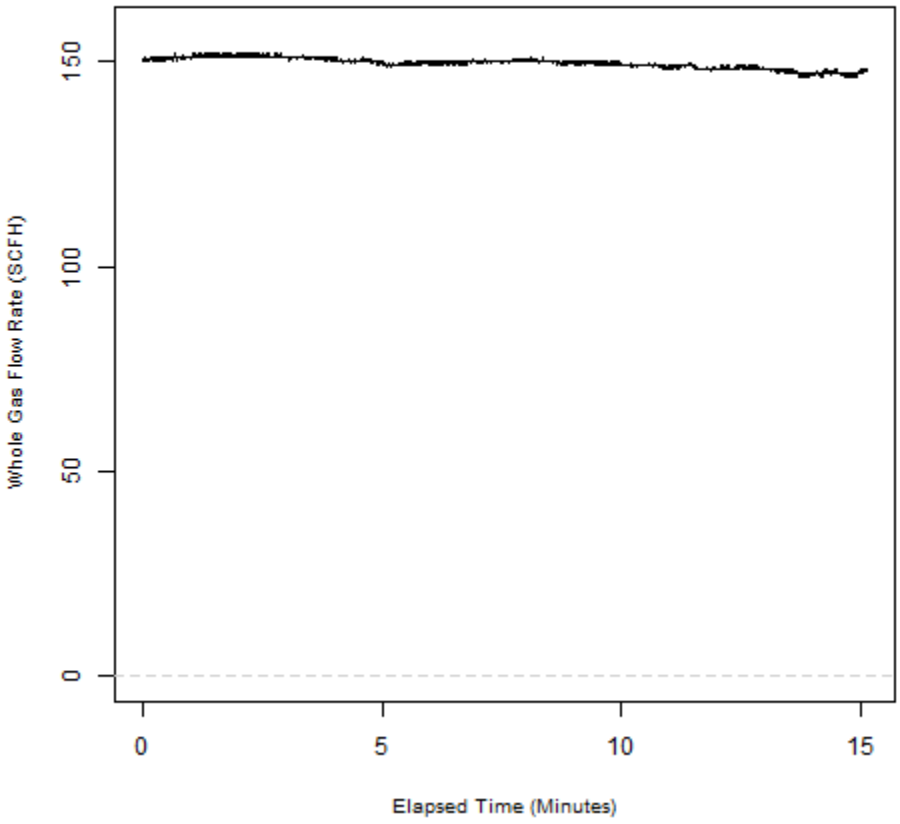
### *A.8 Summary of data on 40 highest emitting devices*

Controller characteristics and time series for measured emissions are reported for the 40 devices with the highest measured emission rates. This information was reviewed by technical experts on pneumatic controller operation to assess whether controllers were operating properly. While these 40 controllers were not removed from operation and subjected to a rigorous performance analysis, the data that were collected may reveal some features of operation. For example, if a device had very high rates of nearly continuous emissions, larger than would be expected for the device design and supply gas pressure, it could be hypothesized that the controller/control valve system had a leak. If a device with intermittent actuation emissions, which appeared to be an intermittent vent controller, did not return to zero flow between actuations, it could be hypothesized that the barrier between the supply gas and the controller was not closing completely. It is important to recognize that these are hypotheses, based on expert opinion. The controllers are categorized, based on these hypotheses, as having "*equipment issues*" or "*operating as expected*".

**CZ09-PC01 [ 1 ] Region: GC**

*Device characteristics:*

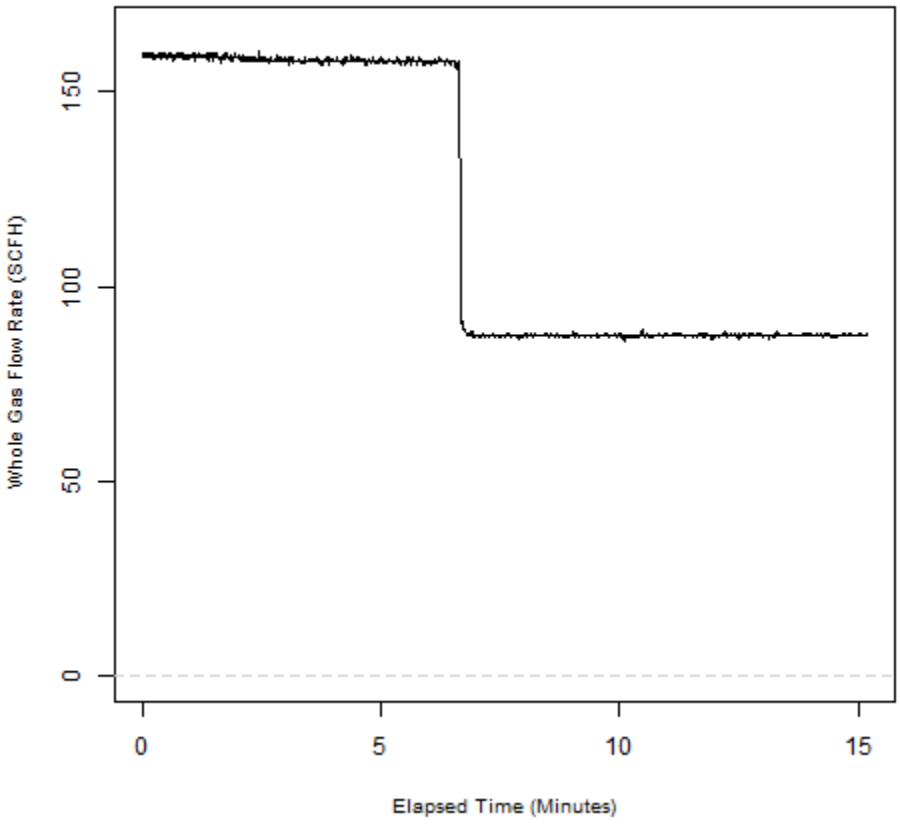
| | |
|---|---|
| Avg. Emission rate (whole gas): | 149.7 scf/h |
| Avg. Emission rate (methane): | 143.8 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 19 psig |
| Assessment of controller operation: | equipment issues |



**CZ02-PC01 [ 2 ] Region: GC**

*Device characteristics:*

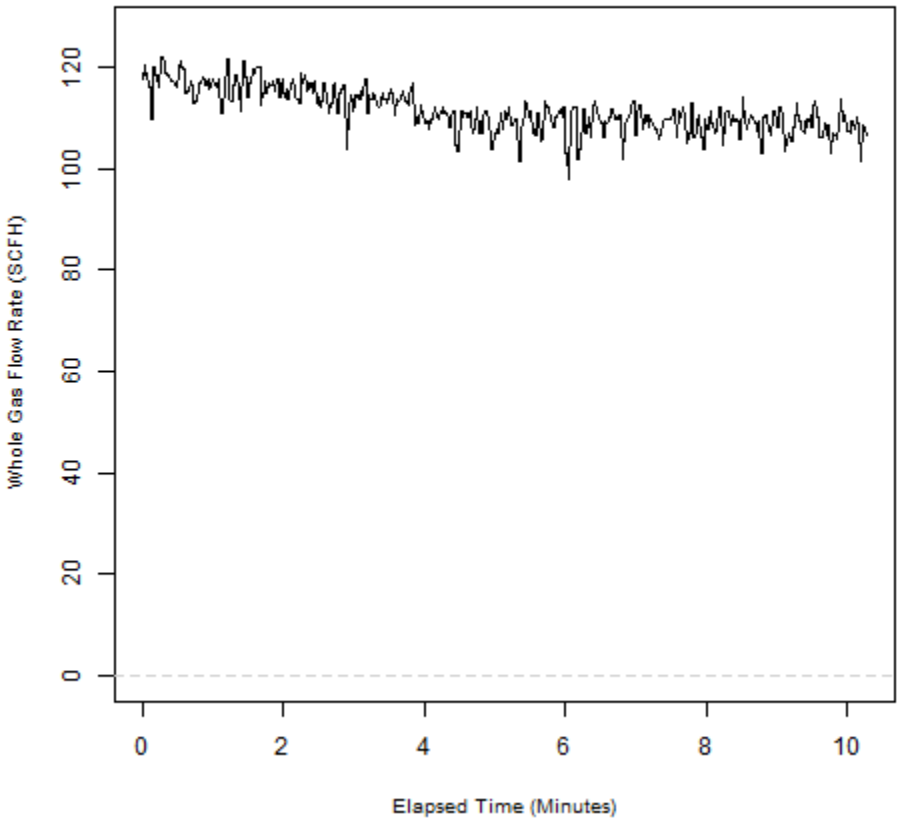
| | |
|---|---|
| Avg. Emission rate (whole gas): | 118.5 scf/h |
| Avg. Emission rate (methane): | 108.0 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | J01 |
| Supply pressure: | 17 psig |
| Assessment of controller operation: | equipment issues |



**AA02-PC08 [ 3 ] Region: MC**

*Device characteristics:*

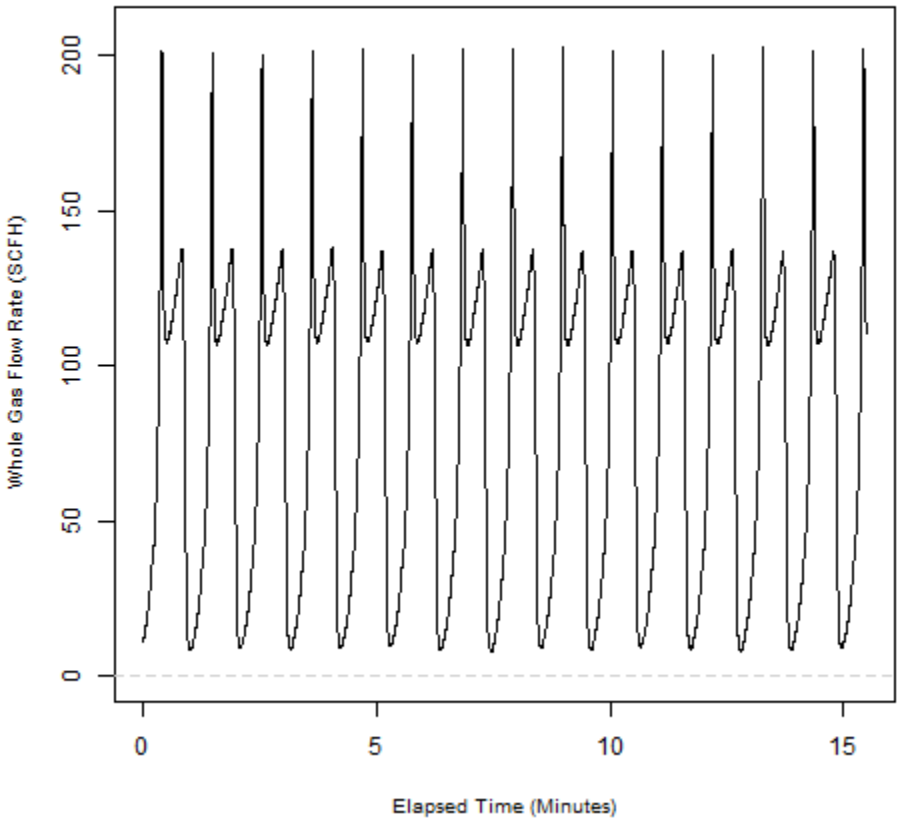
| | |
|---|---|
| Avg. Emission rate (whole gas): | 111.4 scf/h |
| Avg. Emission rate (methane): | 89.7 scf/h |
| Controller application: | Pressure |
| Basic Application: | Compressor |
| Detailed Application: | Compressor - Suction Feed Control |
| Manufacturer/Model (blinded): | I01 |
| Supply pressure: | 60 psig |
| Assessment of controller operation: | equipment issues |



**LB05-PC03 [ 4 ] Region: GC**

*Device characteristics:*

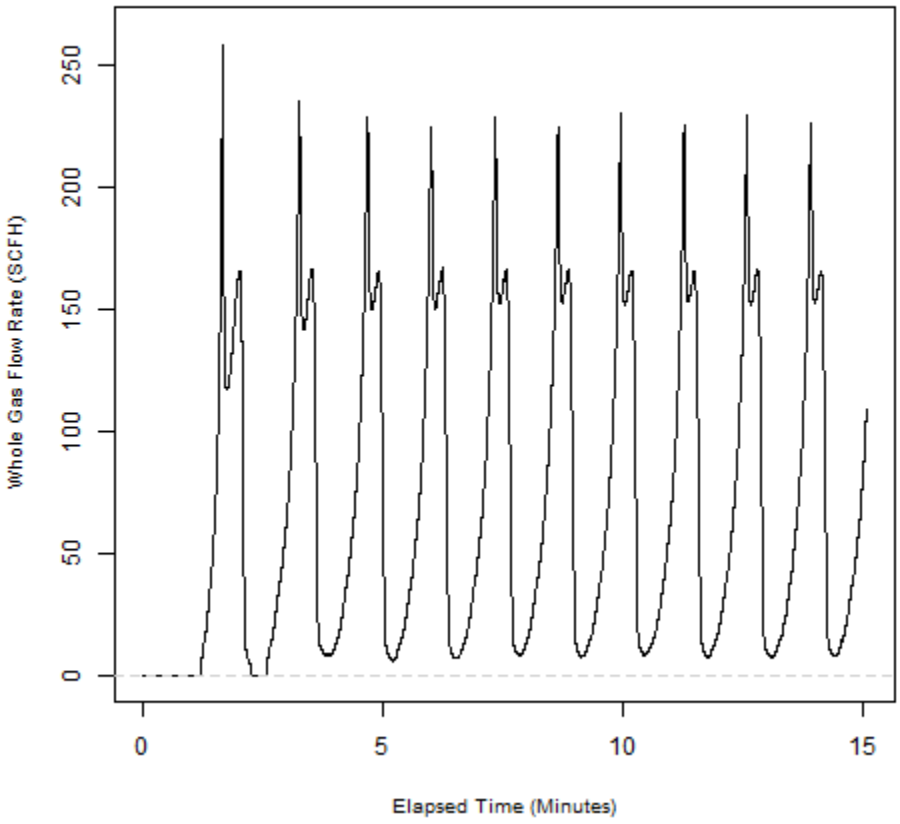
| | |
|---|---|
| Avg. Emission rate (whole gas): | 78.6 scf/h |
| Avg. Emission rate (methane): | 68.9 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | M03 |
| Supply pressure: | 25 psig |
| Assessment of controller operation: | equipment issues |



**LB05-PC01 [ 5 ] Region: GC**

*Device characteristics:*

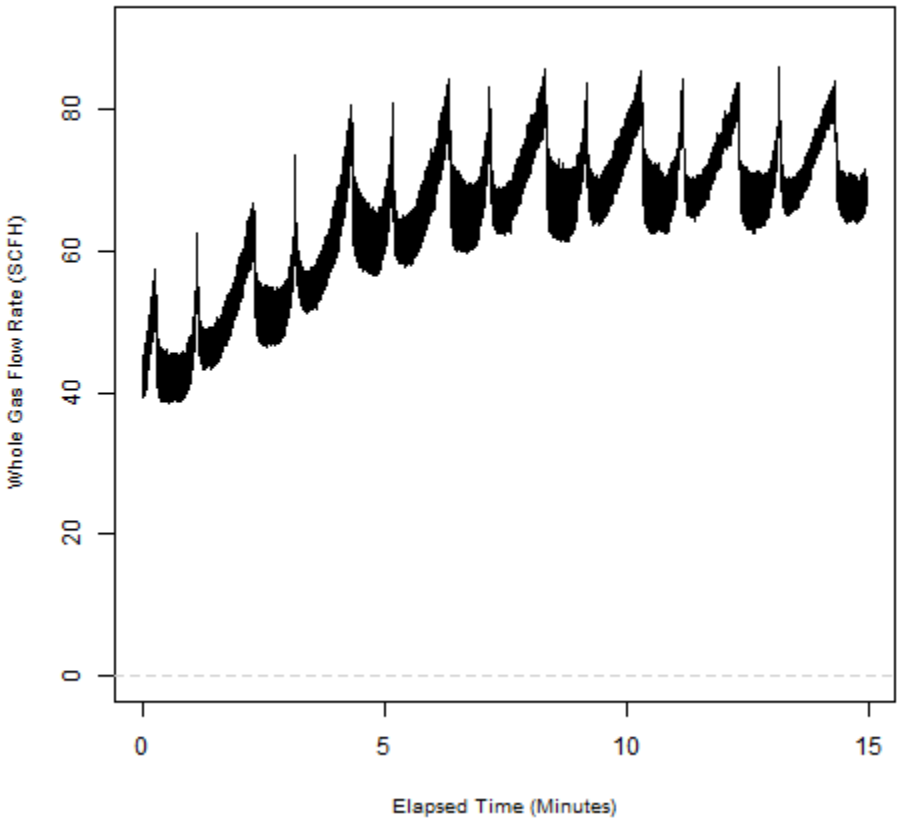
| | |
|---|---|
| Avg. Emission rate (whole gas): | 68.6 scf/h |
| Avg. Emission rate (methane): | 60.2 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | M03 |
| Supply pressure: | 30 psig |
| Assessment of controller operation: | equipment issues |



**LB07-PC02 [ 6 ] Region: GC**

*Device characteristics:*

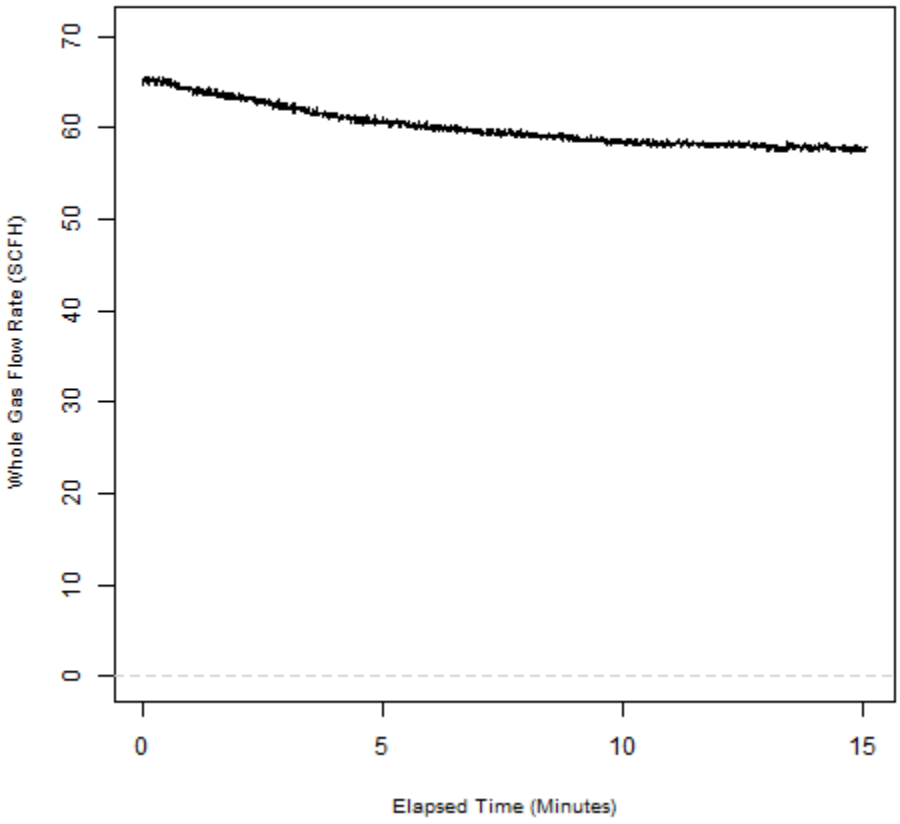
| | |
|---|---|
| Avg. Emission rate (whole gas): | 64.8 scf/h |
| Avg. Emission rate (methane): | 51.2 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M03 |
| Supply pressure: | 24 psig |
| Assessment of controller operation: | equipment issues |



**CZ08-PC01 [ 7 ] Region: GC**

*Device characteristics:*

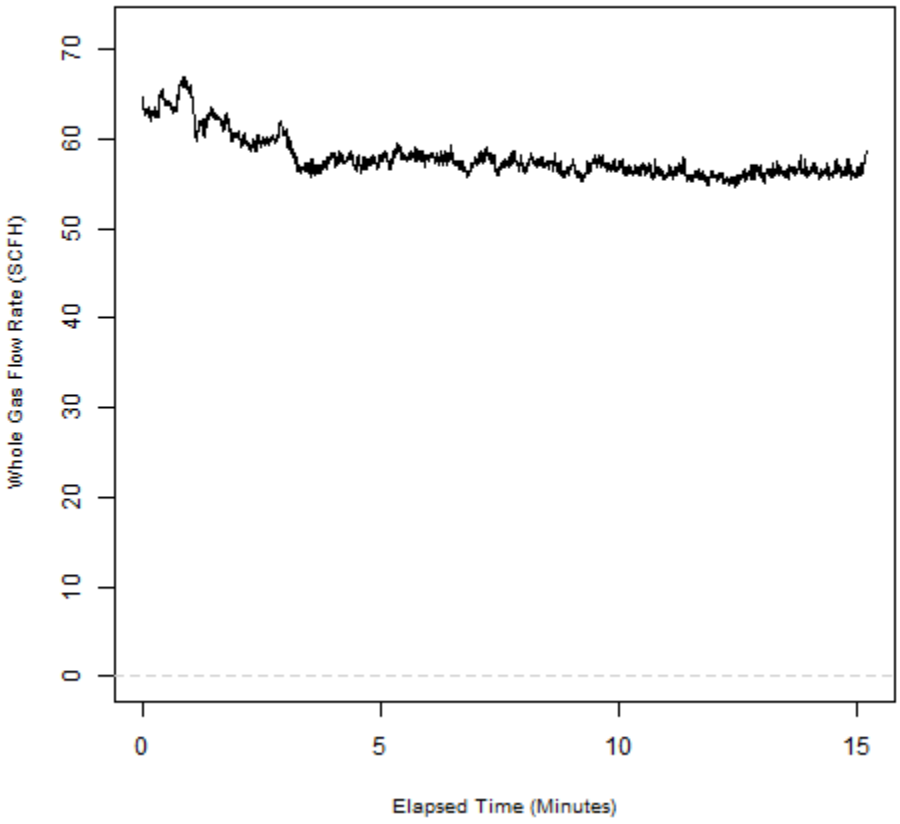
| | |
|---|---|
| Avg. Emission rate (whole gas): | 60.1 scf/h |
| Avg. Emission rate (methane): | 57.8 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 11 psig |
| Assessment of controller operation: | equipment issues |



**GZ02-PC12 [ 8 ]  Region: GC**

*Device characteristics:*

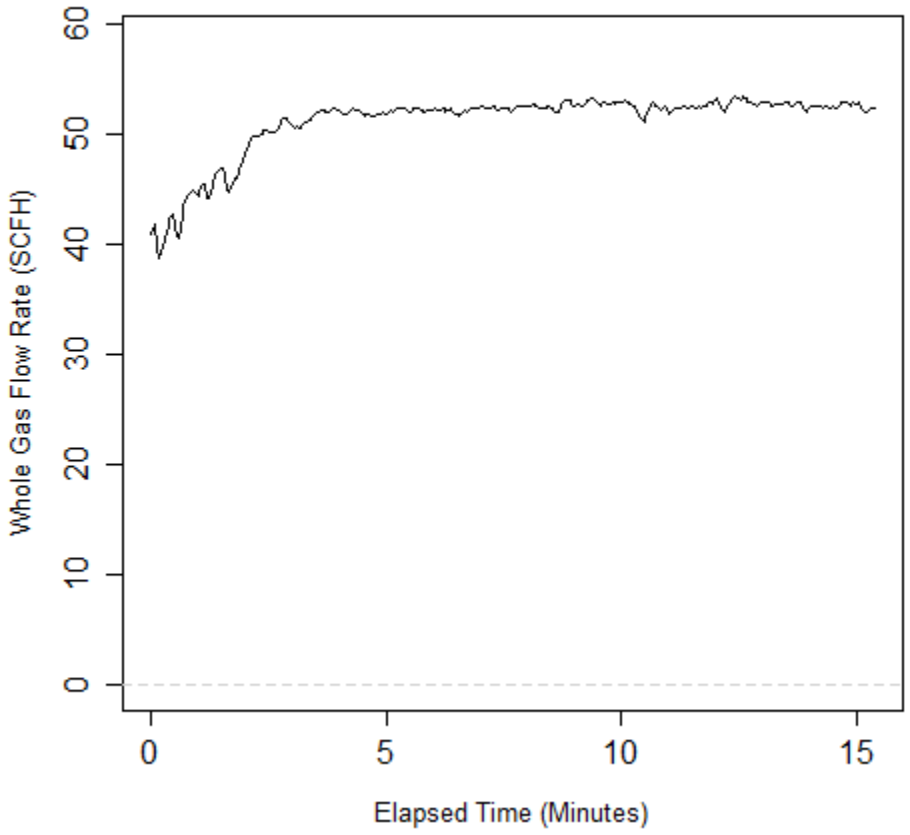
| | |
|---|---|
| Avg. Emission rate (whole gas): | 57.9 scf/h |
| Avg. Emission rate (methane): | 56.5 scf/h |
| Controller application: | Level |
| Basic Application: | Compressor |
| Detailed Application: | Compressor - Liquid Level Control (Stage 2) |
| Manufacturer/Model (blinded): | J01 |
| Supply pressure: | 28 psig |
| Assessment of controller operation: | equipment issues |



**CZ06-PC01 [ 9 ] Region: GC**

*Device characteristics:*

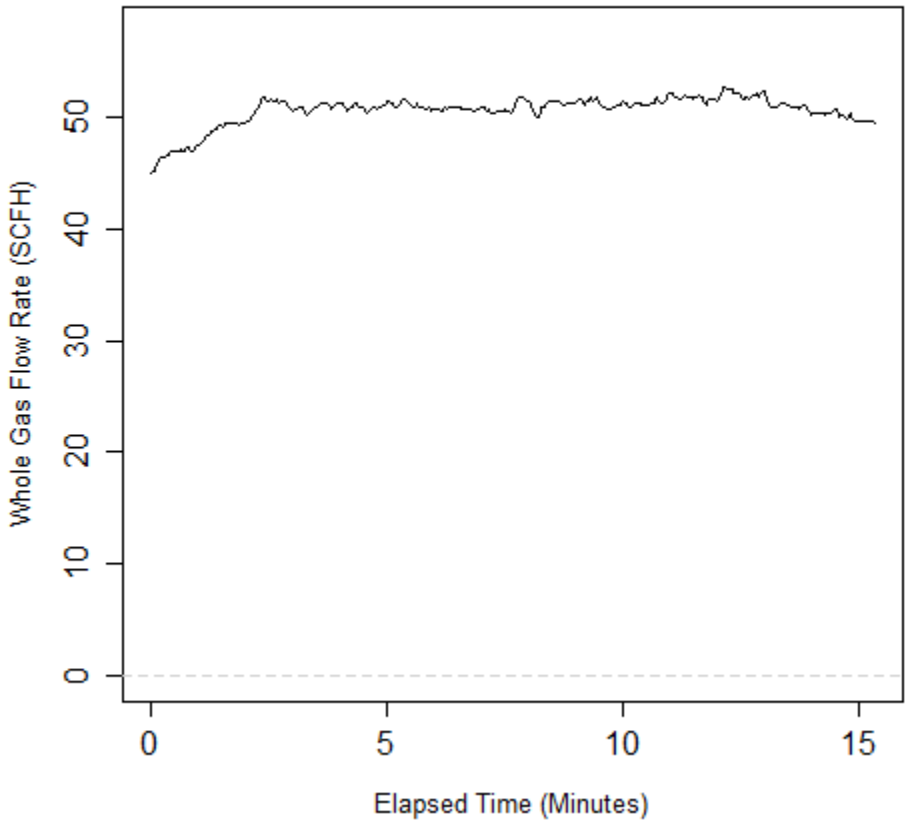
| | |
|---|---|
| Avg. Emission rate (whole gas): | 51.2 scf/h |
| Avg. Emission rate (methane): | 48.2 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | G01 |
| Supply pressure: | 6 psig |
| Assessment of controller operation: | operating as expected |



**CZ06-PC02 [ 10 ] Region: GC**

*Device characteristics:*

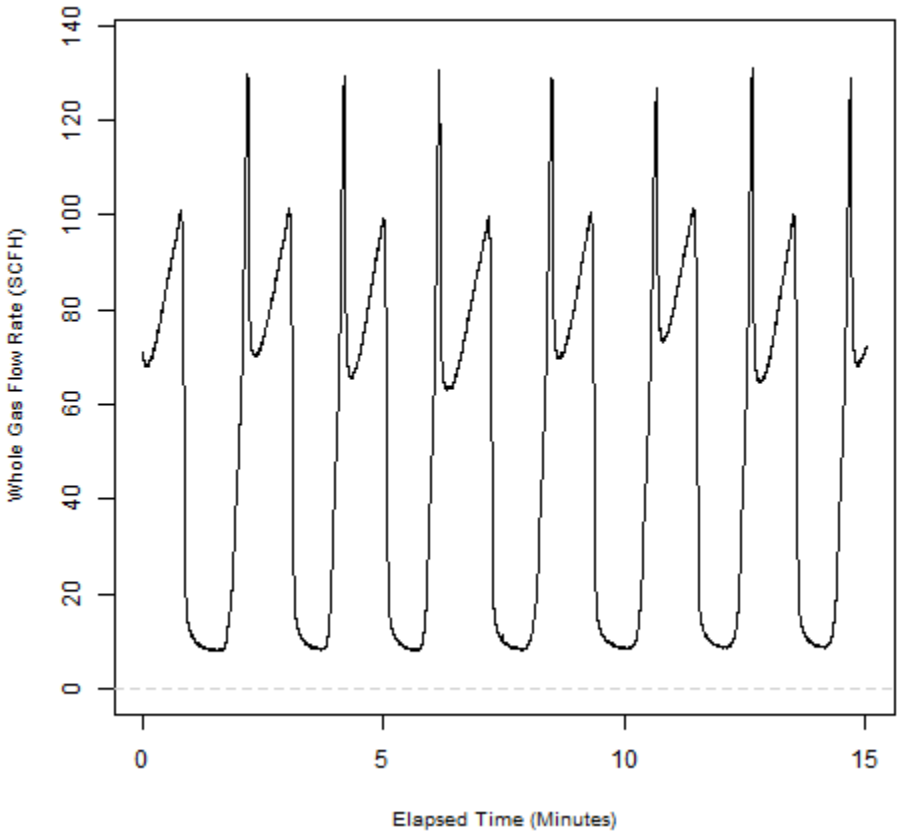
| | |
|---|---|
| Avg. Emission rate (whole gas): | 50.7 scf/h |
| Avg. Emission rate (methane): | 47.7 scf/h |
| Controller application: | Pressure |
| Basic Application: | Plunger Lift |
| Detailed Application: | Plunger Lift |
| Manufacturer/Model (blinded): | E01 |
| Supply pressure: | 20 psig |
| Assessment of controller operation: | equipment issues |



**LB03-PC01 [ 11 ] Region: GC**

*Device characteristics:*

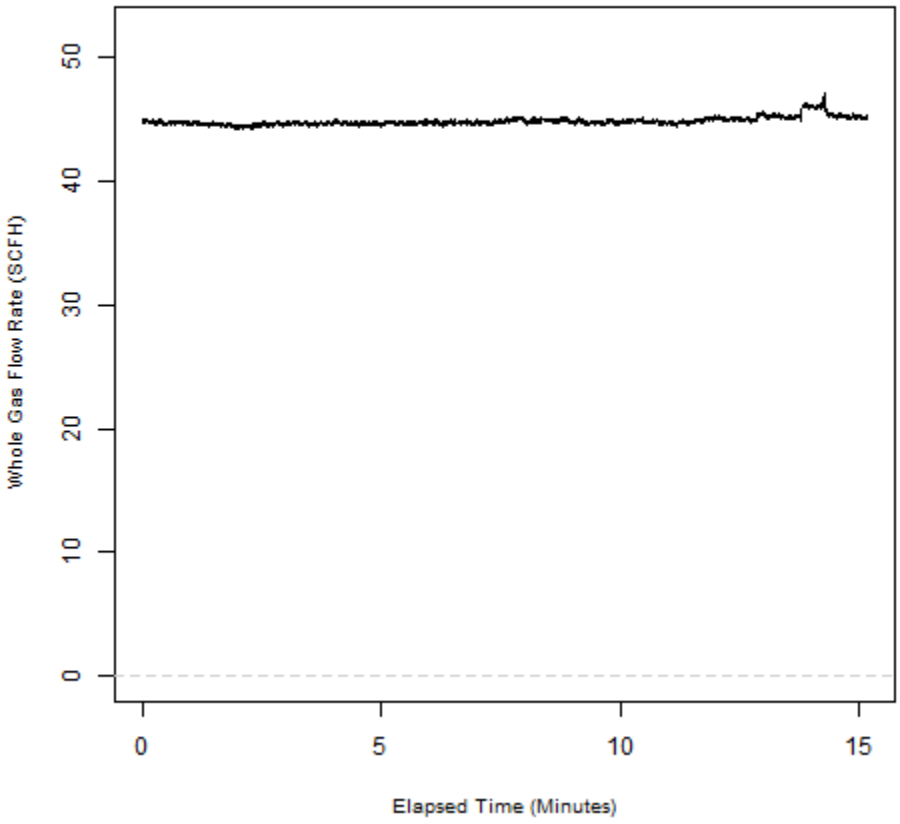
| | |
|---|---|
| Avg. Emission rate (whole gas): | 50.0 scf/h |
| Avg. Emission rate (methane): | 39.7 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 30 psig |
| Assessment of controller operation: | equipment issues |



**CZ09-PC02 [ 12 ]  Region: GC**

*Device characteristics:*

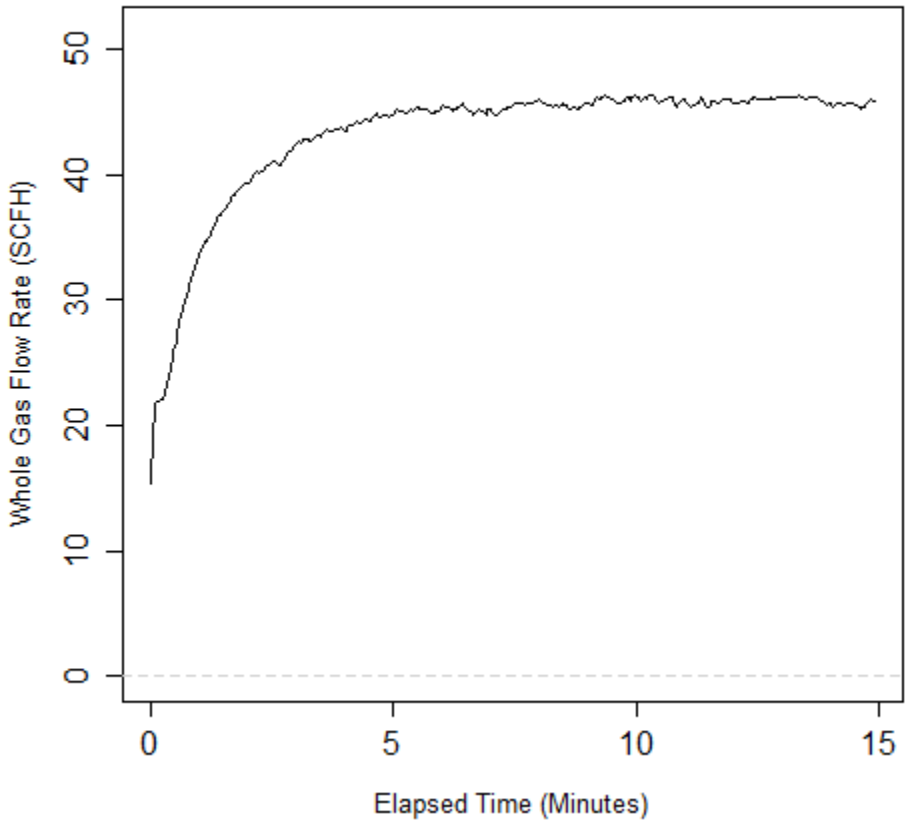
| | |
|---|---|
| Avg. Emission rate (whole gas): | 44.9 scf/h |
| Avg. Emission rate (methane): | 43.1 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 9 psig |
| Assessment of controller operation: | equipment issues |



**GZ02-PC14 [ 13 ] Region: GC**

*Device characteristics:*

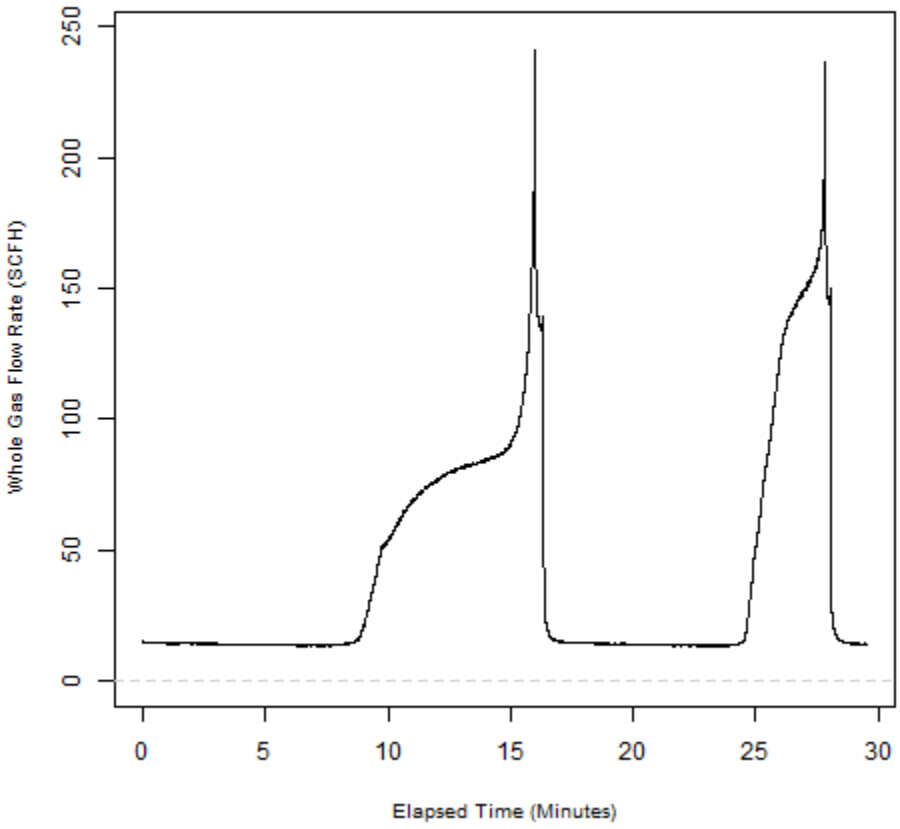
| | |
|---|---|
| Avg. Emission rate (whole gas): | 43.3 scf/h |
| Avg. Emission rate (methane): | 42.2 scf/h |
| Controller application: | Pressure |
| Basic Application: | Compressor |
| Detailed Application: | Compressor - Suction Feed Control |
| Manufacturer/Model (blinded): | I01 |
| Supply pressure: | 42 psig |
| Assessment of controller operation: | equipment issues |



**CZ10-PC01 [ 14 ] Region: GC**

*Device characteristics:*

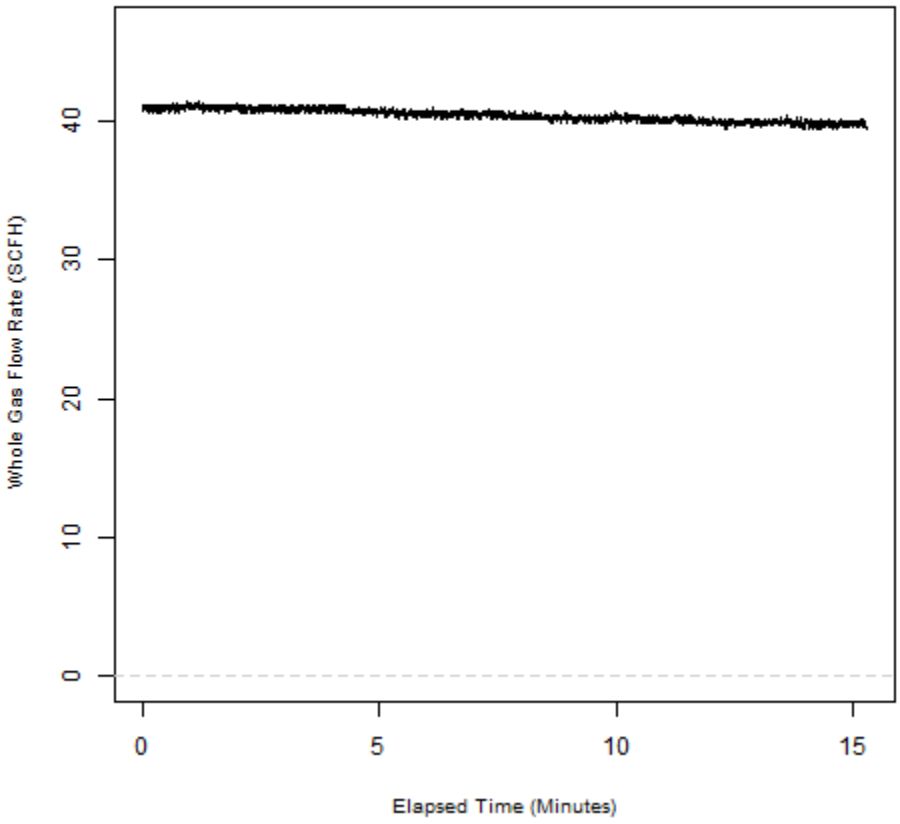
| | |
|---|---|
| Avg. Emission rate (whole gas): | 43.2 scf/h |
| Avg. Emission rate (methane): | 41.5 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 13 psig |
| Assessment of controller operation: | equipment issues |



**CZ05-PC01 [ 15 ]  Region: GC**

*Device characteristics:*

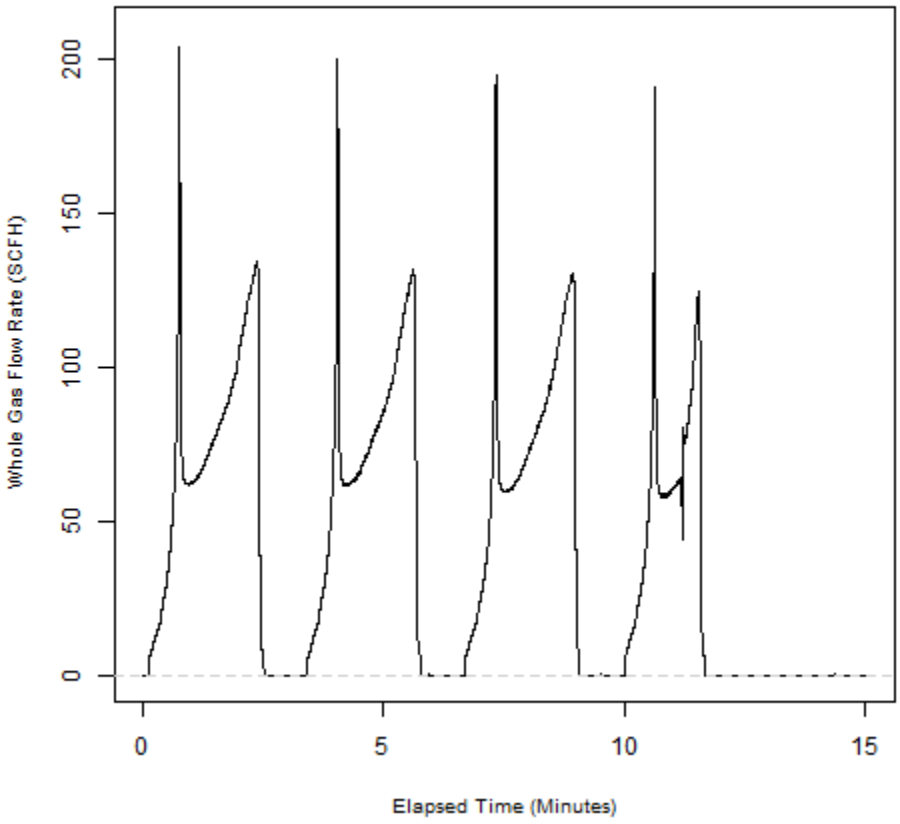
| | |
|---|---|
| Avg. Emission rate (whole gas): | 40.4 scf/h |
| Avg. Emission rate (methane): | 37.9 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | A01 |
| Supply pressure: | 29 psig |
| Assessment of controller operation: | equipment issues |



**LB01-PC01 [ 16 ]  Region: GC**

*Device characteristics:*

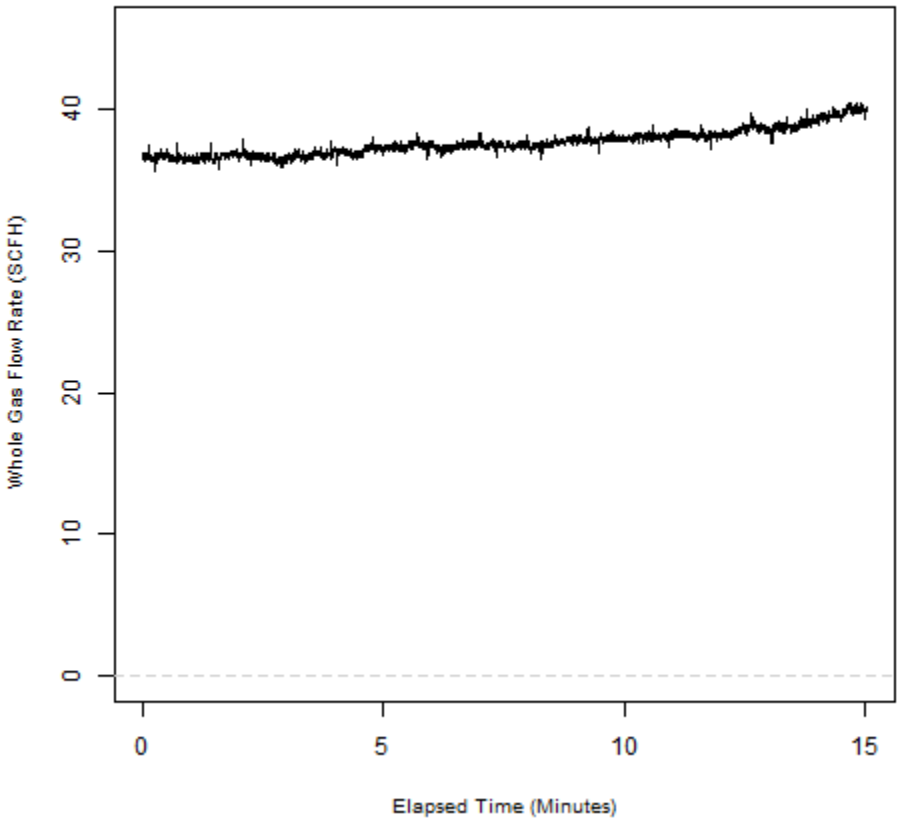
| | |
|---|---|
| Avg. Emission rate (whole gas): | 40.2 scf/h |
| Avg. Emission rate (methane): | 32.3 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | M03 |
| Supply pressure: | 30 psig |
| Assessment of controller operation: | operating as expected |



**GZ03-PC22 [ 17 ] Region: GC**

*Device characteristics:*

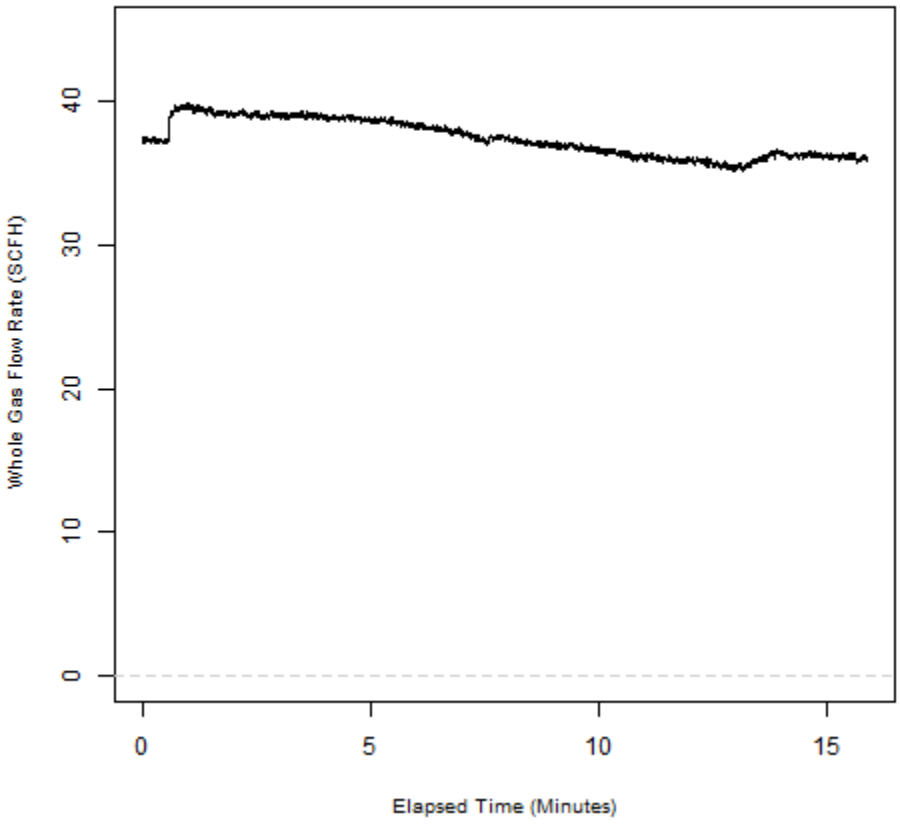
| | |
|---|---|
| Avg. Emission rate (whole gas): | 37.7 scf/h |
| Avg. Emission rate (methane): | 36.6 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 7 psig |
| Assessment of controller operation: | equipment issues |



**XQ04-PC02 [ 18 ]  Region: MC**

*Device characteristics:*

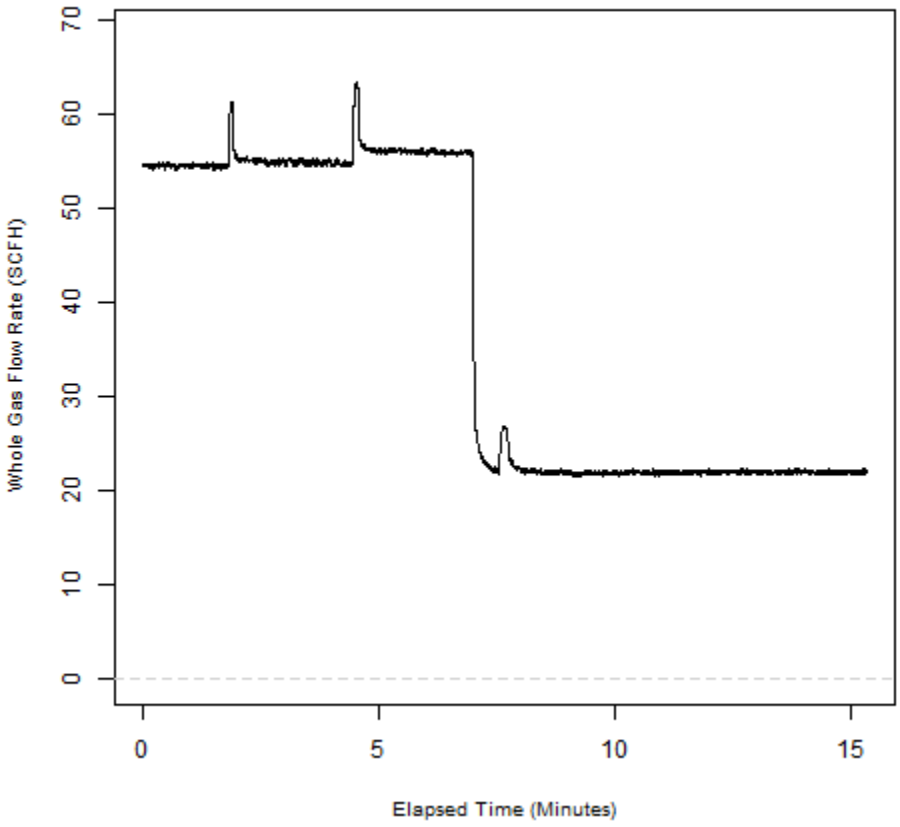
| | |
|---|---|
| Avg. Emission rate (whole gas): | 37.4 scf/h |
| Avg. Emission rate (methane): | 33.5 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | Q02 |
| Supply pressure: | 28 psig |
| Assessment of controller operation: | equipment issues |



**XQ01-PC04 [ 19 ] Region: MC**

*Device characteristics:*

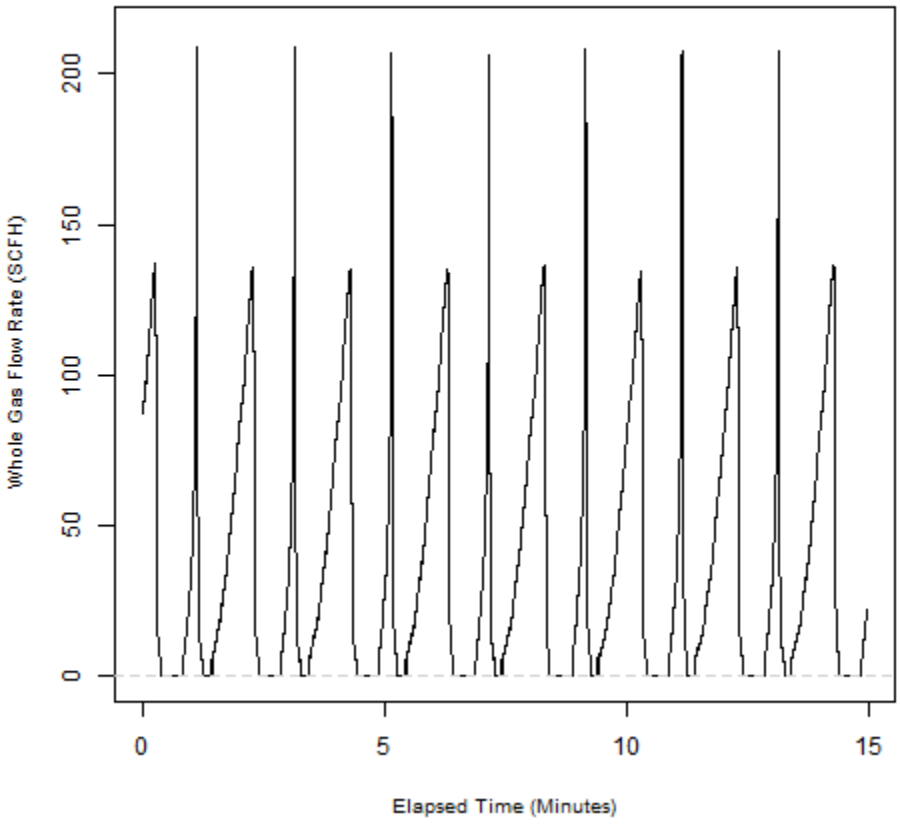
| | |
|---|---|
| Avg. Emission rate (whole gas): | 37.4 scf/h |
| Avg. Emission rate (methane): | 33.0 scf/h |
| Controller application: | Pressure |
| Basic Application: | Plunger Lift |
| Detailed Application: | Plunger Lift |
| Manufacturer/Model (blinded): | F02 |
| Supply pressure: | 15 psig |
| Assessment of controller operation: | equipment issues |



**LB07-PC01 [ 20 ] Region: GC**

*Device characteristics:*

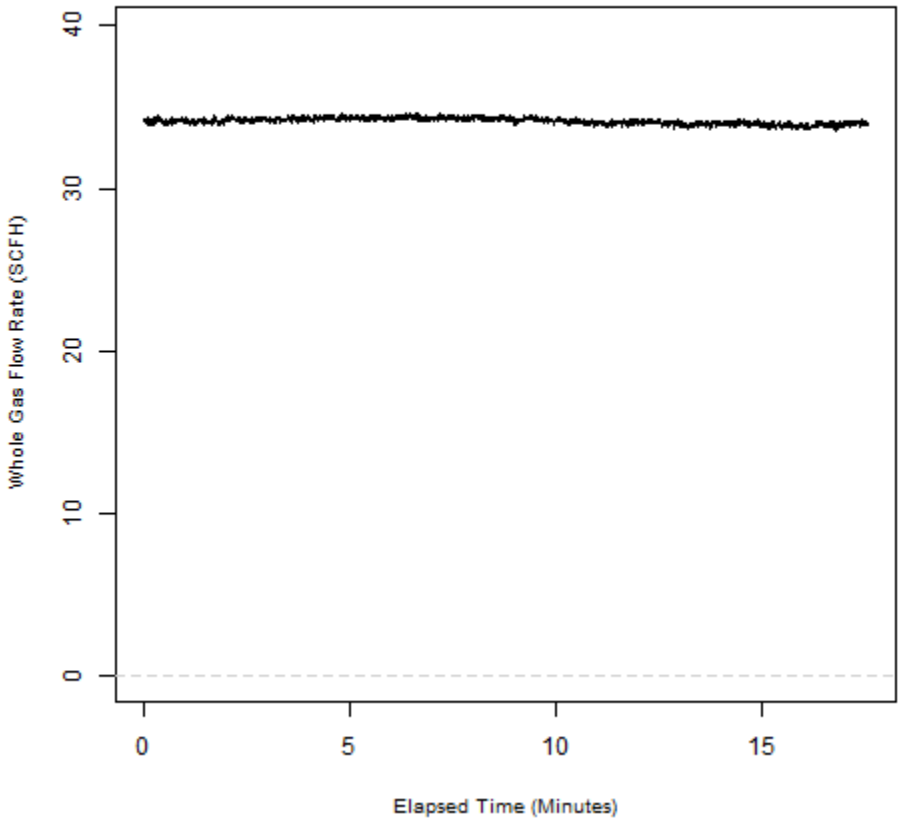
| | |
|---|---|
| Avg. Emission rate (whole gas): | 36.3 scf/h |
| Avg. Emission rate (methane): | 28.7 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | M03 |
| Supply pressure: | 24 psig |
| Assessment of controller operation: | operating as expected |



**GZ03-PC13 [ 21 ] Region: GC**

*Device characteristics:*

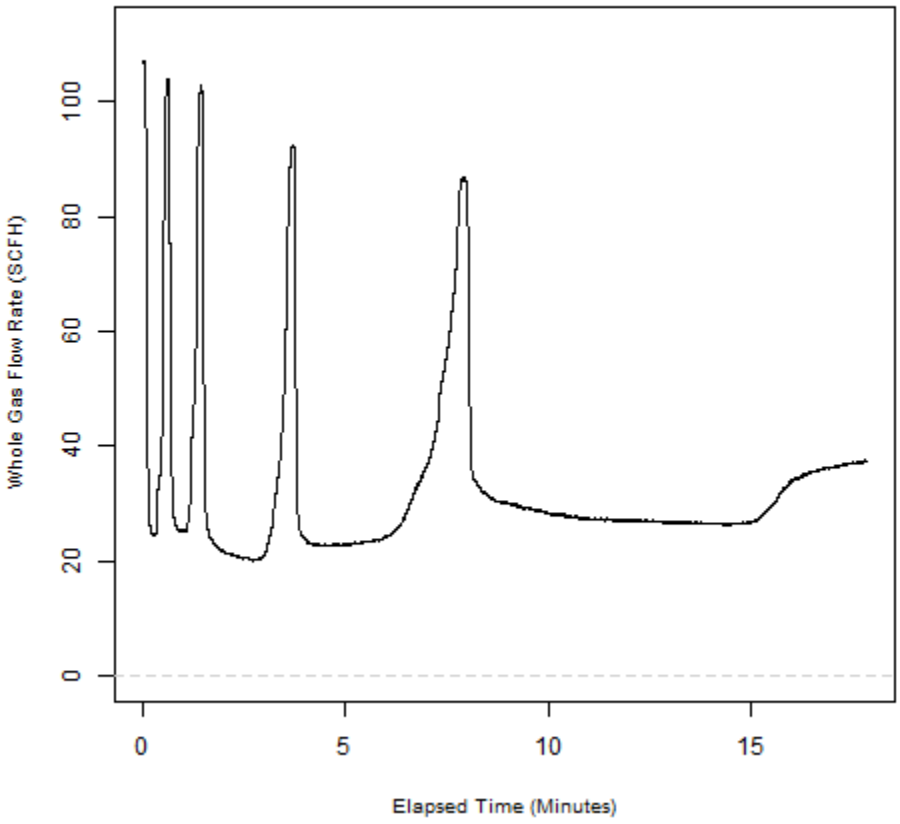
| | |
|---|---|
| Avg. Emission rate (whole gas): | 34.1 scf/h |
| Avg. Emission rate (methane): | 33.2 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 26 psig |
| Assessment of controller operation: | equipment issues |



**GZ04-PC03 [ 22 ] Region: GC**

*Device characteristics:*

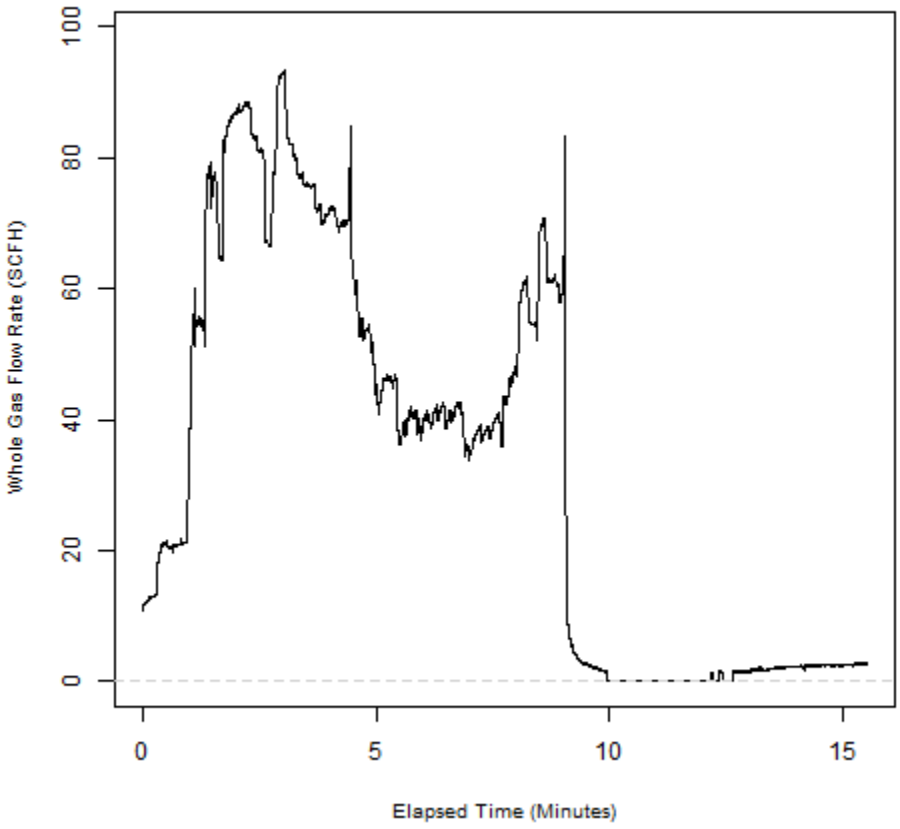
| | |
|---|---|
| Avg. Emission rate (whole gas): | 32.7 scf/h |
| Avg. Emission rate (methane): | 31.8 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 30 psig |
| Assessment of controller operation: | equipment issues |



**GZ03-PC02 [ 23 ] Region: GC**

*Device characteristics:*

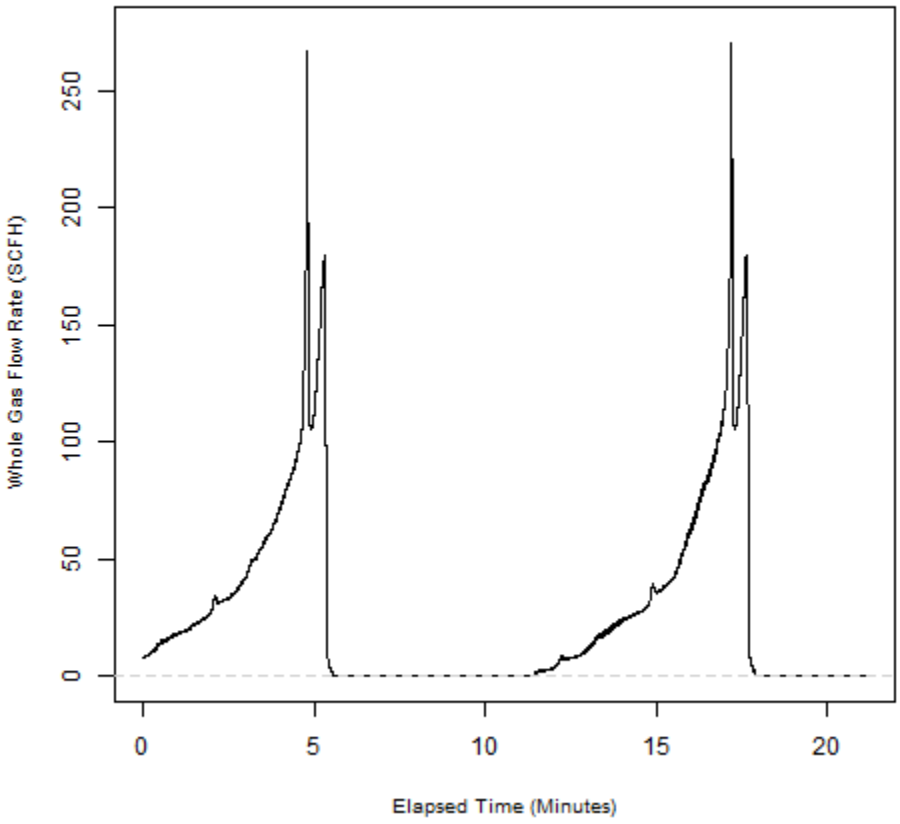
| | |
|---|---|
| Avg. Emission rate (whole gas): | 32.6 scf/h |
| Avg. Emission rate (methane): | 31.7 scf/h |
| Controller application: | Level |
| Basic Application: | Compressor |
| Detailed Application: | Compressor - Liquid Level Control (Stage 2) |
| Manufacturer/Model (blinded): | L01 |
| Supply pressure: | 30 psig |
| Assessment of controller operation: | operating as expected |



**LB07-PC04 [ 24 ]  Region: GC**

*Device characteristics:*

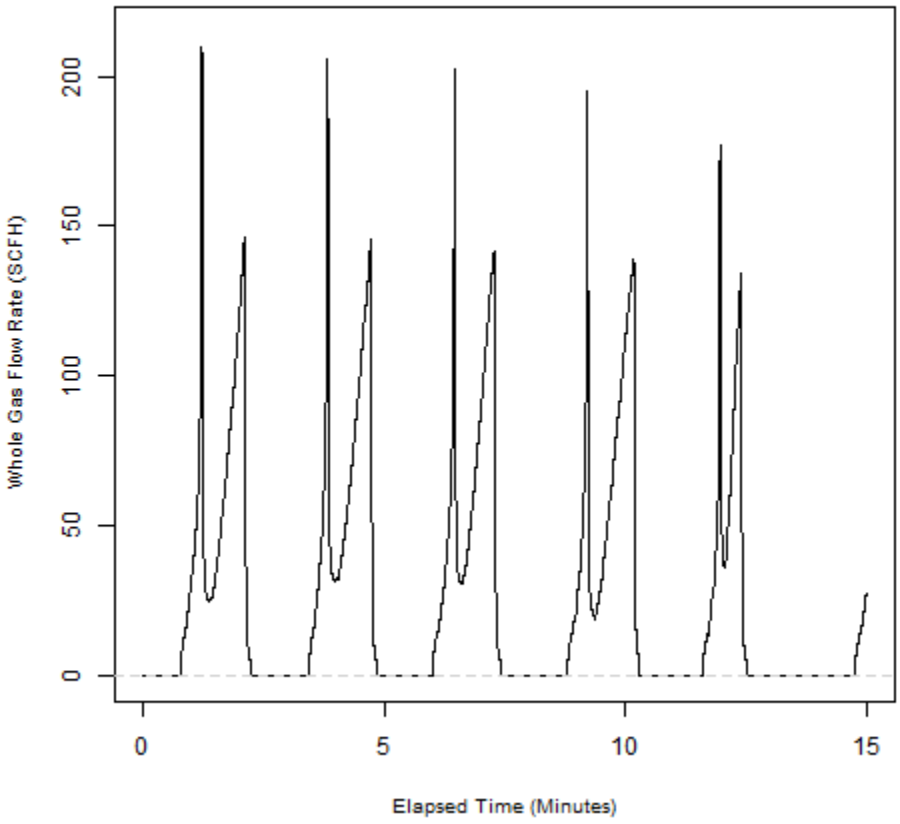
| | |
|---|---|
| Avg. Emission rate (whole gas): | 27.0 scf/h |
| Avg. Emission rate (methane): | 21.4 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M03 |
| Supply pressure: | 28 psig |
| Assessment of controller operation: | equipment issues |



**LB04-PC01 [ 25 ] Region: GC**

*Device characteristics:*

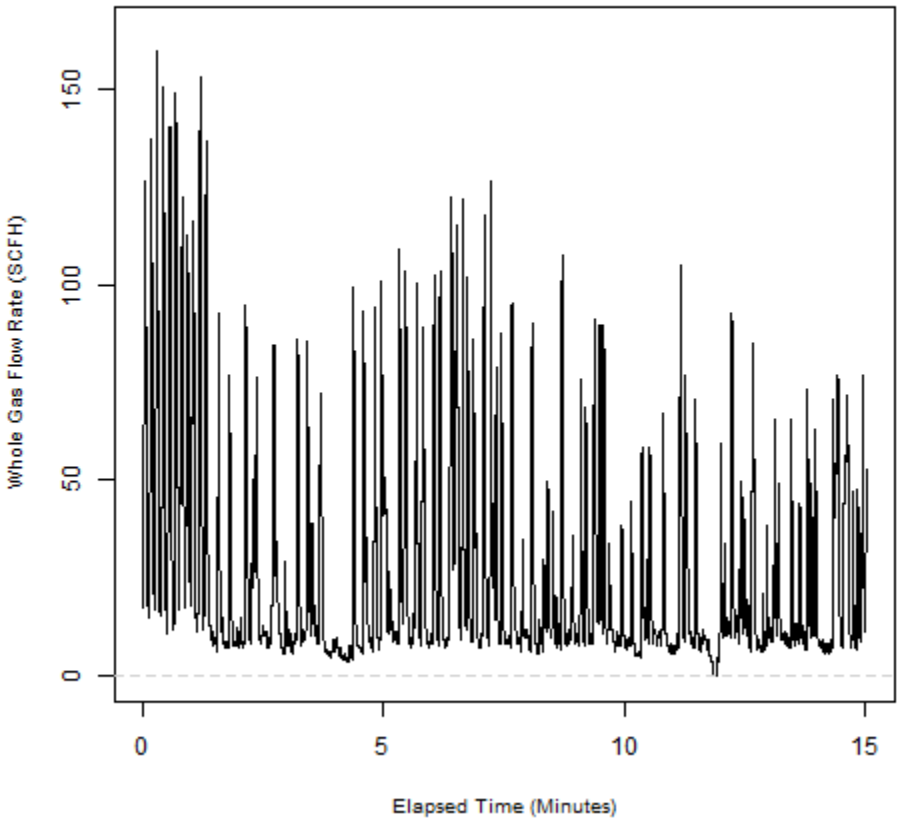
| | |
|---|---|
| Avg. Emission rate (whole gas): | 26.2 scf/h |
| Avg. Emission rate (methane): | 20.7 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | M03 |
| Supply pressure: | 30 psig |
| Assessment of controller operation: | operating as expected |



**AP01-PC12 [ 26 ]  Region: MC**

*Device characteristics:*

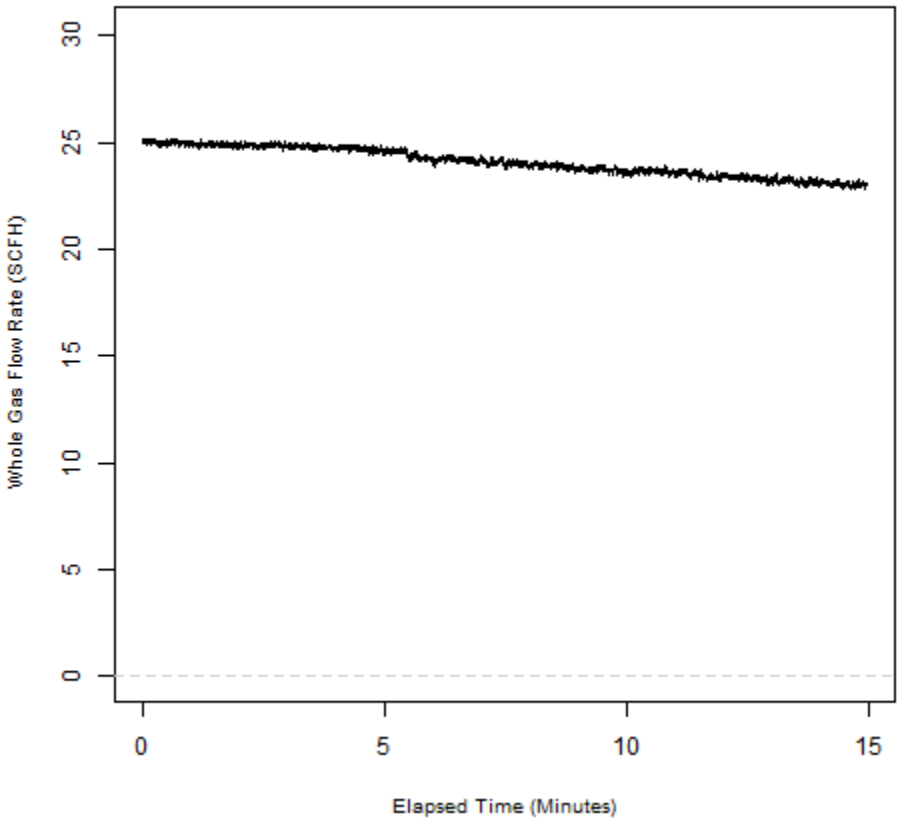
| | |
|---|---|
| Avg. Emission rate (whole gas): | 25.6 scf/h |
| Avg. Emission rate (methane): | 17.0 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | I02 |
| Supply pressure: | 11 psig |
| Assessment of controller operation: | equipment issues |



**XQ05-PC02 [ 27 ]  Region: MC**

*Device characteristics:*

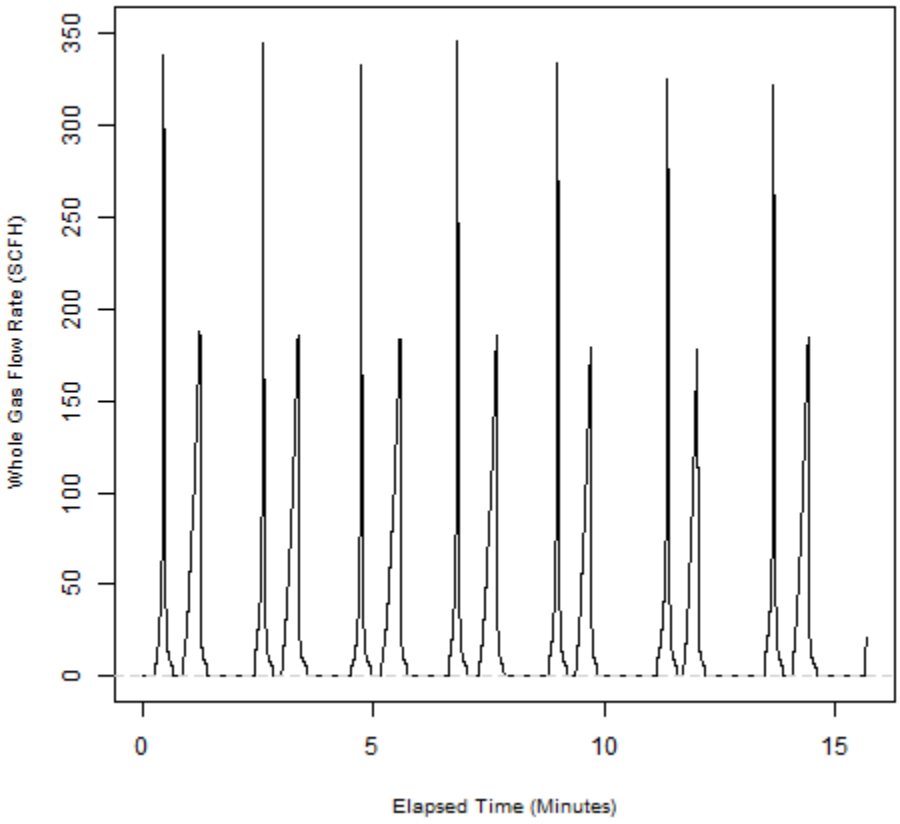
| | |
|---|---|
| Avg. Emission rate (whole gas): | 24.1 scf/h |
| Avg. Emission rate (methane): | 21.7 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | Q02 |
| Supply pressure: | 27 psig |
| Assessment of controller operation: | operating as expected |



**LB06-PC05 [ 28 ]  Region: GC**

*Device characteristics:*

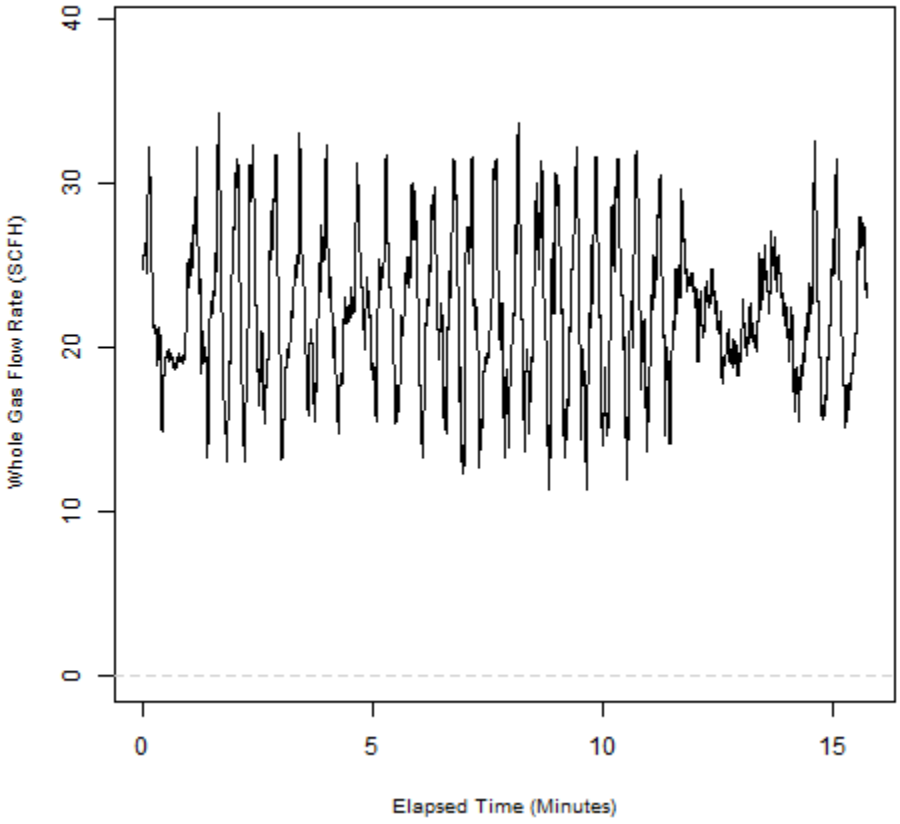
| | |
|---|---|
| Avg. Emission rate (whole gas): | 22.5 scf/h |
| Avg. Emission rate (methane): | 18.3 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | M03 |
| Supply pressure: | 30 psig |
| Assessment of controller operation: | operating as expected |



**CZ11-PC01 [ 29 ]  Region: GC**

*Device characteristics:*

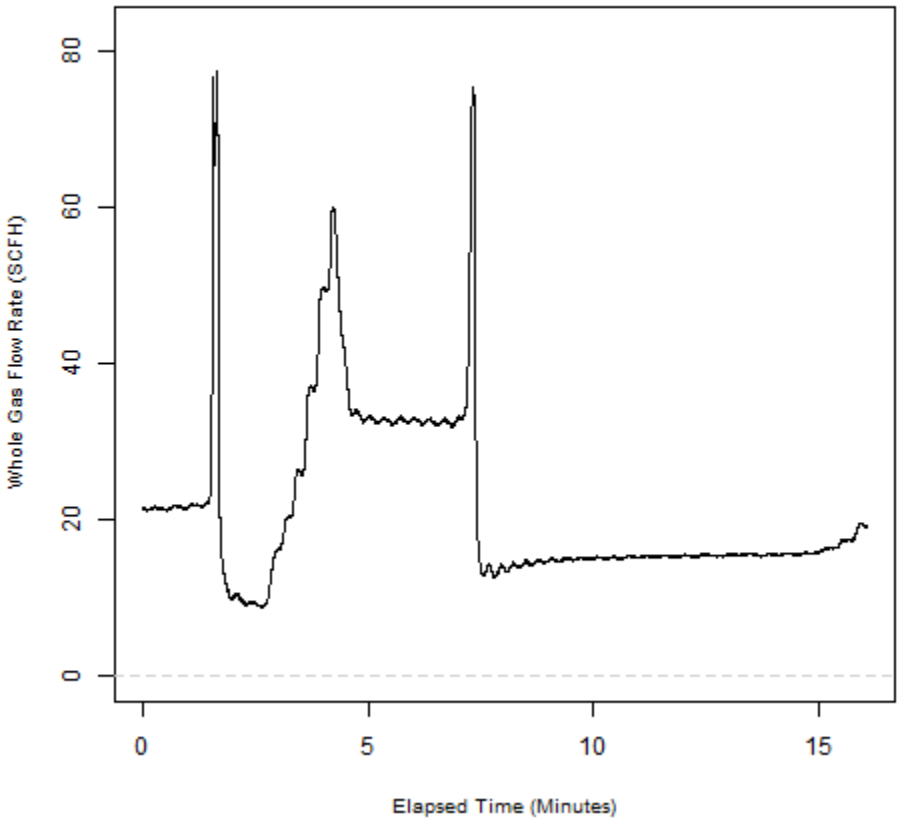
| | |
|---|---|
| Avg. Emission rate (whole gas): | 22.2 scf/h |
| Avg. Emission rate (methane): | 21.3 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 23 psig |
| Assessment of controller operation: | equipment issues |



**CZ08-PC02 [ 30 ] Region: GC**

*Device characteristics:*

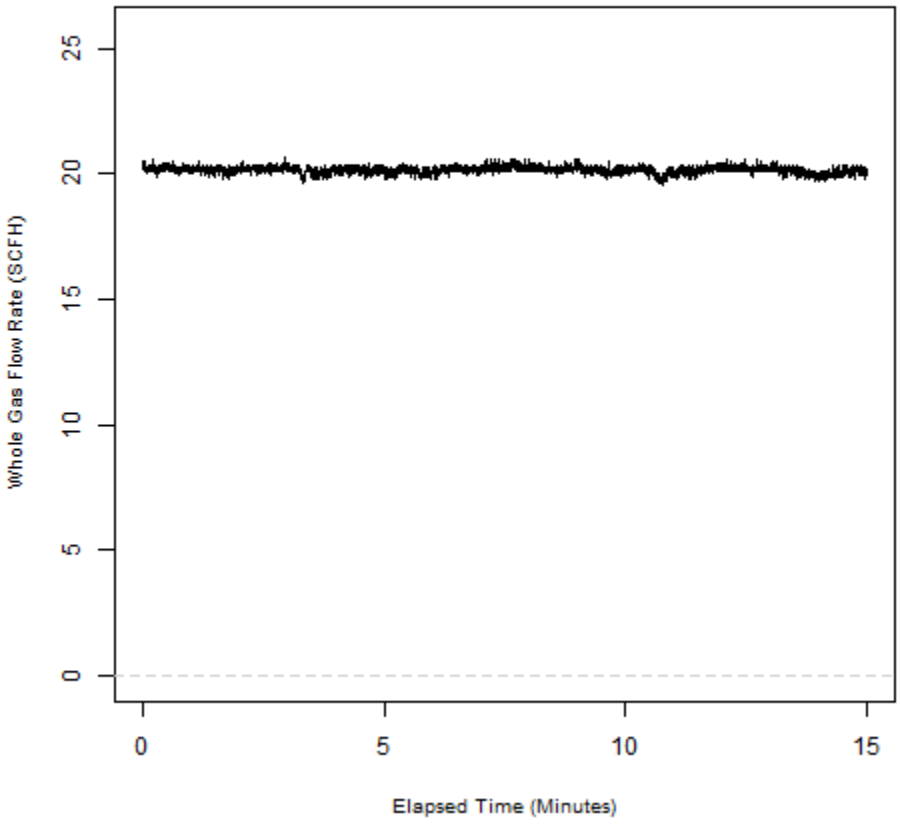
| | |
|---|---|
| Avg. Emission rate (whole gas): | 21.6 scf/h |
| Avg. Emission rate (methane): | 21.1 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 19 psig |
| Assessment of controller operation: | equipment issues |



**XQ06-PC01 [ 31 ] Region: MC**

*Device characteristics:*

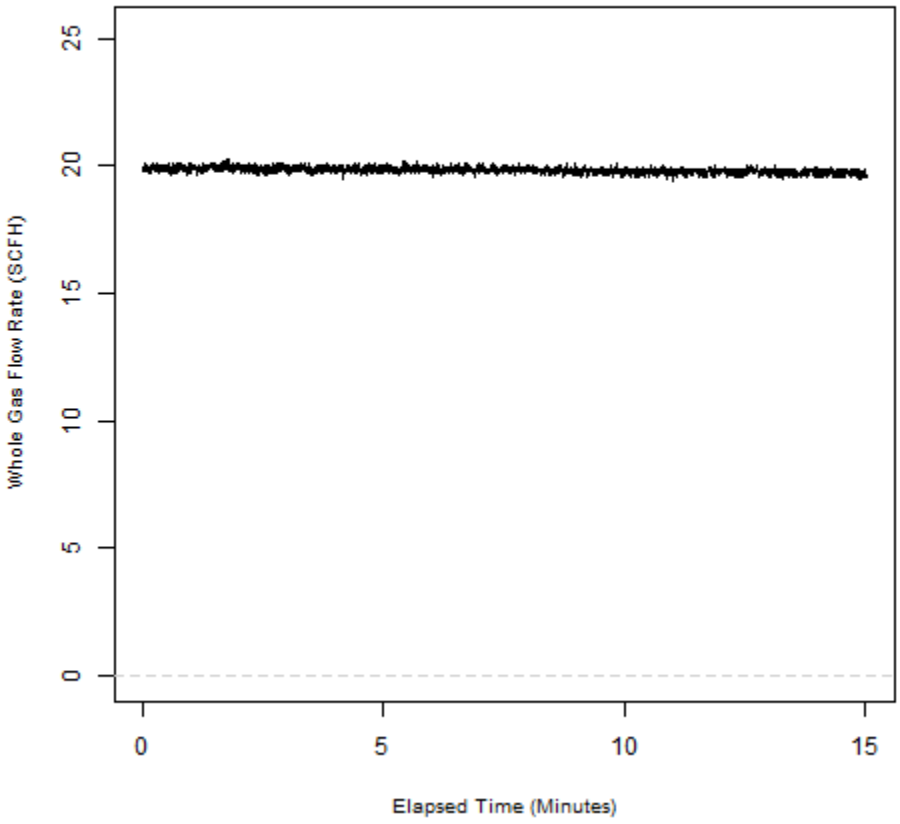
| | |
|---|---|
| Avg. Emission rate (whole gas): | 20.2 scf/h |
| Avg. Emission rate (methane): | 18.0 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | G01 |
| Supply pressure: | 28 psig |
| Assessment of controller operation: | operating as expected |



**RB01-PC23 [ 32 ]  Region: GC**

*Device characteristics:*

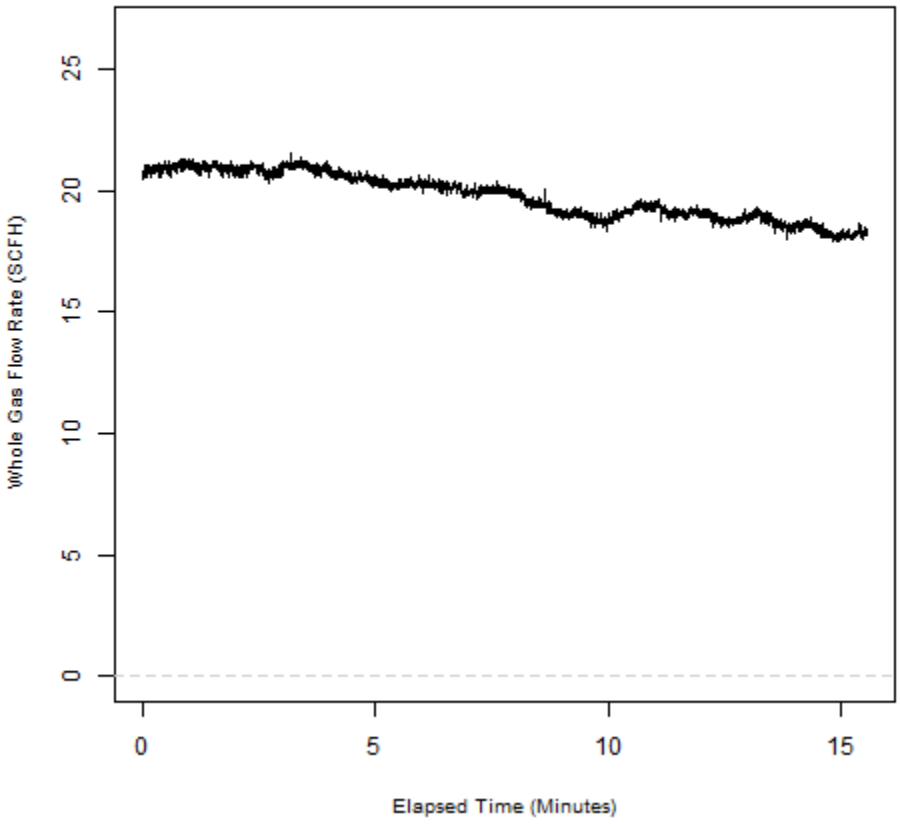
| | |
|---|---|
| Avg. Emission rate (whole gas): | 19.8 scf/h |
| Avg. Emission rate (methane): | 16.3 scf/h |
| Controller application: | Pressure |
| Basic Application: | Dehydration System |
| Detailed Application: | Site Gas Feed Control |
| Manufacturer/Model (blinded): | M05 |
| Supply pressure: | 30 psig |
| Assessment of controller operation: | operating as expected |



**DL01-PC24 [ 33 ] Region: RM**

*Device characteristics:*

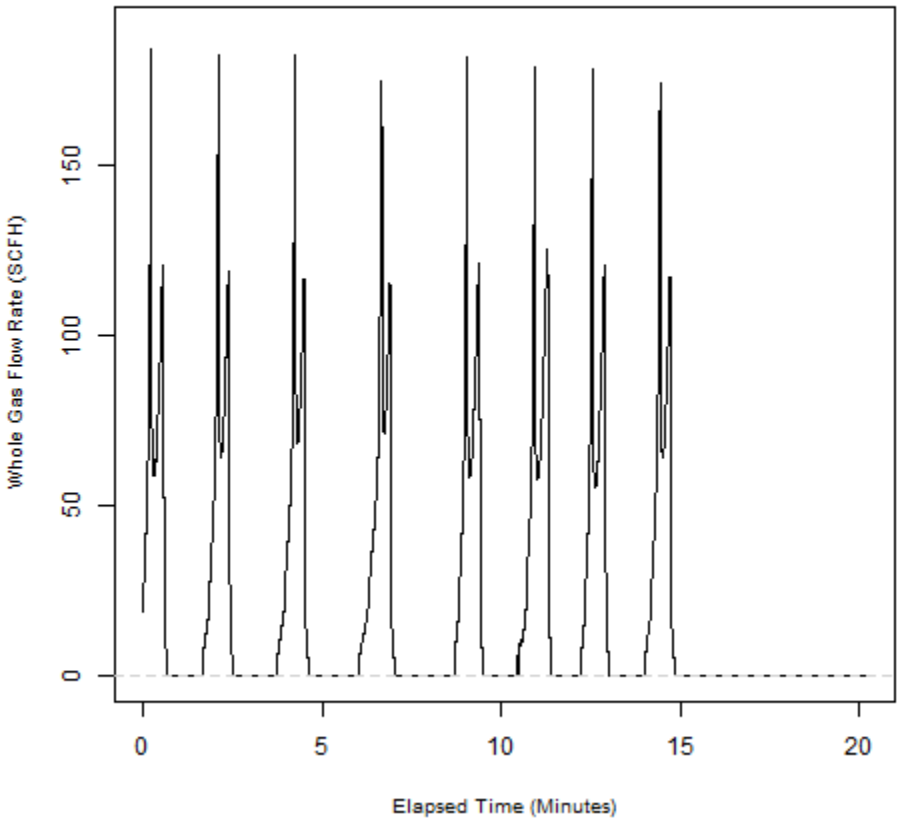
| | |
|---|---|
| Avg. Emission rate (whole gas): | 19.8 scf/h |
| Avg. Emission rate (methane): | 17.7 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Liquid Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 38 psig |
| Assessment of controller operation: | equipment issues |



**LB04-PC03 [ 34 ]  Region: GC**

*Device characteristics:*

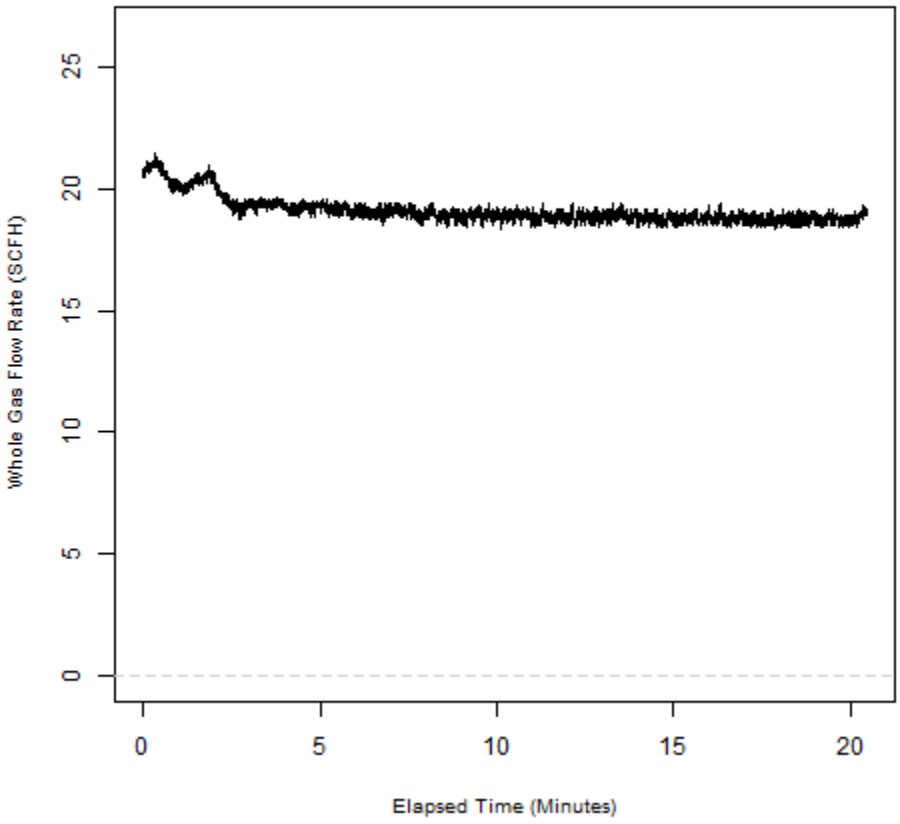
| | |
|---|---|
| Avg. Emission rate (whole gas): | 19.1 scf/h |
| Avg. Emission rate (methane): | 15.0 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | M03 |
| Supply pressure: | 30 psig |
| Assessment of controller operation: | operating as expected |



**RQ03-PC01 [ 35 ] Region: MC**

*Device characteristics:*

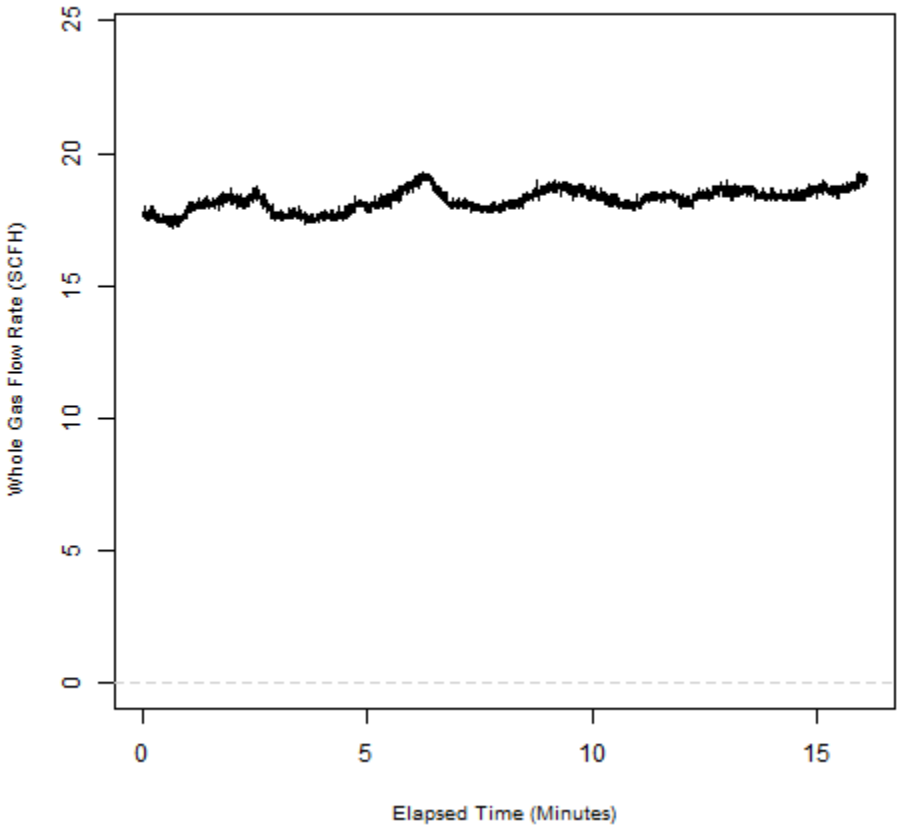
| | |
|---|---|
| Avg. Emission rate (whole gas): | 19.1 scf/h |
| Avg. Emission rate (methane): | 16.3 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | Q02 |
| Supply pressure: | 22 psig |
| Assessment of controller operation: | operating as expected |



**RQ07-PC03 [ 36 ]  Region: MC**

*Device characteristics:*

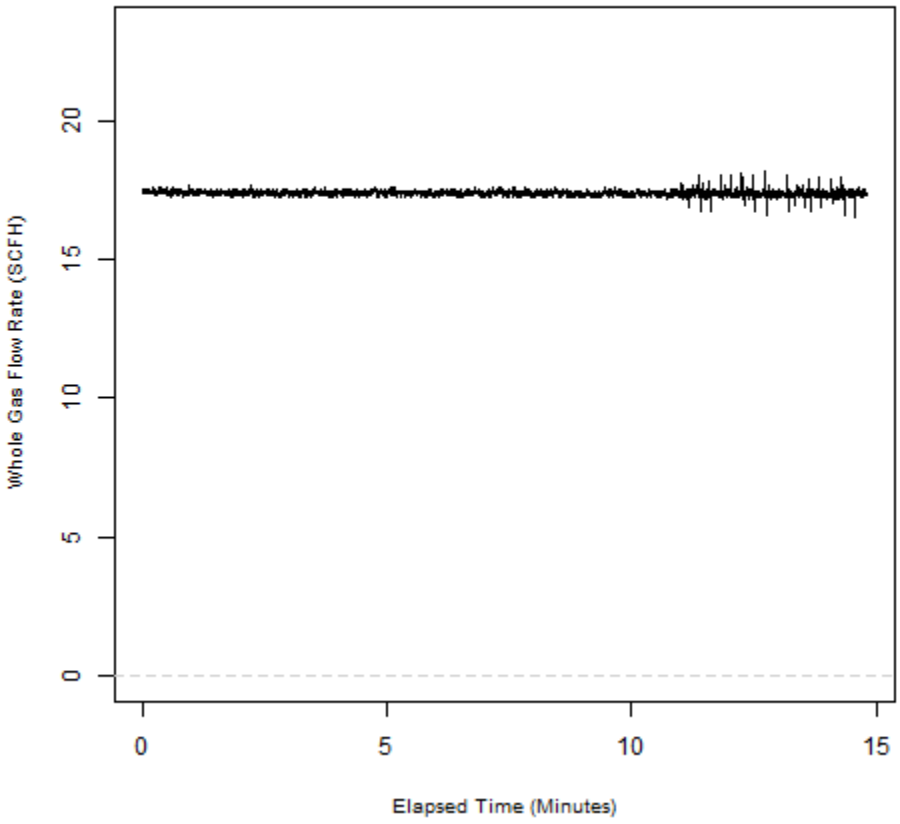
| | |
|---|---|
| Avg. Emission rate (whole gas): | 18.2 scf/h |
| Avg. Emission rate (methane): | 14.2 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | G01 |
| Supply pressure: | 22 psig |
| Assessment of controller operation: | operating as expected |



**RQ05-PC03 [ 37 ]  Region: MC**

*Device characteristics:*

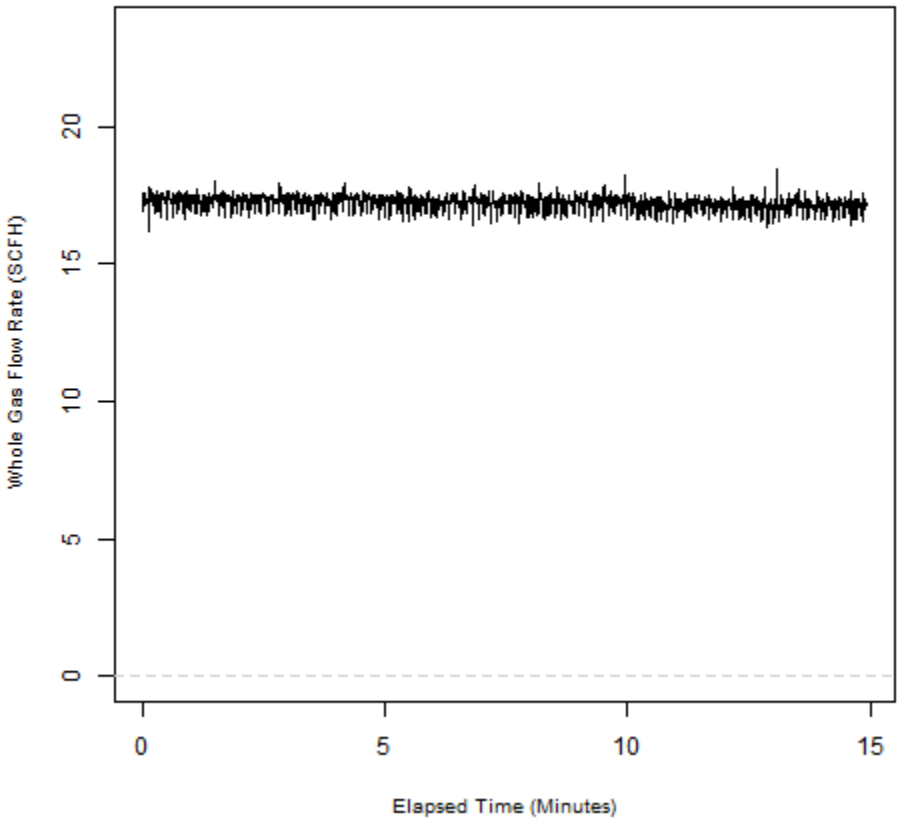
| | |
|---|---|
| Avg. Emission rate (whole gas): | 17.4 scf/h |
| Avg. Emission rate (methane): | 15.3 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Oil Level Control |
| Manufacturer/Model (blinded): | G01 |
| Supply pressure: | 22 psig |
| Assessment of controller operation: | equipment issues |



**RB01-PC13 [ 38 ]  Region: GC**

*Device characteristics:*

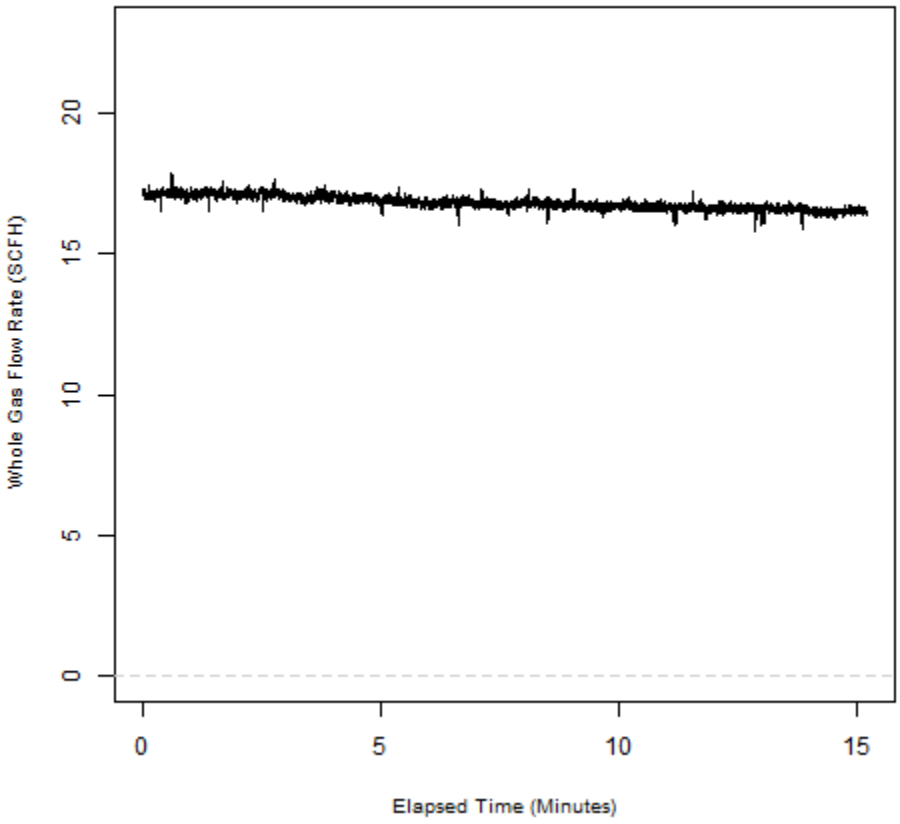
| | |
|---|---|
| Avg. Emission rate (whole gas): | 17.2 scf/h |
| Avg. Emission rate (methane): | 14.2 scf/h |
| Controller application: | Level |
| Basic Application: | Dehydration System |
| Detailed Application: | Contact Tower- Liquid Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 25 psig |
| Assessment of controller operation: | equipment issues |



**VF01-PC22 [ 39 ]  Region: AP**

*Device characteristics:*

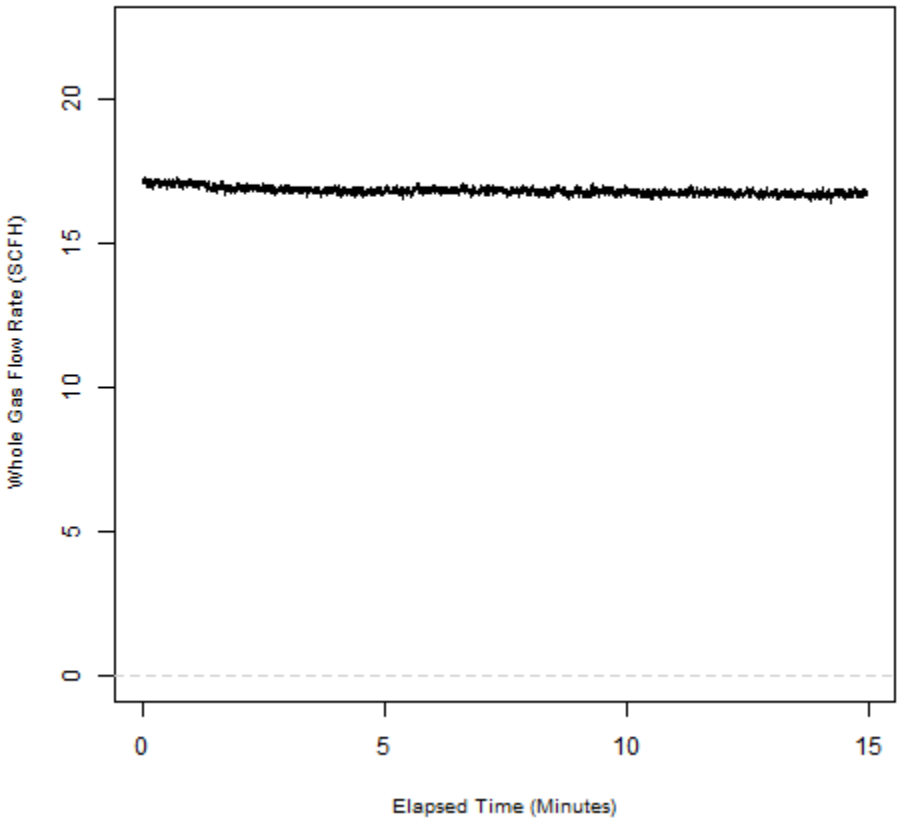
| | |
|---|---|
| Avg. Emission rate (whole gas): | 16.8 scf/h |
| Avg. Emission rate (methane): | 16.4 scf/h |
| Controller application: | Temperature |
| Basic Application: | Process Heater |
| Detailed Application: | Gas Flow to Process Heater |
| Manufacturer/Model (blinded): | I04 |
| Supply pressure: | 7 psig |
| Assessment of controller operation: | equipment issues |



**RB01-PC34 [ 40 ]  Region: GC**

*Device characteristics:*

| | |
|---|---|
| Avg. Emission rate (whole gas): | 16.8 scf/h |
| Avg. Emission rate (methane): | 13.8 scf/h |
| Controller application: | Level |
| Basic Application: | Separator |
| Detailed Application: | Separator - Water Level Control |
| Manufacturer/Model (blinded): | M01 |
| Supply pressure: | 32 psig |
| Assessment of controller operation: | equipment issues |



## B Methane Emissions from Liquids Unloadings

### *B.1 Methods for site selection*

*Goals and Overall Sampling Strategy.* Sampling of emissions from gas well liquids unloadings was conducted in four major regions (Appalachian, Gulf Coast, Mid-continent, Rocky Mountain). The regions are shown in Figure B-1.

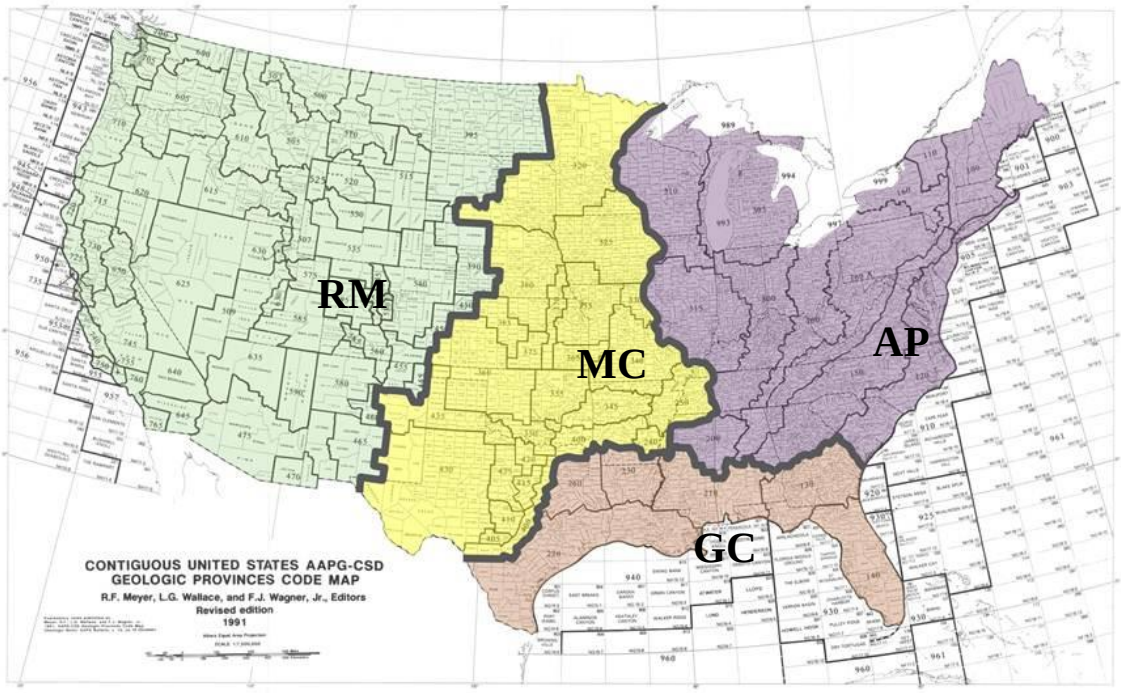



**Figure B-1.** Basins of the American Association of Petroleum Geologists (AAPG) divided into 4 Major Regions for this study: AP=Appalachian; GC=Gulf Coast; MC=Mid-Continent; RM=Rocky Mountain.

It was anticipated that in each of the four regions, gas wells with and without plunger lifts would be sampled, and that within each of these categories, there would be a range of unloading frequencies, durations and liquid production rates. To adequately sample regions, well types (plunger and without plunger) and unloading event characteristics, it was anticipated that measurements of unloading emissions from approximately 100 different wells would be required.

*Selection of Site Visit Duration and Scope.* With a goal of 100 well unloading measurements, the project team conducted approximately 20 one-week visits to natural gas production regions with unloading emissions. It was anticipated that 5 wells could be sampled in a typical week. Production basins with the highest emissions, as reported through the U.S. EPA's Greenhouse Gas Reporting Program, were targeted. Each week of sampling was conducted with a single company in a single basin location.

*Selection of Basins.* Basins in which sampling was conducted were selected based on emissions reported through the EPA's Greenhouse Gas Reporting Program (GHGRP, Reporting Year 2012) Figure B-2 shows Basins reporting unloading emissions through the GHGRP. Any basin colored blue had reported unloading emissions; uncolored (white) basins had no reported emissions. The darkest blue indicates basin total emissions for all reporters in excess of one million metric ton of $CO_2e$ annually (based on a Global Warming Potential for methane of 21), medium blue indicates basin total emissions between 100,000 and 1,000,000 metric tons (MT) $CO_2e$ annually, and lightest blue are basins that reported less than 100,000 MT $CO_2e$ annually. There were 27 basins that reported unloading emissions in 2012.

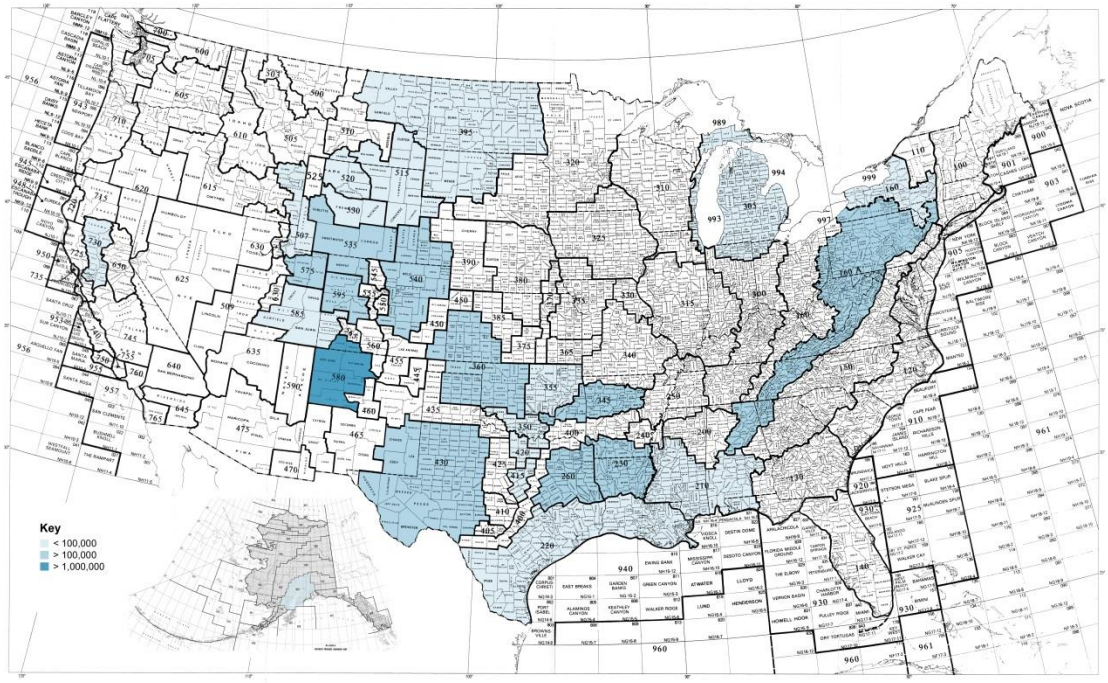



**Figure B-2.** Basins of the American Association of Petroleum Geologists (AAPG) where unloadings were reported in 2012 to the EPA GHGRP.

Ten companies participating in this work reported 60% of the total unloading emissions for GHGRP reporting year 2012, and account for 26% of the wells that reported emissions.

**Table B-1.** Spatial distribution of total unloading emissions reported in the GHGRP compared to the spatial distribution of emissions reported by companies that provided sampling sites

| Region | AAPG Basin | Total GHGRP Emissions for 2012 (MT $CO_2e$) | % of total Basin emissions accounted for by companies providing sampling sites | % of total Basin wells that have unloadings accounted for by companies providing sampling sites |
|---|---|---|---|---|
| Appalachian | 160A - Appalachian Eastern Overthrust | 413,623 | 14.9% | 14.5% |
| | 220 - Gulf Coast Basin | 74,525 | 31.6% | 40.1% |
| GC | 230 - Arkla Basin | 148,126 | 8.4% | 36.9% |
| | 260 - East Texas Basin | 242,828 | 82.4% | 65.5% |
| | 345 - Arkoma Basin | 477.471 | 20.0% | 26.6% |
| MC | 350 - South Oklahoma Folded Belt | 972 | 6.2% | 6.9% |
| | 360 - Anadarko Basin | 310,355 | 1.2% | 13.2% |
| | 415 - Strawn Basin | 43,050 | 48.3% | 54.9% |
| | 420 - Fort Worth Syncline | 32,933 | 14.4% | 39.1% |
| | 430 - Permian Basin | 179,707 | 1.8% | 3.5% |
| RM | 507 - Central Western Overthrust | 42,505 | 14.0% | 32.4% |
| | 530 - Wind River Basin | 4,743 | 84.5% | 23.4% |
| | 535 - Green River Basin | 182,427 | 24.0% | 40.2% |
| | 540 - Denver Basin | 102,335 | 6.1% | 22.3% |
| | 575 - Uintah Basin | 149,584 | 8.9% | 25.6% |
| | 580 - San Juan Basin | 2,315,772 | 96.4% | 87.3% |
| | 595 - Piceance Basin | 943,554 | 79.2% | 12.1% |
| **Total US** | | **5,846,634** | **59.5%** | **25.5%** |

*Selection of Company and Basin Locations* The Study Team, consisting of URS and University of Texas personnel, was solely responsible for the selection of regions and Basins in which to sample. For most basins, more than one of the ten participant companies has reported unloading emissions. If every participant company were visited in each basin where any participant unloading emissions were reported, there would have been 52 weeks of site visits. Since project scope and budget called for approximately 20 sample weeks, a subset of all possible participant sites were selected for sampling.

The selection of company sites required a balance among a number of goals. One goal was to sample at least 3 companies in each major region (AP, GC, MC, RM) shown in Figure B-1. A second goal was to sample the basins with the largest reported emissions in the GHGRP. A third goal was to be able to sample each of the ten participant companies at least once. All companies that reported wells with unloading emissions were sampled in this program.

Once a basin was targeted for sampling, selection of the particular company to visit started with the participant company with the largest reported emissions in the basin, unless that company had already been sampled elsewhere, or unless one of the other participant companies only reported emissions in that single basin. Figure B-3 shows the basins that were sampled during this measurement effort in late 2013 and early 2014. All basins with emissions of more than 100,000 MT $CO_2$e/yr from unloadings, as reported through the GHGRP, were sampled, with the exception of basin 360. The one company targeted for basin 360 did not have had any unloading events for the week selected for a site visit to Basin 360.

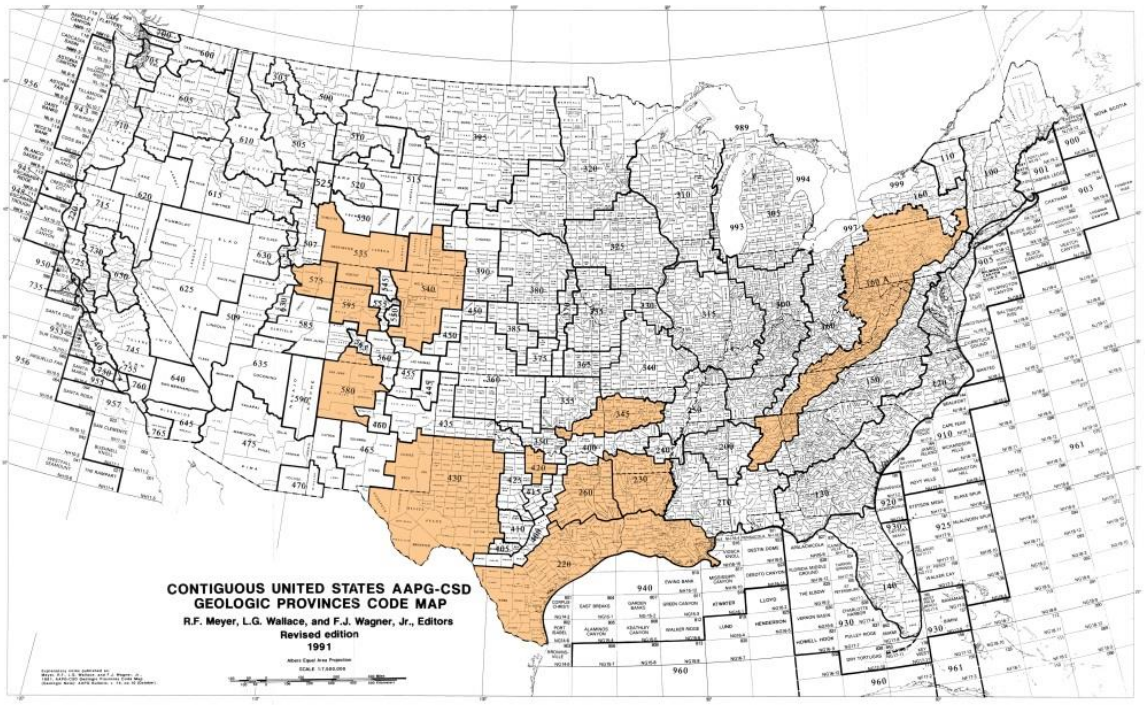



**Figure B-3.** Basins of the American Association of Petroleum Geologists (AAPG) where unloadings measurements were made in this work.

Once a Basin and company to be sampled was selected, local contacts for participant companies provided descriptions of the types of unloadings and typical frequencies expected. No companies refused a site visit. Once at a site, the Study Team measured emissions from as many wells as could be visited and measured in the week. In some cases this involved sampling every unloading that occurred during the week for the company being visited. When more unloadings were available than could be sampled during a week, the Study Team selected which wells to visit.

## *B.2 Corrections to Instrument Flow Measurements based on Temporary Stack Size and Gas Composition*

When safe and technically possible, the flow measurements of gas volumes released during liquid unloadings were taken using a temporary stack affixed to a tank vent that

was equipped with a gas velocity measurement instrument (Fox Thermal Instruments, Model #FT3). On sites where the unloading flow was directed to an open top blowdown tank, rather than a fixed roof tank, a length of pipe was inserted into the piping to the open top tank that was used for the unloading, allowing for measurement of the flow into the tank. The Fox #FT3 device measured velocity over a 1.4" measurement length (with 0.5 inch thickness), which was centered in the temporary stack or pipe. The average-center line velocity measured by the Fox #FT3 was converted to an average velocity in the temporary stack or pipe by assuming that the velocity distribution was well-represented by a one-seventh power law velocity distribution.

$$\frac{v(r)}{v_{max}} = \left(1 - \frac{r}{R}\right)^{1/7} \qquad \text{(B2.1)}$$

where *v(r)* is the velocity at distance r from the tube centerline, and R is the radius of the temporary stack or pipe. Typically, the power law order (in this case 1/7) is a function of the Reynolds number of the flow. However, over a wide range of Reynolds numbers, the differences in the predicted stack velocities are not sensitive to the assumed order of the power law function (between 1/7 and 1/9) except near the stack or pipe wall. In this work, the measurements were made near the center-line, and the effect near the stack or pipe wall would be expected to be minimal.

The specific relationship between the measured velocity and the overall average velocity depended on the size of the stack or pipe, since the 1.4 inch Fox #FT3 probe measured a different proportion of the cross sectional flow for different sized pipes. For all stacks and pipes, the ratio of the center-line (maximum) velocity to the average velocity over the entire pipe was 0.82. So, if the probe had only measured centerline velocity, the ratio of the average velocity to measured centerline velocity would be 0.82. The actual ratio of the measured velocity to the maximum velocity was dependent on the fraction of the diameter of the pipe that was sampled by the 1.4 in. probe. The correction factor was calculated using the one seventh-order power law distribution, and an assumption that the

probe was exactly centered. The parameters for the pipes and stacks used in this study are summarized in Table B-2.

**Table B-2.** Correction factors used to account for the difference in the measured velocity and the average velocity through the pipe or stack. Note that the 2.5" nominal diameter stack was only used for the calibration of some of the Fox #FT3 devices and was not used for in-field measurements during the study.

| Nominal Stack Diameter (in) | Stack Internal Diameter (in) | Proportion of Stack Diameter Measured (r/R) | Ratio of Measured Velocity to Center-Line Velocity (Average velocity =0.82 * centerline velocity) |
|---|---|---|---|
| **2** | 2.060 | 0.68 | 0.93 |
| **2.5** | 2.469 | 0.57 | 0.95 |
| **3** | 3.068 | 0.46 | 0.96 |
| **6** | 5.76 | 0.24 | 0.98 |
| **8** | 7.90 | 0.18 | 0.98 |

The volumetric flow rate is the average velocity in the stack or pipe multiplied by the cross-sectional area available for flow. In the measurements made in this study, the cross-sectional area available for flow is the cross-sectional area of the stack or pipe minus the area obstructed by the flow probe, as shown in Figure B-4. The area available for flow through each of the stack sizes used in this study is shown in Table B-3.

**Figure B-4.** Fox #FT3 velocity probe centered in a 2" nominal diameter stack.

**Table B-3.** Parameters for stacks and pipes used in this study and the unobstructed cross-sectional area for flow, accounting for the Fox #FT3 probe insertion. Note that the 2.5" nominal diameter stack was only used for the calibration of some of the Fox #FT3 devices and was not used for in-field measurements during the study.

| Nominal Stack Diameter (in) | Stack Area ($in^2$) | Area Obstructed by Probe ($in^2$) | Unobstructed Area ($in^2$) |
|---|---|---|---|
| **2** | 3.33 | 0.57 | 2.76 |
| **2.5** | 4.79 | 0.67 | 4.11 |
| **3** | 7.39 | 0.82 | 6.57 |
| **6** | 26.07 | 1.50 | 24.6 |
| **8** | 49.0 | 2.03 | 47.0 |

Thus, the instrument reported flow in standard cubic feet per hour (scf/h) was calculated based on the instrument reported velocity and the cross-sectional area available for flow through the stack or pipe:

$$scf/h_{inst} = v_{inst} * \frac{0.82}{\overline{v_m}/v_{max}} * \frac{A_c}{144} \quad \text{(B2.2)}$$

where $v_{inst}$ is the instrument reported velocity in feet per hour, $v_m/v_{max}$ is the ratio of measured velocity to center-line velocity (Table B-2), and $A_c$ is the unobstructed cross-sectional area of the stack or pipe in square inches (Table B-3). The overall factor converting instrument reading to volumetric flow for each stack and pipe size is summarized in Table B-4.

**Table B-4.** Overall conversion factor for velocity measurement (ft/h) to flow rate (scf/h) for each stack and pipe size used in the project. Note that the 2.5" nominal diameter stack was only used for the calibration of some of the Fox #FT3 devices and was not used for in-field measurements during the study.

| Nominal Stack Diameter (in) | Factor (B) |
|---|---|
| **2** | 0.0169 |
| **2.5** | 0.0246 |
| **3** | 0.0390 |
| **6** | 0.143 |
| **8** | 0.273 |

The Fox FT#3 flow measurement devices were calibrated on pipes with sizes that were not necessarily the same as those utilized in the field measurements for unloadings. The probes were calibrated by the manufacturer by sending a known volume of methane through a pipe of known diameter and cross sectional area. For this study, calibrations were made on different Fox #FT3 instruments using the pipes specified as 2.5" and 3" nominal diameter in Tables B-2 and B-3. Thus, the flow rate calculated by the instrument (using a pipe which was typically a different diameter than the pipe used for calibration) had to be scaled by the ratio of the factor (Table B-4) for the field pipe to the calibration pipe.

In addition, the Fox #FT3 instruments were calibrated by the manufacturer (Fox Thermal Instruments) using pure methane; instrument flow rates were corrected to account for the measured gas compositions, which varied from site to site. Because the flow meter measurement is based on thermal conductivity, the composition correction was based on the relative thermal conductivities of the gas used by pneumatic devices at each site and the pure methane used as a calibration gas.

$$scf/h = scf/h_{inst}\left(\frac{k_{CH4}}{k_{gas}}\right)\left(\frac{B_{field}}{B_{cal}}\right) \quad \text{(B2.3)}$$

where $scf/h_{inst}$ is the raw instrument flow rate reading in standard cubic feet per hour, $k_{CH4}$ is the pure component thermal conductivity (W/m*K) for methane at standard conditions (70ºF and 14.7 psia), and $k_{gas}$ is the thermal conductivity of the gas sampled at standard conditions. The B factors are the values in Table B-4, which convert the measured velocity to a flow rate. The thermal conductivity of the sampled gas ($k_{gas}$) was calculated as a molar weighted average:

$$k_{gas} = \sum_{i=1}^{7} k_i n_i \quad \text{(B2.4)}$$

where $n_i$ is the mole fraction of species $i$ in the gas sample for the site and $k_i$ is the pure component thermal conductivity of the species (http://webbook.nist.gov/chemistry/fluid/) under standard conditions. For this work, the pure component species considered were methane, ethane, propane, nitrogen, air, and carbon dioxide. All higher hydrocarbons with a carbon count of four or greater were lumped with butane for purposes of the gas composition correction.

**Table B-5.** Thermal conductivity of measured species at standard conditions (14.7 psia and 70ºF).

| Species | Thermal Conductivity (W/m*K) |
|---|---|
| **Methane** | 0.033759 |
| **Ethane** | 0.020491 |
| **Propane** | 0.017884 |
| **Butane +** | 0.016181 |
| **Nitrogen** | 0.025473 |
| **Carbon Dioxide** | 0.016331 |

*B.3 Unloading emission data*

**Table B-6.** Unloading emissions from wells with automatically triggered plunger lifts.

| Well Characteristics | | | | | | Emissions Data | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Well** | **Region** | **V or H*** | **Gas prod. rate (scf/d)** | **$CH_4$ in gas (%)** | **$CH_4$ emitted per event (scf)** | **Events sampled** | **Avg. event duration (s)** | **Events per year for well reported by operator** | **Emiss. per year for well based on events reported by operator (MMscf $CH_4$)** |
| UBB 42 0101 | RM | V | 170,000 | 75.7 | 914 | 6 | 147 | 1982 | 1810 |
| UBB 42 0201 | RM | V | 100,000 | 78.7 | 8,621 | 2 | 1208 | 1069 | 9220 |
| UBB 42 0401 | RM | V | 200,000 | 81.9 | 64 | 7 | 389 | 2546 | 163 |
| UBB 42 0501 | RM | V | 140,000 | 82.9 | 659 | 18 | 130 | 606 | 399 |
| UBB 42 0601 | RM | V | 140,000 | 83.4 | 7,278 | 5 | 1208 | 2686 | 19500 |
| UBB 42 0701 | RM | V | 170,000 | 81.1 | 103 | 9 | 276 | 184 | 19 |
| UBB 42 0801 | RM | V | 155,000 | 80.5 | 1,695 | 3 | 433 | 2048 | 3470 |
| UBB 42 0901 | RM | V | 150,000 | 91.5 | 91 | 6 | 70 | 964 | 88 |
| UBB 42 1001 | RM | V | 162,000 | 91.5 | 209 | 5 | 36 | 715 | 149 |
| UBB 42 1101 | RM | V | 175,000 | 80.0 | 1,534 | 76 | 262 | 1011 | 1550 |
| UBB 42 1201 | RM | V | 90,000 | 80.4 | 611 | 7 | 617 | 573 | 350 |
| UBB 43 0101 | RM | V | 180,000 | 78.5 | 1,296 | 8 | 177 | 2873 | 3720 |
| UBB 43 0301 | RM | V | 190,000 | 81.7 | 64 | 6 | 137 | 4698 | 301 |
| UEY 41-0101 | MC | V | 38,000 | 97.8 | 312 | 4 | 400 | 6570 | 2050 |
| UEY 41-0201 | MC | V | 90,000 | 97.8 | 129 | 2 | 274 | 2389 | 308 |
| UEY 41-0301 | MC | V | 129,000 | 97.8 | 215 | 4 | 191 | 7509 | 1614 |
| UEY 41-0401 | MC | V | 107,000 | 97.8 | 549 | 1 | 206 | 3893 | 2137 |
| UBB 50 2601 | RM | V | 54,000 | 76.8 | 915 | 2 | 317 | 643 | 588 |
| UBB 50 2701 | RM | V | 47,000 | 77.7 | 1,998 | 1 | 849 | 4252 | 8495 |
| UBB 50 2801 | RM | V | 32,000 | 78.2 | 56 | 23 | 33 | 4051 | 227 |
| UBB 50 2901 | RM | V | 15,000 | 83.0 | 993 | 14 | 90 | 2482 | 2464 |
| UBB 50 3001 | RM | V | 26,000 | 81.9 | 237 | 7 | 692 | 650 | 154 |
| UBB 50 3101 | RM | V | 46,000 | 80.6 | 58 | 17 | 73 | 1963 | 114 |
| UBB 50 3201 | RM | V | 46,000 | 76.6 | 1,325 | 1 | 309 | 528 | 700 |
| UEF-49-0501 | GC | V | 18,000 | 82.4 | 428 | 2 | 123 | 4238 | 1810 |

* (V)ertical or (H)orizontal.

**Table B-7.** Unloading emissions from wells with manually triggered plunger lifts

| Well Characteristics | | | | | Emissions Data | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Well | Reg. | V or H | Gas prod. rate (scf/d) | $CH_4$ in gas (%) | $CH_4$ emit. per event (scf) | Events samp. | Avg. event duration (s) | Events per year for well reported by operator | Emiss. per year for well based on events reported by operator (MMscf CH4) |
| UBB-45-0101 | RM | V | 20,000 | 77.4 | 9,674 | 1 | 727 | 30 | 290 |
| UBB-45-0201 | RM | V | 20,000 | 77.4 | 11,678 | 1 | 1,529 | 50 | 584 |
| UBB-45-0202 | RM | V | 35,000 | 77.4 | 11,783 | 1 | 1,303 | 50 | 589 |
| UBB-45-0203 | RM | V | 10,000 | 77.4 | 4,703 | 1 | 1,522 | 50 | 235 |
| UBB-45-0204 | RM | V | 25,000 | 77.4 | 3,641 | 1 | 1,708 | 50 | 182 |
| UBB-45-0301 | RM | V | 16,000 | 77.4 | 5,612 | 1 | 1,416 | 2 | 11 |
| UBB-45-0302 | RM | V | 45,000 | 77.4 | 4,008 | 1 | 1,219 | 2 | 8 |
| UBB-45-0401 | RM | V | 25,000 | 77.4 | 16,852 | 1 | 3,714 | 2 | 34 |
| UBB-45-0501 | RM | V | 13,000 | 77.4 | 8,057 | 1 | 3,847 | 5 | 40 |
| UBB-47-0301 | GC | V | 80,000 | 86.5 | 3,937 | 1 | 7,672 | 2 | 8 |
| UDN-44-0203 | RM | V | 125,000 | 88.8 | 4,737 | 1 | 443 | 3 | 14 |
| UDN-44-0304 | RM | V | 43,000 | 90.7 | 14,069 | 1 | 540 | 6 | 84 |
| UDN-44-0405 | RM | V | 343,000 | 89.1 | 8,289 | 1 | 417 | 3 | 25 |
| UDN-44-0506 | RM | V | 231,000 | 89.9 | 6,459 | 1 | 528 | 1 | 6 |
| UDN-44-0507 | RM | V | 248,000 | 88.4 | 8,639 | 1 | 588 | * | |
| UEF-02-0201 | MC | V | 41,000 | 81.1 | 8,290 | 1 | 2,271 | 13 | 108 |
| UEF-02-0202 | MC | V | 15,000 | 84.3 | 6,083 | 1 | 5,637 | 10 | 61 |
| UEF-02-0203 | MC | V | 24,000 | 82.5 | 11,958 | 1 | 2,864 | 12 | 143 |
| UEF-02-0204 | MC | V | 35,000 | 78.4 | 6,272 | 1 | 1,780 | 8 | 50 |
| UEF-02-0205 | MC | V | 24,000 | 81.9 | 14,570 | 1 | 3,458 | 8 | 117 |
| UEF-02-0206 | MC | V | 38,000 | 85.6 | 21,255 | 1 | 4,996 | 4 | 85 |
| UJR-46-0101 | RM | V | 86,000 | 86.4 | 1,665 | 1 | 1,011 | 5 | 8 |
| UJR-46-0401 | RM | V | 36,000 | 86.4 | 993 | 1 | 231 | 6 | 6 |
| UJR-46-0501 | RM | V | 37,000 | 86.4 | 6,744 | 1 | 560 | 16 | 108 |
| UJR-46-0601 | RM | V | 30,000 | 86.4 | 1,220 | 1 | 198 | 1 | 1 |
| UJR-46-0701 | RM | V | 34,000 | 86.4 | 1,261 | 1 | 339 | 11 | 14 |
| UJR-46-0801 | RM | V | 51,000 | 86.4 | 22,364 | 1 | 3,926 | 3 | 67 |
| UJR-46-1001 | RM | V | 110,000 | 86.4 | 8,101 | 1 | 3,149 | 2 | 16 |
| UJR-46-1101 | RM | V | 118,000 | 86.4 | 2,663 | 1 | 559 | 15 | 40 |
| UJR-46-1201 | RM | V | 19,000 | 86.4 | 21,060 | 1 | 1,289 | 8 | 168 |
| UMB-06-0101 | MC | V | 23,000 | 83 | 4,805 | 1 | 790 | 2 | 10 |

**Table B-7** (continued).

| Well Characteristics | | | | | | Emissions Data | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Well** | **Reg.** | **V or H** | **Gas prod. rate (scf/d)** | **$CH_4$ in gas (%)** | **$CH_4$ emit. per event (scf)** | **Events samp.** | **Avg. event duration (s)** | **Events per year for well reported by operator** | **Emiss. per year for well based on events reported by operator (MMscf CH4)** |
| UMB-06-0401 | MC | V | 226,000 | 81.5 | 403 | 1 | 169 | 1 | 0.5 |
| UMB-06-0501 | MC | V | 4,000 | 82.1 | 1,311 | 1 | 474 | 2 | 3 |
| UMB-06-0601 | MC | V | 30,000 | 82.5 | 1,245 | 1 | 387 | 10 | 12 |
| UMB-06-0901 | MC | V | 38,000 | 77.5 | 1,862 | 1 | 688 | 10 | 19 |
| USH-42-0301 | AP | H | 900,000 | 97.3 | 223 | 1 | 86 | 7 | 2 |
| USH-45-0101 | RM | V | 160,000 | 87.8 | 18,277 | 1 | 1,314 | 2 | 37 |
| USH-45-0103 | RM | V | 168,000 | 87.8 | 47,119 | 1 | 1,181 | 3 | 141 |
| USH-45-0105 | RM | V | 87,000 | 87.8 | 8,924 | 2 | 2,720 | 15 | 134 |
| USH-45-0201 | RM | V | 119,000 | 87.8 | 26,668 | 1 | 1,900 | 1 | 27 |
| USH-45-0202 | RM | V | 166,000 | 87.8 | 49,273 | 1 | 1,447 | 11 | 542 |
| USH-45-0203 | RM | V | 151,000 | 87.8 | 15,834 | 2 | 1,638 | 39 | 618 |
| UTG-44-0201 | AP | V | 6,000 | 95.7 | 4,313 | 1 | 10,214 | 20 | 86 |
| UTG-44-0301 | AP | V | 10,000 | 95.7 | 8,622 | 1 | 2,609 | 24 | 207 |
| UTG-44-0401 | AP | V | 4,000 | 95.7 | 4,398 | 1 | 3,213 | 24 | 106 |
| UTG-44-0501 | AP | V | 10,000 | 95.7 | 3,534 | 1 | 1,240 | 24 | 85 |
| UTG-44-0601 | AP | V | 17,000 | 95.7 | 3,964 | 1 | 1,060 | 52 | 206 |
| UTG-44-0701 | AP | V | 6,000 | 95.7 | 10,542 | 1 | 9,807 | 12 | 127 |

**Table B-8.** Unloading emissions from wells without plunger lifts

| Well Characteristics | | | | | Emissions Data | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Well** | **Reg.** | **V or H** | **Gas prod. rate (scf/d)** | **$CH_4$ in gas (%)** | **$CH_4$ emitted per event (scf)** | **Events samp.** | **Avg. event duration (s)** | **Events per year for well reported by operator** | **Emiss. per year for well based on events reported by operator (MMscf CH4)** |
| UBB-47-0101 | GC | V | 150,000 | 92.7 | 555 | 2 | 1,518 | 2 | 1 |
| UBB-47-0201 | GC | V | 100,000 | 80.7 | 6706 | 2 | 3,417 | 4 | 27 |
| UBB-47-0401 | GC | V | 100,000 | 86.5 | 2745 | 1 | 2,104 | 1 | 3 |
| UCG-03-0101 | GC | V | 162,078 | 96.1 | 12237 | 1 | 6,762 | 48 | 587 |
| UCG-03-0102 | GC | V | 155,279 | 96.1 | 13761 | 1 | 6,016 | 6 | 83 |
| UCG-03-0103 | GC | V | 160,791 | 96.1 | 24085 | 1 | 7,919 | 12 | 289 |
| UCG-03-0201 | GC | V | 153,467 | 93.3 | 16029 | 1 | 3,952 | 3 | 48 |
| UCG-03-0202 | GC | V | 269,018 | 93.3 | 24544 | 1 | 4,739 | 3 | 74 |
| UCG-03-0203 | GC | V | 167,000 | 96.1 | 16056 | 1 | 2,504 | 185 | 1975 |
| UCG-03-0204 | GC | V | 43,748 | 93.3 | 9942 | 1 | 5,120 | 81 | 805 |
| UCG-03-0301 | GC | V | 102,050 | 93.3 | 21342 | 1 | 9,819 | 27 | 576 |
| UCG-03-0302 | GC | V | 151,000 | 96.1 | 11436 | 1 | 4,308 | 151 | 1269 |
| UCG-03-0401 | GC | V | 123,017 | 96.1 | 10696 | 1 | 1,270 | 9 | 96 |
| UCG-03-0402 | GC | V | 67,718 | 96.1 | 16487 | 1 | 2,662 | 45 | 742 |
| UEY-41-0601 | MC | H | 400,000 | 95.2 | 73417 | 1 | 11,782 | 1 | 73 |
| UMB-06-0701 | MC | V | 25,000 | 74.3 | 3509 | 1 | 1,841 | 5 | 18 |
| UMB-06-0801 | MC | V | 20,000 | 72.8 | 6460 | 1 | 3,580 | 3 | 19 |
| UMB-06-1101 | MC | V | 21,000 | 81.3 | 6083 | 1 | 1,021 | 12 | 73 |
| UMB-06-1201 | MC | V | 4,787 | 78.4 | 1951 | 1 | 964 | 1 | 2 |

**Table B-8** (continued).

| Well Characteristics | | | | | Emissions Data | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Well** | **Reg.** | **V or H** | **Gas prod. rate (scf/d)** | **$CH_4$ in gas (%)** | **$CH_4$ emitted per event (scf)** | **Events samp.** | **Avg. event duration (s)** | **Events per year for well reported by operator** | **Emiss. per year for well based on events reported by operator (MMscf CH4)** |
| USH-42-0501 | AP | H | 230,000 | 97.3 | 1423 | 1 | 1,252 | 6 | 9 |
| USH-45-0102 | RM | V | 93,000 | 87.8 | 9409 | 1 | 2,411 | 19 | 179 |
| USH-45-0104 | RM | V | 86,000 | 87.8 | 20967 | 1 | 805 | 5 | 105 |
| USH-47-0101 | MC | H | 365,200 | 95.3 | 41919 | 1 | 10,009 | 4 | 168 |
| USH-47-0201 | MC | H | 224,404 | 96.7 | 75974 * | 2 | 14,525 | 95 | 7218 |
| USH-47-0301 | MC | H | 147,231 | 96.7 | 57793 | 1 | 16,161 | 101 | 5837 |
| USH-47-0401 | MC | H | 182,770 | 97.5 | 27055 | 1 | 7,766 | 84 | 2273 |
| USH-47-0601 | MC | H | 258,500 | 94.8 | 47037 | 1 | 3,971 | 70 | 3293 |
| USH-47-0701 | MC | H | 246,356 | 97.8 | 134834 | 1 | 9,741 | 45 | 6068 |
| USH-47-0801 | MC | H | 88,217 | 97.9 | 97937 | 1 | 5,530 | 2 | 196 |
| UTG-44-0101 | AP | V | 10,000 | 95.7 | 4007 | 1 | 629 | 12 | 48 |

*Of the two events measured for this well, one was done without the well being shut-in before the event; since liquids removal was low during this unloading, a second unloading, was done 3 days later with the well shut-in for the 3 days between events. According to the well operator this shut in is required for approximately 6 of the 95 events during a year. The average emissions is therefore a weighted average of the first event (typical of 89 of the 95 events per year) and the much larger event (6 of 95 events per year).

### *B.4 Statistical analyses of variability in unloading emission measurements*

The emission measurement data were combined with well characteristics reported by the host companies to identify possible explanatory variables for the frequency of unloading events and annual unloading emission totals. A natural logarithm (ln) transform was applied to the total gas annual emission values owing to the skewness in this variable. The logarithm transform maintains the ordering of observations but reduces the influence of the larger values on the calculated statistics. The statistical Pearson linear correlations between annual emissions and number of events per year with several other statistical variables were calculated. The correlation is a number between -1.0 and 1.0 that is a measure of the linear association between two variables. A positive correlation between two variables suggests that generally if one observation of the first variable is higher than the average for that variable, then the corresponding value the second variable is also higher than average. A negative correlation between two variables suggests that generally if the first variable is higher than the average for that variable, then the corresponding value of the second variable is lower than average. One must use care in concluding that there is a causal relationship underlying a high positive or negative correlation. One confounding factor could be that there are outliers in the data that have disproportionate impact on average values and therefore in producing a calculated correlation. The natural logarithm transform used on the annual emission total helps to address this. Care must also be used in drawing a conclusion about a correlation close to zero, as a strong relation could exist between variables with correlation = 0.0 that is nonlinear.

Associated with a calculated linear correlation is a probability value (p-value) that represents the approximate probability that a correlation as large as the one calculated could have been the result of a random set of data with no underlying correlation. An individual correlation result with a p-value of 0.05 or less means that the probability that a value as large as the calculated correlation would result if the variables had a random association is small, and thus we conclude the association is likely not random.

The correlations were calculated between company reported *Events per Year*, measured *Event Duration*, estimated *Whole Gas SCF per Year*, and the natural logarithm of *Whole Gas SCF per Year* with 7 well characteristic variables. The results are shown in Table B-9. The correlations with p-values below 0.05 are shown in Table B-10. Although several pairings of emissions variables and well variables appear to be statistically significant, the scatter plot graphs and linear fits suggest most of these relationships do not explain more than a few percent in the variability of emissions, which is the correlation-squared or $R^2$ in linear regression. Well *Total Depth* is an exception, as shown in the line fit graph in Figure B-5. *Total Depth* explains 14% ($R^2 = 0.14$) of the variability in *ln(Whole Gas SCF per Year)* and there is a visible downward trend in the data suggesting emissions decrease with well depth. This may or may not be related to a tendency in deeper wells being newer and thus less prone to unloadings. The variable for well *Age* was statistically significantly positively correlated with the estimated number of *Events per Year* and not-statistically significant but still positively correlated with *Whole Gas SCF per Year*.

**Table B-9.** List of study measurements and estimates compared with reported well characteristics

| **Study measurements** | **Well characteristics** |
|---|---|
| **Event duration** | Surface flow line pressure |
| **Events per year** | Static Shut-in pressure |
| **Whole Gas SCF per Year** | Total Depth |
| **Ln(Whole Gas SCF per Year)** | Production SCF per day |
| | Volume (depth * diameter * diameter / 4) |
| | Age of well |

**Table B-10.** Pairwise linear correlations

| Y Variable | X Variable (study measurements in bold) | # of paired obs. | Linear Correlation | $R^2$ | p-values |
|---|---|---|---|---|---|
| Event duration | **CH4 scf / event** | 106 | 0.6368 | 40.60% | 0.0001 |
| Event duration | CH4 pct | 106 | 0.4434 | 19.70% | 0.0001 |
| Event duration | age | 81 | -0.1954 | 3.80% | 0.0805 |
| | | | | | |
| Events per year | Total Depth | 105 | -0.3926 | 15.40% | 0.0001 |
| Events per year | **Event duration** | 106 | -0.2794 | 7.80% | 0.0037 |
| Events per year | volume | 105 | -0.2438 | 5.90% | 0.0122 |
| Events per year | **CH4 scf / event** | 106 | -0.2244 | 5.00% | 0.0208 |
| Events per year | Static Shut in pressure | 86 | -0.2413 | 5.80% | 0.0252 |
| Events per year | Surface flow line pressure | 96 | -0.1881 | 3.50% | 0.0665 |
| | | | | | |
| ln(Whole gas scf/yr) | Events per year | 106 | 0.4463 | 19.90% | 0.0001 |
| ln(Whole gas scf/yr) | volume | 105 | -0.3138 | 9.80% | 0.0011 |
| ln(Whole gas scf/yr) | **CH4 scf / event** | 106 | 0.2881 | 8.30% | 0.0028 |
| ln(Whole gas scf/yr) | **Event duration** | 106 | 0.2209 | 4.90% | 0.0229 |
| | | | | | |
| Whole gas scf / year | Events per year | 106 | 0.3303 | 10.90% | 0.0005 |
| Whole gas scf / year | Total Depth | 105 | -0.2616 | 6.80% | 0.007 |
| Whole gas scf / year | age | 81 | 0.2508 | 6.30% | 0.0239 |
| Whole gas scf / year | volume | 105 | -0.177 | 3.10% | 0.0708 |
| Whole gas scf / year | **CH4 scf / event** | 106 | 0.1759 | 3.10% | 0.0713 |

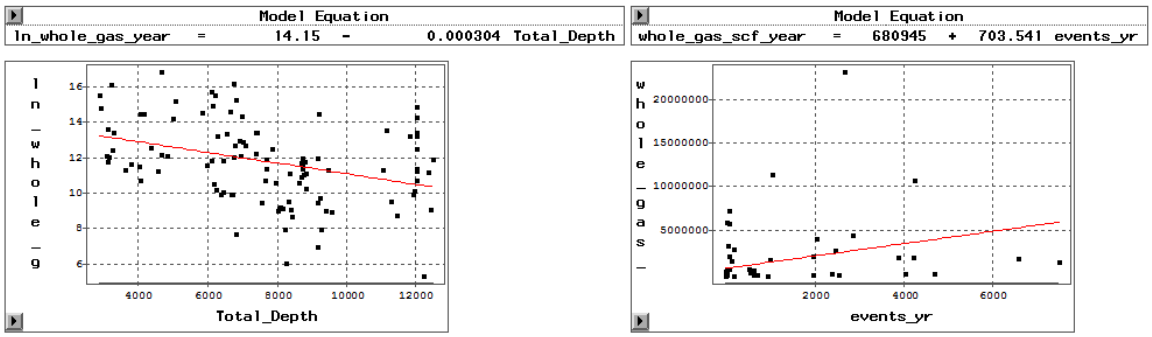



**Figure B-5.** Examples of linear fits for two significantly related variables (*left*: ln whole gas emissions vs. well depth for all wells; *right*: ln whole gas emissions vs. frequency of unloading for automated plunger lift wells.

Additional statistical analyses were done, comparing the observed emissions per event, to emissions per event that would be predicted based on EPA emission estimation methods described in Technical Support Documents available for GHGRP reporting, (http://www.epa.gov/ghgreporting/documents/pdf/2010/Subpart-W_TSD.pdf). Briefly, these emission estimation methods assume that an unloading event vents, at a minimum, the entire volume of the well bore and that the well bore is entirely filled with gas at the shut-in pressure. If, for a plunger lift well, the event lasts more than 30 minutes, the vent rate for the period after 30 minutes is assumed to be at the production rate. If, for a non-plunger lift well, the event lasts more than 60 minutes, the vent rate for the period after 60 minutes is assumed to be at the production rate. The comparisons with the emission estimation method were done for wells on which all of the data required for the emission estimation method were available.

For wells without plunger lift (18 wells with all data available), the observations were higher (statistically significant difference) than the estimates, however, linear correlations, shown in Figure B-6, led to a slope that was not statistically significant. If the two highest observed emissions events are removed from the analysis (events circled in Figure B-6), the correlation does become statistically significant.

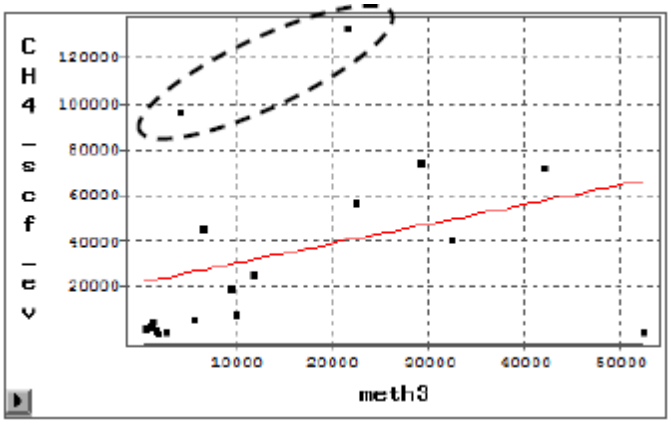



**Figure B-6.-** Comparison of emission predictions using EPA emission estimation methods to observed emissions per event for wells without plunger lift.

For wells with plunger lifts (66 wells), the emission estimates average 20,200 scf/event as compared to an average of 7,100 scf/event for the measurements. The difference is statistically significant (p=0.0001), however the predicts and the observations are positively correlated. Figure B-7 shows the comparison.

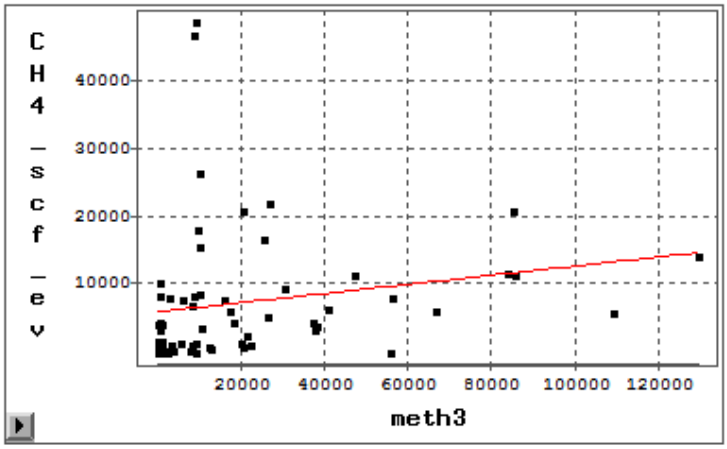



**Figure B-7.** Comparison of emission predictions using EPA emission estimation methods to observed emissions per event for wells with plunger lift.

*B.5 Estimates of emissions from gas well liquid unloadings in the United States*

Emission measurements from a limited set of samples can be used to estimate national emissions by multiplying the average emission measurement by the number of times that emission occurs on the national scale. Often the emission measurement is referred to as an "emission factor" or EF, and the data used to scale up the emissions is called the activity factor (AF). Emissions are calculated as:

$$EF_i * AF_i = ER_i \quad \text{(B5.1)}$$

*where:*

$EF_i$ = Emission Factor for region i

AFi = Activity Factor for region i

$ER_i$ = resulting Emission Rate total for region i

For this work, the activity factors are national counts of natural gas well unloading events. The activity data and the emission factor data are stratified at two levels. First, wells are classified as either with or without plunger lift. Then, within each well category (with or without plunger lift) wells are grouped based on the frequency of unloadings (events per year). The emission factor strata for which activity data are needed are shown in Table B-11.

**Table B-11.** Categories of wells for which emissions were measured

| **Well type (Annual Frequency of events)** | **Measured EF, scf methane per event (95% confidence range)** |
|---|---|
| Plunger Wells (events<100) | 9,450 (6,900-12,400) |
| Plunger Wells (events≥100) | 1,200 (500-2,100) |
| Non Plunger Wells (events<10) | 21,500 (9,600-37,800) |
| Non Plunger Wells (10≤events<50) | 24,100 (8,700-50,400) |
| Non Plunger Wells (50≤events<200) | 35,000 (18,700-53,000) |
| Non Plunger Wells (events≥200) | Not measured, assume 35,000 (see main text) (18,700-53,00) |

*Activity Data:* The primary source of activity data used in this work is a survey of unloading event count collected from companies that participated in this work. These survey data will be supplemented by data on well counts from the GHG Mandatory Reporting Program, for reporting year 2012, released in 2013 (referred to here as EPA 2012 GHGRP) and the 2012 GHG National Emission Inventory, released in 2014 (referred to here as the 2012 GHG NEI).

The EPA 2012 GHG NEI reports that 60,810 natural gas wells have liquids unloadings, out of an estimated 470,913 natural gas wells in the United States (not including oil wells with associated gas production). This represents 13% of gas wells in the EPA 2012/2014 GHG NEI. Of these 60,810 wells, 23,503 are reported as having plunger lifts and 37,307 are reported as not having plunger lifts.

More granular and detailed data is available as part of the EPA 2012 GHGRP. All operators of U.S. upstream petroleum and natural gas production are required to report under the GHGRP, so long as their total emissions from all sources exceeds 25,000 MT $CO_2e$/yr for an entire basin. EPA estimated in the original publication of the Rule that more than 85% of all GHG emitters would have to report, though the percentage may be higher in the oil and gas production sector, given that reporting facilities are defined as large basins. The latest data available from the GHG Mandatory Reporting rule is published in the EPA's Facility Level Information on GreenHouse Gases Tool (FLIGHT) system (http://ghgdata.epa.gov/ghgp/main.do) and data for individual facilities can be downloaded from that system. Data from reporting year 2012 was the latest data available at the time this work was completed. FLIGHT data from reporting year 2012 shows 58,663 wells that report unloading emissions. Of these 58,663 wells from FLIGHT, 32,225 are reported as having plunger lifts and 26,438 are reported as not having plunger lifts. This agrees reasonably well with the EPA NEI estimates for total well count (58,663 from FLIGHT as compared to 60,810 from the GHG NEI), however, the fractions of plunger and non-plunger wells differ for the two data sets. In this work, the fractions of plunger and non-plunger wells from the 2012 GHGRP will be used to

estimate national emissions, based on the assumption that these data are based on more recent assessments of the prevalence of plunger lifts. A sensitivity analysis is presented at the end of this section to assess the effect of this assumption on national emission estimates.

While this work uses total well counts from the 2012 GHGRP FLIGHT data in estimating national emissions, event counts will be based on data from a survey of companies participating in this work. One reason for using survey data for event counts is the lack of complete data on event frequency for non-plunger wells in the 2012 GHGRP FLIGHT data. While it may be feasible to estimate these data from partial reporting in the 2012 GHGRP, this would require making assumptions regarding the representativeness of partial reporting. A second reason for using the survey data collected in this work, rather than GHGRP FLIGHT data for event counts, was apparent quality assurance issues in event counts in the GHGRP FLIGHT data. Specifically, the study team's interpretation of the event reports in the GHGRP suggested very high frequencies of events for some non-plunger wells. These event frequencies appeared to the study team to be physically unreasonable (thousands of events per year for wells that are almost exclusively manually unloaded) and inconsistent with the survey data from companies.

Since event counts for plunger and non-plunger wells are either not reported or inconsistently reported in the FLIGHT data, the companies participating in this study volunteered data on unloading emissions that they had released to the EPA GHGRP for reporting year 2013. Eight of the ten participants were able to provide data. The participant company data, underwent quality assurance review and was then used to determine average event frequencies for the categories of non-plunger and plunger lift wells. The results for non-plunger lift wells are shown in Tables B-12 (national totals) and B-13 (regional distributions). The data in Table S5-3 indicate that event count distributions in the four regions considered in this work are all similar to national averages, but since detailed regional data are available, they will be used in estimating emission event counts in this work.

As an example of how event counts were estimated in Table B-12, consider the national total for non-plunger wells with less than 10 events per year. In the survey 6,378 of the 7,481 wells without plunger lift (85%, see Table B-12) had less than 10 events per year. It therefore is assumed that 85% of the 26,438 wells without plunger lift nationally will have less than 10 events per year, with an average of 2.93 events per well (see Table B-13, B-14). This results in an estimate of 66,000 events for these low event frequency wells in Table B-12. A total event count for all wells without plunger lifts reported through the GHGRP is estimated as 170,000 events, based on national average data, as shown in Table S5-2. If the averaging is done on a regional basis, as shown in Table S5-4, the national event count is estimated as 177,000 events. The regional estimate of event counts was used to produce a national methane emission estimate of 4.4 bcf/yr, as shown in Table B-15.

**Table B-12.** Activity data for wells without plunger lifts, based on surveys of participating companies using nationally averaged data

| Well Type Strata | Total Number of events | % of events provided by participants | Number of Venting Wells | % of wells provided by participants | National Event Count if Participant Event Counts are scaled up by number of wells |
|---|---|---|---|---|---|
| Non Plunger Wells (events<10) | 18,691 | 39 | 6,378 | 85 | 66,000 |
| Non Plunger Wells (10≤events<50) | 20,593 | 43 | 1,016 | 14 | 73,000 |
| Non Plunger Wells (50≤events<200) | 5,969 | 12 | 79 | 1 | 21,000 |
| Non Plunger Wells (events≥201) | 2,705 | 6 | 8 | 0.1 | 9,600 |
| ***Total*** | ***47,958*** | ***100*** | ***7,481*** | ***100*** | ***170,000*** |

**Table B-13.** Regional distributions of event counts, based on surveys of participating companies.

| Company Data Well type (Annual Frequency of events) | AP | | | GC | | | MC | | | RM | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | # of wells | #of events | Events/ Well | # of wells | #of events | Events/ Well | # of wells | #of events | Events/ Well | # of wells | #of events | Events/ Well | # of wells | #of events | Events/ Well |
| Non Plunger lift wells | | | | | | | | | | | | | | | |
| 0-10 | 744 | 2,327 | 3.13 | 1,520 | 4,455 | 2.93 | 2,315 | 6,831 | 2.95 | 1,799 | 5,078 | 2.82 | 6,378 | 18,691 | 2.93 |
| 11-50 | 179 | 3,826 | 21.4 | 180 | 3,491 | 19.4 | 461 | 9,757 | 21.1 | 196 | 3,519 | 18.0 | 1,016 | 20,593 | 20.3 |
| 51-200 | 19 | 1,270 | 66.8 | 11 | 915 | 83.2 | 41 | 3,177 | 77.5 | 8 | 607 | 75.9 | 79 | 5,969 | 75.6 |
| 201+ | 0 | 0 | - | 1 | 355 | 355 | 7 | 2,350 | 336 | 0 | 0 | - | 8 | 2,705 | 338 |
| Plunger lift wells | | | | | | | | | | | | | | | |
| 0-99 | 42 | 302 | 7.19 | 423 | 2,237 | 5.29 | 857 | 4,419 | 5.16 | 3,845 | 60,282 | 15.7 | 5,167 | 67,240 | 13.01 |
| 100+ | 1 | 259 | 259 | 3 | 366 | 122 | 191 | 324,341 | 1,698 | 3,410 | 3,508,080 | 1,029 | 3,605 | 3,833,046 | 1,063 |

**Table B-14**. Regional distributions of non-plunger well event counts, based on surveys of participating companies.

| Company Data Well type (Annual Frequency of events) | AP | | | | GC | | | | MC | | | | RM | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | # of wells | % of wells | Events/ Well | Region Event count | # of wells | % of wells | Events/ Well | Region Event count | # of wells | % of wells | Events/ Well | Region Event count | # of wells | % of wells | Events/ Well | Region Event count | National event count |
| 0-10 | 7812 | 79% | 3.13 | 19,300 | 3855 | 88.8% | 2.93 | 10,000 | 8219 | 82.0% | 2.95 | 19,900 | 6552 | 89.8% | 2.82 | 16,600 | 65,800 |
| 11-50 | | 19% | 21.4 | 31,700 | | 10.5% | 19.4 | 7,900 | | 16.3% | 21.1 | 28,400 | | 9.8% | 18.0 | 11,500 | 79,500 |
| 51-200 | | 2% | 66.8 | 10,500 | | 0.6% | 83.2 | 2,100 | | 1.5% | 77.5 | 9,200 | | 0.4% | 75.9 | 1,990 | 23,800 |
| 201+ | | 0% | - | 0 | | 0.06% | 355 | 800 | | 0.2% | 336 | 6,800 | | - | - | - | 7,600 |
| **Total** | | 100% | | 62,000 | | 100% | | 21,000 | | 100% | | 64,000 | | 100% | | 30,000 | 177,000 |

**Table B-15.** National emission estimate for plunger lift wells

| **Well type (Annual Frequency of events)** | **Event count (events/yr)** | **Measured EF, scf methane per event (95% confidence range)** | **Emissions (billion scf methane/yr)** |
|---|---|---|---|
| Non Plunger Wells (events<10) | 65,800 | 21,500 (9,600-37,800) | 1.4 (0.6-5.2) |
| Non Plunger Wells (10≤events<50) | 79,500 | 24,100(8,700-50,400) | 1.9 (0.7-4.0) |
| Non Plunger Wells (50≤events<200) | 23,800 | 35,000 (18,700-53,000) | 0.8 (0.4-1.3) |
| Non Plunger Wells (events≥200) | 7,600 | Not measured, assume 35,000 (see main text) (18,700-53,000) | 0.3 (0.1-0.4) |
| **Total** | | | 4.4 (2.8-8.5*) |

*Range assumes that emission factors for each frequency range are independent.

**Table B-16**. Regional distributions of plunger lift well counts, and high and low frequency wells used in making national emission estimates

| Well type (Annual Frequency of events) | AP | | GC | | MC | | RM Basin 580 | | RM excluding Basin 580 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | well count | $f_{\text{high or low freq. events}}$ | well count | $f_{\text{high or low freq. events}}$ | well count | $f_{\text{high or low freq. events}}$ | well count | $f_{\text{high or low freq. events}}$ | well count | $f_{\text{high or low freq. events}}$ |
| 0-99 | 10,869 | 0.98 | 1,048 | 0.993 | 5,096 | 0.82 | 5,041 | 0.32 | 10,171 | 0.91 |
| 100+ | | 0.02 | | 0.007 | | 0.18 | | 0.68 | | 0.09 |

National event counts for plunger wells were estimated with a slightly modified procedure. The modifications are necessary because the distribution of high event frequency wells (≥100 events/yr) is not uniform within the Rocky Mountain region. As shown in Table B-16 and Table B-17, Basin 580 in the Rocky Mountain region has a much higher fraction of high frequency plunger lift unloadings than the rest of the region. Therefore, the total number of events associated with high and low frequency wells in the Rocky Mountain region was estimated using two sub-regions.

As an example, the total number of plunger lift wells in Basin 580 of the Rocky Mountain region (from the GHGRP) was 5,041 (Table B-16). Data from the company participant survey (Table B-16) indicated that 68% of the plunger lift wells in Basin 580 had 100 or more events per year, leading to an estimate of 3,404 high frequency plunger lift wells in Basin 580 (Table B-17). Similar calculations were done to estimate the number of low and high frequency wells in each region and sub-region. The event estimates are shown in Table B-17, and suggest a total of 206,500 events/yr for low frequency wells and 6.56 million events/yr for high frequency wells. National emission estimates, based on 5 region averaging (AP, GC, MC, two RM sub-regions), are shown in Table B-18.

**Table B-17.** Activity data for wells with plunger lifts, based on surveys of participating companies

| Well Type | National Total Number of wells | $N_{\text{low or high freq. events, i}}$ (Average number of events per well) | Scaled total Number of events |
|---|---|---|---|
| **AP Plunger Wells (events<100)** | 10,616 | 7.19 | 76,300 |
| **GC Plunger Wells (events<100)** | 1,041 | 5.29 | 5,500 |
| **MC Plunger Wells (events<100)** | 4,167 | 5.16 | 21,500 |
| **RM Plunger Wells (events<100)** | 10,930 | | 103,200 |
| **(Basin 580 only)** | (1,637) | (31.2) | (51,100) |
| **[RM without basin 580]** | [9,293] | [5.61] | [52,100] |
| **Total Plunger Wells (events<100) (5 regions)** | 26,754 | | 206,500 |
| **AP Plunger Wells (events 100+)** | 253 | 259 | 65,500 |
| **GC Plunger Wells (events 100+)** | 7 | 122 | 900 |
| **MC Plunger Wells (events 100+)** | 929 | 1,698 | 1,577,400 |
| **RM Plunger Wells (events 100+)** | 4,282 | | 4,919,400 |
| **(Basin 580 only)** | (3,404) | (976) | (3,322,300) |
| **[RM without basin 580]** | [878] | [1,819] | [1,597,100] |
| **Total Plunger Wells (events 100+) (5 regions)** | 5,471 | | 6,563,200 |
| **National Total (5 regions)** | 32,225 | | 6,769,700 |

**Table B-18.** National emission estimate for plunger lift wells

| Well type (Annual Frequency of events) | Event count, events/yr | Measured EF, scf methane per event (95% confidence range) | Emissions, billion scf methane/yr (95% confidence range) |
|---|---|---|---|
| Plunger Wells (events<100) | 26,500 | 9,450 (6,900-12,400) | 2.0 (1.4-2.6) |
| Plunger Wells (events≥100) | 6,563,000 | 1,200 (500-2,100) | 7.9 (3.3-13.8) |
| **Total** | | | 9.9 (5.2-15.8*) |

*Range assumes that emission factors for each frequency range are independent.

Taken together, methane emissions from both plunger lift wells (Table S5-8) and non-plunger lift wells (Table S5-5) are 14.3 billion scf/yr (270 Gg). The 95% confidence range, assuming that the estimates for plunger lift wells and non-plunger lift wells are independent, is 10-21 billion scf/yr (190-400 Gg/yr).

A sensitivity analysis on national emission estimates was performed using alternative distributions of plunger and non-plunger wells in the national well count. The national emission estimates reported in Tables B-15 and B-18 are based on total counts of plunger and non-plunger lift wells from the 2012 GHGRP. If the data from the 2012 GHG NEI are used instead, the total emission estimates would scale based on the number of wells in each category. So, if the total plunger well count is reduced from 32,225 to 23,503, total estimated emissions from plunger lift wells would decrease to 7.2 bcf (9.9 bcf * 23,503/32,225). This decrease in plunger lift well emissions would be partially offset by increases in emissions from non-plunger wells. The count of plunger lift wells would increase from 26,438 to 37,307 and total estimated emissions from the non-plunger wells would increase to 6.2 bcf (4.4 bcf * 37,307/26,438). Overall, emissions from both plunger lift and non-plunger lift wells would decrease slightly from 14 bcf/yr to 13 bcf/yr.

### *B.6 Comparison between measurements reported in this work and measurements reported by Allen et al. [1]*

Allen *et al*. [1] reported measurements for 9 unloading events. All were manual unloadings of relatively recent horizontal wells, without plunger lifts, in newly developed shale formations. A comparison of the data reported by Allen *et al*. and the measurements reported in this work is provided in Table B-19.

**Table B-19.** Comparison of measurements from Allen, *et al*. [1] and similar measurements made in this work.

| | **Allen, *et al*. [1]** | **Measurements made in this work for horizontal wells without plunger lifts (see horizontal wells in Table B-8)** |
|---|---|---|
| Average emissions per event (scf/event) | 57,000 | 52,000 |
| Range of emissions per event (scf/event) | 950-191,000 | 1,400-135,000 |
| Average frequency of unloadings (events/yr) | 5.9 | 40. |
| Range of frequencies (events/yr) | 1-12 | 1-101 |
| Duration of event (hr) | 1.0 | 2.2 |
| Range of durations (hr) | 0.25-2.77 | 0.35-4.5 |

The measurements from Allen, *et al*. [1] were not combined with the measurements in this work for two reasons:

1. Some of the wells on which Allen, *et al*. [1] made measurements were shut-in for a period of a week or more while the study team made arrangements to get to the

site. This shut-in period was not part of routine unloading practices and may introduce a bias into the measurements.

2. If the measurements of Allen, *et al*. [1] were added to the results from Table B-8, more than half of the wells with manual unloadings would be horizontal wells. This may not accurately represent national populations.

### *B.7 References*

(1) Allen DT, Torres VM, Thomas J, Sullivan D, Harrison M, Hendler, A., Herndon, SC, Kolb, CE, Fraser, MP, Hill, AD, *et al*.(2013) Measurements of Methane Emissions at Natural Gas Production Sites in the United States, *Proc. Natl. Acad. Sci. U.S.A.*, 110: 17768-17773.

## C Analysis of Methane Emissions Attributable to Natural Gas Production

### *C.1 Data used to allocate emissions on an energy and price basis*

**Table C-1.** Energy and Price Data

| | Energy (HHV)* | Energy (LHV) | Price[4] |
|---|---|---|---|
| **$CH_4$** | 1,010 BTU/scf | 913 BTU/scf** | 4 $/Thousand scf |
| **$C_2H_6$** | 1,769 BTU/scf | 1,641 BTU/scf** | 11 $/Million BTU |
| **$C_3H_8$** | 2,518 BTU/scf | 2,385 BTU/scf** | 11 $/Million BTU |
| **$C_4H_{10}$** | 3,262 BTU/scf | 3,109 BTU/scf** | 11 $/Million BTU |
| **$C_5$+** | 4,010 BTU/scf | 3,882 BTU/scf** | 11 $/Million BTU |
| **Hydrocarbon Liquids** | 5.8 Million BTU/bbl | 5.4 Million BTU/bbl*** | 100 $/bbl |
| **Natural Gas** | 1,027 BTU/scf | 983 BTU/scf*** | 4 $/Thousand scf |

*Table 3-7 and Table 3-8. Higher Heating Value (HHV) is used in this work [1].
** Adapted from Fuel Flue Gases, American Gas Association [2].
*** Adapted from GREET, Argonne [3].

### *C.2 Estimating rate of decrease in production over time and ultimate recovery (production)*

The estimated ultimate recovery (EUR) for each of the sites is based on a decline curve analysis (DCA)[5] and historical data for shale plays. To determine production of the well ($q_t$) at time t, based on DCA:

$$q_t = \frac{q_i}{\left(1 + D_i \times b \times t\right)^{\frac{1}{b}}} \qquad \text{(C2.1)}$$

*where:*

$t$ = age of well

$q_t$ = Production of well at time $t$.

$q_i$ = Initial production rate

$D_i$ = initial decline rate

$b$ = decline exponent

O'Sullivan and Paltsev [6] presented data on the rate of decrease of production from horizontal wells from various plays. Data were fitted to equation (C2.1) to determine the value of the two parameters; $D_i$ = 0.1264, and b = 1.2187 (standard error =0.0205, r = 0.9984).

For each production site where measurements were made by Allen, *et al* [8], the age of the wells ($t$) is provided, as well as the gas and oil production at the time of the measurements ($q_t$).

To find the initial production ($q_i$), from equation (C2.1):

$$q_i = q_t \left(1 + 0.1264 \times 1.2187 \times t\right)^{\frac{1}{1.2187}} \tag{C2.2}$$

To find the EUR, from equation (C2.1) and (C2.2):

$$EUR = \int_0^{t_f} q_t \, dt \tag{C2.3}$$

$$EUR = \int_0^{t_f} \frac{q_i}{\left(1 + 0.1264 \times 1.2187 \times t\right)^{\frac{1}{1.2187}}} \, dt \tag{C2.4}$$

Where $t_f$ is the well lifetime,

$$EUR = 36.1746 q_i \left[\left(0.1540 t_f + 1\right)^{0.1794} - 1\right] \tag{C2.5}$$

A well lifetime ($t_f$) of 30 years is assumed for all production sites. A sensitivity test was done, assuming a well lifetime of 15 years. Table C-2 shows gas and oil production at each well at the time of the measurement and the estimated ultimate production.

**Table C-2.** Gas and oil production at the time of the measurement ($q_t$), estimated initial production rate ($q_i$), and estimated ultimate recovery (*EUR*) at each site, assuming well lifetimes of 30 and 15 years. *The two letter code for each site indicates the region in which sampling was done (AP=Appalachia; GC=Gulf Coast; MC=Midcontinent; RM=Rocky Mountains)*

| Site | Age of well (years) | Gas $q_t$ (MMscf/day) | Oil $q_t$ (bbl/day) | Gas $q_i$ (MMscf/yr) | Oil $q_i$ (bbl/yr) | Gas EUR (MMscf) 30-yr | Oil EUR (bbl) 30-yr | Gas EUR (MMscf) 15-yr | Oil EUR (bbl) 15-yr |
|---|---|---|---|---|---|---|---|---|---|
| **AP-1** | 1.0 | 1.10 | 0 | 948 | 0 | 3,035 | 0 | 2,362 | 0 |
| **AP-2** | 0.5 | 5.42 | 0 | 3,385 | 0 | 10,839 | 0 | 8,436 | 0 |
| **AP-3** | 0.8 | 12.0 | 0 | 9,225 | 0 | 29,541 | 0 | 22,992 | 0 |
| **AP-4** | 2.5 | 8.95 | 0 | 13,471 | 0 | 43,137 | 0 | 33,574 | 0 |
| **AP-5** | 0.1 | 5.20 | 0 | 2,181 | 0 | 6,985 | 0 | 5,437 | 0 |
| **AP-6** | 2.7 | 5.21 | 0 | 8,263 | 0 | 26,459 | 0 | 20,593 | 0 |
| **AP-7** | 2.7 | 5.73 | 0 | 9,087 | 0 | 29,099 | 0 | 22,648 | 0 |
| **AP-8** | 0.8 | 1.44 | 3.36 | 1,107 | 2,583 | 3,545 | 8,271 | 2,759 | 6,461 |
| **AP-9** | 3.0 | 4.29 | 0 | 7,316 | 0 | 23,428 | 0 | 18,234 | 0 |
| **AP-10** | 3.0 | 5.80 | 0 | 9,891 | 0 | 31,674 | 0 | 24,652 | 0 |
| **AP-11** | 1.1 | 2.00 | 0 | 1,815 | 0 | 5,811 | 0 | 4,522 | 0 |
| **AP-12** | 2.0 | 1.96 | 0 | 2,546 | 0 | 8,152 | 0 | 6,345 | 0 |
| **AP-13** | 2.7 | 6.05 | 0 | 9,595 | 0 | 30,724 | 0 | 23,913 | 0 |
| **AP-14** | 2.0 | 4.75 | 0 | 6,170 | 0 | 19,756 | 0 | 15,376 | 0 |
| **AP-15** | 3.5 | 1.56 | 0 | 2,965 | 0 | 9,495 | 0 | 7,390 | 0 |
| **AP-16** | 2.2 | 1.48 | 0 | 2,046 | 0 | 6,551 | 0 | 5,098 | 0 |
| **AP-17** | 0.5 | 4.53 | 0 | 2,829 | 0 | 9,059 | 0 | 7,051 | 0 |
| **AP-18** | 0.4 | 27.4 | 0 | 15,751 | 0 | 50,438 | 0 | 39,256 | 0 |
| **AP-19** | 8.8 | 1.73 | 0 | 6,540 | 0 | 20,941 | 0 | 16,299 | 0 |
| **AP-20** | 2.0 | 3.79 | 0 | 4,923 | 0 | 15,764 | 0 | 12,269 | 0 |
| **AP-21** | 0.2 | 5.00 | 0 | 2,363 | 0 | 7,565 | 0 | 5,888 | 0 |
| **AP-22** | 1.5 | 22.5 | 0 | 24,383 | 0 | 78,078 | 0 | 60,768 | 0 |
| **AP-23** | 9.4 | 2.13 | 0 | 8,474 | 0 | 27,135 | 0 | 21,119 | 0 |
| **AP-24** | 2.7 | 31.8 | 0 | 50,432 | 0 | 161,494 | 0 | 125,690 | 0 |
| **AP-25** | 1.0 | 4.06 | 0 | 3,498 | 0 | 11,202 | 0 | 8,719 | 0 |
| **AP-26** | 0.7 | 12.0 | 0 | 8,657 | 0 | 27,721 | 0 | 21,575 | 0 |
| **AP-27** | 1.0 | 5.25 | 0 | 4,524 | 0 | 14,486 | 0 | 11,274 | 0 |
| **AP-28** | 0.6 | 2.50 | 0 | 1,683 | 0 | 5,390 | 0 | 4,195 | 0 |
| **AP-29** | 2.8 | 7.60 | 0 | 12,357 | 0 | 39,571 | 0 | 30,798 | 0 |
| **AP-31** | 0.7 | 12.0 | 0 | 8,657 | 0 | 27,721 | 0 | 21,575 | 0 |
| **AP-32** | 0.6 | 14.4 | 0 | 9,696 | 0 | 31,049 | 0 | 24,165 | 0 |
| **AP-33** | 1.0 | 26.3 | 0 | 22,636 | 0 | 72,484 | 0 | 56,414 | 0 |

**Table C-2** (continued).

| Site | Age of well (years) | Gas $q_t$ (MMscf/day) | Oil $q_t$ (bbl/day) | Gas $q_i$ (MMscf/yr) | Oil $q_i$ (bbl/yr) | Gas EUR (MMscf) 30-yr | Oil EUR (bbl) 30-yr | Gas EUR (MMscf) 15-yr | Oil EUR (bbl) 15-yr |
|---|---|---|---|---|---|---|---|---|---|
| **AP-34** | 1.5 | 14.4 | 0 | 15,593 | 0 | 49,933 | 0 | 38,862 | 0 |
| **AP-35** | 1.0 | 2.63 | 0 | 2,266 | 0 | 7,257 | 0 | 5,648 | 0 |
| **AP-36** | 0.5 | 1.60 | 0 | 999 | 0 | 3,200 | 0 | 2,490 | 0 |
| **AP-37** | 0.8 | 7.20 | 0 | 5,535 | 0 | 17,725 | 0 | 13,795 | 0 |
| **AP-38** | 0.5 | 1.39 | 0 | 868 | 0 | 2,780 | 0 | 2,164 | 0 |
| **AP-39** | 1.8 | 19.4 | 0 | 23,571 | 0 | 75,479 | 0 | 58,745 | 0 |
| **AP-40** | 0.6 | 5.15 | 0 | 3,468 | 0 | 11,104 | 0 | 8,642 | 0 |
| **AP-41** | 0.5 | 11.2 | 0 | 6,995 | 0 | 22,398 | 0 | 17,433 | 0 |
| **AP-42** | 2.7 | 11.3 | 0 | 17,889 | 0 | 57,285 | 0 | 44,585 | 0 |
| **AP-43** | 0.3 | 10.7 | 0 | 5,625 | 0 | 18,012 | 0 | 14,019 | 0 |
| **AP-45** | 2.7 | 2.11 | 0 | 3,346 | 0 | 10,715 | 0 | 8,340 | 0 |
| **AP-46** | 1.0 | 8.00 | 0 | 6,893 | 0 | 22,074 | 0 | 17,180 | 0 |
| **AP-47** | 1.3 | 10.3 | 0 | 10,220 | 0 | 32,726 | 0 | 25,471 | 0 |
| **GC-1** | 1.0 | 0.23 | 273 | 198 | 234,905 | 635 | 752,215 | 494 | 587,544 |
| **GC-2** | 1.5 | 3.76 | 1,175 | 4,080 | 1,275,309 | 13,065 | 4,083,808 | 10,169 | 3,189,806 |
| **GC-3** | 0.3 | 0.89 | 0 | 467 | 0 | 1,494 | 0 | 1,163 | 0 |
| **GC-4** | 1.5 | 9.30 | 1,045 | 10,092 | 1,134,428 | 32,315 | 3,632,677 | 25,151 | 2,837,434 |
| **GC-5** | 1.0 | 3.27 | 1,163 | 2,818 | 1,002,322 | 9,023 | 3,209,646 | 7,022 | 2,507,010 |
| **GC-6** | 1.5 | 4.75 | 454 | 5,154 | 493,122 | 16,505 | 1,579,080 | 12,846 | 1,233,398 |
| **GC-7** | 1.6 | 1.45 | 0 | 1,636 | 0 | 5,240 | 0 | 4,078 | 0 |
| **GC-8** | 3.2 | 0.79 | 0 | 1,409 | 0 | 4,513 | 0 | 3,513 | 0 |
| **GC-9** | 1.5 | 13.4 | 950 | 14,551 | 1,030,561 | 46,597 | 3,300,071 | 36,266 | 2,577,640 |
| **GC-10** | 0.4 | 44.0 | 0 | 25,311 | 0 | 81,050 | 0 | 63,081 | 0 |
| **GC-11** | 2.5 | 5.75 | 0 | 8,655 | 0 | 27,714 | 0 | 21,570 | 0 |
| **GC-12** | 2.7 | 11.8 | 0 | 18,714 | 0 | 59,925 | 0 | 46,640 | 0 |
| **GC-13** | 2.1 | 1.78 | 0 | 2,386 | 0 | 7,642 | 0 | 5,948 | 0 |
| **GC-14** | 1.5 | 4.71 | 919 | 5,111 | 997,410 | 16,366 | 3,193,916 | 12,738 | 2,494,724 |
| **GC-15** | 1.4 | 19.3 | 0 | 20,045 | 0 | 64,188 | 0 | 49,958 | 0 |
| **GC-16** | 0.6 | 4.22 | 2,946 | 2,841 | 1,983,425 | 9,099 | 6,351,344 | 7,082 | 4,960,946 |
| **GC-17** | 0.3 | 33.2 | 0 | 17,378 | 0 | 55,648 | 0 | 43,311 | 0 |
| **GC-18** | 0.3 | 32.8 | 0 | 17,210 | 0 | 55,111 | 0 | 42,893 | 0 |
| **GC-19** | 1.4 | 15.3 | 0 | 15,911 | 0 | 50,950 | 0 | 39,655 | 0 |
| **GC-20** | 2.7 | 0.69 | 0 | 1,094 | 0 | 3,504 | 0 | 2,727 | 0 |
| **GC-21** | 1.8 | 1.20 | 0 | 1,457 | 0 | 4,666 | 0 | 3,632 | 0 |
| **GC-22** | 4.4 | 0.50 | 0 | 1,121 | 0 | 3,589 | 0 | 2,793 | 0 |
| **GC-23** | 0.4 | 12.8 | 0 | 7,335 | 0 | 23,489 | 0 | 18,281 | 0 |

**Table C-2** (continued).

| Site | Age of well (years) | Gas $q_t$ (MMscf/day) | Oil $q_t$ (bbl/day) | Gas $q_i$ (MMscf/yr) | Oil $q_i$ (bbl/yr) | Gas EUR (MMscf) 30-yr | Oil EUR (bbl) 30-yr | Gas EUR (MMscf) 15-yr | Oil EUR (bbl) 15-yr |
|---|---|---|---|---|---|---|---|---|---|
| **GC-24** | 1.5 | 3.00 | 538 | 3,255 | 583,968 | 10,424 | 1,869,989 | 8,113 | 1,460,623 |
| **GC-25** | 8.7 | 0.03 | 0 | 112 | 0 | 360 | 0 | 280 | 0 |
| **GC-26** | 1.5 | 13.9 | 508 | 15,072 | 551,209 | 48,265 | 1,765,086 | 37,564 | 1,378,684 |
| **GC-27** | 10 | 0.09 | 0 | 382 | 0 | 1,222 | 0 | 951 | 0 |
| **GC-28** | 1.6 | 11.8 | 0 | 13,283 | 0 | 42,535 | 0 | 33,105 | 0 |
| **GC-29** | 2.0 | 0.66 | 0 | 857 | 0 | 2,745 | 0 | 2,137 | 0 |
| **GC-30** | 1.1 | 5.99 | 0 | 5,435 | 0 | 17,403 | 0 | 13,545 | 0 |
| **GC-31** | 0.7 | 6.51 | 1,833 | 4,696 | 1,322,018 | 15,039 | 4,233,380 | 11,704 | 3,306,634 |
| **GC-32** | 5.9 | 2.37 | 0 | 6,604 | 0 | 21,146 | 0 | 16,458 | 0 |
| **GC-33** | 4.2 | 0.82 | 0 | 1,777 | 0 | 5,690 | 0 | 4,428 | 0 |
| **GC-34** | 0.4 | 37.3 | 0 | 21,413 | 0 | 68,570 | 0 | 53,368 | 0 |
| **GC-35** | 5.9 | 1.97 | 0 | 5,489 | 0 | 17,577 | 0 | 13,680 | 0 |
| **GC-36** | 0.2 | 0.83 | 0 | 392 | 0 | 1,256 | 0 | 977 | 0 |
| **GC-37** | 1.5 | 6.01 | 1,163 | 6,522 | 1,262,266 | 20,883 | 4,042,042 | 16,254 | 3,157,183 |
| **GC-38** | 1.6 | 1.79 | 0 | 2,020 | 0 | 6,469 | 0 | 5,035 | 0 |
| **GC-39** | 5.6 | 0.67 | 0 | 1,795 | 0 | 5,749 | 0 | 4,474 | 0 |
| **GC-40** | 2.6 | 0.18 | 0 | 278 | 0 | 891 | 0 | 693 | 0 |
| **GC-41** | 6.4 | 0.04 | 0 | 119 | 0 | 379 | 0 | 295 | 0 |
| **GC-42** | 0.3 | 1.43 | 0 | 750 | 0 | 2,401 | 0 | 1,868 | 0 |
| **GC-43** | 8.7 | 0.10 | 0 | 375 | 0 | 1,200 | 0 | 934 | 0 |
| **GC-44** | 8.5 | 0.03 | 0 | 110 | 0 | 354 | 0 | 275 | 0 |
| **GC-45** | 9.9 | 0.02 | 0 | 83 | 0 | 265 | 0 | 206 | 0 |
| **GC-46** | 8.4 | 0.36 | 1.16 | 1,313 | 4,230 | 4,204 | 13,546 | 3,272 | 10,581 |
| **GC-47** | 9.0 | 0.06 | 0 | 231 | 0 | 739 | 0 | 575 | 0 |
| **GC-48** | 3.3 | 0.23 | 0 | 419 | 0 | 1,343 | 0 | 1,045 | 0 |
| **GC-49** | 9.9 | 0.05 | 0 | 207 | 0 | 663 | 0 | 516 | 0 |
| **GC-50** | 3.0 | 3.36 | 0 | 5,730 | 0 | 18,349 | 0 | 14,281 | 0 |
| **GC-51** | 9.5 | 0.07 | 0 | 281 | 0 | 899 | 0 | 700 | 0 |
| **GC-52** | 1.0 | 14.6 | 0 | 12,554 | 0 | 40,202 | 0 | 31,289 | 0 |
| **GC-53** | 0.5 | 1.73 | 0 | 1,080 | 0 | 3,460 | 0 | 2,693 | 0 |
| **GC-54** | 0.5 | 3.16 | 987 | 1,973 | 616,608 | 6,320 | 1,974,509 | 4,918 | 1,542,261 |
| **GC-55** | 0.9 | 47.7 | 0 | 38,891 | 0 | 124,538 | 0 | 96,927 | 0 |
| **GC-56** | 3.5 | 0.94 | 0 | 1,787 | 0 | 5,721 | 0 | 4,453 | 0 |
| **GC-57** | 1.2 | 15.5 | 0 | 14,762 | 0 | 47,272 | 0 | 36,792 | 0 |
| **GC-58** | 7.1 | 0.92 | 0 | 2,949 | 0 | 9,444 | 0 | 7,350 | 0 |
| **MC-1** | 0.9 | 0.88 | 47.1 | 718 | 38,426 | 2,298 | 123,049 | 1,789 | 96,112 |

**Table C-2** (continued).

| Site | Age of well (years) | Gas $q_t$ (MMscf/day) | Oil $q_t$ (bbl/day) | Gas $q_i$ (MMscf/yr) | Oil $q_i$ (bbl/yr) | Gas EUR (MMscf) 30-yr | Oil EUR (bbl) 30-yr | Gas EUR (MMscf) 15-yr | Oil EUR (bbl) 15-yr |
|---|---|---|---|---|---|---|---|---|---|
| **MC-4** | 2.0 | 3.15 | 0 | 4,091 | 0 | 13,102 | 0 | 10,197 | 0 |
| **MC-5** | 0.0 | 0.03 | 0 | 11 | 0 | 35 | 0 | 27 | 0 |
| **MC-6** | 1.1 | 1.47 | 30.1 | 1,334 | 27,273 | 4,271 | 87,333 | 3,324 | 68,215 |
| **MC-7** | 3.0 | 0.10 | 0 | 171 | 0 | 546 | 0 | 425 | 0 |
| **MC-8** | 5.0 | 0.61 | 0 | 1,502 | 0 | 4,810 | 0 | 3,744 | 0 |
| **MC-9** | 3.0 | 0.21 | 0 | 358 | 0 | 1,147 | 0 | 893 | 0 |
| **MC-10** | 2.0 | 2.08 | 0 | 2,702 | 0 | 8,651 | 0 | 6,733 | 0 |
| **MC-11** | 4.0 | 0.98 | 0 | 2,050 | 0 | 6,564 | 0 | 5,108 | 0 |
| **MC-12** | 0.3 | 0.61 | 79.6 | 320 | 41,702 | 1,024 | 133,538 | 797 | 104,305 |
| **MC-13** | 4.0 | 0.43 | 0 | 899 | 0 | 2,880 | 0 | 2,241 | 0 |
| **MC-14** | 0.7 | 0.28 | 0 | 202 | 0 | 647 | 0 | 503 | 0 |
| **MC-16** | 1.1 | 0.91 | 32.4 | 826 | 29,432 | 2,644 | 94,248 | 2,058 | 73,616 |
| **MC-17** | 2.0 | 4.06 | 0 | 5,273 | 0 | 16,887 | 0 | 13,143 | 0 |
| **MC-18** | 4.0 | 0.66 | 0 | 1,380 | 0 | 4,420 | 0 | 3,440 | 0 |
| **MC-19** | 4.0 | 1.39 | 0 | 2,907 | 0 | 9,310 | 0 | 7,246 | 0 |
| **MC-20** | 0.8 | 2.07 | 43.3 | 1,591 | 33,311 | 5,096 | 106,667 | 3,966 | 83,316 |
| **MC-21** | 0.6 | 0.71 | 155 | 478 | 104,583 | 1,531 | 334,897 | 1,191 | 261,584 |
| **MC-22** | 5.0 | 2.90 | 0 | 7,142 | 0 | 22,869 | 0 | 17,799 | 0 |
| **MC-23** | 2.0 | 6.88 | 0 | 8,936 | 0 | 28,616 | 0 | 22,272 | 0 |
| **MC-24** | 5.0 | 0.25 | 0 | 616 | 0 | 1,971 | 0 | 1,534 | 0 |
| **MC-25** | 2.0 | 1.70 | 0 | 2,208 | 0 | 7,071 | 0 | 5,503 | 0 |
| **MC-26** | 5.0 | 0.22 | 0 | 542 | 0 | 1,735 | 0 | 1,350 | 0 |
| **RM-2** | 5.9 | 0.14 | 7.54 | 390 | 21,009 | 1,249 | 67,275 | 972 | 52,548 |
| **RM-3** | 4.0 | 0.05 | 1.73 | 105 | 3,618 | 335 | 11,587 | 261 | 9,050 |
| **RM-4** | 1.0 | 0.42 | 70.0 | 362 | 60,333 | 1,159 | 193,200 | 902 | 150,906 |
| **RM-5** | 3.8 | 0.17 | 8.56 | 343 | 17,254 | 1,097 | 55,251 | 854 | 43,156 |
| **RM-6** | 2.5 | 0.10 | 2.43 | 151 | 3,658 | 482 | 11,712 | 375 | 9,148 |
| **RM-7** | 7.0 | 0.05 | 1.75 | 159 | 5,550 | 508 | 17,771 | 395 | 13,881 |
| **RM-8** | 0.0 | 0.50 | 96.7 | 183 | 35,299 | 584 | 113,035 | 455 | 88,290 |
| **RM-9** | 9.0 | 0.06 | 2.59 | 231 | 9,962 | 739 | 31,901 | 575 | 24,918 |
| **RM-10** | 3.3 | 0.18 | 11.4 | 328 | 20,820 | 1,051 | 66,669 | 818 | 52,074 |
| **RM-11** | 2.0 | 0.20 | 2.09 | 260 | 2,715 | 832 | 8,693 | 647 | 6,790 |
| **RM-12** | 1.0 | 0.07 | 8.76 | 60 | 7,548 | 193 | 24,171 | 150 | 18,879 |
| **RM-13** | 7.0 | 0.11 | 22.9 | 349 | 72,589 | 1,117 | 232,445 | 869 | 181,560 |
| **RM-14** | 5.0 | 0.23 | 7.53 | 566 | 18,544 | 1,814 | 59,380 | 1,412 | 46,381 |
| **RM-15** | 8.0 | 0.29 | 40.5 | 1,019 | 142,251 | 3,262 | 455,519 | 2,539 | 355,800 |

**Table C-2** (continued).

| Site | Age of well (years) | Gas $q_t$ (MMscf/day) | Oil $q_t$ (bbl/day) | Gas $q_i$ (MMscf/yr) | Oil $q_i$ (bbl/yr) | Gas EUR (MMscf) 30-yr | Oil EUR (bbl) 30-yr | Gas EUR (MMscf) 15-yr | Oil EUR (bbl) 15-yr |
|---|---|---|---|---|---|---|---|---|---|
| **RM-16** | 2.5 | 0.03 | 1.63 | 45 | 2,453 | 145 | 7,856 | 113 | 6,136 |
| **RM-17** | 1.0 | 2.58 | 81.0 | 2,223 | 69,768 | 7,119 | 223,413 | 5,541 | 174,505 |
| **RM-18** | 1.0 | 0.32 | 21.6 | 276 | 18,595 | 883 | 59,544 | 687 | 46,509 |
| **RM-19** | 5.0 | 0.23 | 7.53 | 566 | 18,544 | 1,814 | 59,380 | 1,412 | 46,381 |

*C.3 Total Routine Emissions measured by site*

**Table C-3.** Measured methane emissions, assuming a constant emission rate, and a 30-yr well lifetime. Last column represents the ratio of total emissions at each site, over the 30 year period, divided by the estimated gas ultimate recovery; assuming 30-yr well lifetime.

| | | Methane Emissions over a 30 year period (Mg) | | | | |
|---|---|---|---|---|---|---|
| **Site** | **Wells** | **Pneumatic Controllers** | **Pneumatic Pumps** | **Equipment Leaks** | **Total** | **Total Emissions (Mg) / Gas EUR (Mg) (30-yr)** |
| AP-1 | 1 | 38.15 | 0 | 0 | 38.15 | 0.0006 |
| AP-2 | 3 | 41.17 | 0 | 0 | 41.17 | 0.0002 |
| AP-3 | 4 | 259.4 | 0 | 3.027 | 262.4 | 0.0005 |
| AP-4 | 4 | 43.60 | 0 | 46.62 | 90.22 | 0.0001 |
| AP-5 | 6 | 5.449 | 0 | 26.04 | 31.49 | 0.0002 |
| AP-6 | 5 | 8.477 | 58.13 | 0 | 66.60 | 0.0001 |
| AP-7 | 3 | 106.0 | 58.13 | 0 | 164.1 | 0.0003 |
| AP-8 | 1 | 168.5 | 0 | 0 | 168.5 | 0.0019 |
| AP-9 | 4 | 148.0 | 0 | 522.8 | 670.9 | 0.0014 |
| AP-10 | 5 | 304.6 | 0 | 370.0 | 674.5 | 0.0011 |
| AP-11 | 1 | 11.35 | 0 | 0 | 11.35 | 9.9E-05 |
| AP-12 | 1 | 33.30 | 0 | 86.59 | 119.9 | 0.0007 |
| AP-13 | 3 | 240.4 | 58.13 | 0 | 298.5 | 0.0005 |
| AP-14 | 6 | 70.54 | 0 | 0 | 70.54 | 0.0002 |
| AP-15 | 2 | 0 | 0 | 0 | 0 | 0 |
| AP-16 | 1 | 65.39 | 0 | 0 | 65.39 | 0.0005 |
| AP-17 | 2 | 95.06 | 0 | 258.2 | 353.3 | 0.0020 |
| AP-18 | 6 | 5.752 | 0 | 81.74 | 87.49 | 8.8E-05 |
| AP-19 | 3 | 86.59 | 0 | 29.37 | 116.0 | 0.0003 |
| AP-20 | 1 | 0 | 0 | 0 | 0 | 0 |
| AP-21 | 1 | 106.0 | 0 | 47.23 | 153.2 | 0.0010 |
| AP-22 | 3 | 136.2 | 174.4 | 0 | 310.6 | 0.0002 |
| AP-23 | 6 | 125.9 | 58.13 | 136.5 | 320.6 | 0.0006 |
| AP-24 | 2 | 48.14 | 58.13 | 0 | 106.3 | 3.3E-05 |
| AP-25 | 5 | 104.4 | 0 | 1,653 | 1,758 | 0.0080 |
| AP-26 | 3 | 174.4 | 0 | 20.89 | 195.3 | 0.0004 |
| AP-27 | 7 | 335.4 | 0 | 512.5 | 848.0 | 0.0030 |
| AP-28 | 8 | 43.60 | 0 | 0 | 43.60 | 0.0004 |
| AP-29 | 3 | 73.26 | 0 | 90.52 | 163.8 | 0.0002 |
| AP-31 | 5 | 231.6 | 0 | 23.31 | 254.9 | 0.0005 |
| AP-32 | 5 | 51.47 | 0 | 47.23 | 98.70 | 0.0002 |
| AP-33 | 7 | 1,811 | 348.8 | 4.238 | 2,164 | 0.0015 |

**Table C-3** (continued).

| Site | Wells | Methane Emissions over a 30 year period (Mg) | | | | |
|---|---|---|---|---|---|---|
| | | Pneumatic Controllers | Pneumatic Pumps | Equipment Leaks | Total | Total Emissions (Mg) / Gas EUR (Mg) (30-yr) |
| AP-34 | 4 | 1,893 | 290.6 | 0.605 | 2,184 | 0.0022 |
| AP-35 | 3 | 380.4 | 0 | 0 | 380.4 | 0.0027 |
| AP-36 | 1 | 9.082 | 0 | 0 | 9.082 | 0.0001 |
| AP-37 | 5 | 9.082 | 0 | 172.3 | 181.3 | 0.0005 |
| AP-38 | 2 | 116.0 | 0 | 378.7 | 494.7 | 0.0092 |
| AP-39 | 3 | 163.5 | 174.4 | 68.42 | 406.3 | 0.0003 |
| AP-40 | 1 | 3.330 | 58.13 | 3.330 | 64.79 | 0.0003 |
| AP-41 | 8 | 0 | 0 | 29.97 | 29.97 | 6.8E-05 |
| AP-42 | 3 | 877.8 | 174.4 | 0 | 1,052 | 0.0009 |
| AP-43 | 6 | 41.48 | 0 | 852.2 | 893.7 | 0.0025 |
| AP-45 | 2 | 17.26 | 0 | 25.13 | 42.38 | 0.0002 |
| AP-46 | 3 | 272.5 | 0 | 0 | 272.5 | 0.0006 |
| AP-47 | 6 | 40.27 | 0 | 2.422 | 42.69 | 6.5E-05 |
| GC-1 | 3 | 334.2 | 0 | 48.74 | 383.0 | 0.0231 |
| GC-2 | 6 | 635.8 | 0 | 4.541 | 640.3 | 0.0018 |
| GC-3 | 1 | 337.3 | 0 | 0 | 337.3 | 0.0123 |
| GC-4 | 7 | 662.6 | 0 | 48.14 | 710.8 | 0.0008 |
| GC-5 | 6 | 1,695 | 0 | 372.4 | 2,068 | 0.0084 |
| GC-6 | 6 | 847.7 | 0 | 81.14 | 928.8 | 0.0023 |
| GC-7 | 1 | 64.48 | 83.86 | 0 | 148.3 | 0.0015 |
| GC-8 | 1 | 17.26 | 58.13 | 0 | 75.38 | 0.0009 |
| GC-9 | 6 | 75.08 | 0 | 0 | 75.08 | 6.5E-05 |
| GC-10 | 4 | 847.7 | 0 | 0 | 847.7 | 0.0006 |
| GC-11 | 2 | 135.9 | 0 | 22.10 | 158.0 | 0.0003 |
| GC-12 | 0 | 729.0 | 0 | 26.64 | 755.7 | 0.0007 |
| GC-13 | 1 | 248.6 | 0 | 3.633 | 252.2 | 0.0018 |
| GC-14 | 3 | 847.7 | 0 | 0 | 847.7 | 0.0017 |
| GC-15 | 6 | 694.6 | 0 | 258.5 | 953.2 | 0.0008 |
| GC-16 | 0 | 1,673 | 0 | 0 | 1,673 | 0.0075 |
| GC-17 | 3 | 1,082 | 0 | 0 | 1,082 | 0.0011 |
| GC-18 | 3 | 265.8 | 0 | 32.70 | 298.5 | 0.0003 |
| GC-19 | 6 | 1,115 | 0 | 17.26 | 1,132 | 0.0012 |
| GC-20 | 1 | 52.98 | 0 | 19.68 | 72.66 | 0.0011 |
| GC-21 | 1 | 13.32 | 0 | 0 | 13.32 | 0.0002 |
| GC-22 | 1 | 30.88 | 299.7 | 16.65 | 347.2 | 0.0051 |

**Table C-3** (continued).

| Site | Wells | Methane Emissions over a 30 year period (Mg) | | | | |
|---|---|---|---|---|---|---|
| | | Pneumatic Controllers | Pneumatic Pumps | Equipment Leaks | Total | Total Emissions (Mg) / Gas EUR (Mg) (30-yr) |
| GC-23 | 2 | 45.41 | 0 | 0 | 45.41 | 0.0001 |
| GC-24 | 5 | 635.8 | 0 | 27.25 | 663.0 | 0.0023 |
| GC-25 | 1 | 91.73 | 115.0 | 16.65 | 223.4 | 0.0299 |
| GC-26 | 5 | 779.9 | 62.67 | 69.93 | 912.5 | 0.0008 |
| GC-27 | 1 | 79.92 | 93.25 | 0 | 173.2 | 0.0069 |
| GC-28 | 5 | 185.7 | 0 | 27.55 | 213.2 | 0.0003 |
| GC-29 | 1 | 100.5 | 0 | 92.64 | 193.2 | 0.0038 |
| GC-30 | 3 | 94.46 | 286.7 | 98.09 | 479.2 | 0.0015 |
| GC-31 | 0 | 218.0 | 0 | 0 | 218.0 | 0.0006 |
| GC-32 | 1 | 106.0 | 188.3 | 0 | 294.3 | 0.0007 |
| GC-33 | 1 | 52.98 | 86.28 | 0 | 139.3 | 0.0013 |
| GC-34 | 3 | 845.6 | 0 | 0 | 845.6 | 0.0007 |
| GC-35 | 1 | 317.9 | 1,301 | 0 | 1,618 | 0.0048 |
| GC-36 | 1 | 607.9 | 0 | 0 | 607.9 | 0.0267 |
| GC-37 | 16 | 50.86 | 0 | 57.52 | 108.4 | 0.0002 |
| GC-38 | 1 | 61.15 | 58.13 | 0 | 119.3 | 0.0010 |
| GC-39 | 1 | 106.0 | 1,442 | 42.38 | 1,591 | 0.0145 |
| GC-40 | 1 | 156.5 | 0 | 24.22 | 180.7 | 0.0108 |
| GC-41 | 1 | 640.3 | 75.08 | 35.72 | 751.1 | 0.1032 |
| GC-42 | 1 | 534.6 | 0 | 0 | 534.6 | 0.0121 |
| GC-43 | 1 | 71.15 | 58.13 | 0 | 129.3 | 0.0056 |
| GC-44 | 1 | 4.238 | 0 | 0 | 4.238 | 0.0006 |
| GC-45 | 1 | 106.9 | 0 | 0 | 106.9 | 0.0182 |
| GC-46 | 1 | 138.1 | 0 | 0 | 138.1 | 0.0015 |
| GC-47 | 1 | 77.81 | 212.8 | 0 | 290.6 | 0.0186 |
| GC-48 | 1 | 57.22 | 0 | 90.52 | 147.7 | 0.0059 |
| GC-49 | 1 | 65.09 | 7.871 | 215.9 | 288.8 | 0.0206 |
| GC-50 | 2 | 34.51 | 58.13 | 51.47 | 144.1 | 0.0004 |
| GC-51 | 1 | 142.3 | 179.5 | 0 | 321.8 | 0.0170 |
| GC-52 | 3 | 358.1 | 182.3 | 0 | 540.4 | 0.0007 |
| GC-53 | 1 | 455.9 | 0 | 0 | 455.9 | 0.0071 |
| GC-54 | 0 | 50.05 | 0 | 10.90 | 60.95 | 0.0004 |
| GC-55 | 6 | 535.9 | 58.13 | 0 | 594.0 | 0.0003 |
| GC-56 | 1 | 2.422 | 116.3 | 13.93 | 132.6 | 0.0012 |
| GC-57 | 5 | 134.4 | 0 | 93.25 | 227.7 | 0.0003 |

**Table C-3** (continued).

| Site | Wells | Methane Emissions over a 30 year period (Mg) | | | | |
|---|---|---|---|---|---|---|
| | | Pneumatic Controllers | Pneumatic Pumps | Equipment Leaks | Total | Total Emissions (Mg) / Gas EUR (Mg) (30-yr) |
| GC-58 | 1 | 3.027 | 832.4 | 13.02 | 848.4 | 0.0047 |
| MC-1 | 2 | 476.8 | 0.605 | 69.93 | 547.4 | 0.0097 |
| MC-4 | 11 | 122.6 | 149.0 | 133.8 | 405.4 | 0.0015 |
| MC-5 | 2 | 183.2 | 0 | 99.60 | 282.8 | 0.3548 |
| MC-6 | 4 | 1,589 | 0 | 0 | 1,589 | 0.0165 |
| MC-7 | 1 | 51.47 | 11.20 | 0 | 62.67 | 0.0060 |
| MC-8 | 3 | 421.4 | 53.89 | 23.31 | 498.6 | 0.0053 |
| MC-9 | 5 | 299.7 | 58.13 | 101.4 | 459.3 | 0.0207 |
| MC-10 | 3 | 81.14 | 13.32 | 0 | 94.46 | 0.0006 |
| MC-11 | 5 | 502.6 | 74.17 | 294.3 | 871.0 | 0.0069 |
| MC-12 | 1 | 476.8 | 0 | 2.119 | 478.9 | 0.0188 |
| MC-13 | 4 | 1,103 | 58.13 | 0 | 1,161 | 0.0207 |
| MC-14 | 1 | 294.3 | 0 | 3.633 | 297.9 | 0.0197 |
| MC-16 | 2 | 426.3 | 0 | 101.7 | 528.0 | 0.0086 |
| MC-17 | 5 | 1,662 | 59.64 | 39.96 | 1,762 | 0.0054 |
| MC-18 | 1 | 158.9 | 22.40 | 0 | 181.3 | 0.0021 |
| MC-19 | 5 | 963.9 | 101.1 | 0 | 1,065 | 0.0059 |
| MC-20 | 3 | 330.7 | 0 | 88.40 | 419.2 | 0.0036 |
| MC-21 | 3 | 165.7 | 0 | 125.3 | 291.1 | 0.0081 |
| MC-22 | 5 | 4,010 | 73.67 | 56.92 | 4,140 | 0.0093 |
| MC-23 | 5 | 122.6 | 290.6 | 0 | 413.2 | 0.0008 |
| MC-24 | 1 | 106.0 | 58.13 | 0 | 164.1 | 0.0043 |
| MC-25 | 3 | 68.12 | 52.07 | 31.79 | 152.0 | 0.0011 |
| MC-26 | 1 | 106.0 | 4.238 | 0 | 110.2 | 0.0033 |
| RM-2 | 2 | 19.07 | 0 | 8.780 | 27.85 | 0.0008 |
| RM-3 | 7 | 32.70 | 0 | 1.816 | 34.51 | 0.0039 |
| RM-4 | 6 | 8.174 | 0 | 3.027 | 11.20 | 0.0004 |
| RM-5 | 8 | 1,430 | 0 | 92.34 | 1,523 | 0.0526 |
| RM-6 | 2 | 635.8 | 0 | 73.57 | 709.3 | 0.0560 |
| RM-7 | 8 | 635.8 | 0 | 7.266 | 643.0 | 0.0533 |
| RM-8 | 8 | 0 | 0 | 31.18 | 31.18 | 0.0021 |
| RM-9 | 1 | 3.633 | 0 | 4.844 | 8.477 | 0.0004 |
| RM-10 | 1 | 152.6 | 0 | 0.908 | 153.5 | 0.0055 |
| RM-11 | 5 | 0 | 0 | 1.514 | 1.514 | 7.1E-05 |
| RM-12 | 4 | 0 | 0 | 5.752 | 5.752 | 0.0011 |

**Table C-3** (continued).

| Site | Wells | Methane Emissions over a 30 year period (Mg) | | | | |
|---|---|---|---|---|---|---|
| | | Pneumatic Controllers | Pneumatic Pumps | Equipment Leaks | Total | Total Emissions (Mg) / Gas EUR (Mg) (30-yr) |
| RM-13 | 7 | 0 | 0 | 0.605 | 0.605 | 2.1E-05 |
| RM-14 | 1 | 635.8 | 0 | 21.19 | 657.0 | 0.0137 |
| RM-15 | 9 | 0 | 0 | 0 | 0 | 0 |
| RM-16 | 2 | 5.449 | 0 | 4.844 | 10.29 | 0.0027 |
| RM-17 | 4 | 259.8 | 0 | 69.03 | 328.8 | 0.0017 |
| RM-18 | 2 | 43.60 | 0 | 0 | 43.60 | 0.0019 |
| RM-19 | 1 | 12.72 | 0 | 70.24 | 82.95 | 0.0018 |

### *C.4 Mass based allocation of emissions*

To determine the fraction of non-methane hydrocarbon gases that are considered as part of *salable natural gas* (NG) and of *natural gas liquids* (NGL), a composition of 92.8% methane, 5.54% non-methane hydrocarbon (mass) is assumed for NG (the rest is $N_2$, $CO_2$, $H_2S$, and $H_2O$). This natural gas composition is based on frequently used life cycle datasets [7]. Consequently, if the gas produced at each site has a non-methane hydrocarbon content that would produce a *salable natural gas* of up to 5.54% non-methane hydrocarbon (mass) (Methane composition at that site would be 92.8% or higher (94.4% or higher for composition based on hydrocarbons only)), all non-methane hydrocarbon gases are considered as part of NG (for that site there would be no NGL production). On the other hand, if the gas produced at each site is wetter (methane composition at site would be less than 92.8%; 94.4% hydrocarbons only), non-methane hydrocarbon gases would represent more than 5.54% (5.6% hydrocarbon only), and they would be assigned to NG, starting with ethane and then adding subsequent heavier hydrocarbons, until the 5.54% threshold is reached, the remaining portion above 5.54% is considered as part of NGL.

Table C-4 shows the composition of salable natural gas and natural gas liquids (% mass) for each site. Table C-5 shows the fraction of production for each of the salable products (mass basis). Table C-6 shows the allocation of emissions from pneumatic controllers, pneumatic pumps, and equipment leaks over a 30 year period to each of the salable products, based. Table C-7 reports the ratio of allocated emissions to production for each of the three products: Natural Gas, Natural Gas Liquids, and Oil.

**Table C-4.** Composition of salable Natural Gas, and Natural Gas Liquids (% mass).

| Site | Natural Gas | | | | | | Natural Gas Liquids | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % $C_1$ | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas, EUR (Mg) | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas Liquids, EUR (Mg) |
| AP-1 | 96.4 | 3.48 | 0.11 | 0 | 0 | 59,005 | 0 | 0 | 0 | 0 | 0 |
| AP-2 | 95.5 | 4.19 | 0.27 | 0.04 | 0 | 211,289 | 0 | 0 | 0 | 0 | 0 |
| AP-3 | 96.0 | 3.82 | 0.16 | 0.04 | 0 | 576,497 | 0 | 0 | 0 | 0 | 0 |
| AP-4 | 97.2 | 2.76 | 0.08 | 0 | 0 | 836,980 | 0 | 0 | 0 | 0 | 0 |
| AP-5 | 95.8 | 4.03 | 0.19 | 0 | 0 | 136,625 | 0 | 0 | 0 | 0 | 0 |
| AP-6 | 95.7 | 4.04 | 0.24 | 0 | 0 | 516,860 | 0 | 0 | 0 | 0 | 0 |
| AP-7 | 95.7 | 4.03 | 0.22 | 0 | 0 | 565,897 | 0 | 0 | 0 | 0 | 0 |
| AP-8 | 94.4 | 5.60 | 0 | 0 | 0 | 55,351 | 49.3 | 28.60 | 13.78 | 8.34 | 32,392 |
| AP-9 | 97.1 | 2.78 | 0.11 | 0.04 | 0 | 455,027 | 0 | 0 | 0 | 0 | 0 |
| AP-10 | 97.0 | 2.89 | 0.11 | 0 | 0 | 614,983 | 0 | 0 | 0 | 0 | 0 |
| AP-11 | 96.3 | 3.53 | 0.16 | 0.04 | 0 | 113,272 | 0 | 0 | 0 | 0 | 0 |
| AP-12 | 94.4 | 5.23 | 0.03 | 0 | 0 | 160,036 | 0 | 91.4 | 8.65 | 0 | 656.0 |
| AP-13 | 96.0 | 3.82 | 0.16 | 0 | 0 | 599,499 | 0 | 0 | 0 | 0 | 0 |
| AP-14 | 94.9 | 4.68 | 0.32 | 0.07 | 0 | 387,376 | 0 | 0 | 0 | 0 | 0 |
| AP-15 | 97.4 | 2.47 | 0.08 | 0.04 | 0 | 184,176 | 0 | 0 | 0 | 0 | 0 |
| AP-16 | 94.7 | 4.87 | 0.35 | 0.04 | 0 | 128,401 | 0 | 0 | 0 | 0 | 0 |
| AP-17 | 96.6 | 3.22 | 0.14 | 0.04 | 0 | 176,088 | 0 | 0 | 0 | 0 | 0 |
| AP-18 | 95.1 | 4.61 | 0.27 | 0.04 | 0 | 988,031 | 0 | 0 | 0 | 0 | 0 |
| AP-19 | 95.3 | 4.34 | 0.27 | 0.07 | 0 | 410,082 | 0 | 0 | 0 | 0 | 0 |
| AP-20 | 97.2 | 2.68 | 0.11 | 0 | 0 | 305,353 | 0 | 0 | 0 | 0 | 0 |
| AP-21 | 95.6 | 4.14 | 0.22 | 0.04 | 0 | 147,975 | 0 | 0 | 0 | 0 | 0 |
| AP-22 | 96.0 | 3.82 | 0.16 | 0 | 0 | 1,523,474 | 0 | 0 | 0 | 0 | 0 |
| AP-23 | 96.1 | 3.75 | 0.16 | 0 | 0 | 529,064 | 0 | 0 | 0 | 0 | 0 |
| AP-24 | 95.7 | 4.03 | 0.22 | 0 | 0 | 3,140,582 | 0 | 0 | 0 | 0 | 0 |
| AP-25 | 96.9 | 3.00 | 0.14 | 0 | 0 | 217,440 | 0 | 0 | 0 | 0 | 0 |
| AP-26 | 96.0 | 3.82 | 0.16 | 0.04 | 0 | 540,977 | 0 | 0 | 0 | 0 | 0 |
| AP-27 | 96.8 | 3.02 | 0.14 | 0 | 0 | 281,558 | 0 | 0 | 0 | 0 | 0 |
| AP-28 | 96.0 | 3.82 | 0.16 | 0.04 | 0 | 105,196 | 0 | 0 | 0 | 0 | 0 |
| AP-29 | 95.7 | 4.09 | 0.14 | 0.04 | 0 | 773,016 | 0 | 0 | 0 | 0 | 0 |
| AP-31 | 96.0 | 3.82 | 0.16 | 0.04 | 0 | 540,977 | 0 | 0 | 0 | 0 | 0 |
| AP-32 | 96.0 | 3.82 | 0.16 | 0.04 | 0 | 605,927 | 0 | 0 | 0 | 0 | 0 |
| AP-33 | 95.6 | 4.16 | 0.24 | 0 | 0 | 1,417,505 | 0 | 0 | 0 | 0 | 0 |
| AP-34 | 95.7 | 4.09 | 0.22 | 0 | 0 | 975,788 | 0 | 0 | 0 | 0 | 0 |
| AP-35 | 95.6 | 4.04 | 0.24 | 0.04 | 0.10 | 141,472 | 0 | 0 | 0 | 0 | 0 |
| AP-36 | 96.0 | 3.82 | 0.16 | 0.04 | 0 | 62,444 | 0 | 0 | 0 | 0 | 0 |

**Table C-4** (continued).

| Site | Natural Gas | | | | | | Natural Gas Liquids | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % $C_1$ | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas, EUR (Mg) | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas Liquids, EUR (Mg) |
| AP-37 | 95.1 | 4.61 | 0.27 | 0.04 | 0 | 347,208 | 0 | 0 | 0 | 0 | 0 |
| AP-38 | 97.6 | 2.22 | 0.08 | 0.07 | 0 | 53,663 | 0 | 0 | 0 | 0 | 0 |
| AP-39 | 95.4 | 4.34 | 0.24 | 0.04 | 0 | 1,477,859 | 0 | 0 | 0 | 0 | 0 |
| AP-40 | 94.4 | 5.60 | 0 | 0 | 0 | 215,258 | 64.2 | 30.1 | 5.68 | 0 | 5,444 |
| AP-41 | 96.0 | 3.82 | 0.16 | 0.04 | 0 | 437,108 | 0 | 0 | 0 | 0 | 0 |
| AP-42 | 95.4 | 4.32 | 0.24 | 0.04 | 0 | 1,121,524 | 0 | 0 | 0 | 0 | 0 |
| AP-43 | 95.1 | 4.61 | 0.27 | 0.04 | 0 | 352,842 | 0 | 0 | 0 | 0 | 0 |
| AP-45 | 95.5 | 4.27 | 0.19 | 0 | 0 | 209,670 | 0 | 0 | 0 | 0 | 0 |
| AP-46 | 96.1 | 3.65 | 0.16 | 0.07 | 0 | 430,507 | 0 | 0 | 0 | 0 | 0 |
| AP-47 | 94.9 | 4.80 | 0.27 | 0 | 0 | 640,901 | 0 | 0 | 0 | 0 | 0 |
| GC-1 | 94.4 | 5.60 | 0 | 0 | 0 | 9,665 | 38.8 | 30.5 | 17.7 | 13.0 | 6,725 |
| GC-2 | 94.4 | 5.60 | 0 | 0 | 0 | 188,404 | 35.6 | 30.7 | 19.8 | 13.9 | 168,037 |
| GC-3 | 99.8 | 0.16 | 0 | 0 | 0 | 27,566 | 0 | 0 | 0 | 0 | 0 |
| GC-4 | 94.4 | 5.60 | 0 | 0 | 0 | 478,948 | 37.8 | 29.0 | 20.5 | 12.6 | 376,161 |
| GC-5 | 94.4 | 5.60 | 0 | 0 | 0 | 132,917 | 36.2 | 28.9 | 19.8 | 15.1 | 108,584 |
| GC-6 | 94.4 | 5.60 | 0 | 0 | 0 | 264,229 | 43.6 | 27.7 | 17.4 | 11.2 | 139,741 |
| GC-7 | 99.8 | 0.16 | 0 | 0 | 0 | 96,687 | 0 | 0 | 0 | 0 | 0 |
| GC-8 | 99.4 | 0.56 | 0.03 | 0 | 0 | 84,653 | 0 | 0 | 0 | 0 | 0 |
| GC-9 | 94.4 | 5.60 | 0 | 0 | 0 | 746,434 | 43.5 | 27.8 | 17.4 | 11.2 | 394,305 |
| GC-10 | 99.8 | 0.16 | 0 | 0 | 0 | 1,495,472 | 0 | 0 | 0 | 0 | 0 |
| GC-11 | 99.7 | 0.30 | 0 | 0 | 0 | 506,093 | 0 | 0 | 0 | 0 | 0 |
| GC-12 | 99.8 | 0.16 | 0 | 0 | 0 | 1,105,696 | 0 | 0 | 0 | 0 | 0 |
| GC-13 | 99.7 | 0.28 | 0 | 0 | 0 | 139,183 | 0 | 0 | 0 | 0 | 0 |
| GC-14 | 94.4 | 5.60 | 0 | 0 | 0 | 224,356 | 30.8 | 26.6 | 18.6 | 24.0 | 256,432 |
| GC-15 | 99.7 | 0.31 | 0 | 0 | 0 | 1,176,216 | 0 | 0 | 0 | 0 | 0 |
| GC-16 | 94.4 | 5.60 | 0 | 0 | 0 | 140,409 | 44.4 | 31.7 | 14.9 | 8.90 | 81,301 |
| GC-17 | 99.8 | 0.16 | 0 | 0 | 0 | 1,028,161 | 0 | 0 | 0 | 0 | 0 |
| GC-18 | 99.8 | 0.16 | 0 | 0 | 0 | 1,018,236 | 0 | 0 | 0 | 0 | 0 |
| GC-19 | 99.6 | 0.33 | 0.03 | 0 | 0 | 938,788 | 0 | 0 | 0 | 0 | 0 |
| GC-20 | 99.9 | 0.08 | 0 | 0 | 0 | 64,113 | 0 | 0 | 0 | 0 | 0 |
| GC-21 | 99.8 | 0.16 | 0 | 0 | 0 | 86,101 | 0 | 0 | 0 | 0 | 0 |
| GC-22 | 99.6 | 0.29 | 0.06 | 0 | 0 | 65,716 | 0 | 0 | 0 | 0 | 0 |
| GC-23 | 99.8 | 0.16 | 0 | 0 | 0 | 433,391 | 0 | 0 | 0 | 0 | 0 |
| GC-24 | 94.4 | 5.60 | 0 | 0 | 0 | 151,446 | 34.2 | 28.1 | 21.1 | 16.5 | 135,176 |
| GC-25 | 94.4 | 5.60 | 0 | 0 | 0 | 6,787 | 16.1 | 32.5 | 20.5 | 30.9 | 415.3 |

**Table C-4** (continued).

| Site | Natural Gas | | | | | | Natural Gas Liquids | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % $C_1$ | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas, EUR (Mg) | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas Liquids, EUR (Mg) |
| GC-26 | 94.4 | 5.60 | 0 | 0 | 0 | 787,092 | 40.9 | 26.3 | 18.5 | 14.3 | 387,311 |
| GC-27 | 94.4 | 5.60 | 0 | 0 | 0 | 23,124 | 0.6 | 37.1 | 23.6 | 38.7 | 1,044 |
| GC-28 | 99.7 | 0.31 | 0 | 0 | 0 | 782,134 | 0 | 0 | 0 | 0 | 0 |
| GC-29 | 99.7 | 0.24 | 0 | 0 | 0.06 | 50,244 | 0 | 0 | 0 | 0 | 0 |
| GC-30 | 99.8 | 0.16 | 0 | 0 | 0 | 321,101 | 0 | 0 | 0 | 0 | 0 |
| GC-31 | 94.4 | 5.60 | 0 | 0 | 0 | 248,763 | 42.4 | 28.6 | 16.9 | 12.2 | 109,222 |
| GC-32 | 99.7 | 0.26 | 0.06 | 0 | 0 | 386,840 | 0 | 0 | 0 | 0 | 0 |
| GC-33 | 99.5 | 0.38 | 0.09 | 0 | 0 | 103,660 | 0 | 0 | 0 | 0 | 0 |
| GC-34 | 99.8 | 0.16 | 0 | 0 | 0 | 1,265,190 | 0 | 0 | 0 | 0 | 0 |
| GC-35 | 99.8 | 0.22 | 0 | 0 | 0 | 323,297 | 0 | 0 | 0 | 0 | 0 |
| GC-36 | 99.9 | 0.10 | 0 | 0 | 0 | 22,905 | 0 | 0 | 0 | 0 | 0 |
| GC-37 | 94.4 | 5.60 | 0 | 0 | 0 | 299,193 | 33.1 | 27.1 | 19.2 | 20.6 | 282,666 |
| GC-38 | 99.8 | 0.16 | 0 | 0 | 0 | 119,358 | 0 | 0 | 0 | 0 | 0 |
| GC-39 | 97.8 | 1.32 | 0.31 | 0.19 | 0.36 | 106,442 | 0 | 0 | 0 | 0 | 0 |
| GC-40 | 99.7 | 0.24 | 0 | 0 | 0.06 | 16,306 | 0 | 0 | 0 | 0 | 0 |
| GC-41 | 97.8 | 1.32 | 0.31 | 0.19 | 0.36 | 7,027 | 0 | 0 | 0 | 0 | 0 |
| GC-42 | 99.8 | 0.16 | 0 | 0 | 0 | 44,292 | 0 | 0 | 0 | 0 | 0 |
| GC-43 | 97.8 | 1.32 | 0.31 | 0.19 | 0.36 | 22,216 | 0 | 0 | 0 | 0 | 0 |
| GC-44 | 94.4 | 5.60 | 0 | 0 | 0 | 6,629 | 1.50 | 22.2 | 19.6 | 56.7 | 714.6 |
| GC-45 | 94.4 | 5.60 | 0 | 0 | 0 | 4,850 | 29.9 | 24.5 | 16.1 | 29.5 | 788.4 |
| GC-46 | 94.4 | 5.60 | 0 | 0 | 0 | 76,074 | 36.2 | 23.3 | 13.2 | 27.2 | 13,254 |
| GC-47 | 94.4 | 5.60 | 0 | 0 | 0 | 13,820 | 15.6 | 29.3 | 21.0 | 34.0 | 1,197 |
| GC-48 | 99.7 | 0.28 | 0 | 0 | 0 | 24,479 | 0 | 0 | 0 | 0 | 0 |
| GC-49 | 94.4 | 5.60 | 0 | 0 | 0 | 12,400 | 15.6 | 29.3 | 21.0 | 34.0 | 1,074 |
| GC-50 | 98.2 | 1.41 | 0.20 | 0.15 | 0.10 | 347,560 | 0 | 0 | 0 | 0 | 0 |
| GC-51 | 94.4 | 5.60 | 0 | 0 | 0 | 16,828 | 12.3 | 26.9 | 21.1 | 39.7 | 1,394 |
| GC-52 | 99.7 | 0.24 | 0 | 0 | 0.06 | 735,815 | 0 | 0 | 0 | 0 | 0 |
| GC-53 | 99.8 | 0.16 | 0 | 0 | 0 | 63,836 | 0 | 0 | 0 | 0 | 0 |
| GC-54 | 94.4 | 5.60 | 0 | 0 | 0 | 106,335 | 45.1 | 28.1 | 15.6 | 11.2 | 39,993 |
| GC-55 | 99.9 | 0.10 | 0 | 0 | 0 | 2,273,091 | 0 | 0 | 0 | 0 | 0 |
| GC-56 | 99.1 | 0.85 | 0.06 | 0 | 0 | 107,109 | 0 | 0 | 0 | 0 | 0 |
| GC-57 | 99.6 | 0.33 | 0 | 0 | 0.06 | 868,706 | 0 | 0 | 0 | 0 | 0 |
| GC-58 | 97.8 | 1.32 | 0.31 | 0.19 | 0.36 | 174,867 | 0 | 0 | 0 | 0 | 0 |
| MC-1 | 94.4 | 5.60 | 0 | 0 | 0 | 33,134 | 29.0 | 37.6 | 19.5 | 13.8 | 22,571 |
| MC-4 | 94.4 | 5.60 | 0 | 0 | 0 | 249,100 | 58.8 | 31.6 | 8.11 | 1.44 | 7,872 |

**Table C-4** (continued).

| Site | Natural Gas | | | | | | Natural Gas Liquids | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % $C_1$ | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas, EUR (Mg) | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas Liquids, EUR (Mg) |
| MC-5 | 94.4 | 5.60 | 0 | 0 | 0 | 529 | 36.2 | 32.9 | 15.8 | 15.0 | 281.6 |
| MC-6 | 94.4 | 5.60 | 0 | 0 | 0 | 66,789 | 32.5 | 36.0 | 16.8 | 14.7 | 28,134 |
| MC-7 | 98.7 | 1.22 | 0.06 | 0 | 0 | 10,182 | 0 | 0 | 0 | 0 | 0 |
| MC-8 | 97.8 | 2.13 | 0.08 | 0 | 0 | 90,266 | 0 | 0 | 0 | 0 | 0 |
| MC-9 | 97.3 | 2.66 | 0.06 | 0 | 0 | 21,572 | 0 | 0 | 0 | 0 | 0 |
| MC-10 | 98.1 | 1.83 | 0.08 | 0 | 0 | 162,090 | 0 | 0 | 0 | 0 | 0 |
| MC-11 | 97.7 | 2.13 | 0.08 | 0 | 0.06 | 123,083 | 0 | 0 | 0 | 0 | 0 |
| MC-12 | 94.4 | 5.60 | 0 | 0 | 0 | 14,956 | 30.5 | 36.3 | 19.4 | 13.7 | 10,493 |
| MC-13 | 97.3 | 2.61 | 0.06 | 0 | 0 | 54,485 | 0 | 0 | 0 | 0 | 0 |
| MC-14 | 94.4 | 5.60 | 0 | 0 | 0 | 10,271 | 37.5 | 33.2 | 16.9 | 12.5 | 4,745 |
| MC-16 | 94.4 | 5.60 | 0 | 0 | 0 | 42,652 | 36.8 | 34.6 | 16.0 | 12.7 | 18,094 |
| MC-17 | 97.8 | 2.13 | 0.08 | 0 | 0 | 316,873 | 0 | 0 | 0 | 0 | 0 |
| MC-18 | 96.9 | 3.10 | 0 | 0 | 0 | 83,731 | 0 | 0 | 0 | 0 | 0 |
| MC-19 | 97.1 | 2.81 | 0.11 | 0 | 0 | 175,342 | 0 | 0 | 0 | 0 | 0 |
| MC-20 | 94.4 | 5.60 | 0 | 0 | 0 | 80,002 | 36.6 | 35.9 | 15.7 | 11.7 | 35,579 |
| MC-21 | 94.4 | 5.60 | 0 | 0 | 0 | 24,987 | 34.8 | 33.7 | 17.2 | 14.2 | 10,803 |
| MC-22 | 97.2 | 2.69 | 0.11 | 0 | 0 | 432,029 | 0 | 0 | 0 | 0 | 0 |
| MC-23 | 98.3 | 1.60 | 0.06 | 0 | 0.06 | 535,876 | 0 | 0 | 0 | 0 | 0 |
| MC-24 | 97.8 | 2.12 | 0.06 | 0 | 0 | 36,863 | 0 | 0 | 0 | 0 | 0 |
| MC-25 | 98.2 | 1.73 | 0.06 | 0 | 0 | 132,448 | 0 | 0 | 0 | 0 | 0 |
| MC-26 | 97.8 | 2.11 | 0.06 | 0 | 0 | 32,519 | 0 | 0 | 0 | 0 | 0 |
| RM-2 | 94.4 | 5.60 | 0 | 0 | 0 | 18,938 | 33.9 | 25.4 | 16.7 | 24.0 | 13,074 |
| RM-3 | 94.4 | 5.60 | 0 | 0 | 0 | 5,104 | 34.6 | 29.7 | 21.0 | 14.7 | 3,410 |
| RM-4 | 94.4 | 5.60 | 0 | 0 | 0 | 17,958 | 34.6 | 25.6 | 17.9 | 22.0 | 11,015 |
| RM-5 | 94.4 | 5.60 | 0 | 0 | 0 | 16,636 | 33.9 | 25.4 | 16.7 | 24.0 | 11,484 |
| RM-6 | 94.4 | 5.60 | 0 | 0 | 0 | 7,307 | 33.9 | 25.4 | 16.7 | 24.0 | 5,044 |
| RM-7 | 94.4 | 5.60 | 0 | 0 | 0 | 8,457 | 40.6 | 23.6 | 13.5 | 22.3 | 3,182 |
| RM-8 | 94.4 | 5.60 | 0 | 0 | 0 | 8,860 | 33.9 | 25.4 | 16.7 | 24.0 | 6,116 |
| RM-9 | 94.4 | 5.60 | 0 | 0 | 0 | 11,204 | 33.9 | 25.4 | 16.7 | 24.0 | 7,735 |
| RM-10 | 94.4 | 5.60 | 0 | 0 | 0 | 15,931 | 33.9 | 25.4 | 16.7 | 24.0 | 10,998 |
| RM-11 | 94.4 | 5.60 | 0 | 0 | 0 | 12,677 | 38.7 | 29.3 | 20.2 | 11.8 | 8,041 |
| RM-12 | 94.4 | 5.60 | 0 | 0 | 0 | 2,928 | 33.9 | 25.4 | 16.7 | 24.0 | 2,021 |
| RM-13 | 94.4 | 5.60 | 0 | 0 | 0 | 17,051 | 43.0 | 27.4 | 14.0 | 15.6 | 10,738 |
| RM-14 | 94.4 | 5.60 | 0 | 0 | 0 | 27,498 | 33.9 | 25.4 | 16.7 | 24.0 | 18,983 |
| RM-15 | 94.4 | 5.60 | 0 | 0 | 0 | 46,611 | 33.5 | 31.6 | 22.1 | 12.8 | 41,135 |

**Table C-4** (continued).

| Site | Natural Gas | | | | | | Natural Gas Liquids | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % $C_1$ | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas, EUR (Mg) | % $C_2$ | % $C_3$ | % $C_4$ | % $C_5$+ | Natural Gas Liquids, EUR (Mg) |
| RM-16 | 94.4 | 5.60 | 0 | 0 | 0 | 2,192 | 33.9 | 25.4 | 16.7 | 24.0 | 1,513 |
| RM-17 | 94.4 | 5.60 | 0 | 0 | 0 | 103,060 | 37.0 | 32.9 | 19.2 | 11.0 | 84,703 |
| RM-18 | 94.4 | 5.60 | 0 | 0 | 0 | 13,386 | 33.9 | 25.4 | 16.7 | 24.0 | 9,241 |
| RM-19 | 94.4 | 5.60 | 0 | 0 | 0 | 28,106 | 34.6 | 25.6 | 17.9 | 22.0 | 17,240 |
| Weighted Average | 97.3 | 2.61 | 0.120 | 0.007 | 0.003 | | 38.6 | 27.8 | 18.8 | 14.8 | |

**Table C-5.** fraction of production by salable product (mass basis)

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production (mass basis) | Natural Gas Liquids, fraction of total production (mass basis) | Oil, fraction of total production (mass basis) |
|---|---|---|---|---|---|
| AP-1 | 59,005 | 0 | 1 | 0 | 0 |
| AP-2 | 211,289 | 0 | 1 | 0 | 0 |
| AP-3 | 576,497 | 0 | 1 | 0 | 0 |
| AP-4 | 836,980 | 0 | 1 | 0 | 0 |
| AP-5 | 136,625 | 0 | 1 | 0 | 0 |
| AP-6 | 516,860 | 0 | 1 | 0 | 0 |
| AP-7 | 565,897 | 0 | 1 | 0 | 0 |
| AP-8 | 87,743 | 1,037 | 0.62 | 0.36 | 0.01 |
| AP-9 | 455,027 | 0 | 1 | 0 | 0 |
| AP-10 | 614,983 | 0 | 1 | 0 | 0 |
| AP-11 | 113,272 | 0 | 1 | 0 | 0 |
| AP-12 | 160,139 | 0 | 1 | 0 | 0 |
| AP-13 | 599,499 | 0 | 1 | 0 | 0 |
| AP-14 | 387,376 | 0 | 1 | 0 | 0 |
| AP-15 | 184,176 | 0 | 1 | 0 | 0 |
| AP-16 | 128,401 | 0 | 1 | 0 | 0 |
| AP-17 | 176,088 | 0 | 1 | 0 | 0 |
| AP-18 | 988,031 | 0 | 1 | 0 | 0 |
| AP-19 | 410,082 | 0 | 1 | 0 | 0 |
| AP-20 | 305,353 | 0 | 1 | 0 | 0 |
| AP-21 | 147,975 | 0 | 1 | 0 | 0 |
| AP-22 | 1,523,474 | 0 | 1 | 0 | 0 |
| AP-23 | 529,064 | 0 | 1 | 0 | 0 |
| AP-24 | 3,140,582 | 0 | 1 | 0 | 0 |
| AP-25 | 217,440 | 0 | 1 | 0 | 0 |
| AP-26 | 540,977 | 0 | 1 | 0 | 0 |
| AP-27 | 281,558 | 0 | 1 | 0 | 0 |
| AP-28 | 105,196 | 0 | 1 | 0 | 0 |
| AP-29 | 773,016 | 0 | 1 | 0 | 0 |
| AP-31 | 540,977 | 0 | 1 | 0 | 0 |
| AP-32 | 605,927 | 0 | 1 | 0 | 0 |
| AP-33 | 1,417,505 | 0 | 1 | 0 | 0 |
| AP-34 | 975,788 | 0 | 1 | 0 | 0 |
| AP-35 | 141,472 | 0 | 1 | 0 | 0 |
| AP-36 | 62,444 | 0 | 1 | 0 | 0 |
| AP-37 | 347,208 | 0 | 1 | 0 | 0 |

**Table C-5** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production (mass basis) | Natural Gas Liquids, fraction of total production (mass basis) | Oil, fraction of total production (mass basis) |
|---|---|---|---|---|---|
| AP-38 | 53,663 | 0 | 1 | 0 | 0 |
| AP-39 | 1,477,859 | 0 | 1 | 0 | 0 |
| AP-40 | 220,702 | 0 | 0.98 | 0.02 | 0 |
| AP-41 | 437,108 | 0 | 1 | 0 | 0 |
| AP-42 | 1,121,524 | 0 | 1 | 0 | 0 |
| AP-43 | 352,842 | 0 | 1 | 0 | 0 |
| AP-45 | 209,670 | 0 | 1 | 0 | 0 |
| AP-46 | 430,507 | 0 | 1 | 0 | 0 |
| AP-47 | 640,901 | 0 | 1 | 0 | 0 |
| GC-1 | 16,390 | 94,298 | 0.09 | 0.06 | 0.85 |
| GC-2 | 356,441 | 511,946 | 0.22 | 0.19 | 0.59 |
| GC-3 | 27,566 | 0 | 1 | 0 | 0 |
| GC-4 | 855,109 | 455,392 | 0.37 | 0.29 | 0.35 |
| GC-5 | 241,501 | 402,361 | 0.21 | 0.17 | 0.62 |
| GC-6 | 403,970 | 197,954 | 0.44 | 0.23 | 0.33 |
| GC-7 | 96,687 | 0 | 1 | 0 | 0 |
| GC-8 | 84,653 | 0 | 1 | 0 | 0 |
| GC-9 | 1,140,739 | 413,697 | 0.48 | 0.25 | 0.27 |
| GC-10 | 1,495,472 | 0 | 1 | 0 | 0 |
| GC-11 | 506,093 | 0 | 1 | 0 | 0 |
| GC-12 | 1,105,696 | 0 | 1 | 0 | 0 |
| GC-13 | 139,183 | 0 | 1 | 0 | 0 |
| GC-14 | 480,788 | 400,389 | 0.25 | 0.29 | 0.45 |
| GC-15 | 1,176,216 | 0 | 1 | 0 | 0 |
| GC-16 | 221,711 | 796,204 | 0.14 | 0.08 | 0.78 |
| GC-17 | 1,028,161 | 0 | 1 | 0 | 0 |
| GC-18 | 1,018,236 | 0 | 1 | 0 | 0 |
| GC-19 | 938,788 | 0 | 1 | 0 | 0 |
| GC-20 | 64,113 | 0 | 1 | 0 | 0 |
| GC-21 | 86,101 | 0 | 1 | 0 | 0 |
| GC-22 | 65,716 | 0 | 1 | 0 | 0 |
| GC-23 | 433,391 | 0 | 1 | 0 | 0 |
| GC-24 | 286,622 | 234,422 | 0.29 | 0.26 | 0.45 |
| GC-25 | 7,203 | 0 | 0.94 | 0.06 | 0 |
| GC-26 | 1,174,402 | 221,271 | 0.56 | 0.28 | 0.16 |
| GC-27 | 24,168 | 0 | 0.96 | 0.04 | 0 |

**Table C-5** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production (mass basis) | Natural Gas Liquids, fraction of total production (mass basis) | Oil, fraction of total production (mass basis) |
|---|---|---|---|---|---|
| GC-28 | 782,134 | 0 | 1 | 0 | 0 |
| GC-29 | 50,244 | 0 | 1 | 0 | 0 |
| GC-30 | 321,101 | 0 | 1 | 0 | 0 |
| GC-31 | 357,985 | 530,696 | 0.28 | 0.12 | 0.60 |
| GC-32 | 386,840 | 0 | 1 | 0 | 0 |
| GC-33 | 103,660 | 0 | 1 | 0 | 0 |
| GC-34 | 1,265,190 | 0 | 1 | 0 | 0 |
| GC-35 | 323,297 | 0 | 1 | 0 | 0 |
| GC-36 | 22,905 | 0 | 1 | 0 | 0 |
| GC-37 | 581,859 | 506,710 | 0.27 | 0.26 | 0.47 |
| GC-38 | 119,358 | 0 | 1 | 0 | 0 |
| GC-39 | 106,442 | 0 | 1 | 0 | 0 |
| GC-40 | 16,306 | 0 | 1 | 0 | 0 |
| GC-41 | 7,027 | 0 | 1 | 0 | 0 |
| GC-42 | 44,292 | 0 | 1 | 0 | 0 |
| GC-43 | 22,216 | 0 | 1 | 0 | 0 |
| GC-44 | 7,344 | 0 | 0.90 | 0.10 | 0 |
| GC-45 | 5,638 | 0 | 0.86 | 0.14 | 0 |
| GC-46 | 89,328 | 1,698 | 0.84 | 0.15 | 0.02 |
| GC-47 | 15,016 | 0 | 0.92 | 0.08 | 0 |
| GC-48 | 24,479 | 0 | 1 | 0 | 0 |
| GC-49 | 13,474 | 0 | 0.92 | 0.08 | 0 |
| GC-50 | 347,560 | 0 | 1 | 0 | 0 |
| GC-51 | 18,222 | 0 | 0.92 | 0.08 | 0 |
| GC-52 | 735,815 | 0 | 1 | 0 | 0 |
| GC-53 | 63,836 | 0 | 1 | 0 | 0 |
| GC-54 | 146,328 | 247,524 | 0.27 | 0.10 | 0.63 |
| GC-55 | 2,273,091 | 0 | 1 | 0 | 0 |
| GC-56 | 107,109 | 0 | 1 | 0 | 0 |
| GC-57 | 868,706 | 0 | 1 | 0 | 0 |
| GC-58 | 174,867 | 0 | 1 | 0 | 0 |
| MC-1 | 55,705 | 16,021 | 0.46 | 0.31 | 0.22 |
| MC-4 | 256,972 | 0 | 0.97 | 0.03 | 0 |
| MC-5 | 811 | 0 | 0.65 | 0.35 | 0 |
| MC-6 | 94,923 | 11,371 | 0.63 | 0.26 | 0.11 |
| MC-7 | 10,182 | 0 | 1 | 0 | 0 |

**Table C-5** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production (mass basis) | Natural Gas Liquids, fraction of total production (mass basis) | Oil, fraction of total production (mass basis) |
|---|---|---|---|---|---|
| MC-8 | 90,266 | 0 | 1 | 0 | 0 |
| MC-9 | 21,572 | 0 | 1 | 0 | 0 |
| MC-10 | 162,090 | 0 | 1 | 0 | 0 |
| MC-11 | 123,083 | 0 | 1 | 0 | 0 |
| MC-12 | 25,449 | 17,387 | 0.35 | 0.24 | 0.41 |
| MC-13 | 54,485 | 0 | 1 | 0 | 0 |
| MC-14 | 15,015 | 0 | 0.68 | 0.32 | 0 |
| MC-16 | 60,746 | 12,271 | 0.58 | 0.25 | 0.17 |
| MC-17 | 316,873 | 0 | 1 | 0 | 0 |
| MC-18 | 83,731 | 0 | 1 | 0 | 0 |
| MC-19 | 175,342 | 0 | 1 | 0 | 0 |
| MC-20 | 115,581 | 13,888 | 0.62 | 0.27 | 0.11 |
| MC-21 | 35,790 | 43,603 | 0.31 | 0.14 | 0.55 |
| MC-22 | 432,029 | 0 | 1 | 0 | 0 |
| MC-23 | 535,876 | 0 | 1 | 0 | 0 |
| MC-24 | 36,863 | 0 | 1 | 0 | 0 |
| MC-25 | 132,448 | 0 | 1 | 0 | 0 |
| MC-26 | 32,519 | 0 | 1 | 0 | 0 |
| RM-2 | 32,012 | 8,346 | 0.47 | 0.32 | 0.21 |
| RM-3 | 8,514 | 1,437 | 0.51 | 0.34 | 0.14 |
| RM-4 | 28,973 | 23,968 | 0.34 | 0.21 | 0.45 |
| RM-5 | 28,120 | 6,854 | 0.48 | 0.33 | 0.20 |
| RM-6 | 12,352 | 1,453 | 0.53 | 0.37 | 0.11 |
| RM-7 | 11,639 | 2,205 | 0.61 | 0.23 | 0.16 |
| RM-8 | 14,976 | 14,023 | 0.31 | 0.21 | 0.48 |
| RM-9 | 18,939 | 3,958 | 0.49 | 0.34 | 0.17 |
| RM-10 | 26,929 | 8,271 | 0.45 | 0.31 | 0.23 |
| RM-11 | 20,718 | 1,078 | 0.58 | 0.37 | 0.05 |
| RM-12 | 4,950 | 2,999 | 0.37 | 0.25 | 0.38 |
| RM-13 | 27,789 | 28,837 | 0.30 | 0.19 | 0.51 |
| RM-14 | 46,480 | 7,367 | 0.51 | 0.35 | 0.14 |
| RM-15 | 87,746 | 56,512 | 0.32 | 0.29 | 0.39 |
| RM-16 | 3,705 | 975 | 0.47 | 0.32 | 0.21 |
| RM-17 | 187,763 | 27,717 | 0.48 | 0.39 | 0.13 |
| RM-18 | 22,627 | 7,387 | 0.45 | 0.31 | 0.25 |
| RM-19 | 45,346 | 7,367 | 0.53 | 0.33 | 0.14 |

**Table C-6.** Allocation of total (sum of emissions from pneumatic controllers, pneumatic pumps, and equipment leaks) emissions (Mg) by product (mass basis) over a 30 year well lifetime

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| AP-1 | 38.15 | 0 | 0 |
| AP-2 | 41.17 | 0 | 0 |
| AP-3 | 262.4 | 0 | 0 |
| AP-4 | 90.22 | 0 | 0 |
| AP-5 | 31.49 | 0 | 0 |
| AP-6 | 66.60 | 0 | 0 |
| AP-7 | 164.1 | 0 | 0 |
| AP-8 | 105.0 | 61.47 | 1.968 |
| AP-9 | 670.9 | 0 | 0 |
| AP-10 | 674.5 | 0 | 0 |
| AP-11 | 11.35 | 0 | 0 |
| AP-12 | 119.4 | 0.4894 | 0 |
| AP-13 | 298.5 | 0 | 0 |
| AP-14 | 70.54 | 0 | 0 |
| AP-15 | 0 | 0 | 0 |
| AP-16 | 65.39 | 0 | 0 |
| AP-17 | 353.3 | 0 | 0 |
| AP-18 | 87.49 | 0 | 0 |
| AP-19 | 116.0 | 0 | 0 |
| AP-20 | 0 | 0 | 0 |
| AP-21 | 153.2 | 0 | 0 |
| AP-22 | 310.6 | 0 | 0 |
| AP-23 | 320.6 | 0 | 0 |
| AP-24 | 106.3 | 0 | 0 |
| AP-25 | 1,758 | 0 | 0 |
| AP-26 | 195.3 | 0 | 0 |
| AP-27 | 848.0 | 0 | 0 |
| AP-28 | 43.60 | 0 | 0 |
| AP-29 | 163.8 | 0 | 0 |
| AP-31 | 254.9 | 0 | 0 |
| AP-32 | 98.70 | 0 | 0 |
| AP-33 | 2,164 | 0 | 0 |
| AP-34 | 2,184 | 0 | 0 |
| AP-35 | 380.4 | 0 | 0 |
| AP-36 | 9.082 | 0 | 0 |
| AP-37 | 181.3 | 0 | 0 |

**Table C-6** (continued).

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| AP-38 | 494.7 | 0 | 0 |
| AP-39 | 406.3 | 0 | 0 |
| AP-40 | 63.19 | 1.598 | 0 |
| AP-41 | 29.97 | 0 | 0 |
| AP-42 | 1,052 | 0 | 0 |
| AP-43 | 893.7 | 0 | 0 |
| AP-45 | 42.38 | 0 | 0 |
| AP-46 | 272.5 | 0 | 0 |
| AP-47 | 42.69 | 0 | 0 |
| GC-1 | 33.44 | 23.27 | 326.3 |
| GC-2 | 138.9 | 123.9 | 377.5 |
| GC-3 | 337.3 | 0 | 0 |
| GC-4 | 259.8 | 204.0 | 247.0 |
| GC-5 | 426.9 | 348.7 | 1,292 |
| GC-6 | 407.7 | 215.6 | 305.5 |
| GC-7 | 148.3 | 0 | 0 |
| GC-8 | 75.38 | 0 | 0 |
| GC-9 | 36.05 | 19.05 | 19.98 |
| GC-10 | 847.7 | 0 | 0 |
| GC-11 | 158.0 | 0 | 0 |
| GC-12 | 755.7 | 0 | 0 |
| GC-13 | 252.2 | 0 | 0 |
| GC-14 | 215.8 | 246.7 | 385.2 |
| GC-15 | 953.2 | 0 | 0 |
| GC-16 | 230.8 | 133.6 | 1,309 |
| GC-17 | 1,082 | 0 | 0 |
| GC-18 | 298.5 | 0 | 0 |
| GC-19 | 1,132 | 0 | 0 |
| GC-20 | 72.66 | 0 | 0 |
| GC-21 | 13.32 | 0 | 0 |
| GC-22 | 347.2 | 0 | 0 |
| GC-23 | 45.41 | 0 | 0 |
| GC-24 | 192.7 | 172.0 | 298.3 |
| GC-25 | 210.5 | 12.88 | 0 |
| GC-26 | 514.6 | 253.2 | 144.7 |
| GC-27 | 165.7 | 7.481 | 0 |
| GC-28 | 213.2 | 0 | 0 |
| GC-29 | 193.2 | 0 | 0 |

**Table C-6** (continued).

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| GC-30 | 479.2 | 0 | 0 |
| GC-31 | 61.02 | 26.79 | 130.2 |
| GC-32 | 294.3 | 0 | 0 |
| GC-33 | 139.3 | 0 | 0 |
| GC-34 | 845.6 | 0 | 0 |
| GC-35 | 1,618 | 0 | 0 |
| GC-36 | 607.9 | 0 | 0 |
| GC-37 | 29.79 | 28.14 | 50.45 |
| GC-38 | 119.3 | 0 | 0 |
| GC-39 | 1,591 | 0 | 0 |
| GC-40 | 180.7 | 0 | 0 |
| GC-41 | 751.1 | 0 | 0 |
| GC-42 | 534.6 | 0 | 0 |
| GC-43 | 129.3 | 0 | 0 |
| GC-44 | 3.826 | 0.4124 | 0 |
| GC-45 | 91.92 | 14.94 | 0 |
| GC-46 | 115.4 | 20.10 | 2.575 |
| GC-47 | 267.5 | 23.16 | 0 |
| GC-48 | 147.7 | 0 | 0 |
| GC-49 | 265.8 | 23.02 | 0 |
| GC-50 | 144.1 | 0 | 0 |
| GC-51 | 297.2 | 24.62 | 0 |
| GC-52 | 540.4 | 0 | 0 |
| GC-53 | 455.9 | 0 | 0 |
| GC-54 | 16.46 | 6.189 | 38.31 |
| GC-55 | 594.0 | 0 | 0 |
| GC-56 | 132.6 | 0 | 0 |
| GC-57 | 227.7 | 0 | 0 |
| GC-58 | 848.4 | 0 | 0 |
| MC-1 | 252.9 | 172.2 | 122.3 |
| MC-4 | 393.0 | 12.42 | 0 |
| MC-5 | 184.6 | 98.19 | 0 |
| MC-6 | 998.7 | 420.7 | 170.0 |
| MC-7 | 62.67 | 0 | 0 |
| MC-8 | 498.6 | 0 | 0 |
| MC-9 | 459.3 | 0 | 0 |
| MC-10 | 94.46 | 0 | 0 |
| MC-11 | 871.0 | 0 | 0 |

**Table C-6** (continued).

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| MC-12 | 167.2 | 117.3 | 194.4 |
| MC-13 | 1,161 | 0 | 0 |
| MC-14 | 203.8 | 94.13 | 0 |
| MC-16 | 308.4 | 130.8 | 88.73 |
| MC-17 | 1,762 | 0 | 0 |
| MC-18 | 181.3 | 0 | 0 |
| MC-19 | 1,065 | 0 | 0 |
| MC-20 | 259.0 | 115.2 | 44.96 |
| MC-21 | 91.60 | 39.60 | 159.9 |
| MC-22 | 4,140 | 0 | 0 |
| MC-23 | 413.2 | 0 | 0 |
| MC-24 | 164.1 | 0 | 0 |
| MC-25 | 152.0 | 0 | 0 |
| MC-26 | 110.2 | 0 | 0 |
| RM-2 | 13.07 | 9.023 | 5.760 |
| RM-3 | 17.70 | 11.83 | 4.985 |
| RM-4 | 3.800 | 2.331 | 5.071 |
| RM-5 | 724.3 | 500.0 | 298.5 |
| RM-6 | 375.5 | 259.2 | 74.66 |
| RM-7 | 392.8 | 147.8 | 102.4 |
| RM-8 | 9.527 | 6.577 | 15.08 |
| RM-9 | 4.148 | 2.864 | 1.465 |
| RM-10 | 69.47 | 47.96 | 36.07 |
| RM-11 | 0.8804 | 0.5584 | 0.0749 |
| RM-12 | 2.119 | 1.463 | 2.170 |
| RM-13 | 0.1823 | 0.1148 | 0.3084 |
| RM-14 | 335.5 | 231.6 | 89.88 |
| RM-15 | 0 | 0 | 0 |
| RM-16 | 4.821 | 3.328 | 2.144 |
| RM-17 | 157.3 | 129.2 | 42.29 |
| RM-18 | 19.44 | 13.42 | 10.73 |
| RM-19 | 44.23 | 27.13 | 11.59 |

**Table C-7.** Ratio of methane emissions (over a 30 year period) to estimated ultimate recovery of Natural Gas, Natural Gas Liquid, and Oil (Mass Basis) over a 30 year well lifetime.

| Site | Mass Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| AP-1 | 0.0007 | NA | NA |
| AP-2 | 0.0002 | NA | NA |
| AP-3 | 0.0005 | NA | NA |
| AP-4 | 0.0001 | NA | NA |
| AP-5 | 0.0002 | NA | NA |
| AP-6 | 0.0001 | NA | NA |
| AP-7 | 0.0003 | NA | NA |
| AP-8 | 0.0019 | 0.0019 | 0.0019 |
| AP-9 | 0.0015 | NA | NA |
| AP-10 | 0.0011 | NA | NA |
| AP-11 | 0.0001 | NA | NA |
| AP-12 | 0.0008 | 0.0007 | NA |
| AP-13 | 0.0005 | NA | NA |
| AP-14 | 0.0002 | NA | NA |
| AP-15 | 0.0E+00 | NA | NA |
| AP-16 | 0.0005 | NA | NA |
| AP-17 | 0.0020 | NA | NA |
| AP-18 | 9.1E-05 | NA | NA |
| AP-19 | 0.0003 | NA | NA |
| AP-20 | 0.0E+00 | NA | NA |
| AP-21 | 0.0011 | NA | NA |
| AP-22 | 0.0002 | NA | NA |
| AP-23 | 0.0006 | NA | NA |
| AP-24 | 3.5E-05 | NA | NA |
| AP-25 | 0.0082 | NA | NA |
| AP-26 | 0.0004 | NA | NA |
| AP-27 | 0.0031 | NA | NA |
| AP-28 | 0.0004 | NA | NA |
| AP-29 | 0.0002 | NA | NA |
| AP-31 | 0.0005 | NA | NA |
| AP-32 | 0.0002 | NA | NA |
| AP-33 | 0.0016 | NA | NA |
| AP-34 | 0.0023 | NA | NA |
| AP-35 | 0.0027 | NA | NA |

**Table C-7** (continued).

| Site | Mass Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| AP-36 | 0.0001 | NA | NA |
| AP-37 | 0.0005 | NA | NA |
| AP-38 | 0.0093 | NA | NA |
| AP-39 | 0.0003 | NA | NA |
| AP-40 | 0.0003 | 0.0003 | NA |
| AP-41 | 7.0E-05 | NA | NA |
| AP-42 | 0.0010 | NA | NA |
| AP-43 | 0.0026 | NA | NA |
| AP-45 | 0.0002 | NA | NA |
| AP-46 | 0.0006 | NA | NA |
| AP-47 | 6.8E-05 | NA | NA |
| GC-1 | 0.0036 | 0.0035 | 0.0035 |
| GC-2 | 0.0008 | 0.0007 | 0.0007 |
| GC-3 | 0.0122 | NA | NA |
| GC-4 | 0.0006 | 0.0005 | 0.0005 |
| GC-5 | 0.0033 | 0.0032 | 0.0032 |
| GC-6 | 0.0016 | 0.0015 | 0.0015 |
| GC-7 | 0.0015 | NA | NA |
| GC-8 | 0.0009 | NA | NA |
| GC-9 | 5.0E-05 | 4.8E-05 | 4.8E-05 |
| GC-10 | 0.0006 | NA | NA |
| GC-11 | 0.0003 | NA | NA |
| GC-12 | 0.0007 | NA | NA |
| GC-13 | 0.0018 | NA | NA |
| GC-14 | 0.0010 | 0.0010 | 0.0010 |
| GC-15 | 0.0008 | NA | NA |
| GC-16 | 0.0017 | 0.0016 | 0.0016 |
| GC-17 | 0.0011 | NA | NA |
| GC-18 | 0.0003 | NA | NA |
| GC-19 | 0.0012 | NA | NA |
| GC-20 | 0.0011 | NA | NA |
| GC-21 | 0.0002 | NA | NA |
| GC-22 | 0.0053 | NA | NA |
| GC-23 | 0.0001 | NA | NA |
| GC-24 | 0.0013 | 0.0013 | 0.0013 |
| GC-25 | 0.0319 | 0.0310 | NA |

**Table C-7** (continued).

| Site | Mass Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| GC-26 | 0.0007 | 0.0007 | 0.0007 |
| GC-27 | 0.0074 | 0.0072 | NA |
| GC-28 | 0.0003 | NA | NA |
| GC-29 | 0.0039 | NA | NA |
| GC-30 | 0.0015 | NA | NA |
| GC-31 | 0.0003 | 0.0002 | 0.0002 |
| GC-32 | 0.0008 | NA | NA |
| GC-33 | 0.0013 | NA | NA |
| GC-34 | 0.0007 | NA | NA |
| GC-35 | 0.0050 | NA | NA |
| GC-36 | 0.0266 | NA | NA |
| GC-37 | 0.0001 | 1.0E-04 | 1.0E-04 |
| GC-38 | 0.0010 | NA | NA |
| GC-39 | 0.0151 | NA | NA |
| GC-40 | 0.0111 | NA | NA |
| GC-41 | 0.1082 | NA | NA |
| GC-42 | 0.0121 | NA | NA |
| GC-43 | 0.0059 | NA | NA |
| GC-44 | 0.0006 | 0.0006 | NA |
| GC-45 | 0.0195 | 0.0190 | NA |
| GC-46 | 0.0016 | 0.0015 | 0.0015 |
| GC-47 | 0.0199 | 0.0194 | NA |
| GC-48 | 0.0060 | NA | NA |
| GC-49 | 0.0220 | 0.0214 | NA |
| GC-50 | 0.0004 | NA | NA |
| GC-51 | 0.0181 | 0.0177 | NA |
| GC-52 | 0.0007 | NA | NA |
| GC-53 | 0.0071 | NA | NA |
| GC-54 | 0.0002 | 0.0002 | 0.0002 |
| GC-55 | 0.0003 | NA | NA |
| GC-56 | 0.0012 | NA | NA |
| GC-57 | 0.0003 | NA | NA |
| GC-58 | 0.0049 | NA | NA |
| MC-1 | 0.0078 | 0.0076 | 0.0076 |
| MC-4 | 0.0016 | 0.0016 | NA |
| MC-5 | 0.3580 | 0.3487 | NA |

**Table C-7** (continued).

| Site | Mass Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| MC-6 | 0.0154 | 0.0150 | 0.0150 |
| MC-7 | 0.0062 | NA | NA |
| MC-8 | 0.0056 | NA | NA |
| MC-9 | 0.0216 | NA | NA |
| MC-10 | 0.0006 | NA | NA |
| MC-11 | 0.0072 | NA | NA |
| MC-12 | 0.0115 | 0.0112 | 0.0112 |
| MC-13 | 0.0216 | NA | NA |
| MC-14 | 0.0204 | 0.0198 | NA |
| MC-16 | 0.0074 | 0.0072 | 0.0072 |
| MC-17 | 0.0056 | NA | NA |
| MC-18 | 0.0022 | NA | NA |
| MC-19 | 0.0062 | NA | NA |
| MC-20 | 0.0033 | 0.0032 | 0.0032 |
| MC-21 | 0.0038 | 0.0037 | 0.0037 |
| MC-22 | 0.0097 | NA | NA |
| MC-23 | 0.0008 | NA | NA |
| MC-24 | 0.0045 | NA | NA |
| MC-25 | 0.0012 | NA | NA |
| MC-26 | 0.0034 | NA | NA |
| RM-2 | 0.0007 | 0.0007 | 0.0007 |
| RM-3 | 0.0036 | 0.0035 | 0.0035 |
| RM-4 | 0.0002 | 0.0002 | 0.0002 |
| RM-5 | 0.0447 | 0.0435 | 0.0435 |
| RM-6 | 0.0528 | 0.0514 | 0.0514 |
| RM-7 | 0.0477 | 0.0464 | 0.0464 |
| RM-8 | 0.0011 | 0.0011 | 0.0011 |
| RM-9 | 0.0004 | 0.0004 | 0.0004 |
| RM-10 | 0.0045 | 0.0044 | 0.0044 |
| RM-11 | 7.1E-05 | 6.9E-05 | 6.9E-05 |
| RM-12 | 0.0007 | 0.0007 | 0.0007 |
| RM-13 | 1.1E-05 | 1.1E-05 | 1.1E-05 |
| RM-14 | 0.0125 | 0.0122 | 0.0122 |
| RM-15 | 0 | 0 | 0 |
| RM-16 | 0.0023 | 0.0022 | 0.0022 |
| RM-17 | 0.0016 | 0.0015 | 0.0015 |

**Table C-7** (continued).

| Site | Mass Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| RM-18 | 0.0015 | 0.0015 | 0.0015 |
| RM-19 | 0.0016 | 0.0016 | 0.0016 |

### *C.5 Energy based allocation of emissions*

Once production is split into each of the salable products (Natural Gas, Natural Gas Liquids, and Oil), as discussed in section C4, Estimated Ultimate Recovery (EUR) is converted from a mass base to an energy basis, using the conversion factors from section C1. Allocation of emissions is determined based on the heating value of each salable product.

For the case of the higher heating value of Natural Gas Liquids, a *weighted average heating value* is calculated for each site, based on its non-methane hydrocarbon gases composition, where the weighted average energy content is:

$$< Energy_{NMVOC} >= \frac{1}{\text{non methane hydrocarbon}} \left( C_2 \times Energy_{C_2} + C_3 \times Energy_{C_3} + C_4 \times Energy_{C_4} + C_{5+} \times Energy_{C_{5+}} \right) \quad \text{(C5.1)}$$

where $Energy_{Cn}$ refers to the heating value of the individual components from the gas.

Even though a fixed (natural gas) heating value is used for the conversion of salable natural gas in a mass base to an energy base (reported in Table C-1) for all sites, the average heating value of salable natural gas is calculated for each site to assess the potential impact of this assumption. Table C-8 shows the average heating value of both Natural Gas and Natural Gas Liquids. Table C-9 shows the fraction of production for each of the salable products (energy basis). Table C-10 shows the allocation of emissions from pneumatic controllers, pneumatic pumps, and equipment leaks over a 30 year period to each of the salable products, based. Table C-11 reports the ratio of allocated emissions to production for each of the three products: Natural Gas, Natural Gas Liquids, and Oil.

**Table C-8.** Average heating value of Natural Gas and Natural Gas Liquids for each site. For further calculations, in the case Natural Gas (Table C-1), a fixed higher heating value of 1,027 BTU/scf was assumed. In the case of Natural Gas Liquids, the average higher heating value at each site was used.

| Site | Natural Gas, average higher heating value (BTU/scf) | Natural Gas Liquids, average higher heating value (BTU/scf) |
|---|---|---|
| AP-1 | 1,025 | NA |
| AP-2 | 1,029 | NA |
| AP-3 | 1,027 | NA |
| AP-4 | 1,022 | NA |
| AP-5 | 1,027 | NA |
| AP-6 | 1,028 | NA |
| AP-7 | 1,028 | NA |
| AP-8 | 1,033 | 2,180 |
| AP-9 | 1,022 | NA |
| AP-10 | 1,022 | NA |
| AP-11 | 1,025 | NA |
| AP-12 | 1,032 | 2,567 |
| AP-13 | 1,026 | NA |
| AP-14 | 1,031 | NA |
| AP-15 | 1,021 | NA |
| AP-16 | 1,032 | NA |
| AP-17 | 1,024 | NA |
| AP-18 | 1,031 | NA |
| AP-19 | 1,030 | NA |
| AP-20 | 1,021 | NA |
| AP-21 | 1,028 | NA |
| AP-22 | 1,026 | NA |
| AP-23 | 1,026 | NA |
| AP-24 | 1,028 | NA |
| AP-25 | 1,023 | NA |
| AP-26 | 1,027 | NA |
| AP-27 | 1,023 | NA |
| AP-28 | 1,027 | NA |
| AP-29 | 1,028 | NA |
| AP-31 | 1,027 | NA |
| AP-32 | 1,027 | NA |
| AP-33 | 1,028 | NA |
| AP-34 | 1,028 | NA |
| AP-35 | 1,029 | NA |

**Table C-8** (continued).

| Site | Natural Gas, average heating value (BTU/scf) | Natural Gas Liquids, average heating value (BTU/scf) |
|---|---|---|
| AP-36 | 1,027 | NA |
| AP-37 | 1,031 | NA |
| AP-38 | 1,020 | NA |
| AP-39 | 1,029 | NA |
| AP-40 | 1,033 | 1,994 |
| AP-41 | 1,027 | NA |
| AP-42 | 1,029 | NA |
| AP-43 | 1,031 | NA |
| AP-45 | 1,028 | NA |
| AP-46 | 1,026 | NA |
| AP-47 | 1,031 | NA |
| GC-1 | 1,033 | 2,320 |
| GC-2 | 1,033 | 2,367 |
| GC-3 | 1,010 | NA |
| GC-4 | 1,033 | 2,341 |
| GC-5 | 1,033 | 2,370 |
| GC-6 | 1,033 | 2,262 |
| GC-7 | 1,010 | NA |
| GC-8 | 1,012 | NA |
| GC-9 | 1,033 | 2,264 |
| GC-10 | 1,010 | NA |
| GC-11 | 1,011 | NA |
| GC-12 | 1,010 | NA |
| GC-13 | 1,011 | NA |
| GC-14 | 1,033 | 2,490 |
| GC-15 | 1,011 | NA |
| GC-16 | 1,033 | 2,229 |
| GC-17 | 1,010 | NA |
| GC-18 | 1,010 | NA |
| GC-19 | 1,011 | NA |
| GC-20 | 1,010 | NA |
| GC-21 | 1,010 | NA |
| GC-22 | 1,011 | NA |
| GC-23 | 1,010 | NA |
| GC-24 | 1,033 | 2,408 |
| GC-25 | 1,033 | 2,746 |
| GC-26 | 1,033 | 2,314 |

**Table C-8** (continued).

| Site | Natural Gas, average heating value (BTU/scf) | Natural Gas Liquids, average heating value (BTU/scf) |
|---|---|---|
| GC-27 | 1,033 | 3,105 |
| GC-28 | 1,011 | NA |
| GC-29 | 1,011 | NA |
| GC-30 | 1,010 | NA |
| GC-31 | 1,033 | 2,277 |
| GC-32 | 1,011 | NA |
| GC-33 | 1,012 | NA |
| GC-34 | 1,010 | NA |
| GC-35 | 1,011 | NA |
| GC-36 | 1,010 | NA |
| GC-37 | 1,033 | 2,441 |
| GC-38 | 1,010 | NA |
| GC-39 | 1,020 | NA |
| GC-40 | 1,011 | NA |
| GC-41 | 1,020 | NA |
| GC-42 | 1,010 | NA |
| GC-43 | 1,020 | NA |
| GC-44 | 1,033 | 3,327 |
| GC-45 | 1,033 | 2,535 |
| GC-46 | 1,033 | 2,430 |
| GC-47 | 1,033 | 2,792 |
| GC-48 | 1,011 | NA |
| GC-49 | 1,033 | 2,792 |
| GC-50 | 1,018 | NA |
| GC-51 | 1,033 | 2,907 |
| GC-52 | 1,011 | NA |
| GC-53 | 1,010 | NA |
| GC-54 | 1,033 | 2,241 |
| GC-55 | 1,010 | NA |
| GC-56 | 1,013 | NA |
| GC-57 | 1,011 | NA |
| GC-58 | 1,020 | NA |
| MC-1 | 1,033 | 2,430 |
| MC-4 | 1,033 | 2,047 |
| MC-5 | 1,033 | 2,350 |
| MC-6 | 1,033 | 2,388 |
| MC-7 | 1,015 | NA |

**Table C-8** (continued).

| Site | Natural Gas, average heating value (BTU/scf) | Natural Gas Liquids, average heating value (BTU/scf) |
|---|---|---|
| MC-8 | 1,019 | NA |
| MC-9 | 1,021 | NA |
| MC-10 | 1,018 | NA |
| MC-11 | 1,019 | NA |
| MC-12 | 1,033 | 2,414 |
| MC-13 | 1,021 | NA |
| MC-14 | 1,033 | 2,324 |
| MC-16 | 1,033 | 2,328 |
| MC-17 | 1,019 | NA |
| MC-18 | 1,022 | NA |
| MC-19 | 1,022 | NA |
| MC-20 | 1,033 | 2,322 |
| MC-21 | 1,033 | 2,364 |
| MC-22 | 1,021 | NA |
| MC-23 | 1,017 | NA |
| MC-24 | 1,019 | NA |
| MC-25 | 1,017 | NA |
| MC-26 | 1,019 | NA |
| RM-2 | 1,033 | 2,447 |
| RM-3 | 1,033 | 2,389 |
| RM-4 | 1,033 | 2,430 |
| RM-5 | 1,033 | 2,447 |
| RM-6 | 1,033 | 2,447 |
| RM-7 | 1,033 | 2,350 |
| RM-8 | 1,033 | 2,447 |
| RM-9 | 1,033 | 2,447 |
| RM-10 | 1,033 | 2,447 |
| RM-11 | 1,033 | 2,324 |
| RM-12 | 1,033 | 2,447 |
| RM-13 | 1,033 | 2,283 |
| RM-14 | 1,033 | 2,447 |
| RM-15 | 1,033 | 2,391 |
| RM-16 | 1,033 | 2,447 |
| RM-17 | 1,033 | 2,329 |
| RM-18 | 1,033 | 2,447 |
| RM-19 | 1,033 | 2,430 |

**Table C-8** (continued).

| Site | Natural Gas, average heating value (BTU/scf) | Natural Gas Liquids, average heating value (BTU/scf) |
|---|---|---|
| **Weighted Average** | **1,022** | **2,349** |

**Table C-9.** Fraction of production by product (energy basis).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production energy basis) | Natural Gas Liquids, fraction of total production energy basis) | Oil, fraction of total production energy basis) |
|---|---|---|---|---|---|
| AP-1 | 59,005 | 0 | 1 | 0 | 0 |
| AP-2 | 211,289 | 0 | 1 | 0 | 0 |
| AP-3 | 576,497 | 0 | 1 | 0 | 0 |
| AP-4 | 836,980 | 0 | 1 | 0 | 0 |
| AP-5 | 136,625 | 0 | 1 | 0 | 0 |
| AP-6 | 516,860 | 0 | 1 | 0 | 0 |
| AP-7 | 565,897 | 0 | 1 | 0 | 0 |
| AP-8 | 87,743 | 1,037 | 0.64 | 0.35 | 0.01 |
| AP-9 | 455,027 | 0 | 1 | 0 | 0 |
| AP-10 | 614,983 | 0 | 1 | 0 | 0 |
| AP-11 | 113,272 | 0 | 1 | 0 | 0 |
| AP-12 | 160,139 | 0 | 1.00 | 0.004 | 0 |
| AP-13 | 599,499 | 0 | 1 | 0 | 0 |
| AP-14 | 387,376 | 0 | 1 | 0 | 0 |
| AP-15 | 184,176 | 0 | 1 | 0 | 0 |
| AP-16 | 128,401 | 0 | 1 | 0 | 0 |
| AP-17 | 176,088 | 0 | 1 | 0 | 0 |
| AP-18 | 988,031 | 0 | 1 | 0 | 0 |
| AP-19 | 410,082 | 0 | 1 | 0 | 0 |
| AP-20 | 305,353 | 0 | 1 | 0 | 0 |
| AP-21 | 147,975 | 0 | 1 | 0 | 0 |
| AP-22 | 1,523,474 | 0 | 1 | 0 | 0 |
| AP-23 | 529,064 | 0 | 1 | 0 | 0 |
| AP-24 | 3,140,582 | 0 | 1 | 0 | 0 |
| AP-25 | 217,440 | 0 | 1 | 0 | 0 |
| AP-26 | 540,977 | 0 | 1 | 0 | 0 |
| AP-27 | 281,558 | 0 | 1 | 0 | 0 |
| AP-28 | 105,196 | 0 | 1 | 0 | 0 |
| AP-29 | 773,016 | 0 | 1 | 0 | 0 |
| AP-31 | 540,977 | 0 | 1 | 0 | 0 |
| AP-32 | 605,927 | 0 | 1 | 0 | 0 |
| AP-33 | 1,417,505 | 0 | 1 | 0 | 0 |
| AP-34 | 975,788 | 0 | 1 | 0 | 0 |
| AP-35 | 141,472 | 0 | 1 | 0 | 0 |

**Table C-9** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production energy basis) | Natural Gas Liquids, fraction of total production energy basis) | Oil, fraction of total production energy basis) |
|---|---|---|---|---|---|
| AP-36 | 62,444 | 0 | 1 | 0 | 0 |
| AP-37 | 347,208 | 0 | 1 | 0 | 0 |
| AP-38 | 53,663 | 0 | 1 | 0 | 0 |
| AP-39 | 1,477,859 | 0 | 1 | 0 | 0 |
| AP-40 | 220,702 | 0 | 0.98 | 0.02 | 0 |
| AP-41 | 437,108 | 0 | 1 | 0 | 0 |
| AP-42 | 1,121,524 | 0 | 1 | 0 | 0 |
| AP-43 | 352,842 | 0 | 1 | 0 | 0 |
| AP-45 | 209,670 | 0 | 1 | 0 | 0 |
| AP-46 | 430,507 | 0 | 1 | 0 | 0 |
| AP-47 | 640,901 | 0 | 1 | 0 | 0 |
| GC-1 | 16,390 | 94,298 | 0.10 | 0.06 | 0.84 |
| GC-2 | 356,441 | 511,946 | 0.24 | 0.19 | 0.57 |
| GC-3 | 27,566 | 0 | 1 | 0 | 0 |
| GC-4 | 855,109 | 455,392 | 0.39 | 0.28 | 0.33 |
| GC-5 | 241,501 | 402,361 | 0.23 | 0.17 | 0.61 |
| GC-6 | 403,970 | 197,954 | 0.46 | 0.23 | 0.31 |
| GC-7 | 96,687 | 0 | 1 | 0 | 0 |
| GC-8 | 84,653 | 0 | 1 | 0 | 0 |
| GC-9 | 1,140,739 | 413,697 | 0.51 | 0.25 | 0.25 |
| GC-10 | 1,495,472 | 0 | 1 | 0 | 0 |
| GC-11 | 506,093 | 0 | 1 | 0 | 0 |
| GC-12 | 1,105,696 | 0 | 1 | 0 | 0 |
| GC-13 | 139,183 | 0 | 1 | 0 | 0 |
| GC-14 | 480,788 | 400,389 | 0.28 | 0.29 | 0.44 |
| GC-15 | 1,176,216 | 0 | 1 | 0 | 0 |
| GC-16 | 221,711 | 796,204 | 0.15 | 0.08 | 0.77 |
| GC-17 | 1,028,161 | 0 | 1 | 0 | 0 |
| GC-18 | 1,018,236 | 0 | 1 | 0 | 0 |
| GC-19 | 938,788 | 0 | 1 | 0 | 0 |
| GC-20 | 64,113 | 0 | 1 | 0 | 0 |
| GC-21 | 86,101 | 0 | 1 | 0 | 0 |
| GC-22 | 65,716 | 0 | 1 | 0 | 0 |
| GC-23 | 433,391 | 0 | 1 | 0 | 0 |

**Table C-9** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production energy basis) | Natural Gas Liquids, fraction of total production energy basis) | Oil, fraction of total production energy basis) |
|---|---|---|---|---|---|
| GC-24 | 286,622 | 234,422 | 0.31 | 0.26 | 0.43 |
| GC-25 | 7,203 | 0 | 0.95 | 0.05 | 0 |
| GC-26 | 1,174,402 | 221,271 | 0.59 | 0.26 | 0.15 |
| GC-27 | 24,168 | 0 | 0.96 | 0.04 | 0 |
| GC-28 | 782,134 | 0 | 1 | 0 | 0 |
| GC-29 | 50,244 | 0 | 1 | 0 | 0 |
| GC-30 | 321,101 | 0 | 1 | 0 | 0 |
| GC-31 | 357,985 | 530,696 | 0.30 | 0.12 | 0.57 |
| GC-32 | 386,840 | 0 | 1 | 0 | 0 |
| GC-33 | 103,660 | 0 | 1 | 0 | 0 |
| GC-34 | 1,265,190 | 0 | 1 | 0 | 0 |
| GC-35 | 323,297 | 0 | 1 | 0 | 0 |
| GC-36 | 22,905 | 0 | 1 | 0 | 0 |
| GC-37 | 581,859 | 506,710 | 0.30 | 0.26 | 0.45 |
| GC-38 | 119,358 | 0 | 1 | 0 | 0 |
| GC-39 | 106,442 | 0 | 1 | 0 | 0 |
| GC-40 | 16,306 | 0 | 1 | 0 | 0 |
| GC-41 | 7,027 | 0 | 1 | 0 | 0 |
| GC-42 | 44,292 | 0 | 1 | 0 | 0 |
| GC-43 | 22,216 | 0 | 1 | 0 | 0 |
| GC-44 | 7,344 | 0 | 0.91 | 0.09 | 0 |
| GC-45 | 5,638 | 0 | 0.87 | 0.13 | 0 |
| GC-46 | 89,328 | 1,698 | 0.85 | 0.13 | 0.02 |
| GC-47 | 15,016 | 0 | 0.93 | 0.07 | 0 |
| GC-48 | 24,479 | 0 | 1 | 0 | 0 |
| GC-49 | 13,474 | 0 | 0.93 | 0.07 | 0 |
| GC-50 | 347,560 | 0 | 1 | 0 | 0 |
| GC-51 | 18,222 | 0 | 0.93 | 0.07 | 0 |
| GC-52 | 735,815 | 0 | 1 | 0 | 0 |
| GC-53 | 63,836 | 0 | 1 | 0 | 0 |
| GC-54 | 146,328 | 247,524 | 0.29 | 0.10 | 0.61 |
| GC-55 | 2,273,091 | 0 | 1 | 0 | 0 |
| GC-56 | 107,109 | 0 | 1 | 0 | 0 |
| GC-57 | 868,706 | 0 | 1 | 0 | 0 |

**Table C-9** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production energy basis) | Natural Gas Liquids, fraction of total production energy basis) | Oil, fraction of total production energy basis) |
|---|---|---|---|---|---|
| GC-58 | 174,867 | 0 | 1 | 0 | 0 |
| MC-1 | 55,705 | 16,021 | 0.49 | 0.31 | 0.20 |
| MC-4 | 256,972 | 0 | 0.97 | 0.03 | 0 |
| MC-5 | 811 | 0 | 0.67 | 0.33 | 0 |
| MC-6 | 94,923 | 11,371 | 0.65 | 0.25 | 0.10 |
| MC-7 | 10,182 | 0 | 1 | 0 | 0 |
| MC-8 | 90,266 | 0 | 1 | 0 | 0 |
| MC-9 | 21,572 | 0 | 1 | 0 | 0 |
| MC-10 | 162,090 | 0 | 1 | 0 | 0 |
| MC-11 | 123,083 | 0 | 1 | 0 | 0 |
| MC-12 | 25,449 | 17,387 | 0.38 | 0.24 | 0.38 |
| MC-13 | 54,485 | 0 | 1 | 0 | 0 |
| MC-14 | 15,015 | 0 | 0.70 | 0.30 | 0 |
| MC-16 | 60,746 | 12,271 | 0.61 | 0.24 | 0.15 |
| MC-17 | 316,873 | 0 | 1 | 0 | 0 |
| MC-18 | 83,731 | 0 | 1 | 0 | 0 |
| MC-19 | 175,342 | 0 | 1 | 0 | 0 |
| MC-20 | 115,581 | 13,888 | 0.64 | 0.26 | 0.10 |
| MC-21 | 35,790 | 43,603 | 0.35 | 0.14 | 0.52 |
| MC-22 | 432,029 | 0 | 1 | 0 | 0 |
| MC-23 | 535,876 | 0 | 1 | 0 | 0 |
| MC-24 | 36,863 | 0 | 1 | 0 | 0 |
| MC-25 | 132,448 | 0 | 1 | 0 | 0 |
| MC-26 | 32,519 | 0 | 1 | 0 | 0 |
| RM-2 | 32,012 | 8,346 | 0.49 | 0.31 | 0.20 |
| RM-3 | 8,514 | 1,437 | 0.54 | 0.33 | 0.14 |
| RM-4 | 28,973 | 23,968 | 0.36 | 0.20 | 0.43 |
| RM-5 | 28,120 | 6,854 | 0.50 | 0.31 | 0.19 |
| RM-6 | 12,352 | 1,453 | 0.55 | 0.35 | 0.10 |
| RM-7 | 11,639 | 2,205 | 0.63 | 0.22 | 0.15 |
| RM-8 | 14,976 | 14,023 | 0.33 | 0.21 | 0.47 |
| RM-9 | 18,939 | 3,958 | 0.51 | 0.32 | 0.16 |
| RM-10 | 26,929 | 8,271 | 0.48 | 0.30 | 0.22 |
| RM-11 | 20,718 | 1,078 | 0.60 | 0.35 | 0.05 |

**Table C-9** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production energy basis) | Natural Gas Liquids, fraction of total production energy basis) | Oil, fraction of total production energy basis) |
|---|---|---|---|---|---|
| RM-12 | 4,950 | 2,999 | 0.39 | 0.25 | 0.36 |
| RM-13 | 27,789 | 28,837 | 0.32 | 0.19 | 0.49 |
| RM-14 | 46,480 | 7,367 | 0.54 | 0.34 | 0.13 |
| RM-15 | 87,746 | 56,512 | 0.35 | 0.28 | 0.38 |
| RM-16 | 3,705 | 975 | 0.49 | 0.31 | 0.20 |
| RM-17 | 187,763 | 27,717 | 0.50 | 0.38 | 0.12 |
| RM-18 | 22,627 | 7,387 | 0.47 | 0.29 | 0.23 |
| RM-19 | 45,346 | 7,367 | 0.56 | 0.31 | 0.13 |

**Table C-10.** Allocation of total (sum of emissions from pneumatic controllers, pneumatic pumps, and equipment leaks) emissions (Mg) by product (energy basis) over a 30 year well lifetime

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| AP-1 | 38.15 | 0 | 0 |
| AP-2 | 41.17 | 0 | 0 |
| AP-3 | 262.4 | 0 | 0 |
| AP-4 | 90.22 | 0 | 0 |
| AP-5 | 31.49 | 0 | 0 |
| AP-6 | 66.60 | 0 | 0 |
| AP-7 | 164.1 | 0 | 0 |
| AP-8 | 108.2 | 58.44 | 1.801 |
| AP-9 | 670.9 | 0 | 0 |
| AP-10 | 674.5 | 0 | 0 |
| AP-11 | 11.35 | 0 | 0 |
| AP-12 | 119.4 | 0.4491 | 0 |
| AP-13 | 298.5 | 0 | 0 |
| AP-14 | 70.54 | 0 | 0 |
| AP-15 | 0 | 0 | 0 |
| AP-16 | 65.39 | 0 | 0 |
| AP-17 | 353.3 | 0 | 0 |
| AP-18 | 87.49 | 0 | 0 |
| AP-19 | 116.0 | 0 | 0 |
| AP-20 | 0 | 0 | 0 |
| AP-21 | 153.2 | 0 | 0 |
| AP-22 | 310.6 | 0 | 0 |
| AP-23 | 320.6 | 0 | 0 |
| AP-24 | 106.3 | 0 | 0 |
| AP-25 | 1,758 | 0 | 0 |
| AP-26 | 195.3 | 0 | 0 |
| AP-27 | 848.0 | 0 | 0 |
| AP-28 | 43.60 | 0 | 0 |
| AP-29 | 163.8 | 0 | 0 |
| AP-31 | 254.9 | 0 | 0 |
| AP-32 | 98.70 | 0 | 0 |
| AP-33 | 2,164 | 0 | 0 |
| AP-34 | 2,184 | 0 | 0 |
| AP-35 | 380.4 | 0 | 0 |
| AP-36 | 9.082 | 0 | 0 |
| AP-37 | 181.3 | 0 | 0 |
| AP-38 | 494.7 | 0 | 0 |

**Table C-10** (continued).

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| AP-39 | 406.3 | 0 | 0 |
| AP-40 | 63.29 | 1.495 | 0 |
| AP-41 | 29.97 | 0 | 0 |
| AP-42 | 1,052 | 0 | 0 |
| AP-43 | 893.7 | 0 | 0 |
| AP-45 | 42.38 | 0 | 0 |
| AP-46 | 272.5 | 0 | 0 |
| AP-47 | 42.69 | 0 | 0 |
| GC-1 | 37.18 | 23.68 | 322.1 |
| GC-2 | 151.4 | 123.4 | 365.5 |
| GC-3 | 337.3 | 0 | 0 |
| GC-4 | 277.3 | 199.3 | 234.2 |
| GC-5 | 466.3 | 347.7 | 1,254 |
| GC-6 | 431.8 | 209.7 | 287.3 |
| GC-7 | 148.3 | 0 | 0 |
| GC-8 | 75.38 | 0 | 0 |
| GC-9 | 37.97 | 18.42 | 18.69 |
| GC-10 | 847.7 | 0 | 0 |
| GC-11 | 158.0 | 0 | 0 |
| GC-12 | 755.7 | 0 | 0 |
| GC-13 | 252.2 | 0 | 0 |
| GC-14 | 234.2 | 242.2 | 371.2 |
| GC-15 | 953.2 | 0 | 0 |
| GC-16 | 254.7 | 135.8 | 1,283 |
| GC-17 | 1,082 | 0 | 0 |
| GC-18 | 298.5 | 0 | 0 |
| GC-19 | 1,132 | 0 | 0 |
| GC-20 | 72.66 | 0 | 0 |
| GC-21 | 13.32 | 0 | 0 |
| GC-22 | 347.2 | 0 | 0 |
| GC-23 | 45.41 | 0 | 0 |
| GC-24 | 208.0 | 169.1 | 285.9 |
| GC-25 | 211.8 | 11.60 | 0 |
| GC-26 | 536.8 | 241.7 | 134.0 |
| GC-27 | 166.5 | 6.650 | 0 |
| GC-28 | 213.2 | 0 | 0 |
| GC-29 | 193.2 | 0 | 0 |
| GC-30 | 479.2 | 0 | 0 |
| GC-31 | 66.11 | 26.62 | 125.2 |

**Table C-10** (continued).

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| GC-32 | 294.3 | 0 | 0 |
| GC-33 | 139.3 | 0 | 0 |
| GC-34 | 845.6 | 0 | 0 |
| GC-35 | 1,618 | 0 | 0 |
| GC-36 | 607.9 | 0 | 0 |
| GC-37 | 32.24 | 27.65 | 48.49 |
| GC-38 | 119.3 | 0 | 0 |
| GC-39 | 1,591 | 0 | 0 |
| GC-40 | 180.7 | 0 | 0 |
| GC-41 | 751.1 | 0 | 0 |
| GC-42 | 534.6 | 0 | 0 |
| GC-43 | 129.3 | 0 | 0 |
| GC-44 | 3.874 | 0.3641 | 0 |
| GC-45 | 93.22 | 13.65 | 0 |
| GC-46 | 117.2 | 18.48 | 2.324 |
| GC-47 | 269.8 | 20.85 | 0 |
| GC-48 | 147.7 | 0 | 0 |
| GC-49 | 268.1 | 20.72 | 0 |
| GC-50 | 144.1 | 0 | 0 |
| GC-51 | 299.8 | 22.04 | 0 |
| GC-52 | 540.4 | 0 | 0 |
| GC-53 | 455.9 | 0 | 0 |
| GC-54 | 17.86 | 6.172 | 36.92 |
| GC-55 | 594.0 | 0 | 0 |
| GC-56 | 132.6 | 0 | 0 |
| GC-57 | 227.7 | 0 | 0 |
| GC-58 | 848.4 | 0 | 0 |
| MC-1 | 269.0 | 167.1 | 111.2 |
| MC-4 | 393.8 | 11.59 | 0 |
| MC-5 | 190.3 | 92.47 | 0 |
| MC-6 | 1,039 | 399.3 | 151.2 |
| MC-7 | 62.67 | 0 | 0 |
| MC-8 | 498.6 | 0 | 0 |
| MC-9 | 459.3 | 0 | 0 |
| MC-10 | 94.46 | 0 | 0 |
| MC-11 | 871.0 | 0 | 0 |
| MC-12 | 181.8 | 116.4 | 180.7 |
| MC-13 | 1,161 | 0 | 0 |
| MC-14 | 209.3 | 88.55 | 0 |

**Table C-10** (continued).

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| MC-16 | 323.1 | 125.4 | 79.48 |
| MC-17 | 1,762 | 0 | 0 |
| MC-18 | 181.3 | 0 | 0 |
| MC-19 | 1,065 | 0 | 0 |
| MC-20 | 269.4 | 109.8 | 39.99 |
| MC-21 | 100.8 | 39.82 | 150.4 |
| MC-22 | 4,140 | 0 | 0 |
| MC-23 | 413.2 | 0 | 0 |
| MC-24 | 164.1 | 0 | 0 |
| MC-25 | 152.0 | 0 | 0 |
| MC-26 | 110.2 | 0 | 0 |
| RM-2 | 13.78 | 8.620 | 5.451 |
| RM-3 | 18.53 | 11.30 | 4.684 |
| RM-4 | 4.067 | 2.264 | 4.871 |
| RM-5 | 763.2 | 477.4 | 282.2 |
| RM-6 | 393.2 | 245.9 | 70.17 |
| RM-7 | 407.9 | 139.6 | 95.44 |
| RM-8 | 10.24 | 6.403 | 14.54 |
| RM-9 | 4.364 | 2.730 | 1.383 |
| RM-10 | 73.39 | 45.90 | 34.19 |
| RM-11 | 0.9134 | 0.5306 | 0.0697 |
| RM-12 | 2.261 | 1.414 | 2.078 |
| RM-13 | 0.1957 | 0.1128 | 0.2970 |
| RM-14 | 352.1 | 220.2 | 84.65 |
| RM-15 | 0 | 0 | 0 |
| RM-16 | 5.084 | 3.180 | 2.029 |
| RM-17 | 164.9 | 124.1 | 39.79 |
| RM-18 | 20.56 | 12.86 | 10.18 |
| RM-19 | 46.29 | 25.77 | 10.89 |

**Table C-11.** Ratio of methane emissions (over a 30 year period) to estimated ultimate recovery of Natural Gas, Natural Gas Liquid, and Oil (energy Basis) over a 30 year well lifetime.

| | Energy Basis | | |
|---|---|---|---|
| **Site** | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| AP-1 | 0.0007 | NA | NA |
| AP-2 | 0.0002 | NA | NA |
| AP-3 | 0.0005 | NA | NA |
| AP-4 | 0.0001 | NA | NA |
| AP-5 | 0.0002 | NA | NA |
| AP-6 | 0.0001 | NA | NA |
| AP-7 | 0.0003 | NA | NA |
| AP-8 | 0.0020 | 0.0018 | 0.0017 |
| AP-9 | 0.0015 | NA | NA |
| AP-10 | 0.0011 | NA | NA |
| AP-11 | 0.0001 | NA | NA |
| AP-12 | 0.0008 | 0.0007 | NA |
| AP-13 | 0.0005 | NA | NA |
| AP-14 | 0.0002 | NA | NA |
| AP-15 | 0.0E+00 | NA | NA |
| AP-16 | 0.0005 | NA | NA |
| AP-17 | 0.0020 | NA | NA |
| AP-18 | 9.1E-05 | NA | NA |
| AP-19 | 0.0003 | NA | NA |
| AP-20 | 0.0E+00 | NA | NA |
| AP-21 | 0.0011 | NA | NA |
| AP-22 | 0.0002 | NA | NA |
| AP-23 | 0.0006 | NA | NA |
| AP-24 | 3.5E-05 | NA | NA |
| AP-25 | 0.0082 | NA | NA |
| AP-26 | 0.0004 | NA | NA |
| AP-27 | 0.0031 | NA | NA |
| AP-28 | 0.0004 | NA | NA |
| AP-29 | 0.0002 | NA | NA |
| AP-31 | 0.0005 | NA | NA |
| AP-32 | 0.0002 | NA | NA |
| AP-33 | 0.0016 | NA | NA |
| AP-34 | 0.0023 | NA | NA |
| AP-35 | 0.0027 | NA | NA |

**Table C-11** (continued).

| Site | Energy Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| AP-36 | 0.0001 | NA | NA |
| AP-37 | 0.0005 | NA | NA |
| AP-38 | 0.0093 | NA | NA |
| AP-39 | 0.0003 | NA | NA |
| AP-40 | 0.0003 | 0.0003 | NA |
| AP-41 | 7.0E-05 | NA | NA |
| AP-42 | 0.0010 | NA | NA |
| AP-43 | 0.0026 | NA | NA |
| AP-45 | 0.0002 | NA | NA |
| AP-46 | 0.0006 | NA | NA |
| AP-47 | 6.8E-05 | NA | NA |
| GC-1 | 0.0039 | 0.0035 | 0.0034 |
| GC-2 | 0.0008 | 0.0007 | 0.0007 |
| GC-3 | 0.0122 | NA | NA |
| GC-4 | 0.0006 | 0.0005 | 0.0005 |
| GC-5 | 0.0036 | 0.0032 | 0.0031 |
| GC-6 | 0.0017 | 0.0015 | 0.0015 |
| GC-7 | 0.0015 | NA | NA |
| GC-8 | 0.0009 | NA | NA |
| GC-9 | 5.2E-05 | 4.7E-05 | 4.5E-05 |
| GC-10 | 0.0006 | NA | NA |
| GC-11 | 0.0003 | NA | NA |
| GC-12 | 0.0007 | NA | NA |
| GC-13 | 0.0018 | NA | NA |
| GC-14 | 0.0011 | 0.0009 | 0.0009 |
| GC-15 | 0.0008 | NA | NA |
| GC-16 | 0.0019 | 0.0017 | 0.0016 |
| GC-17 | 0.0011 | NA | NA |
| GC-18 | 0.0003 | NA | NA |
| GC-19 | 0.0012 | NA | NA |
| GC-20 | 0.0011 | NA | NA |
| GC-21 | 0.0002 | NA | NA |
| GC-22 | 0.0053 | NA | NA |
| GC-23 | 0.0001 | NA | NA |
| GC-24 | 0.0014 | 0.0013 | 0.0012 |
| GC-25 | 0.0320 | 0.0279 | NA |

**Table C-11** (continued).

| Site | Energy Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| GC-26 | 0.0007 | 0.0006 | 0.0006 |
| GC-27 | 0.0074 | 0.0064 | NA |
| GC-28 | 0.0003 | NA | NA |
| GC-29 | 0.0039 | NA | NA |
| GC-30 | 0.0015 | NA | NA |
| GC-31 | 0.0003 | 0.0002 | 0.0002 |
| GC-32 | 0.0008 | NA | NA |
| GC-33 | 0.0013 | NA | NA |
| GC-34 | 0.0007 | NA | NA |
| GC-35 | 0.0050 | NA | NA |
| GC-36 | 0.0266 | NA | NA |
| GC-37 | 0.0001 | 9.8E-05 | 9.6E-05 |
| GC-38 | 0.0010 | NA | NA |
| GC-39 | 0.0151 | NA | NA |
| GC-40 | 0.0111 | NA | NA |
| GC-41 | 0.1082 | NA | NA |
| GC-42 | 0.0121 | NA | NA |
| GC-43 | 0.0059 | NA | NA |
| GC-44 | 0.0006 | 0.0005 | NA |
| GC-45 | 0.0197 | 0.0173 | NA |
| GC-46 | 0.0016 | 0.0014 | 0.0014 |
| GC-47 | 0.0200 | 0.0174 | NA |
| GC-48 | 0.0060 | NA | NA |
| GC-49 | 0.0222 | 0.0193 | NA |
| GC-50 | 0.0004 | NA | NA |
| GC-51 | 0.0183 | 0.0158 | NA |
| GC-52 | 0.0007 | NA | NA |
| GC-53 | 0.0071 | NA | NA |
| GC-54 | 0.0002 | 0.0002 | 0.0001 |
| GC-55 | 0.0003 | NA | NA |
| GC-56 | 0.0012 | NA | NA |
| GC-57 | 0.0003 | NA | NA |
| GC-58 | 0.0049 | NA | NA |
| MC-1 | 0.0083 | 0.0074 | 0.0069 |
| MC-4 | 0.0016 | 0.0015 | NA |
| MC-5 | 0.3691 | 0.3284 | NA |

**Table C-11** (continued).

| Site | Energy Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| MC-6 | 0.0160 | 0.0142 | 0.0133 |
| MC-7 | 0.0062 | NA | NA |
| MC-8 | 0.0056 | NA | NA |
| MC-9 | 0.0216 | NA | NA |
| MC-10 | 0.0006 | NA | NA |
| MC-11 | 0.0072 | NA | NA |
| MC-12 | 0.0125 | 0.0111 | 0.0104 |
| MC-13 | 0.0216 | NA | NA |
| MC-14 | 0.0209 | 0.0187 | NA |
| MC-16 | 0.0078 | 0.0069 | 0.0065 |
| MC-17 | 0.0056 | NA | NA |
| MC-18 | 0.0022 | NA | NA |
| MC-19 | 0.0062 | NA | NA |
| MC-20 | 0.0035 | 0.0031 | 0.0029 |
| MC-21 | 0.0041 | 0.0037 | 0.0034 |
| MC-22 | 0.0097 | NA | NA |
| MC-23 | 0.0008 | NA | NA |
| MC-24 | 0.0045 | NA | NA |
| MC-25 | 0.0012 | NA | NA |
| MC-26 | 0.0034 | NA | NA |
| RM-2 | 0.0007 | 0.0007 | 0.0007 |
| RM-3 | 0.0037 | 0.0033 | 0.0033 |
| RM-4 | 0.0002 | 0.0002 | 0.0002 |
| RM-5 | 0.0471 | 0.0416 | 0.0412 |
| RM-6 | 0.0553 | 0.0488 | 0.0483 |
| RM-7 | 0.0495 | 0.0439 | 0.0433 |
| RM-8 | 0.0012 | 0.0010 | 0.0010 |
| RM-9 | 0.0004 | 0.0004 | 0.0003 |
| RM-10 | 0.0047 | 0.0042 | 0.0041 |
| RM-11 | 7.4E-05 | 6.6E-05 | 6.5E-05 |
| RM-12 | 0.0008 | 0.0007 | 0.0007 |
| RM-13 | 1.2E-05 | 1.1E-05 | 1.0E-05 |
| RM-14 | 0.0131 | 0.0116 | 0.0115 |
| RM-15 | 0 | 0 | 0 |
| RM-16 | 0.0024 | 0.0021 | 0.0021 |
| RM-17 | 0.0016 | 0.0015 | 0.0014 |

**Table C-11** (continued).

| Site | Energy Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| RM-18 | 0.0016 | 0.0014 | 0.0014 |
| RM-19 | 0.0017 | 0.0015 | 0.0015 |

### *C.6 Price based allocation of emissions*

Once production is split into each of the salable products (Natural Gas, Natural Gas Liquids, and Oil), as discussed in section C4, Estimated Ultimate Recovery is converted from a mass basis into a price base, using the conversion factors from section C1. Allocation of emissions is determined based on the price of each salable product.

Table C-12 shows the fraction of production for each of the salable products (price basis). Table C-13 shows the allocation of emissions from pneumatic controllers, pneumatic pumps, and equipment leaks over a 30 year period to each of the salable products, based. Table C-14 reports the ratio of allocated emissions to production for each of the three products: Natural Gas, Natural Gas Liquids, and Oil.

**Table C-12.** Fraction of production by product (price basis).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production price basis) | Natural Gas Liquids, fraction of total production price basis) | Oil, fraction of total production price basis) |
|---|---|---|---|---|---|
| AP-1 | 59,005 | 0 | 1 | 0 | 0 |
| AP-2 | 211,289 | 0 | 1 | 0 | 0 |
| AP-3 | 576,497 | 0 | 1 | 0 | 0 |
| AP-4 | 836,980 | 0 | 1 | 0 | 0 |
| AP-5 | 136,625 | 0 | 1 | 0 | 0 |
| AP-6 | 516,860 | 0 | 1 | 0 | 0 |
| AP-7 | 565,897 | 0 | 1 | 0 | 0 |
| AP-8 | 87,743 | 1,037 | 0.38 | 0.59 | 0.03 |
| AP-9 | 455,027 | 0 | 1 | 0 | 0 |
| AP-10 | 614,983 | 0 | 1 | 0 | 0 |
| AP-11 | 113,272 | 0 | 1 | 0 | 0 |
| AP-12 | 160,139 | 0 | 0.99 | 0.01 | 0 |
| AP-13 | 599,499 | 0 | 1 | 0 | 0 |
| AP-14 | 387,376 | 0 | 1 | 0 | 0 |
| AP-15 | 184,176 | 0 | 1 | 0 | 0 |
| AP-16 | 128,401 | 0 | 1 | 0 | 0 |
| AP-17 | 176,088 | 0 | 1 | 0 | 0 |
| AP-18 | 988,031 | 0 | 1 | 0 | 0 |
| AP-19 | 410,082 | 0 | 1 | 0 | 0 |
| AP-20 | 305,353 | 0 | 1 | 0 | 0 |
| AP-21 | 147,975 | 0 | 1 | 0 | 0 |
| AP-22 | 1,523,474 | 0 | 1 | 0 | 0 |
| AP-23 | 529,064 | 0 | 1 | 0 | 0 |
| AP-24 | 3,140,582 | 0 | 1 | 0 | 0 |
| AP-25 | 217,440 | 0 | 1 | 0 | 0 |
| AP-26 | 540,977 | 0 | 1 | 0 | 0 |
| AP-27 | 281,558 | 0 | 1 | 0 | 0 |
| AP-28 | 105,196 | 0 | 1 | 0 | 0 |
| AP-29 | 773,016 | 0 | 1 | 0 | 0 |
| AP-31 | 540,977 | 0 | 1 | 0 | 0 |
| AP-32 | 605,927 | 0 | 1 | 0 | 0 |
| AP-33 | 1,417,505 | 0 | 1 | 0 | 0 |
| AP-34 | 975,788 | 0 | 1 | 0 | 0 |
| AP-35 | 141,472 | 0 | 1 | 0 | 0 |
| AP-36 | 62,444 | 0 | 1 | 0 | 0 |
| AP-37 | 347,208 | 0 | 1 | 0 | 0 |

**Table C-12** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production price basis) | Natural Gas Liquids, fraction of total production price basis) | Oil, fraction of total production price basis) |
|---|---|---|---|---|---|
| AP-38 | 53,663 | 0 | 1 | 0 | 0 |
| AP-39 | 1,477,859 | 0 | 1 | 0 | 0 |
| AP-40 | 220,702 | 0 | 0.94 | 0.06 | 0 |
| AP-41 | 437,108 | 0 | 1 | 0 | 0 |
| AP-42 | 1,121,524 | 0 | 1 | 0 | 0 |
| AP-43 | 352,842 | 0 | 1 | 0 | 0 |
| AP-45 | 209,670 | 0 | 1 | 0 | 0 |
| AP-46 | 430,507 | 0 | 1 | 0 | 0 |
| AP-47 | 640,901 | 0 | 1 | 0 | 0 |
| GC-1 | 16,390 | 94,298 | 0.02 | 0.04 | 0.93 |
| GC-2 | 356,441 | 511,946 | 0.07 | 0.16 | 0.76 |
| GC-3 | 27,566 | 0 | 1 | 0 | 0 |
| GC-4 | 855,109 | 455,392 | 0.15 | 0.30 | 0.55 |
| GC-5 | 241,501 | 402,361 | 0.07 | 0.14 | 0.79 |
| GC-6 | 403,970 | 197,954 | 0.19 | 0.26 | 0.55 |
| GC-7 | 96,687 | 0 | 1 | 0 | 0 |
| GC-8 | 84,653 | 0 | 1 | 0 | 0 |
| GC-9 | 1,140,739 | 413,697 | 0.22 | 0.30 | 0.48 |
| GC-10 | 1,495,472 | 0 | 1 | 0 | 0 |
| GC-11 | 506,093 | 0 | 1 | 0 | 0 |
| GC-12 | 1,105,696 | 0 | 1 | 0 | 0 |
| GC-13 | 139,183 | 0 | 1 | 0 | 0 |
| GC-14 | 480,788 | 400,389 | 0.09 | 0.27 | 0.64 |
| GC-15 | 1,176,216 | 0 | 1 | 0 | 0 |
| GC-16 | 221,711 | 796,204 | 0.04 | 0.06 | 0.90 |
| GC-17 | 1,028,161 | 0 | 1 | 0 | 0 |
| GC-18 | 1,018,236 | 0 | 1 | 0 | 0 |
| GC-19 | 938,788 | 0 | 1 | 0 | 0 |
| GC-20 | 64,113 | 0 | 1 | 0 | 0 |
| GC-21 | 86,101 | 0 | 1 | 0 | 0 |
| GC-22 | 65,716 | 0 | 1 | 0 | 0 |
| GC-23 | 433,391 | 0 | 1 | 0 | 0 |
| GC-24 | 286,622 | 234,422 | 0.11 | 0.24 | 0.65 |
| GC-25 | 7,203 | 0 | 0.87 | 0.13 | 0 |
| GC-26 | 1,174,402 | 221,271 | 0.30 | 0.38 | 0.33 |
| GC-27 | 24,168 | 0 | 0.90 | 0.10 | 0 |

**Table C-12** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production price basis) | Natural Gas Liquids, fraction of total production price basis) | Oil, fraction of total production price basis) |
|---|---|---|---|---|---|
| GC-28 | 782,134 | 0 | 1 | 0 | 0 |
| GC-29 | 50,244 | 0 | 1 | 0 | 0 |
| GC-30 | 321,101 | 0 | 1 | 0 | 0 |
| GC-31 | 357,985 | 530,696 | 0.10 | 0.11 | 0.80 |
| GC-32 | 386,840 | 0 | 1 | 0 | 0 |
| GC-33 | 103,660 | 0 | 1 | 0 | 0 |
| GC-34 | 1,265,190 | 0 | 1 | 0 | 0 |
| GC-35 | 323,297 | 0 | 1 | 0 | 0 |
| GC-36 | 22,905 | 0 | 1 | 0 | 0 |
| GC-37 | 581,859 | 506,710 | 0.10 | 0.24 | 0.66 |
| GC-38 | 119,358 | 0 | 1 | 0 | 0 |
| GC-39 | 106,442 | 0 | 1 | 0 | 0 |
| GC-40 | 16,306 | 0 | 1 | 0 | 0 |
| GC-41 | 7,027 | 0 | 1 | 0 | 0 |
| GC-42 | 44,292 | 0 | 1 | 0 | 0 |
| GC-43 | 22,216 | 0 | 1 | 0 | 0 |
| GC-44 | 7,344 | 0 | 0.79 | 0.21 | 0 |
| GC-45 | 5,638 | 0 | 0.71 | 0.29 | 0 |
| GC-46 | 89,328 | 1,698 | 0.65 | 0.29 | 0.06 |
| GC-47 | 15,016 | 0 | 0.82 | 0.18 | 0 |
| GC-48 | 24,479 | 0 | 1 | 0 | 0 |
| GC-49 | 13,474 | 0 | 0.82 | 0.18 | 0 |
| GC-50 | 347,560 | 0 | 1 | 0 | 0 |
| GC-51 | 18,222 | 0 | 0.83 | 0.17 | 0 |
| GC-52 | 735,815 | 0 | 1 | 0 | 0 |
| GC-53 | 63,836 | 0 | 1 | 0 | 0 |
| GC-54 | 146,328 | 247,524 | 0.09 | 0.09 | 0.82 |
| GC-55 | 2,273,091 | 0 | 1 | 0 | 0 |
| GC-56 | 107,109 | 0 | 1 | 0 | 0 |
| GC-57 | 868,706 | 0 | 1 | 0 | 0 |
| GC-58 | 174,867 | 0 | 1 | 0 | 0 |
| MC-1 | 55,705 | 16,021 | 0.22 | 0.38 | 0.40 |
| MC-4 | 256,972 | 0 | 0.92 | 0.08 | 0 |
| MC-5 | 811 | 0 | 0.42 | 0.58 | 0 |
| MC-6 | 94,923 | 11,371 | 0.37 | 0.40 | 0.24 |
| MC-7 | 10,182 | 0 | 1 | 0 | 0 |

**Table C-12** (continued).

| Site | Gas EUR (Mg) (30-yr well lifetime) | Oil EUR (Mg) (30-yr well lifetime) | Natural Gas, fraction of total production price basis) | Natural Gas Liquids, fraction of total production price basis) | Oil, fraction of total production price basis) |
|---|---|---|---|---|---|
| MC-8 | 90,266 | 0 | 1 | 0 | 0 |
| MC-9 | 21,572 | 0 | 1 | 0 | 0 |
| MC-10 | 162,090 | 0 | 1 | 0 | 0 |
| MC-11 | 123,083 | 0 | 1 | 0 | 0 |
| MC-12 | 25,449 | 17,387 | 0.14 | 0.25 | 0.61 |
| MC-13 | 54,485 | 0 | 1 | 0 | 0 |
| MC-14 | 15,015 | 0 | 0.46 | 0.54 | 0 |
| MC-16 | 60,746 | 12,271 | 0.31 | 0.34 | 0.34 |
| MC-17 | 316,873 | 0 | 1 | 0 | 0 |
| MC-18 | 83,731 | 0 | 1 | 0 | 0 |
| MC-19 | 175,342 | 0 | 1 | 0 | 0 |
| MC-20 | 115,581 | 13,888 | 0.36 | 0.41 | 0.23 |
| MC-21 | 35,790 | 43,603 | 0.11 | 0.13 | 0.76 |
| MC-22 | 432,029 | 0 | 1 | 0 | 0 |
| MC-23 | 535,876 | 0 | 1 | 0 | 0 |
| MC-24 | 36,863 | 0 | 1 | 0 | 0 |
| MC-25 | 132,448 | 0 | 1 | 0 | 0 |
| MC-26 | 32,519 | 0 | 1 | 0 | 0 |
| RM-2 | 32,012 | 8,346 | 0.22 | 0.39 | 0.39 |
| RM-3 | 8,514 | 1,437 | 0.26 | 0.45 | 0.29 |
| RM-4 | 28,973 | 23,968 | 0.13 | 0.20 | 0.67 |
| RM-5 | 28,120 | 6,854 | 0.23 | 0.40 | 0.37 |
| RM-6 | 12,352 | 1,453 | 0.28 | 0.50 | 0.22 |
| RM-7 | 11,639 | 2,205 | 0.33 | 0.32 | 0.34 |
| RM-8 | 14,976 | 14,023 | 0.11 | 0.20 | 0.69 |
| RM-9 | 18,939 | 3,958 | 0.24 | 0.42 | 0.34 |
| RM-10 | 26,929 | 8,271 | 0.21 | 0.37 | 0.43 |
| RM-11 | 20,718 | 1,078 | 0.34 | 0.55 | 0.11 |
| RM-12 | 4,950 | 2,999 | 0.15 | 0.26 | 0.60 |
| RM-13 | 27,789 | 28,837 | 0.11 | 0.17 | 0.72 |
| RM-14 | 46,480 | 7,367 | 0.26 | 0.46 | 0.28 |
| RM-15 | 87,746 | 56,512 | 0.12 | 0.28 | 0.60 |
| RM-16 | 3,705 | 975 | 0.22 | 0.39 | 0.39 |
| RM-17 | 187,763 | 27,717 | 0.24 | 0.51 | 0.25 |
| RM-18 | 22,627 | 7,387 | 0.20 | 0.36 | 0.44 |
| RM-19 | 45,346 | 7,367 | 0.28 | 0.44 | 0.29 |

**Table C-13.** Allocation of total (sum of emissions from pneumatic controllers, pneumatic pumps, and equipment leaks) emissions (Mg) by product (price basis) over a 30 year well lifetime.

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| AP-1 | 38.15 | 0 | 0 |
| AP-2 | 41.17 | 0 | 0 |
| AP-3 | 262.4 | 0 | 0 |
| AP-4 | 90.22 | 0 | 0 |
| AP-5 | 31.49 | 0 | 0 |
| AP-6 | 66.60 | 0 | 0 |
| AP-7 | 164.1 | 0 | 0 |
| AP-8 | 64.84 | 98.86 | 4.775 |
| AP-9 | 670.9 | 0 | 0 |
| AP-10 | 674.5 | 0 | 0 |
| AP-11 | 11.35 | 0 | 0 |
| AP-12 | 118.6 | 1.260 | 0 |
| AP-13 | 298.5 | 0 | 0 |
| AP-14 | 70.54 | 0 | 0 |
| AP-15 | 0 | 0 | 0 |
| AP-16 | 65.39 | 0 | 0 |
| AP-17 | 353.3 | 0 | 0 |
| AP-18 | 87.49 | 0 | 0 |
| AP-19 | 116.0 | 0 | 0 |
| AP-20 | 0 | 0 | 0 |
| AP-21 | 153.2 | 0 | 0 |
| AP-22 | 310.6 | 0 | 0 |
| AP-23 | 320.6 | 0 | 0 |
| AP-24 | 106.3 | 0 | 0 |
| AP-25 | 1,758 | 0 | 0 |
| AP-26 | 195.3 | 0 | 0 |
| AP-27 | 848.0 | 0 | 0 |
| AP-28 | 43.60 | 0 | 0 |
| AP-29 | 163.8 | 0 | 0 |
| AP-31 | 254.9 | 0 | 0 |
| AP-32 | 98.70 | 0 | 0 |
| AP-33 | 2,164 | 0 | 0 |
| AP-34 | 2,184 | 0 | 0 |
| AP-35 | 380.4 | 0 | 0 |
| AP-36 | 9.082 | 0 | 0 |
| AP-37 | 181.3 | 0 | 0 |
| AP-38 | 494.7 | 0 | 0 |

**Table C-13** (continued).

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| AP-39 | 406.3 | 0 | 0 |
| AP-40 | 60.74 | 4.052 | 0 |
| AP-41 | 29.97 | 0 | 0 |
| AP-42 | 1,052 | 0 | 0 |
| AP-43 | 893.7 | 0 | 0 |
| AP-45 | 42.38 | 0 | 0 |
| AP-46 | 272.5 | 0 | 0 |
| AP-47 | 42.69 | 0 | 0 |
| GC-1 | 9.305 | 16.74 | 356.9 |
| GC-2 | 45.79 | 105.4 | 489.1 |
| GC-3 | 337.3 | 0 | 0 |
| GC-4 | 105.0 | 213.2 | 392.6 |
| GC-5 | 137.8 | 290.2 | 1,640 |
| GC-6 | 174.7 | 239.6 | 514.5 |
| GC-7 | 148.3 | 0 | 0 |
| GC-8 | 75.38 | 0 | 0 |
| GC-9 | 16.51 | 22.61 | 35.97 |
| GC-10 | 847.7 | 0 | 0 |
| GC-11 | 158.0 | 0 | 0 |
| GC-12 | 755.7 | 0 | 0 |
| GC-13 | 252.2 | 0 | 0 |
| GC-14 | 77.51 | 226.4 | 543.8 |
| GC-15 | 953.2 | 0 | 0 |
| GC-16 | 67.47 | 101.6 | 1,504 |
| GC-17 | 1,082 | 0 | 0 |
| GC-18 | 298.5 | 0 | 0 |
| GC-19 | 1,132 | 0 | 0 |
| GC-20 | 72.66 | 0 | 0 |
| GC-21 | 13.32 | 0 | 0 |
| GC-22 | 347.2 | 0 | 0 |
| GC-23 | 45.41 | 0 | 0 |
| GC-24 | 70.67 | 162.3 | 430.1 |
| GC-25 | 193.5 | 29.93 | 0 |
| GC-26 | 270.2 | 343.6 | 298.7 |
| GC-27 | 155.6 | 17.55 | 0 |
| GC-28 | 213.2 | 0 | 0 |
| GC-29 | 193.2 | 0 | 0 |
| GC-30 | 479.2 | 0 | 0 |
| GC-31 | 20.71 | 23.56 | 173.7 |

**Table C-13** (continued).

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| GC-32 | 294.3 | 0 | 0 |
| GC-33 | 139.3 | 0 | 0 |
| GC-34 | 845.6 | 0 | 0 |
| GC-35 | 1,618 | 0 | 0 |
| GC-36 | 607.9 | 0 | 0 |
| GC-37 | 10.75 | 26.05 | 71.59 |
| GC-38 | 119.3 | 0 | 0 |
| GC-39 | 1,591 | 0 | 0 |
| GC-40 | 180.7 | 0 | 0 |
| GC-41 | 751.1 | 0 | 0 |
| GC-42 | 534.6 | 0 | 0 |
| GC-43 | 129.3 | 0 | 0 |
| GC-44 | 3.349 | 0.8891 | 0 |
| GC-45 | 75.60 | 31.27 | 0 |
| GC-46 | 90.06 | 40.09 | 7.903 |
| GC-47 | 238.6 | 52.08 | 0 |
| GC-48 | 147.7 | 0 | 0 |
| GC-49 | 237.1 | 51.75 | 0 |
| GC-50 | 144.1 | 0 | 0 |
| GC-51 | 266.5 | 55.33 | 0 |
| GC-52 | 540.4 | 0 | 0 |
| GC-53 | 455.9 | 0 | 0 |
| GC-54 | 5.478 | 5.347 | 50.13 |
| GC-55 | 594.0 | 0 | 0 |
| GC-56 | 132.6 | 0 | 0 |
| GC-57 | 227.7 | 0 | 0 |
| GC-58 | 848.4 | 0 | 0 |
| MC-1 | 119.4 | 209.4 | 218.5 |
| MC-4 | 374.3 | 31.11 | 0 |
| MC-5 | 119.2 | 163.6 | 0 |
| MC-6 | 582.2 | 632.0 | 375.2 |
| MC-7 | 62.67 | 0 | 0 |
| MC-8 | 498.6 | 0 | 0 |
| MC-9 | 459.3 | 0 | 0 |
| MC-10 | 94.46 | 0 | 0 |
| MC-11 | 871.0 | 0 | 0 |
| MC-12 | 66.44 | 120.1 | 292.4 |
| MC-13 | 1,161 | 0 | 0 |
| MC-14 | 135.7 | 162.2 | 0 |

**Table C-13** (continued).

| Site | Natural Gas | Natural Gas Liquids | Oil |
|---|---|---|---|
| MC-16 | 165.7 | 181.8 | 180.5 |
| MC-17 | 1,762 | 0 | 0 |
| MC-18 | 181.3 | 0 | 0 |
| MC-19 | 1,065 | 0 | 0 |
| MC-20 | 149.3 | 171.8 | 98.10 |
| MC-21 | 33.37 | 37.23 | 220.5 |
| MC-22 | 4,140 | 0 | 0 |
| MC-23 | 413.2 | 0 | 0 |
| MC-24 | 164.1 | 0 | 0 |
| MC-25 | 152.0 | 0 | 0 |
| MC-26 | 110.2 | 0 | 0 |
| RM-2 | 6.166 | 10.89 | 10.80 |
| RM-3 | 8.985 | 15.47 | 10.05 |
| RM-4 | 1.423 | 2.236 | 7.543 |
| RM-5 | 345.8 | 610.9 | 566.1 |
| RM-6 | 199.5 | 352.3 | 157.6 |
| RM-7 | 214.2 | 207.0 | 221.8 |
| RM-8 | 3.444 | 6.084 | 21.66 |
| RM-9 | 2.033 | 3.591 | 2.853 |
| RM-10 | 31.79 | 56.15 | 65.56 |
| RM-11 | 0.5082 | 0.8338 | 0.1717 |
| RM-12 | 0.8416 | 1.487 | 3.424 |
| RM-13 | 0.0648 | 0.1055 | 0.4353 |
| RM-14 | 171.5 | 302.9 | 182.5 |
| RM-15 | 0 | 0 | 0 |
| RM-16 | 2.271 | 4.011 | 4.011 |
| RM-17 | 78.37 | 166.7 | 83.73 |
| RM-18 | 8.792 | 15.53 | 19.27 |
| RM-19 | 22.96 | 36.09 | 23.90 |

**Table C-14.** Ratio of methane emissions (over a 30 year period) to estimated ultimate recovery of Natural Gas, Natural Gas Liquid, and Oil (price Basis) over a 30 year well lifetime:

| Site | Price Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| AP-1 | 0.0007 | NA | NA |
| AP-2 | 0.0002 | NA | NA |
| AP-3 | 0.0005 | NA | NA |
| AP-4 | 0.0001 | NA | NA |
| AP-5 | 0.0002 | NA | NA |
| AP-6 | 0.0001 | NA | NA |
| AP-7 | 0.0003 | NA | NA |
| AP-8 | 0.0012 | 0.0031 | 0.0046 |
| AP-9 | 0.0015 | NA | NA |
| AP-10 | 0.0011 | NA | NA |
| AP-11 | 0.0001 | NA | NA |
| AP-12 | 0.0008 | 0.0019 | NA |
| AP-13 | 0.0005 | NA | NA |
| AP-14 | 0.0002 | NA | NA |
| AP-15 | 0.0E+00 | NA | NA |
| AP-16 | 0.0005 | NA | NA |
| AP-17 | 0.0020 | NA | NA |
| AP-18 | 9.1E-05 | NA | NA |
| AP-19 | 0.0003 | NA | NA |
| AP-20 | 0.0E+00 | NA | NA |
| AP-21 | 0.0011 | NA | NA |
| AP-22 | 0.0002 | NA | NA |
| AP-23 | 0.0006 | NA | NA |
| AP-24 | 3.5E-05 | NA | NA |
| AP-25 | 0.0082 | NA | NA |
| AP-26 | 0.0004 | NA | NA |
| AP-27 | 0.0031 | NA | NA |
| AP-28 | 0.0004 | NA | NA |
| AP-29 | 0.0002 | NA | NA |
| AP-31 | 0.0005 | NA | NA |
| AP-32 | 0.0002 | NA | NA |
| AP-33 | 0.0016 | NA | NA |
| AP-34 | 0.0023 | NA | NA |
| AP-35 | 0.0027 | NA | NA |

**Table C-14** (continued).

| Site | Price Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| AP-36 | 0.0001 | NA | NA |
| AP-37 | 0.0005 | NA | NA |
| AP-38 | 0.0093 | NA | NA |
| AP-39 | 0.0003 | NA | NA |
| AP-40 | 0.0003 | 0.0007 | NA |
| AP-41 | 7.0E-05 | NA | NA |
| AP-42 | 0.0010 | NA | NA |
| AP-43 | 0.0026 | NA | NA |
| AP-45 | 0.0002 | NA | NA |
| AP-46 | 0.0006 | NA | NA |
| AP-47 | 6.8E-05 | NA | NA |
| GC-1 | 0.0010 | 0.0025 | 0.0038 |
| GC-2 | 0.0002 | 0.0006 | 0.0010 |
| GC-3 | 0.0122 | NA | NA |
| GC-4 | 0.0002 | 0.0006 | 0.0009 |
| GC-5 | 0.0011 | 0.0027 | 0.0041 |
| GC-6 | 0.0007 | 0.0017 | 0.0026 |
| GC-7 | 0.0015 | NA | NA |
| GC-8 | 0.0009 | NA | NA |
| GC-9 | 2.3E-05 | 5.7E-05 | 8.7E-05 |
| GC-10 | 0.0006 | NA | NA |
| GC-11 | 0.0003 | NA | NA |
| GC-12 | 0.0007 | NA | NA |
| GC-13 | 0.0018 | NA | NA |
| GC-14 | 0.0004 | 0.0009 | 0.0014 |
| GC-15 | 0.0008 | NA | NA |
| GC-16 | 0.0005 | 0.0012 | 0.0019 |
| GC-17 | 0.0011 | NA | NA |
| GC-18 | 0.0003 | NA | NA |
| GC-19 | 0.0012 | NA | NA |
| GC-20 | 0.0011 | NA | NA |
| GC-21 | 0.0002 | NA | NA |
| GC-22 | 0.0053 | NA | NA |
| GC-23 | 0.0001 | NA | NA |
| GC-24 | 0.0005 | 0.0012 | 0.0018 |
| GC-25 | 0.0293 | 0.0721 | NA |

**Table C-14** (continued).

| Site | Price Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| GC-26 | 0.0004 | 0.0009 | 0.0013 |
| GC-27 | 0.0069 | 0.0168 | NA |
| GC-28 | 0.0003 | NA | NA |
| GC-29 | 0.0039 | NA | NA |
| GC-30 | 0.0015 | NA | NA |
| GC-31 | 8.5E-05 | 0.0002 | 0.0003 |
| GC-32 | 0.0008 | NA | NA |
| GC-33 | 0.0013 | NA | NA |
| GC-34 | 0.0007 | NA | NA |
| GC-35 | 0.0050 | NA | NA |
| GC-36 | 0.0266 | NA | NA |
| GC-37 | 3.7E-05 | 9.2E-05 | 0.0001 |
| GC-38 | 0.0010 | NA | NA |
| GC-39 | 0.0151 | NA | NA |
| GC-40 | 0.0111 | NA | NA |
| GC-41 | 0.1082 | NA | NA |
| GC-42 | 0.0121 | NA | NA |
| GC-43 | 0.0059 | NA | NA |
| GC-44 | 0.0005 | 0.0012 | NA |
| GC-45 | 0.0160 | 0.0397 | NA |
| GC-46 | 0.0012 | 0.0030 | 0.0047 |
| GC-47 | 0.0177 | 0.0435 | NA |
| GC-48 | 0.0060 | NA | NA |
| GC-49 | 0.0196 | 0.0482 | NA |
| GC-50 | 0.0004 | NA | NA |
| GC-51 | 0.0163 | 0.0397 | NA |
| GC-52 | 0.0007 | NA | NA |
| GC-53 | 0.0071 | NA | NA |
| GC-54 | 5.3E-05 | 0.0001 | 0.0002 |
| GC-55 | 0.0003 | NA | NA |
| GC-56 | 0.0012 | NA | NA |
| GC-57 | 0.0003 | NA | NA |
| GC-58 | 0.0049 | NA | NA |
| MC-1 | 0.0037 | 0.0093 | 0.0136 |
| MC-4 | 0.0015 | 0.0040 | NA |
| MC-5 | 0.2312 | 0.5809 | NA |

**Table C-14** (continued).

| Site | Price Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| MC-6 | 0.0089 | 0.0225 | 0.0330 |
| MC-7 | 0.0062 | NA | NA |
| MC-8 | 0.0056 | NA | NA |
| MC-9 | 0.0216 | NA | NA |
| MC-10 | 0.0006 | NA | NA |
| MC-11 | 0.0072 | NA | NA |
| MC-12 | 0.0046 | 0.0114 | 0.0168 |
| MC-13 | 0.0216 | NA | NA |
| MC-14 | 0.0136 | 0.0342 | NA |
| MC-16 | 0.0040 | 0.0100 | 0.0147 |
| MC-17 | 0.0056 | NA | NA |
| MC-18 | 0.0022 | NA | NA |
| MC-19 | 0.0062 | NA | NA |
| MC-20 | 0.0019 | 0.0048 | 0.0071 |
| MC-21 | 0.0014 | 0.0034 | 0.0051 |
| MC-22 | 0.0097 | NA | NA |
| MC-23 | 0.0008 | NA | NA |
| MC-24 | 0.0045 | NA | NA |
| MC-25 | 0.0012 | NA | NA |
| MC-26 | 0.0034 | NA | NA |
| RM-2 | 0.0003 | 0.0008 | 0.0013 |
| RM-3 | 0.0018 | 0.0045 | 0.0070 |
| RM-4 | 8.1E-05 | 0.0002 | 0.0003 |
| RM-5 | 0.0213 | 0.0532 | 0.0826 |
| RM-6 | 0.0280 | 0.0698 | 0.1084 |
| RM-7 | 0.0260 | 0.0651 | 0.1006 |
| RM-8 | 0.0004 | 0.0010 | 0.0015 |
| RM-9 | 0.0002 | 0.0005 | 0.0007 |
| RM-10 | 0.0020 | 0.0051 | 0.0079 |
| RM-11 | 4.1E-05 | 0.0001 | 0.0002 |
| RM-12 | 0.0003 | 0.0007 | 0.0011 |
| RM-13 | 3.9E-06 | 9.8E-06 | 1.5E-05 |
| RM-14 | 0.0064 | 0.0160 | 0.0248 |
| RM-15 | 0 | 0 | 0 |
| RM-16 | 0.0011 | 0.0027 | 0.0041 |
| RM-17 | 0.0008 | 0.0020 | 0.0030 |

**Table C-14** (continued).

| Site | Price Basis | | |
|---|---|---|---|
| | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| RM-18 | 0.0007 | 0.0017 | 0.0026 |
| RM-19 | 0.0008 | 0.0021 | 0.0032 |

### *C.7 Sensitivity Analysis: Ratio of methane (routine) emissions allocated to each product (Natural Gas, Natural Gas Liquids (NGL), and Oil) divided by production for an assumed well lifetime of 15 years*

Tables C-15 to C-17 shows the ratio of total emissions to produced components when a well lifetime of 15 years is assumed instead of the 30 year lifetime.

**Table C-15.** Ratio of methane (routine) emissions allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil) divided by its respective estimated ultimate recovery (15 years well lifetime), based on a **mass allocation**. The values represent the ratio of the sum of emissions divided by the sum of production across all sites where each specific component is produced.

| | **Pneumatic Controllers** | **Pneumatic Pumps** | **Equipment Leaks** | **Total** |
|---|---|---|---|---|
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)** | 0.0005 | 0.0001 | 0.0001 | 0.0007 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)** | 0.0009 | 1.4E-05 | 9.2E-05 | 0.0010 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 0.0007 | 1.2E-06 | 6.7E-05 | 0.0008 |

**Table C-16.** Ratio of methane (routine) emissions allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil) divided by its respective estimated ultimate recovery (15 years well lifetime), based on an **energy allocation**. The values represent the ratio of the sum of emissions divided by the sum of production across all sites where each specific component is produced.

| | **Pneumatic Controllers** | **Pneumatic Pumps** | **Equipment Leaks** | **Total** |
|---|---|---|---|---|
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)** | 0.0005 | 0.0001 | 0.0001 | 0.0007 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)** | 0.0009 | 1.3E-05 | 8.9E-05 | 0.0010 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 0.0007 | 1.1E-06 | 6.4E-05 | 0.0007 |

**Table C-17.** Ratio of methane (routine) emissions allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil) divided by its respective estimated ultimate recovery (15 years well lifetime), based on a **price allocation**. The values represent the ratio of the sum of emissions divided by the sum of production across all sites where each specific component is produced.

| | **Pneumatic Controllers** | **Pneumatic Pumps** | **Equipment Leaks** | **Total** |
|---|---|---|---|---|
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)** | 0.0005 | 0.0001 | 0.0001 | 0.0007 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)** | 0.0011 | 2.9E-05 | 0.0001 | 0.0012 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 0.0010 | 2.5E-06 | 9.8E-05 | 0.0011 |

### *C.8 Sensitivity Analysis: Ratio of methane emissions from routine production allocated to each product (Natural Gas, Natural Gas Liquids (NGL), and Oil) divided by production when daily production at the time of measurement is used instead of estimated ultimate recovery.*

Tables C-18 to C-20 show the ratio of total emissions to produced components, when daily production at the time of the measurement is used instead of estimated ultimate recovery.

**Table C-18.** Ratio of methane daily emissions allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil) divided by its respective daily production, based on a **mass allocation**. The values represent the ratio of the sum of emissions divided by the sum of production across all sites where each specific product is produced.

| | **Pneumatic Controllers** | **Pneumatic Pumps** | **Equipment Leaks** | **Total** |
|---|---|---|---|---|
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)** | 0.0002 | 5.1E-05 | 2.0E-06 | 0.0003 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)** | 0.0002 | 5.7E-06 | 8.4E-07 | 0.0002 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 7.3E-05 | 2.4E-07 | 2.9E-07 | 7.4E-05 |

**Table C-19.** Ratio of methane daily emissions allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil) divided by its respective daily production, based on an **energy allocation**. The values represent the ratio of the sum of emissions divided by the sum of production across all sites where each specific product is produced.

| | **Pneumatic Controllers** | **Pneumatic Pumps** | **Equipment Leaks** | **Total** |
|---|---|---|---|---|
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)** | 0.0002 | 5.1E-05 | 2.0E-06 | 0.0003 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)** | 0.0002 | 5.2E-06 | 8.2E-07 | 0.0002 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 7.2E-05 | 2.3E-07 | 2.9E-07 | 7.2E-05 |

**Table C-20.** Ratio of methane daily emissions allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil) divided by its respective daily production, based on a **price allocation**. The values represent the ratio of the sum of emissions divided by the sum of production across all sites where each specific product is produced.

| | **Pneumatic Controllers** | **Pneumatic Pumps** | **Equipment Leaks** | **Total** |
|---|---|---|---|---|
| **Emitted Methane (scf) /** Produced **Natural Gas (scf)** | 0.0002 | 5.1E-05 | 1.9E-06 | 0.0002 |
| **Emitted Methane (Mg) /** Produced **Natural Gas Liquids (Mg)** | 0.0002 | 1.2E-05 | 9.7E-07 | 0.0002 |
| **Emitted Methane (Mg) /** Produced **Oil (Mg)** | 8.5E-05 | 3.1E-07 | 3.4E-07 | 8.8E-05 |

**Table C-21.** Measured methane emissions and total production for each completion event where measurements were made by Allen, *et al*,[8] and the host company reported production of gas and oil.

| Event | Methane Emissions (Mg) | Gas EUR (Mg) (30-yr) | Oil EUR (Mg) (30-yr) | Gas EUR (Mg) (15-yr) | Oil EUR (Mg) (15-yr) |
|---|---|---|---|---|---|
| AP1 | 0.4992 | 228.5 | 0 | 177.8 | 0 |
| AP2 | 0.1229 | 137,079 | 0 | 106,695 | 0 |
| AP3 | 1.824 | 155,356 | 0 | 120,921 | 0 |
| GC1 | 2.016 | 93,150 | 166,883 | 72,503 | 129,894 |
| GC2 | 1.728 | 83,835 | 159,245 | 65,253 | 123,948 |
| GC3 | 5.376 | 40,365 | 13,187 | 31,418 | 10,264 |
| GC4 | 3.456 | 24,840 | 11,321 | 19,334 | 8,812 |
| GC5 | 0.3322 | 117,441 | 0 | 91,410 | 0 |
| GC6 | 4.742 | 189,404 | 1,851 | 147,423 | 1,441 |
| GC7 | 1.728 | 46,575 | 116,167 | 36,252 | 90,419 |
| MC1 | 3.840 | 30,592 | 10,465 | 23,812 | 8,145 |
| MC2 | 0.5184 | 30,592 | 20,001 | 23,812 | 15,568 |
| MC3 | 0.0518 | 70,334 | 0 | 54,744 | 0 |
| MC4 | 0.0461 | 85,719 | 0 | 66,720 | 0 |
| MC5 | 0.0403 | 83,521 | 0 | 65,009 | 0 |
| RM3 | 0.1997 | 8,884 | 42,210 | 6,915 | 32,854 |
| RM4 | 0.5760 | 8,884 | 47,599 | 6,915 | 37,049 |
| RM5 | 0.7488 | 11,845 | 51,529 | 9,220 | 40,108 |
| RM6 | 0.6528 | 2,961 | 3,983 | 2,305 | 3,100 |

**Table C-22.** Completion flowback emissions. Based on a **mass allocation**, fraction of production for each salable product and methane emissions allocated to each product.

| **Event** | **Natural Gas, fraction of total production (mass basis)** | **Natural Gas Liquids, fraction of total production (mass basis)** | **Oil, fraction of total production (mass basis)** | Emissions allocated to **Natural Gas** (Mg) | Emissions allocated to **Natural Gas Liquids** (Mg) | Emissions allocated to **Oil** (Mg) |
|---|---|---|---|---|---|---|
| AP1 | 1 | 0 | 0 | 0.4992 | 0 | 0 |
| AP2 | 1 | 0 | 0 | 0.1229 | 0 | 0 |
| AP3 | 1 | 0 | 0 | 1.8240 | 0 | 0 |
| GC1 | 0.20 | 0.16 | 0.64 | 0.4061 | 0.3161 | 1.2938 |
| GC2 | 0.19 | 0.15 | 0.66 | 0.3351 | 0.2609 | 1.1320 |
| GC3 | 0.42 | 0.33 | 0.25 | 2.2785 | 1.7737 | 1.3238 |
| GC4 | 0.39 | 0.30 | 0.31 | 1.3349 | 1.0391 | 1.0820 |
| GC5 | 1 | 0 | 0 | 0.3322 | 0 | 0 |
| GC6 | 0.56 | 0.43 | 0.01 | 2.6408 | 2.0557 | 0.0459 |
| GC7 | 0.16 | 0.13 | 0.71 | 0.2781 | 0.2165 | 1.2335 |
| MC1 | 0.68 | 0.07 | 0.25 | 2.6006 | 0.2607 | 0.9787 |
| MC2 | 0.55 | 0.06 | 0.40 | 0.2849 | 0.0286 | 0.2049 |
| MC3 | 1 | 0 | 0 | 0.0518 | 0 | 0 |
| MC4 | 1 | 0 | 0 | 0.0461 | 0 | 0 |
| MC5 | 1 | 0 | 0 | 0.0403 | 0 | 0 |
| RM3 | 0.10 | 0.07 | 0.83 | 0.0209 | 0.0138 | 0.1650 |
| RM4 | 0.09 | 0.06 | 0.84 | 0.0545 | 0.0361 | 0.4854 |
| RM5 | 0.11 | 0.07 | 0.81 | 0.0842 | 0.0558 | 0.6088 |
| RM6 | 0.26 | 0.17 | 0.57 | 0.1674 | 0.1110 | 0.3744 |

**Table C-23.** Completion flowback emissions. Based on an **energy allocation**, fraction of production for each salable product and methane emissions allocated to each product.

| Event | **Natural Gas, fraction of total production (energy basis)** | **Natural Gas Liquids, fraction of total production (energy basis)** | **Oil, fraction of total production (energy basis)** | Emissions allocated to **Natural Gas** (Mg) | Emissions allocated to **Natural Gas Liquids** (Mg) | Emissions allocated to **Oil** (Mg) |
|---|---|---|---|---|---|---|
| AP1 | 1 | 0 | 0 | 0.4992 | 0 | 0 |
| AP2 | 1 | 0 | 0 | 0.1229 | 0 | 0 |
| AP3 | 1 | 0 | 0 | 1.8240 | 0 | 0 |
| GC1 | 0.22 | 0.16 | 0.62 | 0.4441 | 0.3153 | 1.2566 |
| GC2 | 0.21 | 0.15 | 0.64 | 0.3669 | 0.2605 | 1.1007 |
| GC3 | 0.45 | 0.32 | 0.23 | 2.4151 | 1.7147 | 1.2462 |
| GC4 | 0.41 | 0.29 | 0.30 | 1.4223 | 1.0098 | 1.0239 |
| GC5 | 1 | 0 | 0 | 0.3322 | 0 | 0 |
| GC6 | 0.58 | 0.41 | 0.01 | 2.7486 | 1.9514 | 0.0424 |
| GC7 | 0.18 | 0.13 | 0.70 | 0.3059 | 0.2172 | 1.2050 |
| MC1 | 0.71 | 0.06 | 0.23 | 2.7177 | 0.2476 | 0.8747 |
| MC2 | 0.59 | 0.05 | 0.36 | 0.3038 | 0.0277 | 0.1869 |
| MC3 | 1 | 0 | 0 | 0.0518 | 0 | 0 |
| MC4 | 1 | 0 | 0 | 0.0461 | 0 | 0 |
| MC5 | 1 | 0 | 0 | 0.0403 | 0 | 0 |
| RM3 | 0.12 | 0.07 | 0.82 | 0.0230 | 0.0139 | 0.1629 |
| RM4 | 0.10 | 0.06 | 0.83 | 0.0600 | 0.0362 | 0.4798 |
| RM5 | 0.12 | 0.07 | 0.80 | 0.0925 | 0.0558 | 0.6005 |
| RM6 | 0.28 | 0.17 | 0.56 | 0.1808 | 0.1091 | 0.3629 |

**Table C-24.** Completion flowback emissions. Based on a **price allocation**, fraction of production for each salable product and methane emissions allocated to each product.

| **Event** | **Natural Gas, fraction of total production price basis)** | **Natural Gas Liquids, fraction of total production (price basis)** | **Oil, fraction of total production (price basis)** | Emissions allocated to **Natural Gas** (Mg) | Emissions allocated to **Natural Gas Liquids** (Mg) | Emissions allocated to **Oil** (Mg) |
|---|---|---|---|---|---|---|
| AP1 | 1 | 0 | 0 | 0.4992 | 0 | 0 |
| AP2 | 1 | 0 | 0 | 0.1229 | 0 | 0 |
| AP3 | 1 | 0 | 0 | 1.8240 | 0 | 0 |
| GC1 | 0.06 | 0.13 | 0.81 | 0.1298 | 0.2603 | 1.6259 |
| GC2 | 0.06 | 0.12 | 0.82 | 0.1061 | 0.2127 | 1.4092 |
| GC3 | 0.19 | 0.38 | 0.43 | 1.0164 | 2.0380 | 2.3217 |
| GC4 | 0.16 | 0.32 | 0.51 | 0.5582 | 1.1192 | 1.7787 |
| GC5 | 1 | 0 | 0 | 0.3322 | 0 | 0 |
| GC6 | 0.33 | 0.65 | 0.02 | 1.5430 | 3.0939 | 0.1054 |
| GC7 | 0.05 | 0.10 | 0.85 | 0.0845 | 0.1695 | 1.4740 |
| MC1 | 0.37 | 0.10 | 0.53 | 1.4318 | 0.3684 | 2.0398 |
| MC2 | 0.25 | 0.06 | 0.68 | 0.1302 | 0.0335 | 0.3546 |
| MC3 | 1 | 0 | 0 | 0.0518 | 0 | 0 |
| MC4 | 1 | 0 | 0 | 0.0461 | 0 | 0 |
| MC5 | 1 | 0 | 0 | 0.0403 | 0 | 0 |
| RM3 | 0.03 | 0.05 | 0.92 | 0.0059 | 0.0100 | 0.1838 |
| RM4 | 0.03 | 0.04 | 0.93 | 0.0151 | 0.0258 | 0.5351 |
| RM5 | 0.03 | 0.05 | 0.91 | 0.0238 | 0.0406 | 0.6844 |
| RM6 | 0.09 | 0.15 | 0.77 | 0.0563 | 0.0960 | 0.5005 |

**Table C-25.** Ratio of methane emissions from completion flowback events allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil) divided by its estimated ultimate production (EUR), assuming **30 year well-lifetime**, based in a **mass allocation.**

| | **Mass Basis** | | |
|---|---|---|---|
| **Event** | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| AP1 | 0.0022 | NA | NA |
| AP2 | 9.2E-07 | NA | NA |
| AP3 | 1.2E-05 | NA | NA |
| GC1 | 8.0E-06 | 7.8E-06 | 7.8E-06 |
| GC2 | 7.3E-06 | 7.1E-06 | 7.1E-06 |
| GC3 | 0.0001 | 0.0001 | 0.0001 |
| GC4 | 9.8E-05 | 9.6E-05 | 9.6E-05 |
| GC5 | 2.9E-06 | NA | NA |
| GC6 | 2.5E-05 | 2.5E-05 | 2.5E-05 |
| GC7 | 1.1E-05 | 1.1E-05 | 1.1E-05 |
| MC1 | 9.6E-05 | 9.4E-05 | 9.4E-05 |
| MC2 | 1.1E-05 | 1.0E-05 | 1.0E-05 |
| MC3 | 7.5E-07 | NA | NA |
| MC4 | 5.4E-07 | NA | NA |
| MC5 | 4.9E-07 | NA | NA |
| RM3 | 4.0E-06 | 3.9E-06 | 3.9E-06 |
| RM4 | 1.0E-05 | 1.0E-05 | 1.0E-05 |
| RM5 | 1.2E-05 | 1.2E-05 | 1.2E-05 |
| RM6 | 9.7E-05 | 9.4E-05 | 9.4E-05 |

**Table C-26.** Ratio of methane emissions from completion flowback events allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil) divided by its estimated ultimate production (EUR), assuming **30 year well-lifetime**, based in an **energy allocation**

| | **Energy Basis** | | |
|---|---|---|---|
| **Event** | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| AP1 | 0.0022 | NA | NA |
| AP2 | 9.2E-07 | NA | NA |
| AP3 | 1.2E-05 | NA | NA |
| GC1 | 8.7E-06 | 7.7E-06 | 7.5E-06 |
| GC2 | 8.0E-06 | 7.1E-06 | 6.9E-06 |
| GC3 | 0.0001 | 9.7E-05 | 9.5E-05 |
| GC4 | 0.0001 | 9.3E-05 | 9.0E-05 |
| GC5 | 2.9E-06 | NA | NA |
| GC6 | 2.6E-05 | 2.4E-05 | 2.3E-05 |
| GC7 | 1.2E-05 | 1.1E-05 | 1.0E-05 |
| MC1 | 0.0001 | 8.9E-05 | 8.4E-05 |
| MC2 | 1.1E-05 | 9.9E-06 | 9.3E-06 |
| MC3 | 7.5E-07 | NA | NA |
| MC4 | 5.4E-07 | NA | NA |
| MC5 | 4.9E-07 | NA | NA |
| RM3 | 4.4E-06 | 3.9E-06 | 3.9E-06 |
| RM4 | 1.2E-05 | 1.0E-05 | 1.0E-05 |
| RM5 | 1.3E-05 | 1.2E-05 | 1.2E-05 |
| RM6 | 0.0001 | 9.2E-05 | 9.1E-05 |

**Table C-27.** Ratio of methane emissions from completion flowback events allocated to each salable product (Natural Gas, Natural Gas Liquids, and Oil) divided by its estimated ultimate production (EUR), assuming **30 year well-lifetime**, based in a **price allocation.**

| | **Price Basis** | | |
|---|---|---|---|
| **Event** | Emitted Methane (scf) / EUR **Natural Gas** (scf) | Emitted Methane (Mg) / EUR **Natural Gas Liquids** (Mg) | Emitted Methane (Mg) / EUR **Oil** (Mg) |
| AP1 | 0.0022 | NA | NA |
| AP2 | 9.2E-07 | NA | NA |
| AP3 | 1.2E-05 | NA | NA |
| GC1 | 2.5E-06 | 6.4E-06 | 9.7E-06 |
| GC2 | 2.3E-06 | 5.8E-06 | 8.8E-06 |
| GC3 | 4.6E-05 | 0.0001 | 0.0002 |
| GC4 | 4.1E-05 | 0.0001 | 0.0002 |
| GC5 | 2.9E-06 | NA | NA |
| GC6 | 1.5E-05 | 3.7E-05 | 5.7E-05 |
| GC7 | 3.3E-06 | 8.3E-06 | 1.3E-05 |
| MC1 | 5.3E-05 | 0.0001 | 0.0002 |
| MC2 | 4.8E-06 | 1.2E-05 | 1.8E-05 |
| MC3 | 7.5E-07 | NA | NA |
| MC4 | 5.4E-07 | NA | NA |
| MC5 | 4.9E-07 | NA | NA |
| RM3 | 1.1E-06 | 2.8E-06 | 4.4E-06 |
| RM4 | 2.9E-06 | 7.3E-06 | 1.1E-05 |
| RM5 | 3.4E-06 | 8.6E-06 | 1.3E-05 |
| RM6 | 3.2E-05 | 8.1E-05 | 0.0001 |

*C.10 Rationale for disaggregation of emission sources not directly measured.*

**Table C-28.** Additional sources of methane emissions from natural gas production considered in the EPA GHG national inventory [9]. Rationale for disaggregation of emissions into NG = Natural Gas, NGL= Natural Gas Liquids, and Oil is provided. The column showing net emissions refers to total emissions from each category before the allocation to the corresponding products.

| EPA GHG Inventory Activity | Net Emissions (Gg methane/yr) | Classification | Rationale for classification |
|---|---|---|---|
| Refractures | 143 | (NG+NGL+OIL) | Emission from well associated with all products from well. |
| Gas wells without HF | 13 | (NG+NGL+OIL) | Emission from well associated with all products from well |
| Gas wells with HF | 15 | (NG+NGL+OIL) | Emission from well associated with all products from well |
| Separators | 57 | (NG+NGL+OIL) | Emission from well associated with all products from well |
| Meters/Piping | 54 | (NG+NGL+OIL) | In the absence of specific information, assume these devices handle all products. |
| Heaters | 18 | (NG+NGL+OIL) | In the absence of specific information, assume these devices handle all products. |
| Dehydrators | 16 | (NG+NGL) | Device that handles exclusively gas from the well site, which are separated into NG and NGL products. |
| Workovers without HF | 0.3 | (NG+NGL+OIL) | Emission from well associated with all products from well |
| Liquids Unloading (without plunger lifts) | 149 | (NG+NGL+OIL) | Emission from well associated with all products from well |
| Liquids Unloading (with plunger lifts) | 108 | (NG+NGL+OIL) | Emission from well associated with all products from well |
| Kimray Pumps | 185 | (NG+NGL) | Device that handles exclusively gas. |
| Condensate Tanks without Controls | 94 | (OIL only) | Condensate tanks handle OIL product. |

**Table C-28** (continued).

| EPA GHG Inventory Activity | Net Emissions (Gg methane/yr) | Classification | Rationale for classification |
|---|---|---|---|
| Condensate Tanks with Controls | 52 | (OIL only) | Condensate tanks handle OIL product. |
| Gas Engines | 227 | (NG+NGL) | Device that handles exclusively gas. |
| Dehydrators Vents | 41 | (NG+NGL) | Device that handles exclusively gas. |
| Small Reciprocating Compressors | 49 | (NG+NGL) | Device that handles exclusively gas. |
| Large Reciprocating Compressors | | (NG+NGL) | Device that handles exclusively gas. |
| Large Reciprocating Stations | | (NG+NGL) | Device that handles exclusively gas. |
| Pipeline Leaks | 90 | (NG+NGL) | Pipelines handle gas products. |
| Well Drilling | 0.4 | (NG+NGL+OIL) | Emission from well associated with all products from well |
| Vessel Blowdowns | 0.4 | (NG+NGL) | Involves venting of gas products. |
| Pipeline Blowdowns | 2 | (NG+NGL) | Involves venting of gas products. |
| Compressor Blowdowns | 2 | (NG+NGL) | Involves venting of gas products. |
| Compressor Starts | 3 | (NG+NGL) | Involves venting of gas products. |
| Pressure Relief Valves | 0.4 | (NG+NGL) | Involves venting of gas products. |
| Mishaps | 1 | (NG+NGL+OIL) | In the absence of specific information, assume these events are associated with all products. |

### *C.11 References*

(1) API. (2009). Compendium of Greenhouse Gas Emissions Methodologies for Oil and Natural Gas Industry. Washington, DC: American Petroleum Institute.

(2) American Gas Association. (1951). Fuel Flue Gases.

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(4) EIA. (2012). Annual Energy Outlook. DOE/EIA.

(5) EIA. (2013). Oil and Gas Supply Module of the National Energy Modeling System: Model Documentation 2013, Appendix 2.c. Retrieved 1, 14, 2014, from http://www.eia.gov/forecasts/aeo/nems/documentation/ogsm/pdf/m063(2013).pdf

(6) O'Sullivan, F., & Paltsev, S. (2012). Shale gas production: potential versus actual greenhouse gas emissions. Environmental Research Letters , 7, 1-7.

(7) NETL. 2012. Role of Alternative Energy Sources: Natural Gas Technology Assessment. U.S. Department of Energy.

(8) Allen DT, Torres VM, Thomas J, Sullivan D, Harrison M, et al. 2013. Measurements of Methane Emissions at Natural Gas Production Sites: Study Appendices and Database, Austin, Texas: University of Texas http://dept.ceer.utexas.edu/methane/study/

(9) EPA. (2013, April 12). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. Retrieved 4 22, 2013, from http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

# D Criteria and Air Toxics Emissions from Shale Gas Production

## *D.1 Hydrocarbon concentrations at Flower Mound Shiloh and Hinton monitoring sites*

The concentrations of light alkanes at EML are higher than at the other two sites. At EML, the average morning maximum concentrations of ethane, propane, and butane total close to 100 ppbC, while at Flower Mound Shiloh and Hinton, the morning totals are 60 ppbC and 40 ppbC respectively. Summed over all days and hours in the 20 month sampling period, the average concentrations at EML for ethane, propane, and butane are 31.3, 19.4, and 9.2 ppbC, respectively. For Flower Mound Shiloh those averages are 18.4, 13.0, and 7.8, respectively. In the case of Hinton, the averages are 15.5 for ethane, 11.0 for propane, and 6.5 for butane.

Figures D-1 and D-2 show daily average hydrocarbon concentrations at Flower Mound Shiloh and Hinton, respectively. The dominant species (ethane, propane and butane) are similar to EML, since, in addition to being associated with emissions from natural gas production, these species are commonly found in regional background hydrocarbon samples.

Figure D-3 shows average diurnal hydrocarbon concentrations at Flower Mound Shiloh for observations with winds between 135º and 225º, the wind directions for which Flower Mound Shiloh was used as a background site.

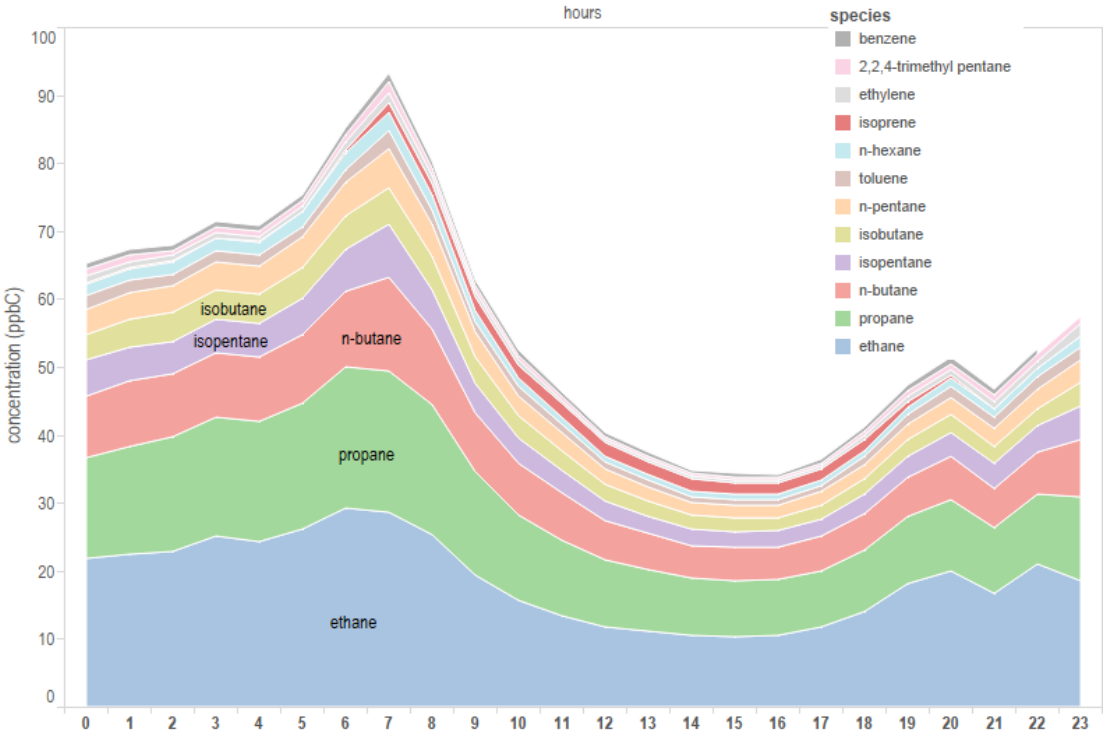


**Figure D-1.** Diurnal pattern of hydrocarbon concentrations (ppbC) at Flower Mound Shiloh averaged over 20 months of sampling.

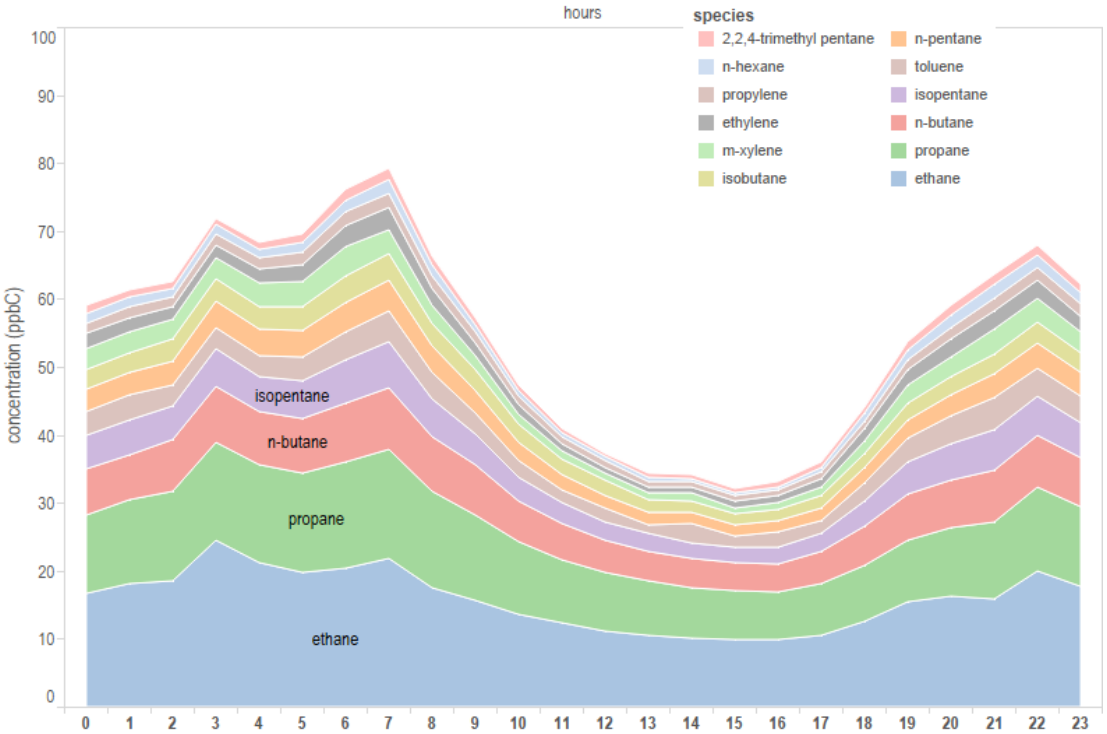


**Figure D-2.** Diurnal pattern of hydrocarbon concentrations (ppbC) at Hinton averaged over 20 months of sampling.

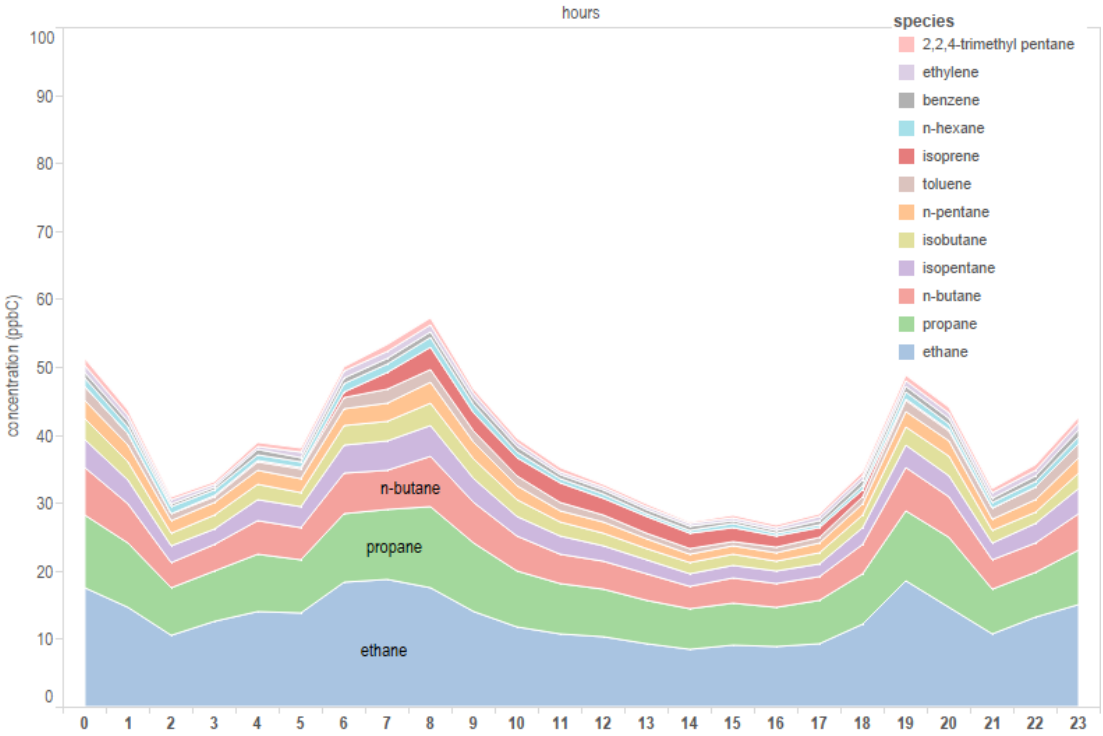


**Figure D-3.** Average diurnal pattern of hydrocarbon concentrations at Flower Mound Shiloh filtering for hours when wind direction was between 135 º – 225 º.

## *D.2 Comparison of measurements and model predictions when Hinton is used as background site but data is filtered for the same hours considered in the Flower Mound Shiloh dataset*

Figure D-4 shows a comparison between predicted VOC concentrations calculated using the AERMOD dispersion model, and the observed, background corrected alkane concentrations as they were measured at the EML monitoring site. When Hinton was used as a background site, all directions were considered, however, as a sensitivity test, the present analysis reflects only those hours considered in the final dataset of Flower Mound Shiloh (filtering for wind directions with the least influence from natural gas sources for that particular monitoring site).

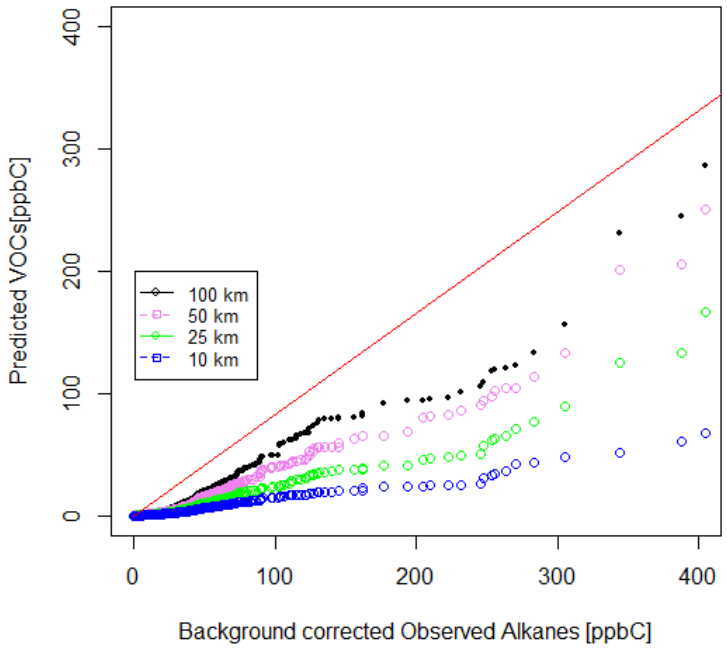


**Figure D-4.** Predicted total VOC concentrations vs. background corrected observed summed alkane concentrations at EML, when *Hinton was used as background site*, filtering for the same hours that were considered in the Flower Mound Shiloh final dataset. For four sets of dispersion calculations, within 10, 25, 50, and 100 km radii of the observation site. The red line has a slope of 0.83 since 83% of the total VOC are speciated as alkanes.

The regression has a slope of 0.55 (standard error 0.009), for observations over 50 ppbC, as compared to a slope of 0.66 when Flower Mound Shiloh is used as background site.

### *D.3 Calculation of emissions from pneumatic devices, chemical injection pumps, and equipment leaks based on Allen, et al (2013)*

Table D-1 shows the emission factors used to estimate emissions from pneumatic devices, chemical injection pumps, and equipment leaks from production sites. For estimated emissions of propane and higher alkanes, a weighted average gas composition for the Barnett Shale was used (89.16% methane, 4.24% ethane; 2.67% $C_3$+ alkanes

(molar basis; weighted by total gas production for each site), or 77.37% methane, and 7.45% $C_3$+ alkanes (mass basis)).

**Table D-1.** Routine emissions from production sites.

| | **Methane Scf/min per device*** | **Activity factor for the Barnett Shale**** | **Methane Scf/min per well** | **Methane Mg/yr per well***** | **$C_3$+ Mg/yr per well †** |
|---|---|---|---|---|---|
| **Pneumatic Devices** | 0.175 | 8,086 devices | 0.507 | 5.116 | 0.493 |
| **Chemical Injection Pumps** | 0.192 | 1,972 devices | 0.136 | 1.369 | 0.132 |
| **Equipment Leaks (per well)** | 0.064 | 2,791 wells | 0.064 | 0.646 | 0.062 |
| **Total** | 0.431 | | 0.707 | 7.131 | 0.687 |

* Emission factors were obtained from the Supporting information of Allen, *et al* (2013), Tables S2-2, 3, 4.

** Activity factors for the Barnett Shale were calculated from total counts (for the host companies that participated in the study) for the play (based on AAPG basin classification) from the database from Allen *et al*'s.

*** 1scf of methane = 19.2 g of methane.

† Mg/yr per well of propane and higher alkanes are obtained by multiplying Methane Mg/yr per well by the mass ratio of $C_3$+ to methane (7.45%/77.37% = 0.096).

The total methane emissions of 7.13 Mg per year per well from pneumatic devices, chemical injection pumps, and equipment leaks, result in 0.687 Mg/yr per well of propane and higher alkanes, multiplied by the total number of wells reported by the TCEQ for the year 2011; 14,886 the total emissions would be roughly 10,200 tons per year of propane and higher alkanes.

# E Developing a Methane, Ethane, and Propane Emission Inventory for the Barnett Shale Production Region

## *E.1 Spatial interpolation of percent VOC*

For the 8,025 sites with reported VOC emissions in the TCEQ special inventory, only 30% reported %VOC values. Figure E-1 shows the spatial distribution of sites with known %VOC and with unknown %VOC. Assuming that %VOC and gas composition are well characterized by the spatial location of sites, it is expected that the missing values can be estimated from neighboring sites with known gas composition using an inverse distance weight (IDW) method for interpolation. Figure E-2 shows the spatially resolved distribution of grid cells with interpolated %VOC values.

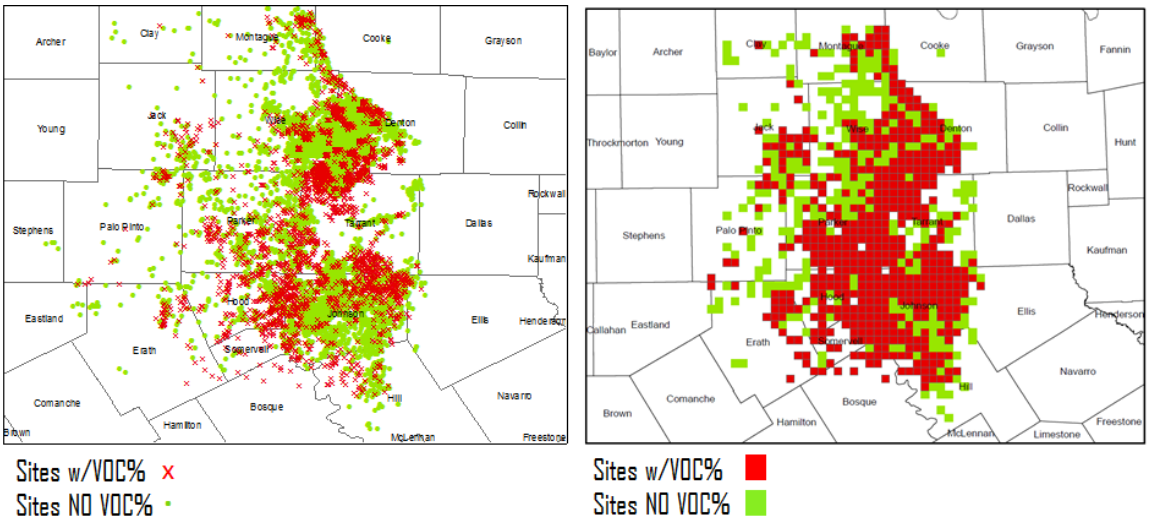


**Figure E-1.** Location of sites from the TCEQ special inventory, with known, and unknown %VOC.

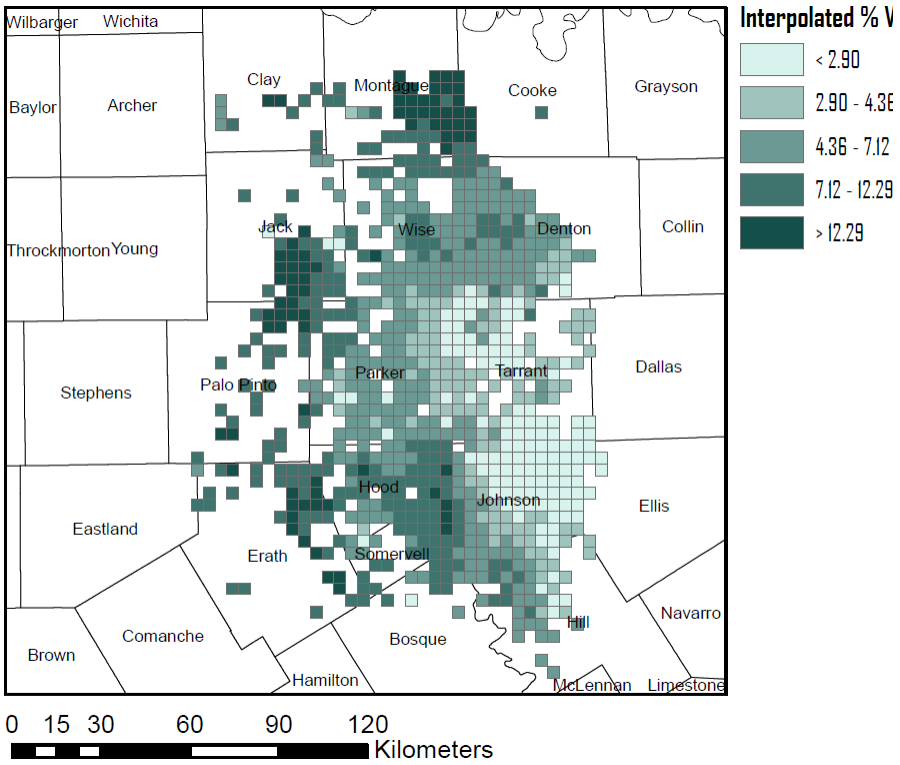


**Figure E-2.** Spatially resolved distribution of interpolated %VOC for grid cells that contain Natural Gas production sites. Coloring scheme shows the values of %VOC for each grid cell.

### *E.2 Detailed methodology for the estimation of emissions by source category*

*Condensate and oil Tanks:* Correlations developed by Vazquez and Beggs [1] were used to estimate dissolved gas in oil. The correlations estimate gas solubility based on temperature, pressure, and API gravity. Average conditions for separators feeding liquids to tanks were determined (70 psig, 40° API) [2] from data collected at gas wells in the Barnett Shale, yielding an estimated dissolved gas loading of 80 scf/bbl of condensate [2, 3]. The dissolved gas loading is multiplied by the site-specific condensate and oil production to yield the volume of dissolved gas vented per unit of time. To estimate methane, ethane, and propane emissions, it is assumed that these three species are the only species that flash, and that the relative composition of the three species in the vented gas is similar to the produced gas. Site-specific estimated %C1, %C2, %C3 values are used to determine vented emissions.

*Water Tanks:* For Water Tanks the solubility of methane, ethane, and propane in water was estimated based on Henry's law [2, 4] and site specific produced water production rate.

Because the solubility of methane, ethane, and propane in water depends on separator conditions, average temperature and pressure for a separator were determined (70 psig, 60° F) from data collected at production sites in the Barnett Shale [2]. Combining the average temperature and pressure with site-specific gas composition, partial pressures of methane, ethane and propane above the water tank were computed using Henry's law. Partial pressures were multiplied by the amount of water per barrel (8830 moles/bbl), density of the species, and site-specific water production rates to yield C1, C2, and C3 emissions.

*Loadings:* It was assumed that loadings of liquids from tanks to vehicles would generate no additional methane, ethane, propane emissions besides those that were already accounted for in the tanks source category.

*Frac Tanks:* Allen, *et al*. [2] reported methane emission rates for 5 completion flowback events in the Mid Continent region (where the Barnett Shale production region is situated), with an average regional emission rate of 2.8 MMscf/yr . It is assumed that methane emissions from frac tanks are equal to those emissions, and ethane, propane emissions are estimated based on the site-specific gas composition.

*All other source categories:* For the rest of the source categories, it is assumed that methane, ethane, and propane emissions can be scaled directly from the VOC emissions, based on the gas composition. A special consideration was taken for fugitive emissions. In a previously published work [5] a correction factor was developed in a comparison between the TCEQ special inventory and ambient VOC concentrations. Fugitive emissions are corrected for their underestimation in the special inventory based on emission rates estimated from direct measurements [2].

VOC emissions from pneumatic devices, chemical injection pumps, and equipment leaks, are 0.021 scf/min [2], or 0.687 Mg/yr per well. For a count of 14,886 producing wells in the Barnett Shale [5], VOC emissions from those sources would be roughly 10,200 tons per year. This is 159% higher than the corresponding estimate for similar categories in the TCEQ inventory (3,935 tons per year for fugitives).

Emissions were estimated for each source category, then summed by site to spatially locate them, and finally summed up by grid cell. To determine the corresponding methane, ethane, propane emissions from VOC emissions without source category, VOC emissions were spatially distributed among the rest of the sites (weighted by the magnitude of VOC emissions) and methane, ethane, propane emissions were also scaled based on VOC emissions and the gas composition of the site where they were assigned.

*E.3 Estimated methane emissions by grid cell*

Table E-1 shows final data set of gird cells, with location and production data.

**Table E-1.** Location and production data for each grid cell in the final data set.

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 1066 | 31 | 15 | 0.1 | 0.0 |
| 1139 | 30 | 16 | 313.8 | 300.8 |
| 1285 | 28 | 18 | 106.1 | 878.5 |
| 1287 | 30 | 18 | 149.6 | 229.2 |
| 1288 | 31 | 18 | 319.7 | 1368.4 |
| 1359 | 28 | 19 | 158.1 | 160.9 |
| 1360 | 29 | 19 | 97.3 | 781.6 |
| 1361 | 30 | 19 | 184.2 | 325.8 |
| 1364 | 33 | 19 | 264.1 | 339.9 |
| 1416 | 11 | 20 | 2.9 | 0.0 |
| 1428 | 23 | 20 | 6.9 | 113.1 |
| 1433 | 28 | 20 | 182.2 | 15.9 |
| 1434 | 29 | 20 | 1145.0 | 606.9 |
| 1435 | 30 | 20 | 2076.7 | 204.1 |
| 1436 | 31 | 20 | 1566.6 | 409.3 |
| 1437 | 32 | 20 | 184.6 | 286.4 |
| 1493 | 14 | 21 | 11.6 | 0.0 |
| 1494 | 15 | 21 | 1.5 | 0.0 |
| 1496 | 17 | 21 | 13.5 | 42.4 |
| 1498 | 19 | 21 | 0.0 | 413.9 |
| 1504 | 25 | 21 | 45.5 | 101.7 |
| 1505 | 26 | 21 | 259.1 | 253.8 |
| 1506 | 27 | 21 | 1314.2 | 73.8 |
| 1507 | 28 | 21 | 98.2 | 191.7 |
| 1508 | 29 | 21 | 1435.6 | 353.9 |
| 1509 | 30 | 21 | 1413.1 | 649.5 |
| 1510 | 31 | 21 | 1009.1 | 644.6 |
| 1511 | 32 | 21 | 37.8 | 467.0 |
| 1557 | 4 | 22 | 0.0 | 0.0 |
| 1558 | 5 | 22 | 0.0 | 0.0 |
| 1566 | 13 | 22 | 236.0 | 0.0 |
| 1568 | 15 | 22 | 0.0 | 274.7 |
| 1569 | 16 | 22 | 44.8 | 0.0 |
| 1574 | 21 | 22 | 0.6 | 163.4 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 1575 | 22 | 22 | 0.0 | 2246.4 |
| 1580 | 27 | 22 | 790.0 | 902.2 |
| 1581 | 28 | 22 | 1434.1 | 242.7 |
| 1582 | 29 | 22 | 724.3 | 298.0 |
| 1583 | 30 | 22 | 2536.3 | 484.7 |
| 1584 | 31 | 22 | 1130.1 | 538.1 |
| 1639 | 12 | 23 | 4.0 | 0.0 |
| 1640 | 13 | 23 | 5.9 | 0.0 |
| 1642 | 15 | 23 | 0.0 | 54.3 |
| 1646 | 19 | 23 | 50.7 | 0.0 |
| 1647 | 20 | 23 | 1.8 | 947.4 |
| 1648 | 21 | 23 | 5.0 | 0.0 |
| 1649 | 22 | 23 | 119.5 | 1346.1 |
| 1650 | 23 | 23 | 9.6 | 3585.8 |
| 1651 | 24 | 23 | 316.5 | 10735.0 |
| 1652 | 25 | 23 | 96.3 | 3928.6 |
| 1653 | 26 | 23 | 721.0 | 560.3 |
| 1654 | 27 | 23 | 332.5 | 4428.8 |
| 1655 | 28 | 23 | 913.7 | 556.6 |
| 1656 | 29 | 23 | 130.9 | 70.7 |
| 1657 | 30 | 23 | 1316.2 | 1532.8 |
| 1658 | 31 | 23 | 1367.5 | 1251.8 |
| 1659 | 32 | 23 | 0.0 | 345.5 |
| 1717 | 16 | 24 | 163.9 | 35.2 |
| 1718 | 17 | 24 | 91.0 | 0.0 |
| 1722 | 21 | 24 | 0.0 | 1279.3 |
| 1723 | 22 | 24 | 568.5 | 635.3 |
| 1724 | 23 | 24 | 711.5 | 1410.9 |
| 1725 | 24 | 24 | 173.0 | 3156.3 |
| 1726 | 25 | 24 | 189.0 | 1425.9 |
| 1727 | 26 | 24 | 408.4 | 3151.1 |
| 1728 | 27 | 24 | 100.0 | 6783.5 |
| 1729 | 28 | 24 | 866.0 | 1014.2 |
| 1730 | 29 | 24 | 236.0 | 449.6 |
| 1731 | 30 | 24 | 539.4 | 912.2 |
| 1732 | 31 | 24 | 122.8 | 1488.2 |
| 1786 | 11 | 25 | 0.0 | 56.7 |
| 1787 | 12 | 25 | 6.4 | 23.9 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 1789 | 14 | 25 | 97.0 | 0.0 |
| 1790 | 15 | 25 | 328.4 | 0.0 |
| 1794 | 19 | 25 | 769.0 | 1379.9 |
| 1795 | 20 | 25 | 669.5 | 527.7 |
| 1796 | 21 | 25 | 4160.0 | 2030.4 |
| 1797 | 22 | 25 | 1196.9 | 1816.7 |
| 1798 | 23 | 25 | 2762.1 | 951.5 |
| 1799 | 24 | 25 | 346.1 | 2475.7 |
| 1800 | 25 | 25 | 737.6 | 1728.5 |
| 1801 | 26 | 25 | 627.0 | 2273.4 |
| 1802 | 27 | 25 | 520.5 | 3947.8 |
| 1803 | 28 | 25 | 386.9 | 2278.6 |
| 1804 | 29 | 25 | 1296.0 | 1113.3 |
| 1805 | 30 | 25 | 1018.4 | 738.5 |
| 1806 | 31 | 25 | 893.3 | 3243.0 |
| 1809 | 34 | 25 | 89.1 | 679.0 |
| 1859 | 10 | 26 | 4.0 | 396.4 |
| 1862 | 13 | 26 | 0.0 | 127.0 |
| 1863 | 14 | 26 | 114.2 | 0.0 |
| 1864 | 15 | 26 | 44.6 | 0.0 |
| 1865 | 16 | 26 | 38.0 | 0.0 |
| 1868 | 19 | 26 | 662.0 | 698.6 |
| 1869 | 20 | 26 | 0.0 | 378.7 |
| 1870 | 21 | 26 | 3284.9 | 2624.9 |
| 1871 | 22 | 26 | 3178.7 | 2309.4 |
| 1872 | 23 | 26 | 945.8 | 3133.7 |
| 1873 | 24 | 26 | 214.4 | 5702.6 |
| 1874 | 25 | 26 | 860.0 | 2849.9 |
| 1875 | 26 | 26 | 4738.7 | 4470.7 |
| 1876 | 27 | 26 | 605.5 | 7229.7 |
| 1877 | 28 | 26 | 924.1 | 2531.4 |
| 1878 | 29 | 26 | 718.9 | 7251.8 |
| 1879 | 30 | 26 | 1289.1 | 1169.9 |
| 1880 | 31 | 26 | 1039.7 | 4254.5 |
| 1881 | 32 | 26 | 251.2 | 2847.3 |
| 1883 | 34 | 26 | 158.7 | 506.9 |
| 1932 | 9 | 27 | 1195.8 | 39.8 |
| 1933 | 10 | 27 | 42.3 | 518.5 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 1938 | 15 | 27 | 49.3 | 53.1 |
| 1941 | 18 | 27 | 236.3 | 0.0 |
| 1942 | 19 | 27 | 1790.8 | 2282.6 |
| 1943 | 20 | 27 | 533.3 | 1986.0 |
| 1944 | 21 | 27 | 85.4 | 2138.3 |
| 1945 | 22 | 27 | 2078.7 | 3749.2 |
| 1946 | 23 | 27 | 4156.3 | 1455.1 |
| 1947 | 24 | 27 | 3751.5 | 3456.8 |
| 1948 | 25 | 27 | 4289.8 | 1913.3 |
| 1949 | 26 | 27 | 4645.7 | 2603.1 |
| 1950 | 27 | 27 | 1471.2 | 2138.4 |
| 1951 | 28 | 27 | 78.4 | 3763.8 |
| 1952 | 29 | 27 | 2212.5 | 8880.6 |
| 1953 | 30 | 27 | 2343.2 | 6404.7 |
| 1954 | 31 | 27 | 378.7 | 9203.5 |
| 1955 | 32 | 27 | 134.3 | 8981.7 |
| 1956 | 33 | 27 | 233.1 | 5407.3 |
| 2005 | 8 | 28 | 189.1 | 0.0 |
| 2006 | 9 | 28 | 645.1 | 0.0 |
| 2007 | 10 | 28 | 134.4 | 103.2 |
| 2008 | 11 | 28 | 28.1 | 130.9 |
| 2009 | 12 | 28 | 0.0 | 255.0 |
| 2011 | 14 | 28 | 53.0 | 0.0 |
| 2012 | 15 | 28 | 101.0 | 0.0 |
| 2013 | 16 | 28 | 69.0 | 392.3 |
| 2014 | 17 | 28 | 267.2 | 0.0 |
| 2015 | 18 | 28 | 1400.5 | 460.0 |
| 2016 | 19 | 28 | 1651.3 | 655.6 |
| 2017 | 20 | 28 | 4664.1 | 2799.8 |
| 2018 | 21 | 28 | 1099.9 | 2478.9 |
| 2019 | 22 | 28 | 1223.4 | 3815.6 |
| 2020 | 23 | 28 | 7836.3 | 2688.6 |
| 2021 | 24 | 28 | 6506.3 | 969.8 |
| 2022 | 25 | 28 | 11117.1 | 3783.0 |
| 2023 | 26 | 28 | 282.9 | 906.6 |
| 2024 | 27 | 28 | 517.8 | 4984.4 |
| 2025 | 28 | 28 | 1017.4 | 3953.7 |
| 2026 | 29 | 28 | 2301.5 | 6456.9 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 2027 | 30 | 28 | 3702.9 | 7608.2 |
| 2028 | 31 | 28 | 5997.8 | 11717.2 |
| 2029 | 32 | 28 | 346.7 | 8808.0 |
| 2030 | 33 | 28 | 0.2 | 3960.4 |
| 2072 | 1 | 29 | 6.0 | 84.3 |
| 2073 | 2 | 29 | 306.5 | 76.7 |
| 2080 | 9 | 29 | 1140.9 | 45.3 |
| 2081 | 10 | 29 | 198.9 | 58.1 |
| 2082 | 11 | 29 | 501.9 | 126.7 |
| 2083 | 12 | 29 | 215.1 | 151.5 |
| 2084 | 13 | 29 | 1.6 | 0.0 |
| 2086 | 15 | 29 | 6.6 | 0.0 |
| 2087 | 16 | 29 | 331.9 | 1022.2 |
| 2088 | 17 | 29 | 501.2 | 481.0 |
| 2089 | 18 | 29 | 2470.1 | 715.4 |
| 2090 | 19 | 29 | 1289.8 | 469.5 |
| 2091 | 20 | 29 | 4717.3 | 5356.6 |
| 2092 | 21 | 29 | 6081.3 | 2748.3 |
| 2093 | 22 | 29 | 2931.3 | 4112.8 |
| 2094 | 23 | 29 | 10950.6 | 3991.5 |
| 2095 | 24 | 29 | 10516.9 | 682.5 |
| 2096 | 25 | 29 | 9851.4 | 3044.7 |
| 2097 | 26 | 29 | 11244.1 | 4209.1 |
| 2098 | 27 | 29 | 3795.4 | 3191.7 |
| 2099 | 28 | 29 | 3399.7 | 7569.1 |
| 2100 | 29 | 29 | 343.3 | 10756.4 |
| 2101 | 30 | 29 | 5273.5 | 13484.9 |
| 2102 | 31 | 29 | 883.7 | 9044.4 |
| 2103 | 32 | 29 | 1626.7 | 2307.1 |
| 2104 | 33 | 29 | 2044.2 | 3365.9 |
| 2147 | 2 | 30 | 4.6 | 81.2 |
| 2149 | 4 | 30 | 21.6 | 4.8 |
| 2154 | 9 | 30 | 1308.8 | 23.5 |
| 2155 | 10 | 30 | 452.0 | 0.0 |
| 2156 | 11 | 30 | 1127.7 | 0.0 |
| 2158 | 13 | 30 | 153.1 | 1.1 |
| 2159 | 14 | 30 | 0.0 | 0.0 |
| 2160 | 15 | 30 | 156.3 | 0.0 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 2162 | 17 | 30 | 0.0 | 0.0 |
| 2163 | 18 | 30 | 707.3 | 809.7 |
| 2165 | 20 | 30 | 4198.1 | 1193.5 |
| 2166 | 21 | 30 | 3190.9 | 100.4 |
| 2167 | 22 | 30 | 6050.0 | 1484.3 |
| 2168 | 23 | 30 | 10443.4 | 2879.2 |
| 2169 | 24 | 30 | 4113.9 | 325.2 |
| 2170 | 25 | 30 | 12274.3 | 166.1 |
| 2171 | 26 | 30 | 8056.1 | 6367.8 |
| 2172 | 27 | 30 | 5743.1 | 4075.0 |
| 2173 | 28 | 30 | 12153.7 | 6470.0 |
| 2174 | 29 | 30 | 2338.1 | 27955.3 |
| 2175 | 30 | 30 | 1407.1 | 9713.2 |
| 2176 | 31 | 30 | 1674.5 | 10613.9 |
| 2177 | 32 | 30 | 1194.1 | 8609.9 |
| 2178 | 33 | 30 | 448.5 | 4355.4 |
| 2179 | 34 | 30 | 47.0 | 6381.3 |
| 2225 | 6 | 31 | 0.1 | 0.0 |
| 2227 | 8 | 31 | 0.0 | 0.0 |
| 2228 | 9 | 31 | 37.0 | 0.0 |
| 2229 | 10 | 31 | 68.0 | 11.3 |
| 2230 | 11 | 31 | 268.7 | 0.0 |
| 2233 | 14 | 31 | 21.8 | 0.0 |
| 2234 | 15 | 31 | 907.9 | 0.0 |
| 2235 | 16 | 31 | 0.0 | 0.0 |
| 2236 | 17 | 31 | 548.3 | 0.0 |
| 2237 | 18 | 31 | 3068.9 | 106.0 |
| 2238 | 19 | 31 | 3518.0 | 227.8 |
| 2239 | 20 | 31 | 5438.2 | 1486.9 |
| 2240 | 21 | 31 | 6443.7 | 1575.9 |
| 2241 | 22 | 31 | 3540.5 | 3168.0 |
| 2242 | 23 | 31 | 2031.5 | 4294.4 |
| 2243 | 24 | 31 | 2416.6 | 1183.7 |
| 2244 | 25 | 31 | 3892.7 | 6007.8 |
| 2245 | 26 | 31 | 2331.2 | 4021.6 |
| 2246 | 27 | 31 | 8580.8 | 4359.3 |
| 2247 | 28 | 31 | 2347.7 | 18740.9 |
| 2248 | 29 | 31 | 5481.2 | 10386.7 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 2249 | 30 | 31 | 3947.2 | 7243.5 |
| 2250 | 31 | 31 | 7040.0 | 6549.5 |
| 2251 | 32 | 31 | 6828.9 | 8177.6 |
| 2252 | 33 | 31 | 1296.6 | 3025.2 |
| 2294 | 1 | 32 | 403.8 | 0.0 |
| 2296 | 3 | 32 | 6.3 | 10.3 |
| 2297 | 4 | 32 | 0.1 | 0.0 |
| 2299 | 6 | 32 | 0.1 | 0.0 |
| 2301 | 8 | 32 | 59.8 | 0.0 |
| 2302 | 9 | 32 | 0.1 | 0.0 |
| 2303 | 10 | 32 | 155.0 | 13.0 |
| 2304 | 11 | 32 | 4.8 | 0.0 |
| 2305 | 12 | 32 | 0.0 | 0.0 |
| 2307 | 14 | 32 | 0.9 | 0.0 |
| 2308 | 15 | 32 | 1827.9 | 66.8 |
| 2309 | 16 | 32 | 102.1 | 23.4 |
| 2310 | 17 | 32 | 440.2 | 1158.7 |
| 2311 | 18 | 32 | 738.0 | 715.1 |
| 2312 | 19 | 32 | 2573.1 | 299.2 |
| 2313 | 20 | 32 | 3076.9 | 440.6 |
| 2314 | 21 | 32 | 3832.4 | 282.4 |
| 2315 | 22 | 32 | 2793.7 | 1002.1 |
| 2316 | 23 | 32 | 407.4 | 7510.2 |
| 2317 | 24 | 32 | 5337.9 | 9125.4 |
| 2318 | 25 | 32 | 1791.6 | 9807.7 |
| 2319 | 26 | 32 | 11580.8 | 963.8 |
| 2320 | 27 | 32 | 7233.2 | 6024.2 |
| 2321 | 28 | 32 | 7457.3 | 2814.8 |
| 2322 | 29 | 32 | 22350.9 | 2053.2 |
| 2323 | 30 | 32 | 17141.5 | 3930.0 |
| 2324 | 31 | 32 | 12437.6 | 4664.1 |
| 2325 | 32 | 32 | 9079.4 | 3891.9 |
| 2326 | 33 | 32 | 1170.9 | 14056.5 |
| 2328 | 35 | 32 | 511.8 | 4873.1 |
| 2368 | 1 | 33 | 308.4 | 0.0 |
| 2374 | 7 | 33 | 10.7 | 0.0 |
| 2379 | 12 | 33 | 3.8 | 0.0 |
| 2380 | 13 | 33 | 30.9 | 0.0 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 2381 | 14 | 33 | 94.1 | 0.0 |
| 2382 | 15 | 33 | 385.5 | 45.4 |
| 2383 | 16 | 33 | 536.5 | 537.1 |
| 2384 | 17 | 33 | 2705.4 | 491.4 |
| 2385 | 18 | 33 | 663.1 | 683.3 |
| 2386 | 19 | 33 | 3313.3 | 1276.1 |
| 2387 | 20 | 33 | 1099.9 | 455.6 |
| 2388 | 21 | 33 | 4377.9 | 391.2 |
| 2389 | 22 | 33 | 1600.2 | 2394.4 |
| 2390 | 23 | 33 | 1109.2 | 4257.7 |
| 2391 | 24 | 33 | 3169.3 | 3887.8 |
| 2392 | 25 | 33 | 9825.8 | 15217.1 |
| 2393 | 26 | 33 | 10188.9 | 1479.8 |
| 2394 | 27 | 33 | 19623.3 | 3048.3 |
| 2395 | 28 | 33 | 24398.6 | 1986.3 |
| 2396 | 29 | 33 | 18065.7 | 13119.0 |
| 2397 | 30 | 33 | 10846.1 | 4231.2 |
| 2398 | 31 | 33 | 2130.4 | 9100.1 |
| 2399 | 32 | 33 | 8869.2 | 20822.6 |
| 2400 | 33 | 33 | 7529.0 | 11556.7 |
| 2401 | 34 | 33 | 930.6 | 5500.7 |
| 2402 | 35 | 33 | 960.1 | 2368.0 |
| 2448 | 7 | 34 | 0.0 | 0.0 |
| 2449 | 8 | 34 | 0.0 | 0.0 |
| 2454 | 13 | 34 | 2.4 | 0.0 |
| 2456 | 15 | 34 | 3.1 | 0.0 |
| 2458 | 17 | 34 | 617.7 | 840.8 |
| 2459 | 18 | 34 | 1126.2 | 3526.4 |
| 2460 | 19 | 34 | 2145.8 | 202.6 |
| 2461 | 20 | 34 | 299.0 | 564.3 |
| 2462 | 21 | 34 | 1983.4 | 67.7 |
| 2463 | 22 | 34 | 1067.2 | 2281.4 |
| 2465 | 24 | 34 | 7985.2 | 1465.6 |
| 2466 | 25 | 34 | 15666.4 | 6230.2 |
| 2467 | 26 | 34 | 11160.2 | 10074.6 |
| 2468 | 27 | 34 | 13431.8 | 11040.7 |
| 2469 | 28 | 34 | 19695.2 | 5769.1 |
| 2470 | 29 | 34 | 9455.2 | 3252.7 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 2471 | 30 | 34 | 17114.2 | 5371.1 |
| 2472 | 31 | 34 | 10119.7 | 8277.9 |
| 2473 | 32 | 34 | 7132.3 | 8562.8 |
| 2474 | 33 | 34 | 10871.6 | 7375.0 |
| 2475 | 34 | 34 | 2150.6 | 11447.6 |
| 2518 | 3 | 35 | 15.8 | 0.0 |
| 2519 | 4 | 35 | 28.2 | 0.0 |
| 2523 | 8 | 35 | 141.3 | 0.0 |
| 2528 | 13 | 35 | 40.5 | 0.0 |
| 2529 | 14 | 35 | 159.2 | 172.9 |
| 2530 | 15 | 35 | 0.8 | 62.1 |
| 2531 | 16 | 35 | 1418.9 | 92.7 |
| 2532 | 17 | 35 | 599.7 | 175.9 |
| 2533 | 18 | 35 | 312.4 | 1192.0 |
| 2534 | 19 | 35 | 72.4 | 1996.6 |
| 2535 | 20 | 35 | 1123.0 | 1807.3 |
| 2536 | 21 | 35 | 1385.4 | 68.1 |
| 2537 | 22 | 35 | 4036.4 | 4417.0 |
| 2538 | 23 | 35 | 6472.8 | 4278.0 |
| 2539 | 24 | 35 | 2105.1 | 1728.6 |
| 2540 | 25 | 35 | 3805.6 | 2645.9 |
| 2541 | 26 | 35 | 5531.2 | 2398.5 |
| 2542 | 27 | 35 | 6500.3 | 6492.0 |
| 2543 | 28 | 35 | 14895.6 | 4700.0 |
| 2544 | 29 | 35 | 8588.9 | 1867.6 |
| 2545 | 30 | 35 | 14354.0 | 3416.3 |
| 2546 | 31 | 35 | 17553.3 | 11781.1 |
| 2548 | 33 | 35 | 4338.4 | 3880.7 |
| 2549 | 34 | 35 | 4569.4 | 5678.8 |
| 2593 | 4 | 36 | 6.0 | 0.0 |
| 2599 | 10 | 36 | 127.0 | 0.0 |
| 2603 | 14 | 36 | 195.4 | 105.4 |
| 2604 | 15 | 36 | 0.0 | 11.3 |
| 2605 | 16 | 36 | 1034.2 | 148.5 |
| 2606 | 17 | 36 | 470.4 | 382.2 |
| 2607 | 18 | 36 | 418.9 | 140.4 |
| 2608 | 19 | 36 | 1301.6 | 0.0 |
| 2609 | 20 | 36 | 492.9 | 136.2 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 2610 | 21 | 36 | 1244.5 | 350.8 |
| 2611 | 22 | 36 | 3773.7 | 2078.0 |
| 2612 | 23 | 36 | 7047.2 | 6389.2 |
| 2613 | 24 | 36 | 5844.5 | 4352.1 |
| 2614 | 25 | 36 | 3434.3 | 2364.1 |
| 2615 | 26 | 36 | 2753.7 | 2391.5 |
| 2616 | 27 | 36 | 1365.5 | 13083.2 |
| 2617 | 28 | 36 | 9295.9 | 6755.4 |
| 2618 | 29 | 36 | 11080.9 | 5039.0 |
| 2619 | 30 | 36 | 13591.7 | 9985.5 |
| 2620 | 31 | 36 | 7153.1 | 1454.7 |
| 2622 | 33 | 36 | 5220.9 | 3618.8 |
| 2623 | 34 | 36 | 0.0 | 5260.0 |
| 2666 | 3 | 37 | 0.0 | 0.0 |
| 2669 | 6 | 37 | 0.0 | 0.0 |
| 2673 | 10 | 37 | 0.0 | 0.0 |
| 2674 | 11 | 37 | 135.1 | 0.0 |
| 2676 | 13 | 37 | 16.3 | 0.0 |
| 2677 | 14 | 37 | 61.2 | 0.0 |
| 2678 | 15 | 37 | 253.5 | 107.3 |
| 2679 | 16 | 37 | 1766.9 | 0.0 |
| 2680 | 17 | 37 | 474.9 | 51.3 |
| 2681 | 18 | 37 | 562.6 | 61.4 |
| 2682 | 19 | 37 | 771.9 | 3593.2 |
| 2684 | 21 | 37 | 1982.1 | 208.2 |
| 2685 | 22 | 37 | 1983.1 | 278.2 |
| 2686 | 23 | 37 | 1107.6 | 939.4 |
| 2687 | 24 | 37 | 3588.4 | 5032.5 |
| 2688 | 25 | 37 | 1405.0 | 5338.1 |
| 2690 | 27 | 37 | 1643.2 | 4456.4 |
| 2691 | 28 | 37 | 8050.7 | 4241.4 |
| 2692 | 29 | 37 | 2718.4 | 7433.9 |
| 2743 | 6 | 38 | 0.0 | 0.0 |
| 2748 | 11 | 38 | 21.9 | 0.0 |
| 2749 | 12 | 38 | 147.9 | 0.0 |
| 2750 | 13 | 38 | 327.9 | 0.0 |
| 2751 | 14 | 38 | 1174.5 | 10.9 |
| 2752 | 15 | 38 | 254.3 | 0.0 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 2753 | 16 | 38 | 460.0 | 86.0 |
| 2754 | 17 | 38 | 1138.9 | 170.5 |
| 2755 | 18 | 38 | 2159.2 | 0.0 |
| 2756 | 19 | 38 | 361.2 | 83.3 |
| 2757 | 20 | 38 | 1832.4 | 20.2 |
| 2758 | 21 | 38 | 5248.8 | 0.0 |
| 2759 | 22 | 38 | 3011.9 | 2166.6 |
| 2760 | 23 | 38 | 2892.7 | 3762.1 |
| 2761 | 24 | 38 | 2450.0 | 739.5 |
| 2762 | 25 | 38 | 251.0 | 1602.7 |
| 2765 | 28 | 38 | 3645.4 | 12140.2 |
| 2766 | 29 | 38 | 1624.2 | 8721.1 |
| 2767 | 30 | 38 | 8100.4 | 8946.0 |
| 2768 | 31 | 38 | 456.0 | 4379.4 |
| 2816 | 5 | 39 | 75.2 | 0.0 |
| 2818 | 7 | 39 | 0.0 | 0.0 |
| 2821 | 10 | 39 | 0.0 | 46.0 |
| 2822 | 11 | 39 | 42.8 | 99.7 |
| 2824 | 13 | 39 | 921.1 | 0.0 |
| 2825 | 14 | 39 | 646.0 | 159.3 |
| 2826 | 15 | 39 | 490.4 | 48.7 |
| 2827 | 16 | 39 | 147.7 | 0.4 |
| 2829 | 18 | 39 | 732.9 | 0.0 |
| 2830 | 19 | 39 | 316.4 | 82.1 |
| 2831 | 20 | 39 | 875.0 | 1526.4 |
| 2832 | 21 | 39 | 1571.1 | 373.0 |
| 2833 | 22 | 39 | 3344.4 | 1122.1 |
| 2834 | 23 | 39 | 2343.5 | 2012.5 |
| 2835 | 24 | 39 | 489.9 | 1973.9 |
| 2837 | 26 | 39 | 0.0 | 5808.7 |
| 2839 | 28 | 39 | 2482.3 | 5.3 |
| 2841 | 30 | 39 | 5446.2 | 354.1 |
| 2842 | 31 | 39 | 382.3 | 9411.3 |
| 2843 | 32 | 39 | 5311.4 | 2570.0 |
| 2897 | 12 | 40 | 0.0 | 21.6 |
| 2898 | 13 | 40 | 166.7 | 0.0 |
| 2899 | 14 | 40 | 159.2 | 156.3 |
| 2900 | 15 | 40 | 406.2 | 799.8 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 2902 | 17 | 40 | 1075.1 | 62.3 |
| 2903 | 18 | 40 | 1870.4 | 156.7 |
| 2904 | 19 | 40 | 315.9 | 0.0 |
| 2905 | 20 | 40 | 501.6 | 10.2 |
| 2906 | 21 | 40 | 8496.1 | 39.6 |
| 2907 | 22 | 40 | 6366.2 | 113.9 |
| 2908 | 23 | 40 | 11035.9 | 338.5 |
| 2909 | 24 | 40 | 1078.4 | 2752.0 |
| 2910 | 25 | 40 | 1442.0 | 4269.4 |
| 2912 | 27 | 40 | 3521.0 | 5881.9 |
| 2913 | 28 | 40 | 4273.6 | 2027.0 |
| 2914 | 29 | 40 | 8562.9 | 260.1 |
| 2915 | 30 | 40 | 5489.9 | 0.0 |
| 2916 | 31 | 40 | 2178.1 | 1707.7 |
| 2962 | 3 | 41 | 3.8 | 0.0 |
| 2966 | 7 | 41 | 52.8 | 140.8 |
| 2971 | 12 | 41 | 0.2 | 326.4 |
| 2973 | 14 | 41 | 41.4 | 0.0 |
| 2974 | 15 | 41 | 376.5 | 42.7 |
| 2975 | 16 | 41 | 129.5 | 0.0 |
| 2976 | 17 | 41 | 82.3 | 52.5 |
| 2977 | 18 | 41 | 207.6 | 0.0 |
| 2978 | 19 | 41 | 182.3 | 153.3 |
| 2979 | 20 | 41 | 846.1 | 210.4 |
| 2980 | 21 | 41 | 1613.1 | 30.5 |
| 2981 | 22 | 41 | 1702.0 | 627.1 |
| 2982 | 23 | 41 | 4607.7 | 562.0 |
| 2984 | 25 | 41 | 4209.0 | 9109.6 |
| 2985 | 26 | 41 | 6733.3 | 9458.9 |
| 2986 | 27 | 41 | 3467.8 | 7916.4 |
| 2987 | 28 | 41 | 1332.5 | 7337.1 |
| 2989 | 30 | 41 | 1442.1 | 11.2 |
| 2990 | 31 | 41 | 1014.3 | 121.1 |
| 2991 | 32 | 41 | 7710.2 | 0.0 |
| 2992 | 33 | 41 | 7.7 | 0.0 |
| 3038 | 5 | 42 | 60.4 | 0.0 |
| 3040 | 7 | 42 | 188.7 | 0.0 |
| 3041 | 8 | 42 | 201.3 | 30.8 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 3043 | 10 | 42 | 8.9 | 1237.8 |
| 3045 | 12 | 42 | 0.0 | 177.2 |
| 3046 | 13 | 42 | 119.5 | 56.7 |
| 3047 | 14 | 42 | 50.0 | 191.5 |
| 3048 | 15 | 42 | 12.5 | 88.5 |
| 3050 | 17 | 42 | 4.3 | 54.6 |
| 3051 | 18 | 42 | 56.6 | 119.6 |
| 3052 | 19 | 42 | 2139.3 | 846.0 |
| 3053 | 20 | 42 | 802.8 | 157.1 |
| 3054 | 21 | 42 | 818.4 | 938.9 |
| 3055 | 22 | 42 | 3576.3 | 3823.5 |
| 3056 | 23 | 42 | 444.4 | 3186.2 |
| 3057 | 24 | 42 | 5942.1 | 7047.0 |
| 3058 | 25 | 42 | 531.1 | 8680.5 |
| 3059 | 26 | 42 | 3425.0 | 12467.1 |
| 3060 | 27 | 42 | 1437.0 | 7954.4 |
| 3061 | 28 | 42 | 326.0 | 10338.9 |
| 3062 | 29 | 42 | 520.1 | 14513.1 |
| 3067 | 34 | 42 | 409.5 | 0.0 |
| 3113 | 6 | 43 | 50.1 | 0.0 |
| 3117 | 10 | 43 | 56.0 | 525.7 |
| 3119 | 12 | 43 | 0.0 | 94.0 |
| 3120 | 13 | 43 | 135.5 | 0.0 |
| 3121 | 14 | 43 | 417.0 | 2.6 |
| 3123 | 16 | 43 | 16.8 | 0.0 |
| 3124 | 17 | 43 | 71.4 | 0.0 |
| 3125 | 18 | 43 | 0.0 | 246.0 |
| 3126 | 19 | 43 | 204.0 | 304.3 |
| 3127 | 20 | 43 | 202.1 | 152.4 |
| 3128 | 21 | 43 | 891.5 | 704.2 |
| 3129 | 22 | 43 | 2481.9 | 3491.7 |
| 3130 | 23 | 43 | 2669.6 | 1717.9 |
| 3131 | 24 | 43 | 11926.2 | 4692.2 |
| 3132 | 25 | 43 | 4664.0 | 3202.2 |
| 3133 | 26 | 43 | 2595.6 | 11896.9 |
| 3134 | 27 | 43 | 288.9 | 9962.0 |
| 3136 | 29 | 43 | 775.6 | 7622.1 |
| 3140 | 33 | 43 | 3528.0 | 0.0 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 3188 | 7 | 44 | 6.3 | 0.0 |
| 3189 | 8 | 44 | 4.6 | 0.0 |
| 3191 | 10 | 44 | 290.3 | 0.0 |
| 3192 | 11 | 44 | 75.9 | 14.8 |
| 3196 | 15 | 44 | 110.4 | 93.2 |
| 3198 | 17 | 44 | 131.1 | 0.0 |
| 3199 | 18 | 44 | 67.4 | 390.2 |
| 3200 | 19 | 44 | 168.5 | 326.2 |
| 3201 | 20 | 44 | 218.4 | 81.1 |
| 3202 | 21 | 44 | 651.3 | 55.9 |
| 3203 | 22 | 44 | 2367.0 | 641.0 |
| 3204 | 23 | 44 | 8898.0 | 2903.3 |
| 3205 | 24 | 44 | 16383.8 | 5358.9 |
| 3206 | 25 | 44 | 16873.7 | 1681.2 |
| 3207 | 26 | 44 | 9557.7 | 2691.7 |
| 3208 | 27 | 44 | 1173.7 | 7661.8 |
| 3213 | 32 | 44 | 1135.1 | 58.1 |
| 3214 | 33 | 44 | 3649.9 | 478.4 |
| 3215 | 34 | 44 | 3283.1 | 4775.3 |
| 3261 | 6 | 45 | 109.5 | 0.0 |
| 3262 | 7 | 45 | 128.8 | 0.0 |
| 3263 | 8 | 45 | 5601.1 | 0.0 |
| 3264 | 9 | 45 | 1022.0 | 43.7 |
| 3265 | 10 | 45 | 54.2 | 17.0 |
| 3266 | 11 | 45 | 393.2 | 200.7 |
| 3267 | 12 | 45 | 63.9 | 139.5 |
| 3268 | 13 | 45 | 354.9 | 284.3 |
| 3269 | 14 | 45 | 261.1 | 195.3 |
| 3270 | 15 | 45 | 95.5 | 297.3 |
| 3273 | 18 | 45 | 50.8 | 210.5 |
| 3274 | 19 | 45 | 65.4 | 184.0 |
| 3275 | 20 | 45 | 158.3 | 1183.7 |
| 3276 | 21 | 45 | 1390.8 | 1763.7 |
| 3277 | 22 | 45 | 5972.8 | 1863.1 |
| 3278 | 23 | 45 | 13050.6 | 7540.9 |
| 3279 | 24 | 45 | 18351.2 | 8897.8 |
| 3280 | 25 | 45 | 15661.6 | 8355.0 |
| 3281 | 26 | 45 | 17038.6 | 11859.2 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 3282 | 27 | 45 | 11500.5 | 7826.1 |
| 3283 | 28 | 45 | 1916.9 | 5267.1 |
| 3284 | 29 | 45 | 1052.0 | 3410.0 |
| 3288 | 33 | 45 | 2513.7 | 1545.6 |
| 3289 | 34 | 45 | 11664.4 | 487.9 |
| 3337 | 8 | 46 | 100.1 | 188.1 |
| 3338 | 9 | 46 | 0.0 | 44.5 |
| 3339 | 10 | 46 | 103.6 | 0.0 |
| 3340 | 11 | 46 | 54.2 | 137.4 |
| 3343 | 14 | 46 | 115.0 | 0.0 |
| 3344 | 15 | 46 | 3.0 | 10.6 |
| 3345 | 16 | 46 | 142.7 | 0.0 |
| 3346 | 17 | 46 | 9.8 | 0.0 |
| 3347 | 18 | 46 | 298.1 | 148.6 |
| 3348 | 19 | 46 | 136.6 | 471.2 |
| 3349 | 20 | 46 | 210.3 | 668.3 |
| 3350 | 21 | 46 | 1012.8 | 949.0 |
| 3351 | 22 | 46 | 5020.5 | 1312.5 |
| 3352 | 23 | 46 | 8299.3 | 7787.8 |
| 3353 | 24 | 46 | 13368.6 | 7452.3 |
| 3354 | 25 | 46 | 11861.2 | 8293.6 |
| 3355 | 26 | 46 | 12443.1 | 8180.1 |
| 3356 | 27 | 46 | 13419.0 | 9300.6 |
| 3357 | 28 | 46 | 4839.3 | 8640.2 |
| 3358 | 29 | 46 | 655.7 | 10648.4 |
| 3410 | 7 | 47 | 0.0 | 25.2 |
| 3412 | 9 | 47 | 0.0 | 0.0 |
| 3413 | 10 | 47 | 398.6 | 26.7 |
| 3414 | 11 | 47 | 241.9 | 205.5 |
| 3415 | 12 | 47 | 42.7 | 218.7 |
| 3416 | 13 | 47 | 274.8 | 44.0 |
| 3420 | 17 | 47 | 146.7 | 88.9 |
| 3421 | 18 | 47 | 176.5 | 272.6 |
| 3422 | 19 | 47 | 134.2 | 911.4 |
| 3423 | 20 | 47 | 47.6 | 445.3 |
| 3424 | 21 | 47 | 483.1 | 849.1 |
| 3425 | 22 | 47 | 3185.4 | 3064.2 |
| 3426 | 23 | 47 | 1810.5 | 2194.7 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 3427 | 24 | 47 | 3280.7 | 5007.7 |
| 3428 | 25 | 47 | 12040.9 | 10343.6 |
| 3429 | 26 | 47 | 12737.8 | 5301.5 |
| 3430 | 27 | 47 | 9893.3 | 6859.9 |
| 3431 | 28 | 47 | 3549.6 | 8700.8 |
| 3432 | 29 | 47 | 1948.9 | 9597.9 |
| 3433 | 30 | 47 | 1195.9 | 9841.2 |
| 3435 | 32 | 47 | 181.8 | 943.2 |
| 3485 | 8 | 48 | 38.1 | 137.2 |
| 3486 | 9 | 48 | 58.9 | 53.3 |
| 3487 | 10 | 48 | 965.3 | 190.8 |
| 3488 | 11 | 48 | 601.1 | 186.0 |
| 3489 | 12 | 48 | 37.7 | 306.7 |
| 3490 | 13 | 48 | 393.5 | 68.3 |
| 3492 | 15 | 48 | 63.2 | 11.7 |
| 3493 | 16 | 48 | 51.3 | 0.0 |
| 3494 | 17 | 48 | 126.6 | 0.0 |
| 3495 | 18 | 48 | 664.3 | 0.0 |
| 3496 | 19 | 48 | 809.2 | 447.6 |
| 3497 | 20 | 48 | 9.6 | 1663.5 |
| 3498 | 21 | 48 | 2255.1 | 1627.4 |
| 3499 | 22 | 48 | 7666.9 | 1083.8 |
| 3500 | 23 | 48 | 7331.3 | 3173.0 |
| 3501 | 24 | 48 | 9157.5 | 4120.8 |
| 3502 | 25 | 48 | 5814.3 | 2499.6 |
| 3503 | 26 | 48 | 12762.0 | 1604.0 |
| 3504 | 27 | 48 | 4933.1 | 2918.5 |
| 3505 | 28 | 48 | 5764.1 | 2731.0 |
| 3506 | 29 | 48 | 2415.8 | 4351.0 |
| 3507 | 30 | 48 | 383.1 | 7266.2 |
| 3508 | 31 | 48 | 1026.3 | 6861.3 |
| 3509 | 32 | 48 | 2799.3 | 5871.2 |
| 3559 | 8 | 49 | 191.2 | 0.0 |
| 3560 | 9 | 49 | 0.4 | 0.0 |
| 3561 | 10 | 49 | 874.4 | 15.9 |
| 3562 | 11 | 49 | 805.6 | 0.0 |
| 3563 | 12 | 49 | 176.6 | 30.1 |
| 3564 | 13 | 49 | 3.5 | 0.0 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 3568 | 17 | 49 | 348.7 | 24.9 |
| 3569 | 18 | 49 | 808.2 | 61.9 |
| 3570 | 19 | 49 | 541.1 | 120.2 |
| 3571 | 20 | 49 | 125.1 | 2309.9 |
| 3572 | 21 | 49 | 4142.3 | 894.8 |
| 3573 | 22 | 49 | 5902.1 | 1358.3 |
| 3574 | 23 | 49 | 9734.1 | 2327.5 |
| 3575 | 24 | 49 | 13701.8 | 4968.6 |
| 3576 | 25 | 49 | 9229.4 | 315.1 |
| 3577 | 26 | 49 | 15067.6 | 423.9 |
| 3578 | 27 | 49 | 7077.1 | 2626.9 |
| 3579 | 28 | 49 | 2794.3 | 2021.9 |
| 3580 | 29 | 49 | 6470.2 | 2751.8 |
| 3581 | 30 | 49 | 592.7 | 2060.7 |
| 3582 | 31 | 49 | 2177.2 | 1587.1 |
| 3583 | 32 | 49 | 4383.4 | 6391.8 |
| 3633 | 8 | 50 | 54.6 | 0.0 |
| 3634 | 9 | 50 | 603.8 | 0.0 |
| 3635 | 10 | 50 | 572.4 | 0.0 |
| 3636 | 11 | 50 | 39.9 | 0.0 |
| 3637 | 12 | 50 | 3.0 | 0.7 |
| 3640 | 15 | 50 | 10.2 | 0.0 |
| 3641 | 16 | 50 | 448.3 | 0.0 |
| 3642 | 17 | 50 | 48.5 | 55.8 |
| 3644 | 19 | 50 | 194.8 | 86.7 |
| 3645 | 20 | 50 | 910.8 | 2753.3 |
| 3646 | 21 | 50 | 1709.6 | 3186.0 |
| 3647 | 22 | 50 | 2000.1 | 314.1 |
| 3648 | 23 | 50 | 7532.0 | 536.3 |
| 3649 | 24 | 50 | 5743.9 | 734.0 |
| 3650 | 25 | 50 | 6783.5 | 147.8 |
| 3651 | 26 | 50 | 10242.0 | 976.0 |
| 3652 | 27 | 50 | 14456.4 | 4403.5 |
| 3653 | 28 | 50 | 6270.7 | 2432.1 |
| 3654 | 29 | 50 | 3794.8 | 2604.8 |
| 3655 | 30 | 50 | 2491.2 | 2588.4 |
| 3656 | 31 | 50 | 1358.8 | 1852.2 |
| 3657 | 32 | 50 | 1867.2 | 465.8 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 3658 | 33 | 50 | 1159.4 | 115.2 |
| 3659 | 34 | 50 | 56.4 | 0.0 |
| 3707 | 8 | 51 | 0.0 | 0.0 |
| 3708 | 9 | 51 | 14.4 | 0.0 |
| 3709 | 10 | 51 | 141.7 | 0.0 |
| 3710 | 11 | 51 | 377.4 | 0.0 |
| 3711 | 12 | 51 | 15.2 | 0.0 |
| 3712 | 13 | 51 | 59.0 | 0.0 |
| 3713 | 14 | 51 | 105.5 | 0.0 |
| 3717 | 18 | 51 | 116.8 | 0.0 |
| 3718 | 19 | 51 | 727.3 | 857.0 |
| 3719 | 20 | 51 | 604.6 | 2600.7 |
| 3720 | 21 | 51 | 7559.1 | 3112.7 |
| 3721 | 22 | 51 | 1943.0 | 175.2 |
| 3722 | 23 | 51 | 2151.2 | 361.0 |
| 3723 | 24 | 51 | 1806.4 | 159.7 |
| 3724 | 25 | 51 | 4102.1 | 3.8 |
| 3725 | 26 | 51 | 4789.0 | 147.1 |
| 3726 | 27 | 51 | 5017.3 | 490.3 |
| 3727 | 28 | 51 | 9060.0 | 1224.8 |
| 3728 | 29 | 51 | 2886.2 | 1710.1 |
| 3729 | 30 | 51 | 1807.2 | 1375.1 |
| 3730 | 31 | 51 | 466.8 | 281.3 |
| 3731 | 32 | 51 | 2830.8 | 0.0 |
| 3780 | 7 | 52 | 0.0 | 0.0 |
| 3783 | 10 | 52 | 358.4 | 0.0 |
| 3786 | 13 | 52 | 60.0 | 0.0 |
| 3787 | 14 | 52 | 57.3 | 0.0 |
| 3789 | 16 | 52 | 0.0 | 6.0 |
| 3791 | 18 | 52 | 85.8 | 168.7 |
| 3792 | 19 | 52 | 419.6 | 1303.9 |
| 3793 | 20 | 52 | 1857.3 | 1844.7 |
| 3794 | 21 | 52 | 3218.1 | 107.9 |
| 3795 | 22 | 52 | 5056.4 | 238.6 |
| 3796 | 23 | 52 | 544.5 | 289.8 |
| 3797 | 24 | 52 | 1117.9 | 376.3 |
| 3798 | 25 | 52 | 2840.4 | 1138.0 |
| 3799 | 26 | 52 | 3790.5 | 742.8 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 3800 | 27 | 52 | 3468.5 | 99.4 |
| 3801 | 28 | 52 | 4071.8 | 744.2 |
| 3802 | 29 | 52 | 1750.1 | 766.4 |
| 3803 | 30 | 52 | 4255.1 | 62.1 |
| 3804 | 31 | 52 | 225.0 | 0.0 |
| 3805 | 32 | 52 | 217.1 | 0.0 |
| 3855 | 8 | 53 | 0.0 | 0.0 |
| 3864 | 17 | 53 | 59.5 | 161.2 |
| 3865 | 18 | 53 | 4221.8 | 423.8 |
| 3866 | 19 | 53 | 2982.4 | 316.8 |
| 3867 | 20 | 53 | 198.9 | 492.9 |
| 3868 | 21 | 53 | 246.3 | 177.7 |
| 3869 | 22 | 53 | 948.5 | 931.3 |
| 3870 | 23 | 53 | 148.7 | 0.0 |
| 3871 | 24 | 53 | 261.6 | 686.5 |
| 3872 | 25 | 53 | 1834.7 | 318.3 |
| 3873 | 26 | 53 | 1830.3 | 326.2 |
| 3874 | 27 | 53 | 2862.6 | 1236.7 |
| 3875 | 28 | 53 | 1657.2 | 2156.8 |
| 3876 | 29 | 53 | 2641.8 | 37.2 |
| 3877 | 30 | 53 | 1254.7 | 0.0 |
| 3878 | 31 | 53 | 473.3 | 0.0 |
| 3936 | 15 | 54 | 3.1 | 0.0 |
| 3938 | 17 | 54 | 0.1 | 48.6 |
| 3939 | 18 | 54 | 1091.5 | 183.3 |
| 3940 | 19 | 54 | 1114.5 | 845.6 |
| 3941 | 20 | 54 | 202.4 | 1397.5 |
| 3944 | 23 | 54 | 10.9 | 1094.8 |
| 3945 | 24 | 54 | 390.9 | 793.7 |
| 3946 | 25 | 54 | 1108.8 | 812.2 |
| 3947 | 26 | 54 | 575.8 | 3622.5 |
| 3948 | 27 | 54 | 1788.2 | 1103.0 |
| 3949 | 28 | 54 | 913.4 | 66.4 |
| 3950 | 29 | 54 | 298.6 | 0.0 |
| 4000 | 5 | 55 | 0.0 | 0.0 |
| 4004 | 9 | 55 | 0.0 | 4.2 |
| 4008 | 13 | 55 | 0.0 | 0.0 |
| 4012 | 17 | 55 | 249.9 | 151.8 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 4014 | 19 | 55 | 135.9 | 0.0 |
| 4018 | 23 | 55 | 78.0 | 787.9 |
| 4019 | 24 | 55 | 4.6 | 590.7 |
| 4020 | 25 | 55 | 34.0 | 120.8 |
| 4021 | 26 | 55 | 214.3 | 2371.2 |
| 4022 | 27 | 55 | 510.3 | 776.1 |
| 4023 | 28 | 55 | 243.5 | 117.4 |
| 4024 | 29 | 55 | 32.7 | 0.0 |
| 4081 | 12 | 56 | 11.2 | 0.0 |
| 4085 | 16 | 56 | 0.1 | 0.0 |
| 4087 | 18 | 56 | 8.7 | 237.3 |
| 4088 | 19 | 56 | 14.3 | 1127.2 |
| 4092 | 23 | 56 | 46.4 | 392.9 |
| 4093 | 24 | 56 | 10.0 | 1806.7 |
| 4094 | 25 | 56 | 602.4 | 1301.3 |
| 4095 | 26 | 56 | 971.4 | 2507.1 |
| 4096 | 27 | 56 | 219.3 | 1519.6 |
| 4158 | 15 | 57 | 0.1 | 0.0 |
| 4159 | 16 | 57 | 0.0 | 0.0 |
| 4160 | 17 | 57 | 36.1 | 46.7 |
| 4162 | 19 | 57 | 2.8 | 3091.5 |
| 4163 | 20 | 57 | 214.0 | 3324.5 |
| 4164 | 21 | 57 | 74.9 | 2153.5 |
| 4165 | 22 | 57 | 21.2 | 1811.2 |
| 4166 | 23 | 57 | 23.2 | 2052.0 |
| 4167 | 24 | 57 | 1034.1 | 1135.8 |
| 4168 | 25 | 57 | 1050.0 | 5486.1 |
| 4169 | 26 | 57 | 410.9 | 8869.7 |
| 4228 | 11 | 58 | 11.2 | 0.0 |
| 4229 | 12 | 58 | 0.0 | 0.0 |
| 4235 | 18 | 58 | 5.7 | 2049.4 |
| 4236 | 19 | 58 | 28.6 | 2294.4 |
| 4237 | 20 | 58 | 160.5 | 3918.1 |
| 4238 | 21 | 58 | 64.4 | 1181.5 |
| 4240 | 23 | 58 | 0.0 | 450.3 |
| 4241 | 24 | 58 | 451.8 | 3907.9 |
| 4242 | 25 | 58 | 200.8 | 2339.7 |
| 4302 | 11 | 59 | 41.4 | 0.0 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 4306 | 15 | 59 | 118.1 | 415.0 |
| 4307 | 16 | 59 | 54.9 | 256.7 |
| 4311 | 20 | 59 | 116.3 | 118.9 |
| 4313 | 22 | 59 | 18.8 | 70.9 |
| 4314 | 23 | 59 | 2.1 | 1327.3 |
| 4315 | 24 | 59 | 87.1 | 2445.4 |
| 4376 | 11 | 60 | 0.0 | 3.4 |
| 4382 | 17 | 60 | 0.0 | 200.0 |
| 4383 | 18 | 60 | 13.4 | 1202.3 |
| 4384 | 19 | 60 | 100.0 | 95.5 |
| 4385 | 20 | 60 | 0.0 | 122.8 |
| 4386 | 21 | 60 | 0.0 | 241.6 |
| 4387 | 22 | 60 | 0.0 | 3317.8 |
| 4388 | 23 | 60 | 0.0 | 3667.0 |
| 4389 | 24 | 60 | 3.7 | 957.2 |
| 4442 | 3 | 61 | 0.7 | 0.0 |
| 4443 | 4 | 61 | 0.0 | 0.0 |
| 4458 | 19 | 61 | 0.0 | 0.0 |
| 4459 | 20 | 61 | 0.0 | 30.1 |
| 4460 | 21 | 61 | 0.0 | 58.0 |
| 4461 | 22 | 61 | 0.0 | 2149.7 |
| 4462 | 23 | 61 | 0.0 | 332.0 |
| 4463 | 24 | 61 | 0.0 | 780.2 |
| 4516 | 3 | 62 | 0.0 | 0.0 |
| 4522 | 9 | 62 | 0.0 | 0.0 |
| 4527 | 14 | 62 | 0.0 | 6.6 |
| 4528 | 15 | 62 | 0.0 | 3.5 |
| 4529 | 16 | 62 | 0.0 | 0.0 |
| 4531 | 18 | 62 | 0.0 | 0.0 |
| 4532 | 19 | 62 | 0.0 | 0.0 |
| 4533 | 20 | 62 | 0.0 | 0.0 |
| 4534 | 21 | 62 | 0.0 | 147.7 |
| 4535 | 22 | 62 | 0.0 | 562.9 |
| 4536 | 23 | 62 | 5.1 | 260.3 |
| 4537 | 24 | 62 | 0.0 | 291.4 |
| 4543 | 30 | 62 | 0.0 | 0.0 |
| 4590 | 3 | 63 | 0.0 | 0.0 |
| 4594 | 7 | 63 | 0.0 | 0.0 |

**Table E-1** (continued).

| Grid Cell ID[a] | i[b] | j[b] | 2009 Natural Gas Production (MMscf/y)[c] | 2013 Natural Gas Production (MMscf/y)[d] |
|---|---|---|---|---|
| 4595 | 8 | 63 | 0.0 | 0.0 |
| 4597 | 10 | 63 | 0.0 | 0.0 |
| 4599 | 12 | 63 | 0.0 | 0.0 |
| 4600 | 13 | 63 | 0.0 | 123.8 |
| 4605 | 18 | 63 | 0.0 | 0.0 |
| 4606 | 19 | 63 | 0.0 | 0.0 |
| 4607 | 20 | 63 | 0.0 | 0.0 |
| 4608 | 21 | 63 | 0.0 | 136.0 |
| 4609 | 22 | 63 | 424.6 | 83.6 |
| 4610 | 23 | 63 | 0.0 | 79.8 |
| 4672 | 11 | 64 | 0.0 | 0.0 |
| 4674 | 13 | 64 | 0.0 | 0.0 |
| 4679 | 18 | 64 | 0.0 | 0.0 |
| 4680 | 19 | 64 | 0.0 | 0.0 |
| 4682 | 21 | 64 | 0.0 | 0.0 |
| 4683 | 22 | 64 | 15.6 | 0.0 |
| 4684 | 23 | 64 | 64.2 | 0.0 |
| 4753 | 18 | 65 | 0.0 | 0.0 |
| 4756 | 21 | 65 | 0.0 | 0.0 |
| 4757 | 22 | 65 | 0.0 | 0.0 |
| 4758 | 23 | 65 | 0.0 | 0.0 |

(a) Grid ID represents the number of the cell from the domain. Starting at the lower left corner; followed by cell values in row-major order.
(b) i,j represent the coordinates of each grid cell in the domain, with $x_0$=140, $y_0$= -680 (4km by 4km domain. [6]
(c) Represents sum of Natural Gas Production for all the sites in the special emission inventory, within each grid cell.
(d) Obtained from Texas Rail Road Commission.

For each grid cell, Table E-2 shows final data set of estimated emissions for 2009.

**Table E-2.** Estimated methane, ethane and propane emissions, as well as methane to ethane and methane to propane ratios, for each grid cell, for 2009.

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 1066 | 1.8 | 0.2 | 0.2 | 14.5 | 28.0 |
| 1139 | 0.1 | 0.0 | 0.0 | 14.4 | 27.7 |
| 1285 | 0.1 | 0.0 | 0.0 | 14.0 | 25.8 |
| 1287 | 0.0 | 0.0 | 0.0 | 14.8 | 29.2 |
| 1288 | 2.2 | 0.3 | 0.2 | 15.1 | 30.9 |
| 1359 | 0.1 | 0.0 | 0.0 | 13.2 | 26.3 |
| 1360 | 1.8 | 0.2 | 0.2 | 14.2 | 27.3 |
| 1361 | 0.7 | 0.1 | 0.1 | 15.2 | 33.6 |
| 1364 | 0.0 | 0.0 | 0.0 | 15.6 | 33.5 |
| 1416 | 0.5 | 0.1 | 0.1 | 11.6 | 18.4 |
| 1428 | 1.4 | 0.2 | 0.2 | 12.5 | 20.3 |
| 1433 | 1.0 | 0.1 | 0.1 | 12.8 | 21.9 |
| 1434 | 2.9 | 0.4 | 0.4 | 12.0 | 19.7 |
| 1435 | 2.9 | 0.4 | 0.2 | 15.3 | 38.8 |
| 1436 | 3.5 | 0.4 | 0.1 | 18.8 | 67.9 |
| 1437 | 0.1 | 0.0 | 0.0 | 17.4 | 45.6 |
| 1493 | 0.9 | 0.1 | 0.1 | 11.4 | 18.0 |
| 1494 | 1.4 | 0.2 | 0.2 | 11.6 | 18.8 |
| 1496 | 1.5 | 0.2 | 0.2 | 11.4 | 18.1 |
| 1498 | 0.3 | 0.0 | 0.0 | 17.9 | 57.9 |
| 1504 | 2.0 | 0.3 | 0.3 | 12.5 | 20.3 |
| 1505 | 5.7 | 0.9 | 0.9 | 11.5 | 17.4 |
| 1506 | 3.8 | 0.7 | 0.6 | 10.5 | 16.7 |
| 1507 | 0.7 | 0.1 | 0.1 | 12.0 | 20.4 |
| 1508 | 7.1 | 1.0 | 0.9 | 12.7 | 21.3 |
| 1509 | 1.5 | 0.2 | 0.1 | 14.9 | 34.4 |
| 1510 | 10.0 | 1.2 | 0.4 | 16.0 | 73.3 |
| 1511 | 0.3 | 0.0 | 0.0 | 18.5 | 56.8 |
| 1557 | 0.6 | 0.1 | 0.1 | 11.8 | 18.2 |
| 1558 | 0.6 | 0.1 | 0.1 | 11.7 | 17.8 |
| 1566 | 0.9 | 0.4 | 0.6 | 4.2 | 4.1 |
| 1568 | 0.0 | 0.0 | 0.0 | NA | NA |
| 1569 | 2.8 | 0.5 | 0.4 | 11.5 | 18.3 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 1574 | 1.4 | 0.2 | 0.2 | 11.6 | 18.4 |
| 1575 | 1.4 | 0.2 | 0.2 | 12.0 | 19.0 |
| 1580 | 4.7 | 0.8 | 0.8 | 11.0 | 16.7 |
| 1581 | 3.4 | 0.5 | 0.4 | 12.3 | 20.7 |
| 1582 | 7.2 | 0.9 | 0.6 | 15.1 | 31.7 |
| 1583 | 10.9 | 1.1 | 0.5 | 18.1 | 59.3 |
| 1584 | 3.5 | 0.4 | 0.2 | 17.0 | 50.9 |
| 1639 | 0.0 | 0.0 | 0.0 | 5.4 | 5.6 |
| 1640 | 0.0 | 0.0 | 0.0 | 7.8 | 9.2 |
| 1642 | 0.7 | 0.1 | 0.1 | 11.9 | 18.5 |
| 1646 | 0.1 | 0.0 | 0.0 | 12.4 | 23.4 |
| 1647 | 0.2 | 0.0 | 0.0 | 14.3 | 31.5 |
| 1648 | 0.7 | 0.1 | 0.1 | 11.6 | 19.2 |
| 1649 | 3.3 | 0.5 | 0.5 | 12.0 | 19.4 |
| 1650 | 4.2 | 0.6 | 0.5 | 12.6 | 21.0 |
| 1651 | 1.0 | 0.1 | 0.1 | 15.0 | 34.5 |
| 1652 | 3.1 | 0.5 | 0.4 | 12.4 | 20.3 |
| 1653 | 9.8 | 1.6 | 1.5 | 11.7 | 18.1 |
| 1654 | 3.3 | 0.5 | 0.4 | 12.7 | 20.9 |
| 1655 | 4.6 | 0.7 | 0.7 | 11.5 | 17.7 |
| 1656 | 1.6 | 0.2 | 0.2 | 13.1 | 22.3 |
| 1657 | 2.6 | 0.3 | 0.1 | 17.0 | 52.5 |
| 1658 | 13.2 | 1.2 | 0.3 | 21.0 | 109.7 |
| 1659 | 0.0 | 0.0 | 0.0 | 16.8 | 42.4 |
| 1717 | 5.4 | 0.9 | 0.8 | 11.3 | 18.4 |
| 1718 | 5.5 | 1.0 | 0.9 | 10.5 | 15.9 |
| 1722 | 0.0 | 0.0 | 0.0 | 11.5 | 17.3 |
| 1723 | 8.6 | 1.3 | 1.2 | 12.1 | 19.5 |
| 1724 | 2.3 | 0.4 | 0.3 | 11.9 | 19.4 |
| 1725 | 0.0 | 0.0 | 0.0 | 13.6 | 24.2 |
| 1726 | 0.3 | 0.0 | 0.0 | 13.2 | 23.3 |
| 1727 | 7.2 | 1.1 | 1.0 | 12.0 | 18.9 |
| 1728 | 3.4 | 0.5 | 0.5 | 11.8 | 18.5 |
| 1729 | 1.8 | 0.3 | 0.2 | 12.9 | 22.6 |
| 1730 | 0.0 | 0.0 | 0.0 | 14.6 | 28.4 |
| 1731 | 0.1 | 0.0 | 0.0 | 16.5 | 38.8 |
| 1732 | 0.1 | 0.0 | 0.0 | 17.6 | 47.8 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 1786 | 0.0 | 0.0 | 0.0 | 6.4 | 7.0 |
| 1787 | 1.8 | 0.5 | 0.4 | 7.0 | 12.0 |
| 1789 | 0.5 | 0.1 | 0.1 | 12.8 | 27.9 |
| 1790 | 6.6 | 1.0 | 0.8 | 12.3 | 23.3 |
| 1794 | 6.2 | 1.1 | 1.0 | 10.9 | 17.8 |
| 1795 | 4.9 | 0.9 | 0.8 | 10.0 | 16.2 |
| 1796 | 25.2 | 4.7 | 4.7 | 10.1 | 14.8 |
| 1797 | 5.8 | 1.0 | 0.9 | 11.1 | 16.8 |
| 1798 | 2.2 | 0.4 | 0.3 | 11.9 | 22.4 |
| 1799 | 2.2 | 0.3 | 0.3 | 13.3 | 23.6 |
| 1800 | 0.3 | 0.0 | 0.0 | 13.4 | 33.0 |
| 1801 | 0.2 | 0.0 | 0.0 | 14.8 | 32.9 |
| 1802 | 0.6 | 0.1 | 0.0 | 15.4 | 33.9 |
| 1803 | 2.3 | 0.3 | 0.2 | 14.6 | 28.9 |
| 1804 | 0.2 | 0.0 | 0.0 | 15.8 | 34.5 |
| 1805 | 0.3 | 0.0 | 0.0 | 17.1 | 43.2 |
| 1806 | 2.6 | 0.2 | 0.1 | 19.8 | 84.7 |
| 1809 | 0.1 | 0.0 | 0.0 | 16.9 | 41.7 |
| 1859 | 0.0 | 0.0 | 0.0 | 5.1 | 5.3 |
| 1862 | 0.0 | 0.0 | 0.0 | NA | NA |
| 1863 | 5.6 | 0.7 | 0.5 | 14.6 | 29.0 |
| 1864 | 2.3 | 0.2 | 0.1 | 18.8 | 68.8 |
| 1865 | 0.8 | 0.1 | 0.1 | 14.3 | 33.1 |
| 1868 | 32.5 | 5.2 | 4.4 | 11.6 | 20.1 |
| 1869 | 1.0 | 0.2 | 0.2 | 10.4 | 15.7 |
| 1870 | 7.9 | 1.6 | 1.7 | 9.4 | 12.6 |
| 1871 | 3.4 | 0.8 | 0.9 | 8.1 | 10.5 |
| 1872 | 0.6 | 0.1 | 0.1 | 11.5 | 18.2 |
| 1873 | 0.2 | 0.0 | 0.0 | 13.0 | 24.3 |
| 1874 | 0.2 | 0.0 | 0.0 | 15.0 | 33.9 |
| 1875 | 1.2 | 0.1 | 0.1 | 15.9 | 37.7 |
| 1876 | 0.1 | 0.0 | 0.0 | 15.4 | 32.5 |
| 1877 | 0.5 | 0.1 | 0.0 | 16.4 | 42.4 |
| 1878 | 0.2 | 0.0 | 0.0 | 17.0 | 42.3 |
| 1879 | 2.1 | 0.2 | 0.1 | 19.5 | 72.7 |
| 1880 | 3.8 | 0.4 | 0.2 | 18.4 | 60.3 |
| 1881 | 2.4 | 0.3 | 0.2 | 16.4 | 41.9 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 1883 | 0.2 | 0.0 | 0.0 | 17.3 | 44.9 |
| 1932 | 3.1 | 1.0 | 1.4 | 5.7 | 6.1 |
| 1933 | 0.2 | 0.1 | 0.1 | 8.2 | 10.2 |
| 1938 | 2.2 | 0.3 | 0.1 | 16.3 | 42.6 |
| 1941 | 2.5 | 0.5 | 0.4 | 10.0 | 17.2 |
| 1942 | 15.9 | 2.8 | 2.8 | 10.6 | 15.9 |
| 1943 | 7.4 | 1.3 | 1.3 | 10.5 | 15.6 |
| 1944 | 7.4 | 1.3 | 1.3 | 10.9 | 15.8 |
| 1945 | 6.8 | 1.6 | 1.9 | 8.0 | 9.9 |
| 1946 | 2.9 | 0.5 | 0.6 | 10.1 | 14.0 |
| 1947 | 2.1 | 0.3 | 0.2 | 15.3 | 33.7 |
| 1948 | 0.2 | 0.0 | 0.0 | 15.0 | 30.1 |
| 1949 | 7.8 | 0.8 | 0.4 | 18.0 | 51.6 |
| 1950 | 0.2 | 0.0 | 0.0 | 16.0 | 35.7 |
| 1951 | 0.0 | 0.0 | 0.0 | 16.6 | 39.8 |
| 1952 | 1.1 | 0.1 | 0.1 | 16.9 | 44.0 |
| 1953 | 0.2 | 0.0 | 0.0 | 18.2 | 53.8 |
| 1954 | 18.3 | 1.9 | 0.6 | 17.8 | 79.3 |
| 1955 | 2.5 | 0.3 | 0.1 | 17.7 | 48.7 |
| 1956 | 2.7 | 0.3 | 0.1 | 17.6 | 51.4 |
| 2005 | 2.2 | 0.4 | 0.4 | 10.9 | 16.1 |
| 2006 | 2.6 | 0.9 | 1.2 | 5.5 | 5.9 |
| 2007 | 1.4 | 0.3 | 0.3 | 9.1 | 11.9 |
| 2008 | 0.6 | 0.1 | 0.1 | 9.4 | 12.3 |
| 2009 | 0.0 | 0.0 | 0.0 | NA | NA |
| 2011 | 0.6 | 0.1 | 0.1 | 12.2 | 24.0 |
| 2012 | 1.2 | 0.2 | 0.1 | 13.6 | 31.1 |
| 2013 | 7.0 | 1.0 | 0.8 | 13.6 | 24.4 |
| 2014 | 7.6 | 1.1 | 1.0 | 12.3 | 20.4 |
| 2015 | 13.6 | 2.4 | 2.4 | 10.7 | 15.9 |
| 2016 | 24.1 | 4.3 | 4.3 | 10.5 | 15.3 |
| 2017 | 34.2 | 6.1 | 6.1 | 10.6 | 15.5 |
| 2018 | 12.0 | 2.3 | 2.4 | 9.8 | 13.8 |
| 2019 | 7.5 | 2.3 | 2.9 | 6.2 | 7.1 |
| 2020 | 3.5 | 0.8 | 0.9 | 8.2 | 10.6 |
| 2021 | 0.8 | 0.1 | 0.1 | 13.5 | 25.1 |
| 2022 | 3.9 | 0.4 | 0.2 | 17.8 | 51.0 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 2023 | 0.0 | 0.0 | 0.0 | 15.8 | 34.5 |
| 2024 | 0.7 | 0.1 | 0.0 | 16.7 | 42.6 |
| 2025 | 12.8 | 1.6 | 0.5 | 14.6 | 65.9 |
| 2026 | 0.3 | 0.0 | 0.0 | 18.0 | 51.7 |
| 2027 | 0.4 | 0.0 | 0.0 | 17.5 | 50.2 |
| 2028 | 47.2 | 4.6 | 2.0 | 19.0 | 63.4 |
| 2029 | 6.5 | 0.5 | 0.1 | 23.3 | 252.5 |
| 2030 | 0.1 | 0.0 | 0.0 | 19.0 | 63.1 |
| 2072 | 0.6 | 0.1 | 0.1 | 11.5 | 18.0 |
| 2073 | 3.5 | 0.6 | 0.5 | 10.7 | 17.5 |
| 2080 | 4.7 | 1.6 | 2.3 | 5.4 | 5.7 |
| 2081 | 0.8 | 0.2 | 0.3 | 7.3 | 8.7 |
| 2082 | 2.2 | 0.6 | 0.8 | 6.4 | 7.4 |
| 2083 | 1.7 | 0.4 | 0.5 | 7.3 | 8.9 |
| 2084 | 0.0 | 0.0 | 0.0 | 10.5 | 14.7 |
| 2086 | 0.6 | 0.1 | 0.1 | 14.9 | 33.5 |
| 2087 | 6.2 | 0.8 | 0.6 | 14.1 | 27.4 |
| 2088 | 12.4 | 2.1 | 2.0 | 11.0 | 16.8 |
| 2089 | 17.9 | 3.2 | 3.2 | 10.4 | 15.6 |
| 2090 | 8.4 | 1.5 | 1.5 | 10.4 | 15.1 |
| 2091 | 34.4 | 6.1 | 6.3 | 10.5 | 15.0 |
| 2092 | 18.4 | 3.9 | 4.3 | 8.7 | 11.7 |
| 2093 | 2.4 | 1.1 | 1.5 | 4.1 | 4.4 |
| 2094 | 17.4 | 4.8 | 4.0 | 6.7 | 11.9 |
| 2095 | 1.1 | 0.2 | 0.1 | 12.5 | 20.4 |
| 2096 | 0.2 | 0.0 | 0.0 | 14.8 | 29.2 |
| 2097 | 0.8 | 0.1 | 0.1 | 15.9 | 37.7 |
| 2098 | 6.0 | 0.6 | 0.3 | 18.2 | 54.5 |
| 2099 | 1.8 | 0.2 | 0.1 | 17.1 | 70.0 |
| 2100 | 0.4 | 0.0 | 0.0 | 19.0 | 63.3 |
| 2101 | 3.4 | 0.3 | 0.1 | 19.7 | 76.2 |
| 2102 | 1.3 | 0.1 | 0.0 | 19.7 | 79.1 |
| 2103 | 7.7 | 0.7 | 0.2 | 20.3 | 90.2 |
| 2104 | 2.5 | 0.2 | 0.1 | 19.8 | 78.7 |
| 2147 | 0.6 | 0.1 | 0.1 | 11.1 | 17.3 |
| 2149 | 0.0 | 0.0 | 0.0 | NA | NA |
| 2154 | 5.5 | 1.6 | 2.2 | 6.3 | 7.1 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 2155 | 0.9 | 0.2 | 0.2 | 8.5 | 12.7 |
| 2156 | 5.2 | 1.4 | 1.9 | 6.8 | 7.6 |
| 2158 | 4.7 | 0.8 | 0.7 | 11.3 | 17.4 |
| 2159 | 1.0 | 0.2 | 0.2 | 11.0 | 15.9 |
| 2160 | 1.9 | 0.4 | 0.4 | 9.6 | 13.0 |
| 2162 | 0.9 | 0.1 | 0.1 | 11.6 | 17.5 |
| 2163 | 8.3 | 1.4 | 1.4 | 11.1 | 16.5 |
| 2165 | 25.0 | 4.4 | 4.4 | 10.7 | 15.6 |
| 2166 | 13.4 | 3.1 | 3.7 | 8.1 | 10.0 |
| 2167 | 12.0 | 2.7 | 2.9 | 8.5 | 11.3 |
| 2168 | 6.4 | 0.8 | 0.6 | 14.4 | 28.6 |
| 2169 | 0.6 | 0.1 | 0.1 | 13.6 | 24.4 |
| 2170 | 0.7 | 0.1 | 0.0 | 16.2 | 38.6 |
| 2171 | 14.0 | 1.2 | 0.2 | 22.5 | 188.6 |
| 2172 | 4.1 | 0.4 | 0.1 | 20.3 | 106.7 |
| 2173 | 51.3 | 4.0 | 0.4 | 23.8 | 374.1 |
| 2174 | 1.8 | 0.2 | 0.1 | 19.9 | 87.8 |
| 2175 | 6.3 | 0.6 | 0.2 | 19.9 | 90.3 |
| 2176 | 16.1 | 1.5 | 0.5 | 20.7 | 95.8 |
| 2177 | 4.5 | 0.4 | 0.1 | 20.7 | 99.7 |
| 2178 | 17.8 | 1.6 | 0.6 | 20.3 | 86.3 |
| 2179 | 2.4 | 0.2 | 0.1 | 19.2 | 72.5 |
| 2225 | 0.1 | 0.0 | 0.0 | 10.3 | 14.4 |
| 2227 | 0.0 | 0.0 | 0.0 | NA | NA |
| 2228 | 1.5 | 0.3 | 0.3 | 9.6 | 12.6 |
| 2229 | 0.2 | 0.0 | 0.0 | 9.5 | 13.5 |
| 2230 | 1.5 | 0.4 | 0.5 | 7.5 | 9.1 |
| 2233 | 0.3 | 0.0 | 0.0 | 13.2 | 23.4 |
| 2234 | 5.1 | 1.1 | 1.3 | 8.5 | 11.2 |
| 2235 | 0.1 | 0.0 | 0.0 | 11.0 | 16.0 |
| 2236 | 6.2 | 1.0 | 1.0 | 11.4 | 17.1 |
| 2237 | 8.2 | 1.3 | 1.3 | 11.6 | 17.6 |
| 2238 | 21.5 | 3.7 | 3.7 | 10.8 | 16.1 |
| 2239 | 56.7 | 9.7 | 9.7 | 11.0 | 16.0 |
| 2240 | 32.7 | 5.5 | 5.2 | 11.1 | 17.3 |
| 2241 | 7.7 | 1.5 | 1.5 | 9.7 | 13.9 |
| 2242 | 8.2 | 1.4 | 0.8 | 11.3 | 26.7 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 2243 | 6.1 | 0.7 | 0.5 | 15.8 | 36.8 |
| 2244 | 6.8 | 0.7 | 0.4 | 17.5 | 52.4 |
| 2245 | 114.2 | 8.6 | 0.3 | 24.7 | 1001.0 |
| 2246 | 14.3 | 1.4 | 0.5 | 19.6 | 77.7 |
| 2247 | 1.4 | 0.1 | 0.0 | 19.6 | 88.8 |
| 2248 | 21.7 | 2.3 | 0.5 | 17.3 | 121.8 |
| 2249 | 7.6 | 0.7 | 0.1 | 21.7 | 139.9 |
| 2250 | 12.0 | 1.1 | 0.3 | 20.9 | 102.9 |
| 2251 | 163.6 | 12.9 | 0.7 | 23.8 | 651.2 |
| 2252 | 4.1 | 0.4 | 0.1 | 20.9 | 117.6 |
| 2294 | 7.9 | 1.3 | 1.1 | 11.3 | 20.2 |
| 2296 | 1.1 | 0.2 | 0.2 | 10.2 | 14.6 |
| 2297 | 0.9 | 0.3 | 0.4 | 5.0 | 5.8 |
| 2299 | 0.1 | 0.0 | 0.0 | 10.6 | 15.1 |
| 2301 | 0.9 | 0.2 | 0.2 | 10.6 | 14.9 |
| 2302 | 0.1 | 0.0 | 0.0 | 10.6 | 14.9 |
| 2303 | 1.1 | 0.2 | 0.2 | 10.4 | 14.8 |
| 2304 | 1.1 | 0.2 | 0.2 | 10.6 | 15.1 |
| 2305 | 0.5 | 0.1 | 0.1 | 11.3 | 16.7 |
| 2307 | 0.1 | 0.0 | 0.0 | 11.2 | 19.4 |
| 2308 | 4.5 | 1.3 | 1.7 | 6.2 | 7.0 |
| 2309 | 0.2 | 0.0 | 0.0 | 11.5 | 18.5 |
| 2310 | 5.1 | 0.7 | 0.6 | 13.4 | 23.5 |
| 2311 | 1.0 | 0.1 | 0.1 | 12.7 | 21.3 |
| 2312 | 7.7 | 1.2 | 1.2 | 11.7 | 18.1 |
| 2313 | 17.1 | 2.9 | 3.0 | 10.9 | 15.9 |
| 2314 | 17.3 | 3.1 | 3.2 | 10.3 | 14.8 |
| 2315 | 4.6 | 1.4 | 1.8 | 6.1 | 6.9 |
| 2316 | 2.0 | 0.3 | 0.3 | 12.0 | 20.7 |
| 2317 | 6.4 | 0.7 | 0.4 | 16.5 | 41.9 |
| 2318 | 1.4 | 0.1 | 0.1 | 18.3 | 56.1 |
| 2319 | 2.2 | 0.2 | 0.1 | 18.3 | 57.9 |
| 2320 | 14.3 | 1.2 | 0.3 | 21.6 | 130.1 |
| 2321 | 29.0 | 2.5 | 0.5 | 21.9 | 150.5 |
| 2322 | 145.9 | 11.5 | 1.1 | 23.8 | 352.7 |
| 2323 | 34.1 | 3.0 | 0.9 | 21.0 | 106.4 |
| 2324 | 66.5 | 5.3 | 0.7 | 23.3 | 262.9 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 2325 | 49.0 | 4.0 | 0.7 | 22.7 | 197.2 |
| 2326 | 54.0 | 4.2 | 0.3 | 24.2 | 479.5 |
| 2328 | 2.4 | 0.2 | 0.1 | 20.0 | 81.4 |
| 2368 | 2.7 | 0.5 | 0.4 | 10.8 | 18.9 |
| 2374 | 0.0 | 0.0 | 0.0 | 11.2 | 16.5 |
| 2379 | 0.0 | 0.0 | 0.0 | 12.1 | 19.0 |
| 2380 | 0.3 | 0.1 | 0.0 | 10.0 | 21.4 |
| 2381 | 1.3 | 0.2 | 0.1 | 14.2 | 30.7 |
| 2382 | 6.1 | 1.0 | 0.9 | 11.5 | 18.4 |
| 2383 | 4.9 | 0.7 | 0.6 | 12.6 | 21.7 |
| 2384 | 45.7 | 6.4 | 5.3 | 13.4 | 23.6 |
| 2385 | 6.1 | 0.8 | 0.5 | 14.4 | 31.2 |
| 2386 | 2.0 | 0.4 | 0.3 | 10.6 | 20.6 |
| 2387 | 6.0 | 1.1 | 1.0 | 10.6 | 16.4 |
| 2388 | 10.8 | 2.4 | 2.7 | 8.4 | 10.8 |
| 2389 | 11.1 | 2.8 | 2.7 | 7.4 | 11.2 |
| 2390 | 4.2 | 0.6 | 0.5 | 12.7 | 22.1 |
| 2391 | 6.9 | 0.7 | 0.3 | 18.8 | 67.6 |
| 2392 | 55.6 | 4.7 | 1.0 | 22.1 | 146.6 |
| 2393 | 5.0 | 0.5 | 0.2 | 18.2 | 64.7 |
| 2394 | 11.2 | 1.0 | 0.4 | 20.0 | 84.6 |
| 2395 | 37.0 | 3.3 | 0.9 | 21.1 | 113.7 |
| 2396 | 14.2 | 1.4 | 0.5 | 19.4 | 79.9 |
| 2397 | 7.1 | 0.6 | 0.2 | 20.5 | 97.8 |
| 2398 | 7.2 | 0.6 | 0.2 | 21.2 | 122.6 |
| 2399 | 118.7 | 9.3 | 0.8 | 23.9 | 397.1 |
| 2400 | 73.3 | 6.3 | 1.0 | 21.7 | 199.3 |
| 2401 | 2.1 | 0.2 | 0.0 | 21.3 | 117.7 |
| 2402 | 0.0 | 0.0 | 0.0 | 20.0 | 78.7 |
| 2448 | 0.0 | 0.0 | 0.0 | 11.6 | 17.5 |
| 2449 | 0.9 | 0.1 | 0.1 | 11.5 | 17.9 |
| 2454 | 0.0 | 0.0 | 0.0 | 13.2 | 22.6 |
| 2456 | 0.1 | 0.0 | 0.0 | 13.2 | 26.2 |
| 2458 | 1.7 | 0.2 | 0.2 | 13.3 | 27.8 |
| 2459 | 5.8 | 0.8 | 0.6 | 13.6 | 26.8 |
| 2460 | 8.8 | 1.6 | 1.6 | 10.6 | 15.3 |
| 2461 | 2.9 | 0.5 | 0.4 | 11.7 | 18.4 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 2462 | 2.9 | 0.7 | 0.7 | 8.3 | 11.3 |
| 2463 | 4.2 | 0.9 | 0.9 | 9.0 | 12.3 |
| 2465 | 6.3 | 0.8 | 0.6 | 14.8 | 31.4 |
| 2466 | 4.0 | 0.5 | 0.2 | 14.7 | 46.4 |
| 2467 | 0.9 | 0.1 | 0.1 | 17.4 | 45.9 |
| 2468 | 0.2 | 0.0 | 0.0 | 18.8 | 59.7 |
| 2469 | 7.9 | 0.8 | 0.3 | 19.6 | 82.8 |
| 2470 | 9.4 | 0.9 | 0.3 | 20.4 | 92.4 |
| 2471 | 12.3 | 1.2 | 0.4 | 19.9 | 81.3 |
| 2472 | 9.4 | 0.9 | 0.3 | 20.1 | 101.9 |
| 2473 | 69.5 | 5.6 | 0.8 | 23.1 | 242.2 |
| 2474 | 34.1 | 2.7 | 0.3 | 23.8 | 360.0 |
| 2475 | 0.3 | 0.0 | 0.0 | 20.9 | 98.0 |
| 2518 | 0.1 | 0.0 | 0.0 | 6.4 | 8.2 |
| 2519 | 0.2 | 0.1 | 0.1 | 6.9 | 8.3 |
| 2523 | 0.6 | 0.1 | 0.1 | 12.0 | 18.6 |
| 2528 | 0.2 | 0.0 | 0.0 | 11.5 | 25.4 |
| 2529 | 1.2 | 0.2 | 0.1 | 14.8 | 29.9 |
| 2530 | 0.2 | 0.0 | 0.0 | 14.6 | 32.9 |
| 2531 | 4.0 | 0.5 | 0.3 | 14.8 | 31.6 |
| 2532 | 10.9 | 1.0 | 0.3 | 20.1 | 96.1 |
| 2533 | 2.8 | 0.4 | 0.3 | 13.5 | 24.1 |
| 2534 | 9.7 | 1.9 | 1.2 | 9.7 | 22.1 |
| 2535 | 4.3 | 0.6 | 0.4 | 14.6 | 31.6 |
| 2536 | 8.5 | 1.2 | 1.0 | 13.1 | 23.0 |
| 2537 | 17.2 | 2.4 | 1.9 | 13.6 | 25.2 |
| 2538 | 9.6 | 1.3 | 1.0 | 14.1 | 27.3 |
| 2539 | 3.9 | 0.6 | 0.5 | 12.9 | 23.5 |
| 2540 | 2.4 | 0.3 | 0.2 | 15.8 | 34.8 |
| 2541 | 3.3 | 0.5 | 0.4 | 12.2 | 21.9 |
| 2542 | 0.2 | 0.0 | 0.0 | 18.7 | 58.8 |
| 2543 | 8.7 | 0.8 | 0.3 | 20.5 | 94.8 |
| 2544 | 12.5 | 1.1 | 0.4 | 20.4 | 91.6 |
| 2545 | 9.8 | 0.9 | 0.3 | 20.4 | 92.7 |
| 2546 | 21.0 | 1.9 | 0.6 | 20.4 | 89.8 |
| 2548 | 0.8 | 0.1 | 0.0 | 15.7 | 89.9 |
| 2549 | 1.8 | 0.2 | 0.1 | 20.4 | 96.7 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 2593 | 0.4 | 0.1 | 0.1 | 10.4 | 14.4 |
| 2599 | 1.1 | 0.2 | 0.2 | 10.7 | 16.8 |
| 2603 | 5.0 | 0.7 | 0.5 | 14.4 | 27.3 |
| 2604 | 0.2 | 0.0 | 0.0 | 14.3 | 31.1 |
| 2605 | 15.6 | 1.6 | 0.8 | 17.9 | 51.1 |
| 2606 | 2.0 | 0.3 | 0.2 | 14.1 | 26.6 |
| 2607 | 9.0 | 1.4 | 1.2 | 12.5 | 20.4 |
| 2608 | 32.1 | 3.4 | 1.8 | 17.6 | 47.9 |
| 2609 | 4.8 | 0.6 | 0.5 | 14.3 | 27.9 |
| 2610 | 11.6 | 1.5 | 1.2 | 14.0 | 26.6 |
| 2611 | 16.9 | 1.6 | 0.5 | 19.7 | 89.0 |
| 2612 | 12.5 | 1.7 | 1.3 | 13.8 | 25.6 |
| 2613 | 8.9 | 1.1 | 0.7 | 14.7 | 33.6 |
| 2614 | 2.0 | 0.2 | 0.1 | 17.8 | 54.2 |
| 2615 | 0.0 | 0.0 | 0.0 | 17.4 | 46.0 |
| 2616 | 4.0 | 0.4 | 0.2 | 19.1 | 69.0 |
| 2617 | 6.7 | 0.6 | 0.2 | 20.0 | 87.0 |
| 2618 | 22.4 | 2.0 | 0.6 | 20.6 | 96.3 |
| 2619 | 10.7 | 1.0 | 0.3 | 20.0 | 92.6 |
| 2620 | 1.8 | 0.2 | 0.1 | 19.6 | 77.3 |
| 2622 | 0.2 | 0.0 | 0.0 | 19.2 | 66.2 |
| 2623 | 0.0 | 0.0 | 0.0 | 19.1 | 63.9 |
| 2666 | 2.0 | 0.3 | 0.3 | 10.7 | 17.3 |
| 2669 | 0.0 | 0.0 | 0.0 | NA | NA |
| 2673 | 0.1 | 0.0 | 0.0 | 5.4 | 5.7 |
| 2674 | 1.4 | 0.2 | 0.2 | 10.7 | 16.0 |
| 2676 | 0.4 | 0.1 | 0.0 | 16.4 | 44.2 |
| 2677 | 2.6 | 0.3 | 0.2 | 14.4 | 29.7 |
| 2678 | 2.7 | 0.4 | 0.3 | 14.3 | 29.0 |
| 2679 | 28.5 | 3.6 | 2.6 | 14.9 | 29.7 |
| 2680 | 4.5 | 0.6 | 0.4 | 15.4 | 33.6 |
| 2681 | 5.5 | 0.7 | 0.6 | 13.8 | 24.8 |
| 2682 | 9.4 | 1.2 | 1.0 | 14.1 | 26.8 |
| 2684 | 7.0 | 0.8 | 0.4 | 16.9 | 47.0 |
| 2685 | 6.4 | 0.7 | 0.4 | 16.9 | 48.2 |
| 2686 | 5.3 | 0.6 | 0.4 | 16.3 | 40.5 |
| 2687 | 3.9 | 0.5 | 0.2 | 16.2 | 45.1 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 2688 | 0.4 | 0.0 | 0.0 | 17.2 | 47.8 |
| 2690 | 0.0 | 0.0 | 0.0 | 18.1 | 52.8 |
| 2691 | 5.5 | 0.6 | 0.2 | 17.0 | 63.0 |
| 2692 | 5.8 | 0.6 | 0.3 | 18.3 | 61.5 |
| 2743 | 0.0 | 0.0 | 0.0 | NA | NA |
| 2748 | 0.3 | 0.1 | 0.0 | 10.7 | 24.3 |
| 2749 | 3.2 | 0.4 | 0.3 | 14.4 | 32.1 |
| 2750 | 4.4 | 0.4 | 0.2 | 19.2 | 78.9 |
| 2751 | 7.5 | 0.8 | 0.4 | 17.7 | 56.7 |
| 2752 | 3.5 | 0.5 | 0.5 | 12.6 | 21.4 |
| 2753 | 8.7 | 1.1 | 0.8 | 14.9 | 30.6 |
| 2754 | 12.7 | 1.3 | 0.6 | 17.9 | 54.8 |
| 2755 | 19.5 | 2.4 | 1.7 | 15.1 | 31.3 |
| 2756 | 0.6 | 0.1 | 0.1 | 12.5 | 27.1 |
| 2757 | 11.1 | 1.4 | 1.0 | 15.2 | 32.0 |
| 2758 | 56.1 | 6.3 | 3.7 | 16.6 | 41.2 |
| 2759 | 11.7 | 1.2 | 0.5 | 18.5 | 70.0 |
| 2760 | 21.6 | 2.3 | 1.2 | 17.6 | 51.1 |
| 2761 | 4.0 | 0.4 | 0.2 | 18.0 | 62.1 |
| 2762 | 0.4 | 0.0 | 0.0 | 17.0 | 45.8 |
| 2765 | 0.7 | 0.1 | 0.0 | 17.8 | 49.2 |
| 2766 | 6.2 | 0.7 | 0.4 | 16.5 | 41.4 |
| 2767 | 5.5 | 0.8 | 0.6 | 13.7 | 26.0 |
| 2768 | 0.0 | 0.0 | 0.0 | 17.4 | 46.0 |
| 2816 | 1.3 | 0.2 | 0.2 | 10.9 | 17.3 |
| 2818 | 0.3 | 0.1 | 0.1 | 11.9 | 18.6 |
| 2821 | 0.0 | 0.0 | 0.0 | NA | NA |
| 2822 | 0.3 | 0.1 | 0.0 | 11.4 | 25.5 |
| 2824 | 5.3 | 0.6 | 0.4 | 15.2 | 36.1 |
| 2825 | 4.9 | 0.6 | 0.4 | 14.6 | 30.2 |
| 2826 | 4.2 | 0.6 | 0.5 | 13.3 | 25.3 |
| 2827 | 1.4 | 0.2 | 0.1 | 14.5 | 28.1 |
| 2829 | 7.0 | 1.0 | 0.8 | 13.2 | 23.6 |
| 2830 | 5.6 | 0.8 | 0.6 | 12.9 | 24.1 |
| 2831 | 10.9 | 1.4 | 1.0 | 14.6 | 31.3 |
| 2832 | 23.7 | 2.6 | 1.4 | 17.2 | 46.9 |
| 2833 | 24.7 | 2.6 | 1.3 | 17.9 | 52.9 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 2834 | 13.8 | 1.7 | 1.1 | 15.7 | 34.8 |
| 2835 | 0.0 | 0.0 | 0.0 | 17.2 | 44.3 |
| 2837 | 0.0 | 0.0 | 0.0 | 17.4 | 45.7 |
| 2839 | 0.0 | 0.0 | 0.0 | 18.0 | 51.8 |
| 2841 | 7.7 | 1.1 | 1.0 | 12.8 | 21.3 |
| 2842 | 0.5 | 0.1 | 0.0 | 16.5 | 38.7 |
| 2843 | 0.1 | 0.0 | 0.0 | 17.4 | 46.3 |
| 2897 | 0.0 | 0.0 | 0.0 | NA | NA |
| 2898 | 4.4 | 0.5 | 0.3 | 16.3 | 41.8 |
| 2899 | 0.4 | 0.1 | 0.0 | 15.2 | 33.4 |
| 2900 | 0.6 | 0.1 | 0.1 | 15.1 | 31.3 |
| 2902 | 10.3 | 1.5 | 1.2 | 13.2 | 24.3 |
| 2903 | 6.6 | 0.9 | 0.6 | 14.3 | 27.7 |
| 2904 | 3.3 | 0.4 | 0.3 | 15.5 | 35.5 |
| 2905 | 3.4 | 0.4 | 0.3 | 14.8 | 33.1 |
| 2906 | 49.9 | 5.6 | 3.3 | 16.7 | 41.2 |
| 2907 | 52.9 | 5.9 | 3.4 | 16.8 | 42.6 |
| 2908 | 27.4 | 3.7 | 1.7 | 13.9 | 44.3 |
| 2909 | 0.1 | 0.0 | 0.0 | 17.3 | 44.9 |
| 2910 | 0.9 | 0.1 | 0.0 | 17.9 | 52.2 |
| 2912 | 0.2 | 0.0 | 0.0 | 18.1 | 51.9 |
| 2913 | 0.8 | 0.1 | 0.0 | 18.0 | 57.6 |
| 2914 | 0.2 | 0.0 | 0.0 | 17.5 | 46.7 |
| 2915 | 0.7 | 0.1 | 0.0 | 17.3 | 47.7 |
| 2916 | 1.3 | 0.1 | 0.1 | 18.0 | 53.9 |
| 2962 | 0.2 | 0.0 | 0.0 | 11.2 | 18.2 |
| 2966 | 0.9 | 0.2 | 0.2 | 9.4 | 13.2 |
| 2971 | 0.0 | 0.0 | 0.0 | 12.0 | 18.8 |
| 2973 | 0.3 | 0.0 | 0.0 | 14.1 | 26.1 |
| 2974 | 7.8 | 1.0 | 0.8 | 14.1 | 26.3 |
| 2975 | 0.9 | 0.1 | 0.1 | 14.1 | 26.9 |
| 2976 | 2.8 | 0.4 | 0.3 | 13.8 | 26.7 |
| 2977 | 0.3 | 0.0 | 0.0 | 12.3 | 30.7 |
| 2978 | 0.1 | 0.0 | 0.0 | 15.6 | 33.5 |
| 2979 | 2.0 | 0.2 | 0.1 | 15.8 | 36.7 |
| 2980 | 15.5 | 1.7 | 0.9 | 17.4 | 46.3 |
| 2981 | 9.2 | 1.1 | 0.6 | 15.8 | 41.8 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 2982 | 13.8 | 1.5 | 0.8 | 16.9 | 46.8 |
| 2984 | 3.8 | 0.4 | 0.2 | 18.7 | 62.2 |
| 2985 | 6.1 | 0.6 | 0.2 | 20.1 | 86.4 |
| 2986 | 3.0 | 0.3 | 0.1 | 18.9 | 67.1 |
| 2987 | 2.7 | 0.3 | 0.1 | 17.6 | 64.8 |
| 2989 | 1.8 | 0.2 | 0.1 | 17.5 | 46.6 |
| 2990 | 0.1 | 0.0 | 0.0 | 17.9 | 50.1 |
| 2991 | 5.6 | 0.5 | 0.2 | 20.5 | 97.4 |
| 2992 | 0.0 | 0.0 | 0.0 | 18.0 | 50.9 |
| 3038 | 0.8 | 0.1 | 0.1 | 11.0 | 15.9 |
| 3040 | 5.0 | 1.3 | 1.3 | 7.1 | 10.6 |
| 3041 | 2.1 | 0.5 | 0.5 | 8.6 | 12.4 |
| 3043 | 14.6 | 2.5 | 2.6 | 10.8 | 15.6 |
| 3045 | 3.3 | 0.6 | 0.6 | 11.0 | 15.9 |
| 3046 | 1.6 | 0.3 | 0.3 | 11.1 | 16.3 |
| 3047 | 1.0 | 0.2 | 0.1 | 10.6 | 22.4 |
| 3048 | 1.1 | 0.1 | 0.1 | 14.1 | 26.0 |
| 3050 | 0.2 | 0.0 | 0.0 | 14.5 | 32.2 |
| 3051 | 0.0 | 0.0 | 0.0 | 15.4 | 32.5 |
| 3052 | 0.4 | 0.0 | 0.0 | 15.8 | 37.0 |
| 3053 | 3.9 | 0.4 | 0.2 | 16.5 | 51.2 |
| 3054 | 3.3 | 0.4 | 0.2 | 17.1 | 43.7 |
| 3055 | 4.1 | 0.4 | 0.2 | 18.7 | 63.2 |
| 3056 | 2.0 | 0.2 | 0.1 | 18.5 | 58.4 |
| 3057 | 7.6 | 0.8 | 0.4 | 18.4 | 56.7 |
| 3058 | 3.2 | 0.3 | 0.1 | 20.0 | 82.9 |
| 3059 | 9.1 | 0.9 | 0.4 | 19.3 | 70.1 |
| 3060 | 8.4 | 0.8 | 0.2 | 20.8 | 101.5 |
| 3061 | 0.5 | 0.1 | 0.0 | 18.1 | 56.8 |
| 3062 | 0.0 | 0.0 | 0.0 | 17.4 | 46.3 |
| 3067 | 0.1 | 0.0 | 0.0 | 16.7 | 40.6 |
| 3113 | 0.7 | 0.1 | 0.1 | 9.5 | 13.3 |
| 3117 | 0.9 | 0.2 | 0.2 | 9.6 | 13.7 |
| 3119 | 1.9 | 0.3 | 0.3 | 11.2 | 16.5 |
| 3120 | 0.7 | 0.1 | 0.1 | 10.5 | 15.1 |
| 3121 | 2.3 | 0.5 | 0.5 | 8.5 | 11.8 |
| 3123 | 0.0 | 0.0 | 0.0 | 14.2 | 26.8 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 3124 | 0.0 | 0.0 | 0.0 | 14.8 | 29.3 |
| 3125 | 0.0 | 0.0 | 0.0 | 15.3 | 31.6 |
| 3126 | 0.0 | 0.0 | 0.0 | 15.9 | 35.3 |
| 3127 | 0.1 | 0.0 | 0.0 | 16.6 | 39.6 |
| 3128 | 1.0 | 0.1 | 0.1 | 17.4 | 49.5 |
| 3129 | 2.9 | 0.3 | 0.1 | 19.1 | 66.5 |
| 3130 | 5.5 | 0.5 | 0.2 | 19.3 | 71.0 |
| 3131 | 5.4 | 0.5 | 0.2 | 18.5 | 61.1 |
| 3132 | 3.5 | 0.5 | 0.4 | 13.7 | 25.8 |
| 3133 | 2.3 | 0.2 | 0.1 | 18.5 | 62.3 |
| 3134 | 2.9 | 0.3 | 0.1 | 19.4 | 80.5 |
| 3136 | 0.7 | 0.1 | 0.0 | 17.0 | 44.9 |
| 3140 | 0.1 | 0.0 | 0.0 | 16.5 | 39.1 |
| 3188 | 0.2 | 0.0 | 0.1 | 7.6 | 8.9 |
| 3189 | 0.3 | 0.1 | 0.1 | 6.5 | 7.2 |
| 3191 | 1.4 | 0.5 | 0.7 | 5.0 | 5.4 |
| 3192 | 1.2 | 0.3 | 0.3 | 8.1 | 10.2 |
| 3196 | 1.9 | 0.3 | 0.2 | 13.2 | 22.5 |
| 3198 | 0.2 | 0.0 | 0.0 | 14.6 | 28.4 |
| 3199 | 2.5 | 0.4 | 0.3 | 13.1 | 22.3 |
| 3200 | 0.7 | 0.1 | 0.1 | 15.2 | 31.2 |
| 3201 | 4.2 | 0.5 | 0.3 | 16.4 | 38.2 |
| 3202 | 0.2 | 0.0 | 0.0 | 17.5 | 46.9 |
| 3203 | 2.0 | 0.2 | 0.1 | 18.4 | 59.4 |
| 3204 | 5.6 | 0.5 | 0.2 | 19.6 | 76.6 |
| 3205 | 13.7 | 1.7 | 1.3 | 14.7 | 29.7 |
| 3206 | 9.1 | 1.0 | 0.6 | 17.2 | 45.3 |
| 3207 | 9.3 | 1.0 | 0.5 | 17.7 | 49.3 |
| 3208 | 5.3 | 0.5 | 0.2 | 19.6 | 77.3 |
| 3213 | 0.0 | 0.0 | 0.0 | 16.1 | 36.6 |
| 3214 | 0.1 | 0.0 | 0.0 | 16.1 | 36.6 |
| 3215 | 0.1 | 0.0 | 0.0 | 16.1 | 36.4 |
| 3261 | 2.4 | 0.6 | 0.6 | 8.3 | 11.0 |
| 3262 | 1.1 | 0.4 | 0.4 | 5.6 | 7.1 |
| 3263 | 21.5 | 7.9 | 10.7 | 5.1 | 5.5 |
| 3264 | 25.5 | 10.1 | 14.4 | 4.7 | 4.9 |
| 3265 | 0.5 | 0.1 | 0.1 | 7.5 | 9.0 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 3266 | 4.0 | 0.9 | 1.0 | 8.5 | 10.7 |
| 3267 | 1.4 | 0.3 | 0.3 | 10.7 | 15.3 |
| 3268 | 3.1 | 0.5 | 0.5 | 11.3 | 17.7 |
| 3269 | 1.7 | 0.3 | 0.3 | 11.7 | 18.3 |
| 3270 | 0.2 | 0.0 | 0.0 | 13.9 | 29.3 |
| 3273 | 0.3 | 0.0 | 0.0 | 12.1 | 30.3 |
| 3274 | 1.5 | 0.2 | 0.1 | 15.4 | 32.5 |
| 3275 | 9.3 | 1.1 | 0.7 | 16.2 | 37.0 |
| 3276 | 3.2 | 0.4 | 0.2 | 16.9 | 44.7 |
| 3277 | 31.6 | 3.3 | 1.6 | 18.1 | 54.1 |
| 3278 | 8.0 | 0.8 | 0.3 | 19.2 | 70.9 |
| 3279 | 28.4 | 2.7 | 0.9 | 20.0 | 84.8 |
| 3280 | 7.3 | 1.1 | 0.9 | 12.6 | 21.5 |
| 3281 | 3.9 | 0.4 | 0.2 | 17.5 | 47.4 |
| 3282 | 17.9 | 1.7 | 0.6 | 20.1 | 87.6 |
| 3283 | 3.2 | 0.4 | 0.1 | 16.9 | 64.5 |
| 3284 | 2.1 | 0.4 | 0.4 | 10.4 | 16.0 |
| 3288 | 0.1 | 0.0 | 0.0 | 15.9 | 35.1 |
| 3289 | 0.2 | 0.0 | 0.0 | 15.9 | 35.1 |
| 3337 | 12.3 | 3.9 | 5.2 | 5.9 | 6.5 |
| 3338 | 1.8 | 0.5 | 0.7 | 6.7 | 7.7 |
| 3339 | 2.1 | 0.5 | 0.6 | 8.4 | 10.5 |
| 3340 | 0.6 | 0.1 | 0.1 | 9.8 | 13.2 |
| 3343 | 0.9 | 0.2 | 0.2 | 8.7 | 10.8 |
| 3344 | 0.9 | 0.1 | 0.1 | 12.8 | 23.5 |
| 3345 | 2.9 | 0.4 | 0.3 | 15.2 | 31.5 |
| 3346 | 0.5 | 0.1 | 0.0 | 16.6 | 45.6 |
| 3347 | 1.4 | 0.2 | 0.1 | 15.2 | 31.0 |
| 3348 | 6.6 | 0.7 | 0.4 | 17.1 | 43.5 |
| 3349 | 0.3 | 0.0 | 0.0 | 15.9 | 35.2 |
| 3350 | 9.7 | 1.1 | 0.7 | 16.3 | 38.3 |
| 3351 | 54.1 | 6.1 | 3.7 | 16.6 | 40.2 |
| 3352 | 50.0 | 4.8 | 1.9 | 19.5 | 72.4 |
| 3353 | 32.5 | 3.0 | 0.9 | 20.4 | 95.7 |
| 3354 | 22.9 | 2.8 | 1.0 | 15.5 | 64.7 |
| 3355 | 1.0 | 0.1 | 0.1 | 17.1 | 43.3 |
| 3356 | 6.4 | 0.7 | 0.2 | 17.5 | 83.8 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 3357 | 5.7 | 0.6 | 0.2 | 18.2 | 63.4 |
| 3358 | 1.0 | 0.1 | 0.1 | 13.1 | 40.7 |
| 3410 | 0.5 | 0.1 | 0.1 | 8.5 | 10.9 |
| 3412 | 0.0 | 0.0 | 0.0 | NA | NA |
| 3413 | 0.9 | 0.2 | 0.3 | 7.1 | 8.2 |
| 3414 | 1.2 | 0.2 | 0.3 | 8.9 | 11.4 |
| 3415 | 1.1 | 0.2 | 0.2 | 10.7 | 15.5 |
| 3416 | 2.7 | 0.4 | 0.4 | 11.7 | 18.1 |
| 3420 | 0.4 | 0.1 | 0.0 | 14.6 | 28.4 |
| 3421 | 0.3 | 0.0 | 0.0 | 14.7 | 28.9 |
| 3422 | 1.8 | 0.2 | 0.1 | 15.3 | 36.2 |
| 3423 | 1.4 | 0.2 | 0.1 | 14.9 | 29.9 |
| 3424 | 4.3 | 0.6 | 0.4 | 14.1 | 27.6 |
| 3425 | 27.7 | 3.8 | 3.1 | 13.5 | 24.5 |
| 3426 | 18.4 | 1.9 | 1.0 | 17.8 | 50.5 |
| 3427 | 11.0 | 1.1 | 0.4 | 19.6 | 79.9 |
| 3428 | 2.2 | 0.2 | 0.1 | 17.4 | 46.0 |
| 3429 | 8.9 | 1.4 | 1.3 | 11.9 | 18.8 |
| 3430 | 1.6 | 0.2 | 0.1 | 14.0 | 29.5 |
| 3431 | 2.6 | 0.3 | 0.2 | 15.4 | 34.8 |
| 3432 | 6.6 | 1.0 | 0.9 | 12.3 | 20.4 |
| 3433 | 2.9 | 0.5 | 0.4 | 10.7 | 17.8 |
| 3435 | 0.1 | 0.0 | 0.0 | 14.2 | 61.5 |
| 3485 | 0.6 | 0.1 | 0.2 | 7.5 | 9.2 |
| 3486 | 0.5 | 0.1 | 0.1 | 7.8 | 9.4 |
| 3487 | 2.9 | 0.7 | 0.8 | 7.5 | 9.9 |
| 3488 | 4.4 | 1.0 | 1.1 | 8.7 | 11.2 |
| 3489 | 0.7 | 0.1 | 0.1 | 10.1 | 15.2 |
| 3490 | 2.2 | 0.5 | 0.5 | 9.0 | 12.0 |
| 3492 | 0.1 | 0.0 | 0.0 | 13.2 | 22.8 |
| 3493 | 0.0 | 0.0 | 0.0 | 13.7 | 24.5 |
| 3494 | 0.0 | 0.0 | 0.0 | 14.1 | 26.2 |
| 3495 | 8.2 | 1.1 | 0.9 | 14.0 | 25.9 |
| 3496 | 11.0 | 1.6 | 1.5 | 12.6 | 20.7 |
| 3497 | 1.2 | 0.2 | 0.1 | 13.9 | 25.3 |
| 3498 | 25.4 | 3.5 | 2.8 | 13.7 | 24.6 |
| 3499 | 2.7 | 0.4 | 0.3 | 13.7 | 24.4 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 3500 | 0.7 | 0.1 | 0.1 | 15.5 | 33.2 |
| 3501 | 2.8 | 0.3 | 0.2 | 15.2 | 31.6 |
| 3502 | 5.0 | 0.7 | 0.5 | 14.1 | 26.2 |
| 3503 | 6.3 | 0.8 | 0.6 | 14.4 | 27.8 |
| 3504 | 17.7 | 2.4 | 1.9 | 13.8 | 25.1 |
| 3505 | 17.2 | 2.3 | 1.8 | 14.0 | 26.0 |
| 3506 | 21.5 | 2.9 | 2.4 | 13.7 | 24.8 |
| 3507 | 0.3 | 0.0 | 0.0 | 12.9 | 37.8 |
| 3508 | 1.2 | 0.1 | 0.1 | 16.6 | 42.1 |
| 3509 | 19.1 | 1.8 | 0.6 | 19.9 | 81.5 |
| 3559 | 7.1 | 1.7 | 2.0 | 7.8 | 9.5 |
| 3560 | 0.0 | 0.0 | 0.0 | 7.1 | 8.7 |
| 3561 | 1.6 | 0.5 | 0.6 | 6.4 | 7.1 |
| 3562 | 2.4 | 0.8 | 1.1 | 5.6 | 6.0 |
| 3563 | 1.0 | 0.2 | 0.3 | 8.9 | 11.3 |
| 3564 | 0.3 | 0.0 | 0.0 | 12.8 | 24.9 |
| 3568 | 2.6 | 0.3 | 0.3 | 14.0 | 26.2 |
| 3569 | 4.9 | 0.7 | 0.6 | 13.2 | 22.7 |
| 3570 | 3.7 | 0.5 | 0.5 | 12.9 | 21.9 |
| 3571 | 0.7 | 0.1 | 0.1 | 11.9 | 24.2 |
| 3572 | 24.0 | 3.3 | 2.8 | 13.4 | 23.4 |
| 3573 | 14.1 | 2.1 | 1.8 | 12.7 | 21.1 |
| 3574 | 3.0 | 0.4 | 0.3 | 13.9 | 25.2 |
| 3575 | 1.0 | 0.1 | 0.1 | 14.3 | 27.2 |
| 3576 | 5.7 | 0.8 | 0.6 | 14.2 | 26.5 |
| 3577 | 6.3 | 0.8 | 0.7 | 14.1 | 26.4 |
| 3578 | 2.8 | 0.4 | 0.3 | 14.1 | 26.2 |
| 3579 | 8.7 | 1.2 | 0.9 | 14.0 | 25.8 |
| 3580 | 14.7 | 2.0 | 1.6 | 13.8 | 25.6 |
| 3581 | 1.6 | 0.2 | 0.1 | 16.8 | 42.2 |
| 3582 | 2.8 | 0.3 | 0.2 | 17.3 | 48.4 |
| 3583 | 4.9 | 0.6 | 0.3 | 15.7 | 44.4 |
| 3633 | 0.6 | 0.2 | 0.2 | 7.4 | 8.6 |
| 3634 | 4.4 | 1.3 | 1.8 | 6.0 | 6.5 |
| 3635 | 4.2 | 1.1 | 1.5 | 6.9 | 7.8 |
| 3636 | 0.6 | 0.1 | 0.1 | 9.0 | 11.7 |
| 3637 | 0.2 | 0.0 | 0.0 | 11.6 | 19.3 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 3640 | 0.1 | 0.0 | 0.0 | 11.9 | 18.4 |
| 3641 | 2.7 | 0.6 | 0.8 | 8.1 | 10.0 |
| 3642 | 0.1 | 0.0 | 0.0 | 12.9 | 21.8 |
| 3644 | 0.0 | 0.0 | 0.0 | 12.9 | 21.5 |
| 3645 | 8.9 | 1.7 | 1.8 | 9.9 | 13.3 |
| 3646 | 5.4 | 0.8 | 0.6 | 12.9 | 22.9 |
| 3647 | 11.0 | 1.7 | 1.5 | 12.2 | 19.6 |
| 3648 | 21.0 | 3.1 | 2.8 | 12.6 | 20.7 |
| 3649 | 10.2 | 1.4 | 1.2 | 13.2 | 22.8 |
| 3650 | 10.8 | 1.5 | 1.3 | 13.2 | 22.8 |
| 3651 | 2.0 | 0.3 | 0.2 | 13.7 | 24.5 |
| 3652 | 3.5 | 0.5 | 0.4 | 13.6 | 24.8 |
| 3653 | 6.8 | 0.9 | 0.8 | 13.7 | 24.9 |
| 3654 | 3.2 | 0.5 | 0.4 | 12.8 | 25.0 |
| 3655 | 4.2 | 0.5 | 0.4 | 14.6 | 28.6 |
| 3656 | 3.5 | 0.4 | 0.3 | 16.1 | 37.3 |
| 3657 | 3.5 | 0.4 | 0.2 | 17.4 | 47.9 |
| 3658 | 0.1 | 0.0 | 0.0 | 15.7 | 34.2 |
| 3659 | 0.0 | 0.0 | 0.0 | 15.3 | 31.6 |
| 3707 | 0.3 | 0.1 | 0.1 | 9.1 | 11.6 |
| 3708 | 0.0 | 0.0 | 0.0 | 7.5 | 8.8 |
| 3709 | 0.4 | 0.1 | 0.1 | 7.3 | 10.6 |
| 3710 | 0.8 | 0.1 | 0.2 | 10.1 | 13.8 |
| 3711 | 1.6 | 0.2 | 0.1 | 18.3 | 66.6 |
| 3712 | 3.6 | 0.4 | 0.2 | 18.1 | 60.5 |
| 3713 | 0.6 | 0.1 | 0.1 | 11.4 | 17.4 |
| 3717 | 0.6 | 0.1 | 0.1 | 12.8 | 21.4 |
| 3718 | 4.1 | 0.7 | 0.6 | 11.7 | 18.0 |
| 3719 | 12.1 | 1.9 | 1.7 | 12.1 | 19.2 |
| 3720 | 43.4 | 6.7 | 6.1 | 12.1 | 19.6 |
| 3721 | 18.9 | 2.8 | 2.5 | 12.6 | 21.1 |
| 3722 | 3.8 | 0.6 | 0.5 | 12.8 | 21.4 |
| 3723 | 18.2 | 2.9 | 2.7 | 11.8 | 18.4 |
| 3724 | 21.0 | 3.2 | 2.9 | 12.4 | 20.2 |
| 3725 | 19.2 | 2.8 | 2.5 | 12.6 | 21.1 |
| 3726 | 5.3 | 0.8 | 0.7 | 12.3 | 19.6 |
| 3727 | 1.3 | 0.2 | 0.2 | 13.3 | 23.0 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 3728 | 0.2 | 0.0 | 0.0 | 13.7 | 24.6 |
| 3729 | 1.4 | 0.2 | 0.1 | 15.3 | 32.5 |
| 3730 | 1.1 | 0.1 | 0.1 | 14.4 | 29.4 |
| 3731 | 6.8 | 0.8 | 0.5 | 15.2 | 35.1 |
| 3780 | 40.1 | 3.1 | 0.1 | 24.6 | 1160.8 |
| 3783 | 4.3 | 1.2 | 1.5 | 6.9 | 7.8 |
| 3786 | 0.6 | 0.1 | 0.1 | 13.4 | 30.0 |
| 3787 | 0.7 | 0.1 | 0.1 | 11.3 | 17.4 |
| 3789 | 0.1 | 0.0 | 0.0 | 12.8 | 21.3 |
| 3791 | 1.2 | 0.2 | 0.2 | 12.8 | 21.5 |
| 3792 | 1.9 | 0.3 | 0.3 | 11.8 | 18.3 |
| 3793 | 7.5 | 1.3 | 1.3 | 10.8 | 15.7 |
| 3794 | 23.6 | 3.5 | 3.1 | 12.6 | 20.8 |
| 3795 | 60.9 | 9.3 | 8.4 | 12.3 | 19.8 |
| 3796 | 4.0 | 0.6 | 0.5 | 12.6 | 21.7 |
| 3797 | 7.2 | 1.1 | 0.9 | 12.5 | 20.8 |
| 3798 | 21.3 | 3.2 | 3.0 | 12.3 | 19.7 |
| 3799 | 25.8 | 4.1 | 3.9 | 11.8 | 18.3 |
| 3800 | 35.3 | 5.4 | 4.9 | 12.3 | 19.7 |
| 3801 | 36.2 | 5.6 | 5.3 | 12.0 | 18.9 |
| 3802 | 5.4 | 0.8 | 0.6 | 13.2 | 22.8 |
| 3803 | 4.7 | 0.7 | 0.5 | 12.7 | 24.4 |
| 3804 | 0.3 | 0.0 | 0.0 | 13.8 | 25.9 |
| 3805 | 1.0 | 0.1 | 0.1 | 13.8 | 27.6 |
| 3855 | 0.1 | 0.0 | 0.0 | 11.0 | 16.2 |
| 3864 | 1.2 | 0.2 | 0.2 | 12.9 | 22.1 |
| 3865 | 17.7 | 2.1 | 1.4 | 15.7 | 34.4 |
| 3866 | 12.7 | 2.0 | 1.8 | 12.0 | 19.0 |
| 3867 | 0.9 | 0.1 | 0.1 | 12.0 | 18.8 |
| 3868 | 5.2 | 0.8 | 0.7 | 12.7 | 20.9 |
| 3869 | 10.1 | 1.5 | 1.3 | 12.6 | 20.8 |
| 3870 | 3.1 | 0.5 | 0.4 | 12.5 | 20.7 |
| 3871 | 3.5 | 0.5 | 0.5 | 12.7 | 20.9 |
| 3872 | 33.7 | 5.2 | 4.9 | 12.0 | 19.0 |
| 3873 | 39.9 | 6.2 | 5.7 | 12.1 | 19.1 |
| 3874 | 88.8 | 13.3 | 12.0 | 12.5 | 20.3 |
| 3875 | 49.8 | 7.8 | 7.3 | 12.0 | 18.6 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 3876 | 39.1 | 4.4 | 2.7 | 16.5 | 39.6 |
| 3877 | 17.4 | 2.5 | 2.2 | 12.9 | 21.9 |
| 3878 | 0.6 | 0.1 | 0.1 | 13.7 | 24.4 |
| 3936 | 1.3 | 0.2 | 0.2 | 11.8 | 21.2 |
| 3938 | 0.3 | 0.0 | 0.0 | 12.9 | 21.6 |
| 3939 | 1.4 | 0.2 | 0.2 | 13.0 | 21.8 |
| 3940 | 2.2 | 0.3 | 0.3 | 12.5 | 21.2 |
| 3941 | 1.0 | 0.1 | 0.1 | 12.7 | 21.0 |
| 3944 | 2.7 | 0.4 | 0.4 | 12.5 | 20.2 |
| 3945 | 13.9 | 2.1 | 1.9 | 12.5 | 20.6 |
| 3946 | 17.8 | 2.6 | 2.2 | 12.9 | 22.3 |
| 3947 | 16.2 | 2.4 | 2.2 | 12.5 | 20.2 |
| 3948 | 53.5 | 7.9 | 7.1 | 12.6 | 20.8 |
| 3949 | 20.8 | 3.0 | 2.7 | 12.9 | 21.5 |
| 3950 | 6.5 | 1.0 | 0.9 | 12.5 | 20.4 |
| 4000 | 0.1 | 0.0 | 0.0 | 12.0 | 18.9 |
| 4004 | 5.9 | 0.9 | 0.9 | 11.7 | 18.1 |
| 4008 | 0.1 | 0.0 | 0.0 | 12.4 | 20.0 |
| 4012 | 0.5 | 0.1 | 0.1 | 12.7 | 21.0 |
| 4014 | 0.3 | 0.0 | 0.0 | 12.7 | 20.9 |
| 4018 | 1.7 | 0.2 | 0.2 | 12.8 | 21.4 |
| 4019 | 0.1 | 0.0 | 0.0 | 12.9 | 23.0 |
| 4020 | 3.9 | 0.6 | 0.5 | 13.0 | 22.0 |
| 4021 | 3.7 | 0.5 | 0.5 | 12.9 | 22.1 |
| 4022 | 8.3 | 1.2 | 1.1 | 12.7 | 21.0 |
| 4023 | 2.1 | 0.3 | 0.3 | 12.9 | 21.5 |
| 4024 | 0.3 | 0.0 | 0.0 | 13.0 | 22.1 |
| 4081 | 0.6 | 0.1 | 0.1 | 12.4 | 20.0 |
| 4085 | 0.2 | 0.0 | 0.0 | 12.5 | 20.3 |
| 4087 | 2.0 | 0.3 | 0.3 | 12.5 | 20.1 |
| 4088 | 1.8 | 0.3 | 0.2 | 12.4 | 20.0 |
| 4092 | 6.9 | 1.0 | 0.9 | 12.7 | 20.9 |
| 4093 | 1.0 | 0.1 | 0.1 | 13.4 | 23.5 |
| 4094 | 7.7 | 1.1 | 0.9 | 13.6 | 24.7 |
| 4095 | 19.7 | 2.5 | 1.8 | 14.8 | 29.5 |
| 4096 | 6.6 | 1.4 | 1.6 | 8.8 | 11.1 |
| 4158 | 0.5 | 0.1 | 0.1 | 12.3 | 19.7 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 4159 | 5.1 | 0.9 | 0.7 | 10.5 | 20.1 |
| 4160 | 0.6 | 0.1 | 0.1 | 12.0 | 19.3 |
| 4162 | 0.7 | 0.1 | 0.1 | 11.8 | 18.8 |
| 4163 | 15.5 | 2.5 | 2.3 | 11.9 | 18.4 |
| 4164 | 2.9 | 0.5 | 0.4 | 11.8 | 18.1 |
| 4165 | 1.9 | 0.3 | 0.3 | 11.7 | 18.1 |
| 4166 | 2.9 | 0.5 | 0.4 | 11.9 | 18.8 |
| 4167 | 8.6 | 1.4 | 1.3 | 11.5 | 17.8 |
| 4168 | 11.6 | 1.7 | 1.5 | 12.7 | 21.4 |
| 4169 | 9.1 | 1.3 | 1.2 | 12.7 | 21.1 |
| 4228 | 0.2 | 0.0 | 0.0 | 12.4 | 19.9 |
| 4229 | 0.0 | 0.0 | 0.0 | 12.3 | 19.8 |
| 4235 | 1.1 | 0.2 | 0.2 | 11.6 | 17.6 |
| 4236 | 3.7 | 0.6 | 0.6 | 11.3 | 17.1 |
| 4237 | 3.3 | 0.6 | 0.6 | 11.2 | 16.4 |
| 4238 | 2.6 | 0.5 | 0.5 | 10.4 | 15.5 |
| 4240 | 0.3 | 0.1 | 0.1 | 10.8 | 15.5 |
| 4241 | 12.9 | 2.1 | 2.1 | 11.3 | 16.8 |
| 4242 | 2.9 | 0.5 | 0.4 | 11.6 | 17.6 |
| 4302 | 0.7 | 0.1 | 0.1 | 12.2 | 19.5 |
| 4306 | 6.6 | 1.0 | 1.0 | 11.9 | 18.4 |
| 4307 | 1.9 | 0.3 | 0.3 | 11.5 | 17.6 |
| 4311 | 5.4 | 1.0 | 1.0 | 10.3 | 14.3 |
| 4313 | 1.7 | 0.4 | 0.5 | 7.5 | 9.0 |
| 4314 | 0.8 | 0.2 | 0.2 | 8.7 | 11.0 |
| 4315 | 10.1 | 2.1 | 2.4 | 9.0 | 11.6 |
| 4376 | 0.7 | 0.1 | 0.1 | 12.1 | 19.2 |
| 4382 | 0.0 | 0.0 | 0.0 | NA | NA |
| 4383 | 1.3 | 0.2 | 0.3 | 10.0 | 13.5 |
| 4384 | 0.6 | 0.1 | 0.1 | 9.5 | 14.6 |
| 4385 | 4.6 | 0.9 | 1.0 | 9.3 | 12.5 |
| 4386 | 0.1 | 0.0 | 0.0 | 7.2 | 11.4 |
| 4387 | 0.9 | 0.2 | 0.3 | 8.0 | 9.6 |
| 4388 | 2.6 | 0.7 | 1.0 | 6.4 | 7.1 |
| 4389 | 13.2 | 4.6 | 6.5 | 5.3 | 5.5 |
| 4442 | 1.2 | 0.2 | 0.2 | 12.3 | 20.0 |
| 4443 | 0.0 | 0.0 | 0.0 | 12.3 | 19.6 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 4458 | 10.7 | 3.0 | 3.8 | 6.7 | 7.7 |
| 4459 | 2.6 | 0.6 | 0.7 | 8.2 | 10.2 |
| 4460 | 1.9 | 0.4 | 0.5 | 8.0 | 9.7 |
| 4461 | 4.7 | 1.2 | 1.5 | 7.3 | 8.5 |
| 4462 | 8.5 | 2.8 | 3.9 | 5.7 | 6.0 |
| 4463 | 2.5 | 0.7 | 0.8 | 7.0 | 7.9 |
| 4516 | 0.0 | 0.0 | 0.0 | NA | NA |
| 4522 | 0.7 | 0.1 | 0.1 | 11.3 | 16.9 |
| 4527 | 2.7 | 0.3 | 0.2 | 15.6 | 48.8 |
| 4528 | 0.0 | 0.0 | 0.0 | 12.8 | 21.3 |
| 4529 | 0.0 | 0.0 | 0.0 | NA | NA |
| 4531 | 0.4 | 0.1 | 0.1 | 7.9 | 9.6 |
| 4532 | 0.1 | 0.0 | 0.1 | 6.1 | 6.8 |
| 4533 | 1.6 | 0.4 | 0.5 | 6.8 | 8.2 |
| 4534 | 5.1 | 1.8 | 2.6 | 5.2 | 5.4 |
| 4535 | 3.4 | 0.9 | 1.2 | 7.0 | 8.1 |
| 4536 | 4.5 | 1.3 | 1.7 | 6.3 | 7.2 |
| 4537 | 0.0 | 0.0 | 0.0 | 7.1 | 8.1 |
| 4543 | 0.7 | 0.1 | 0.1 | 12.3 | 19.7 |
| 4590 | 0.3 | 0.1 | 0.0 | 12.4 | 19.9 |
| 4594 | 1.1 | 0.3 | 0.3 | 7.2 | 9.0 |
| 4595 | 0.0 | 0.0 | 0.0 | 7.8 | 9.3 |
| 4597 | 0.5 | 0.1 | 0.1 | 11.2 | 18.1 |
| 4599 | 0.0 | 0.0 | 0.0 | NA | NA |
| 4600 | 1.1 | 0.2 | 0.2 | 11.7 | 18.5 |
| 4605 | 1.2 | 0.3 | 0.4 | 6.8 | 7.8 |
| 4606 | 4.4 | 1.3 | 1.6 | 6.6 | 7.6 |
| 4607 | 25.7 | 9.3 | 12.5 | 5.2 | 5.7 |
| 4608 | 4.5 | 1.6 | 2.2 | 5.4 | 5.7 |
| 4609 | 9.4 | 1.9 | 2.2 | 9.1 | 11.7 |
| 4610 | 1.8 | 0.5 | 0.6 | 6.7 | 7.5 |
| 4672 | 0.3 | 0.1 | 0.1 | 11.8 | 18.2 |
| 4674 | 1.4 | 0.2 | 0.2 | 11.6 | 17.5 |
| 4679 | 1.1 | 0.4 | 0.5 | 5.4 | 5.7 |
| 4680 | 4.5 | 1.7 | 2.3 | 4.9 | 5.5 |
| 4682 | 13.0 | 4.7 | 6.6 | 5.2 | 5.4 |
| 4683 | 8.7 | 3.2 | 4.5 | 5.1 | 5.3 |

**Table E-2** (continued).

| Grid Cell ID | 2009 Methane emissions (kg/h) | 2009 Ethane emissions (kg/h) | 2009 Propane emissions (kg/h) | Methane to Ethane ratio | Methane to Propane ratio |
|---|---|---|---|---|---|
| 4684 | 1.9 | 0.6 | 0.7 | 6.5 | 7.2 |
| 4753 | 1.1 | 0.3 | 0.3 | 7.8 | 9.3 |
| 4756 | 1.0 | 0.3 | 0.4 | 6.3 | 7.0 |
| 4757 | 1.2 | 0.4 | 0.5 | 6.0 | 6.5 |
| 4758 | 0.1 | 0.0 | 0.0 | 6.6 | 7.4 |

For each grid cell, Table S3-3 shows EF factor, activity factor and estimated 2013 methane emissions.

**Table E-3.** Estimated methane 2013 emissions, based on emission factor (methane emissions 2009 / natural gas production 2009) and activity factor (natural gas production 2013) per grid cell.

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 1066 | NA | NA | NA |
| 1139 | 0.0002 | 300.8 | 0.1 |
| 1285 | 0.0006 | 878.5 | 1.1 |
| 1287 | 0.0001 | 229.2 | 0.0 |
| 1288 | 0.0031 | 1368.4 | 9.3 |
| 1359 | 0.0004 | 160.9 | 0.1 |
| 1360 | 0.0087 | 781.6 | 14.8 |
| 1361 | 0.0017 | 325.8 | 1.2 |
| 1364 | 0.0000 | 339.9 | 0.0 |
| 1416 | 0.0792 | 0.0 | 0.0 |
| 1428 | 0.0954 | 113.1 | 23.7 |
| 1433 | 0.0024 | 15.9 | 0.1 |
| 1434 | 0.0011 | 606.9 | 1.5 |
| 1435 | 0.0006 | 204.1 | 0.3 |
| 1436 | 0.0010 | 409.3 | 0.9 |
| 1437 | 0.0002 | 286.4 | 0.1 |
| 1493 | 0.0334 | 0.0 | 0.0 |
| 1494 | 0.4181 | 0.0 | 0.0 |
| 1496 | 0.0495 | 42.4 | 4.6 |
| 1498 | NA | NA | NA |
| 1504 | 0.0197 | 101.7 | 4.4 |
| 1505 | 0.0100 | 253.8 | 5.6 |
| 1506 | 0.0013 | 73.8 | 0.2 |
| 1507 | 0.0033 | 191.7 | 1.4 |
| 1508 | 0.0022 | 353.9 | 1.7 |
| 1509 | 0.0005 | 649.5 | 0.7 |
| 1510 | 0.0045 | 644.6 | 6.4 |
| 1511 | 0.0031 | 467.0 | 3.2 |
| 1557 | NA | 0.0 | NA |
| 1558 | NA | 0.0 | NA |
| 1566 | 0.0018 | 0.0 | 0.0 |
| 1568 | NA | 274.7 | NA |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 1569 | 0.0289 | 0.0 | 0.0 |
| 1574 | NA | NA | NA |
| 1575 | NA | 2246.4 | NA |
| 1580 | 0.0027 | 902.2 | 5.4 |
| 1581 | 0.0011 | 242.7 | 0.6 |
| 1582 | 0.0045 | 298.0 | 3.0 |
| 1583 | 0.0020 | 484.7 | 2.1 |
| 1584 | 0.0014 | 538.1 | 1.7 |
| 1639 | 0.0040 | 0.0 | 0.0 |
| 1640 | 0.0033 | 0.0 | 0.0 |
| 1642 | NA | 54.3 | NA |
| 1646 | 0.0011 | 0.0 | 0.0 |
| 1647 | 0.0405 | 947.4 | 84.1 |
| 1648 | 0.0624 | 0.0 | 0.0 |
| 1649 | 0.0127 | 1346.1 | 37.4 |
| 1650 | 0.1984 | 3585.8 | 1559.5 |
| 1651 | 0.0015 | 10735.0 | 35.3 |
| 1652 | 0.0145 | 3928.6 | 124.9 |
| 1653 | 0.0062 | 560.3 | 7.6 |
| 1654 | 0.0045 | 4428.8 | 43.4 |
| 1655 | 0.0023 | 556.6 | 2.8 |
| 1656 | 0.0057 | 70.7 | 0.9 |
| 1657 | 0.0009 | 1532.8 | 3.0 |
| 1658 | 0.0044 | 1251.8 | 12.1 |
| 1659 | 0.7271 | 345.5 | 550.5 |
| 1717 | 0.0151 | 35.2 | 1.2 |
| 1718 | 0.0275 | 0.0 | 0.0 |
| 1722 | NA | 1279.3 | NA |
| 1723 | 0.0069 | 635.3 | 9.6 |
| 1724 | 0.0015 | 1410.9 | 4.6 |
| 1725 | 0.0001 | 3156.3 | 0.7 |
| 1726 | 0.0008 | 1425.9 | 2.4 |
| 1727 | 0.0080 | 3151.1 | 55.4 |
| 1728 | 0.0156 | 6783.5 | 231.3 |
| 1729 | 0.0010 | 1014.2 | 2.1 |
| 1730 | 0.0000 | 449.6 | 0.0 |
| 1731 | 0.0000 | 912.2 | 0.1 |
| 1732 | 0.0003 | 1488.2 | 0.8 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 1786 | NA | 56.7 | NA |
| 1787 | 0.1256 | 23.9 | 6.6 |
| 1789 | 0.0024 | 0.0 | 0.0 |
| 1790 | 0.0091 | 0.0 | 0.0 |
| 1794 | 0.0037 | 1379.9 | 11.2 |
| 1795 | 0.0034 | 527.7 | 3.9 |
| 1796 | 0.0028 | 2030.4 | 12.3 |
| 1797 | 0.0022 | 1816.7 | 8.8 |
| 1798 | 0.0004 | 951.5 | 0.8 |
| 1799 | 0.0029 | 2475.7 | 15.8 |
| 1800 | 0.0002 | 1728.5 | 0.8 |
| 1801 | 0.0002 | 2273.4 | 0.8 |
| 1802 | 0.0005 | 3947.8 | 4.5 |
| 1803 | 0.0027 | 2278.6 | 13.3 |
| 1804 | 0.0001 | 1113.3 | 0.2 |
| 1805 | 0.0001 | 738.5 | 0.2 |
| 1806 | 0.0013 | 3243.0 | 9.6 |
| 1809 | 0.0003 | 679.0 | 0.5 |
| 1859 | 0.0028 | 396.4 | 2.4 |
| 1862 | NA | 127.0 | NA |
| 1863 | 0.0222 | 0.0 | 0.0 |
| 1864 | 0.0236 | 0.0 | 0.0 |
| 1865 | 0.0092 | 0.0 | 0.0 |
| 1868 | 0.0224 | 698.6 | 34.3 |
| 1869 | NA | NA | NA |
| 1870 | 0.0011 | 2624.9 | 6.3 |
| 1871 | 0.0005 | 2309.4 | 2.5 |
| 1872 | 0.0003 | 3133.7 | 2.0 |
| 1873 | 0.0004 | 5702.6 | 5.3 |
| 1874 | 0.0001 | 2849.9 | 0.7 |
| 1875 | 0.0001 | 4470.7 | 1.2 |
| 1876 | 0.0001 | 7229.7 | 1.1 |
| 1877 | 0.0002 | 2531.4 | 1.3 |
| 1878 | 0.0001 | 7251.8 | 1.6 |
| 1879 | 0.0008 | 1169.9 | 1.9 |
| 1880 | 0.0017 | 4254.5 | 15.5 |
| 1881 | 0.0043 | 2847.3 | 27.0 |
| 1883 | 0.0004 | 506.9 | 0.5 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 1932 | 0.0012 | 39.8 | 0.1 |
| 1933 | 0.0025 | 518.5 | 2.8 |
| 1938 | 0.0202 | 53.1 | 2.4 |
| 1941 | 0.0049 | 0.0 | 0.0 |
| 1942 | 0.0041 | 2282.6 | 20.3 |
| 1943 | 0.0064 | 1986.0 | 27.6 |
| 1944 | 0.0394 | 2138.3 | 184.9 |
| 1945 | 0.0015 | 3749.2 | 12.3 |
| 1946 | 0.0003 | 1455.1 | 1.0 |
| 1947 | 0.0003 | 3456.8 | 2.0 |
| 1948 | 0.0000 | 1913.3 | 0.1 |
| 1949 | 0.0008 | 2603.1 | 4.3 |
| 1950 | 0.0001 | 2138.4 | 0.3 |
| 1951 | 0.0002 | 3763.8 | 1.7 |
| 1952 | 0.0002 | 8880.6 | 4.6 |
| 1953 | 0.0000 | 6404.7 | 0.6 |
| 1954 | 0.0220 | 9203.5 | 444.8 |
| 1955 | 0.0084 | 8981.7 | 164.8 |
| 1956 | 0.0053 | 5407.3 | 62.6 |
| 2005 | 0.0054 | 0.0 | 0.0 |
| 2006 | 0.0019 | 0.0 | 0.0 |
| 2007 | 0.0047 | 103.2 | 1.1 |
| 2008 | 0.0096 | 130.9 | 2.8 |
| 2009 | NA | 255.0 | NA |
| 2011 | 0.0052 | 0.0 | 0.0 |
| 2012 | 0.0054 | 0.0 | 0.0 |
| 2013 | 0.0460 | 392.3 | 39.6 |
| 2014 | 0.0129 | 0.0 | 0.0 |
| 2015 | 0.0044 | 460.0 | 4.5 |
| 2016 | 0.0067 | 655.6 | 9.6 |
| 2017 | 0.0033 | 2799.8 | 20.5 |
| 2018 | 0.0050 | 2478.9 | 27.1 |
| 2019 | 0.0028 | 3815.6 | 23.4 |
| 2020 | 0.0002 | 2688.6 | 1.2 |
| 2021 | 0.0001 | 969.8 | 0.1 |
| 2022 | 0.0002 | 3783.0 | 1.3 |
| 2023 | 0.0000 | 906.6 | 0.1 |
| 2024 | 0.0006 | 4984.4 | 6.3 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 2025 | 0.0058 | 3953.7 | 49.8 |
| 2026 | 0.0001 | 6456.9 | 0.8 |
| 2027 | 0.0001 | 7608.2 | 0.8 |
| 2028 | 0.0036 | 11717.2 | 92.2 |
| 2029 | 0.0085 | 8808.0 | 164.3 |
| 2030 | 0.1769 | 3960.4 | 1535.7 |
| 2072 | 0.0483 | 84.3 | 8.9 |
| 2073 | 0.0052 | 76.7 | 0.9 |
| 2080 | 0.0019 | 45.3 | 0.2 |
| 2081 | 0.0019 | 58.1 | 0.2 |
| 2082 | 0.0020 | 126.7 | 0.6 |
| 2083 | 0.0035 | 151.5 | 1.2 |
| 2084 | 0.0020 | 0.0 | 0.0 |
| 2086 | 0.0439 | 0.0 | 0.0 |
| 2087 | 0.0085 | 1022.2 | 19.1 |
| 2088 | 0.0112 | 481.0 | 11.9 |
| 2089 | 0.0033 | 715.4 | 5.2 |
| 2090 | 0.0030 | 469.5 | 3.0 |
| 2091 | 0.0033 | 5356.6 | 39.1 |
| 2092 | 0.0014 | 2748.3 | 8.3 |
| 2093 | 0.0004 | 4112.8 | 3.4 |
| 2094 | 0.0007 | 3991.5 | 6.3 |
| 2095 | 0.0000 | 682.5 | 0.1 |
| 2096 | 0.0000 | 3044.7 | 0.1 |
| 2097 | 0.0000 | 4209.1 | 0.3 |
| 2098 | 0.0007 | 3191.7 | 5.0 |
| 2099 | 0.0002 | 7569.1 | 4.0 |
| 2100 | 0.0006 | 10756.4 | 13.0 |
| 2101 | 0.0003 | 13484.9 | 8.7 |
| 2102 | 0.0007 | 9044.4 | 13.0 |
| 2103 | 0.0022 | 2307.1 | 10.9 |
| 2104 | 0.0006 | 3365.9 | 4.1 |
| 2147 | 0.0548 | 81.2 | 9.8 |
| 2149 | 0.0000 | 4.8 | 0.0 |
| 2154 | 0.0019 | 23.5 | 0.1 |
| 2155 | 0.0009 | 0.0 | 0.0 |
| 2156 | 0.0021 | 0.0 | 0.0 |
| 2158 | 0.0139 | 1.1 | 0.0 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 2159 | NA | 0.0 | NA |
| 2160 | 0.0056 | 0.0 | 0.0 |
| 2162 | NA | 0.0 | NA |
| 2163 | 0.0054 | 809.7 | 9.5 |
| 2165 | 0.0027 | 1193.5 | 7.1 |
| 2166 | 0.0019 | 100.4 | 0.4 |
| 2167 | 0.0009 | 1484.3 | 2.9 |
| 2168 | 0.0003 | 2879.2 | 1.8 |
| 2169 | 0.0001 | 325.2 | 0.0 |
| 2170 | 0.0000 | 166.1 | 0.0 |
| 2171 | 0.0008 | 6367.8 | 11.0 |
| 2172 | 0.0003 | 4075.0 | 2.9 |
| 2173 | 0.0019 | 6470.0 | 27.3 |
| 2174 | 0.0003 | 27955.3 | 21.4 |
| 2175 | 0.0020 | 9713.2 | 43.4 |
| 2176 | 0.0044 | 10613.9 | 102.1 |
| 2177 | 0.0017 | 8609.9 | 32.2 |
| 2178 | 0.0181 | 4355.4 | 172.6 |
| 2179 | 0.0230 | 6381.3 | 321.8 |
| 2225 | 0.4873 | 0.0 | 0.0 |
| 2227 | NA | 0.0 | NA |
| 2228 | 0.0183 | 0.0 | 0.0 |
| 2229 | 0.0012 | 11.3 | 0.0 |
| 2230 | 0.0026 | 0.0 | 0.0 |
| 2233 | 0.0060 | 0.0 | 0.0 |
| 2234 | 0.0026 | 0.0 | 0.0 |
| 2235 | NA | 0.0 | NA |
| 2236 | 0.0052 | 0.0 | 0.0 |
| 2237 | 0.0012 | 106.0 | 0.3 |
| 2238 | 0.0028 | 227.8 | 1.4 |
| 2239 | 0.0048 | 1486.9 | 15.5 |
| 2240 | 0.0023 | 1575.9 | 8.0 |
| 2241 | 0.0010 | 3168.0 | 6.9 |
| 2242 | 0.0018 | 4294.4 | 17.4 |
| 2243 | 0.0012 | 1183.7 | 3.0 |
| 2244 | 0.0008 | 6007.8 | 10.4 |
| 2245 | 0.0224 | 4021.6 | 197.0 |
| 2246 | 0.0008 | 4359.3 | 7.3 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 2247 | 0.0003 | 18740.9 | 11.5 |
| 2248 | 0.0018 | 10386.7 | 41.1 |
| 2249 | 0.0009 | 7243.5 | 14.0 |
| 2250 | 0.0008 | 6549.5 | 11.2 |
| 2251 | 0.0109 | 8177.6 | 195.9 |
| 2252 | 0.0014 | 3025.2 | 9.6 |
| 2294 | 0.0089 | 0.0 | 0.0 |
| 2296 | 0.0823 | 10.3 | 1.9 |
| 2297 | NA | NA | NA |
| 2299 | 0.4413 | 0.0 | 0.0 |
| 2301 | 0.0067 | 0.0 | 0.0 |
| 2302 | 0.4935 | 0.0 | 0.0 |
| 2303 | 0.0031 | 13.0 | 0.1 |
| 2304 | 0.1069 | 0.0 | 0.0 |
| 2305 | NA | 0.0 | NA |
| 2307 | 0.0521 | 0.0 | 0.0 |
| 2308 | 0.0011 | 66.8 | 0.2 |
| 2309 | 0.0011 | 23.4 | 0.1 |
| 2310 | 0.0053 | 1158.7 | 13.5 |
| 2311 | 0.0006 | 715.1 | 1.0 |
| 2312 | 0.0014 | 299.2 | 0.9 |
| 2313 | 0.0025 | 440.6 | 2.5 |
| 2314 | 0.0021 | 282.4 | 1.3 |
| 2315 | 0.0008 | 1002.1 | 1.6 |
| 2316 | 0.0023 | 7510.2 | 37.2 |
| 2317 | 0.0006 | 9125.4 | 11.0 |
| 2318 | 0.0004 | 9807.7 | 7.9 |
| 2319 | 0.0001 | 963.8 | 0.2 |
| 2320 | 0.0009 | 6024.2 | 11.9 |
| 2321 | 0.0018 | 2814.8 | 11.0 |
| 2322 | 0.0030 | 2053.2 | 13.4 |
| 2323 | 0.0009 | 3930.0 | 7.8 |
| 2324 | 0.0024 | 4664.1 | 24.9 |
| 2325 | 0.0025 | 3891.9 | 21.0 |
| 2326 | 0.0211 | 14056.5 | 648.7 |
| 2328 | 0.0021 | 4873.1 | 22.8 |
| 2368 | 0.0040 | 0.0 | 0.0 |
| 2374 | 0.0001 | 0.0 | 0.0 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 2379 | 0.0053 | 0.0 | 0.0 |
| 2380 | 0.0040 | 0.0 | 0.0 |
| 2381 | 0.0065 | 0.0 | 0.0 |
| 2382 | 0.0072 | 45.4 | 0.7 |
| 2383 | 0.0042 | 537.1 | 4.9 |
| 2384 | 0.0077 | 491.4 | 8.3 |
| 2385 | 0.0042 | 683.3 | 6.3 |
| 2386 | 0.0003 | 1276.1 | 0.8 |
| 2387 | 0.0025 | 455.6 | 2.5 |
| 2388 | 0.0011 | 391.2 | 1.0 |
| 2389 | 0.0032 | 2394.4 | 16.6 |
| 2390 | 0.0017 | 4257.7 | 16.2 |
| 2391 | 0.0010 | 3887.8 | 8.5 |
| 2392 | 0.0026 | 15217.1 | 86.1 |
| 2393 | 0.0002 | 1479.8 | 0.7 |
| 2394 | 0.0003 | 3048.3 | 1.7 |
| 2395 | 0.0007 | 1986.3 | 3.0 |
| 2396 | 0.0004 | 13119.0 | 10.3 |
| 2397 | 0.0003 | 4231.2 | 2.8 |
| 2398 | 0.0015 | 9100.1 | 30.8 |
| 2399 | 0.0061 | 20822.6 | 278.7 |
| 2400 | 0.0044 | 11556.7 | 112.5 |
| 2401 | 0.0010 | 5500.7 | 12.4 |
| 2402 | 0.0000 | 2368.0 | 0.1 |
| 2448 | NA | 0.0 | NA |
| 2449 | NA | 0.0 | NA |
| 2454 | 0.0000 | 0.0 | 0.0 |
| 2456 | 0.0205 | 0.0 | 0.0 |
| 2458 | 0.0013 | 840.8 | 2.4 |
| 2459 | 0.0024 | 3526.4 | 18.3 |
| 2460 | 0.0019 | 202.6 | 0.8 |
| 2461 | 0.0045 | 564.3 | 5.5 |
| 2462 | 0.0007 | 67.7 | 0.1 |
| 2463 | 0.0018 | 2281.4 | 8.9 |
| 2465 | 0.0004 | 1465.6 | 1.2 |
| 2466 | 0.0001 | 6230.2 | 1.6 |
| 2467 | 0.0000 | 10074.6 | 0.8 |
| 2468 | 0.0000 | 11040.7 | 0.2 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 2469 | 0.0002 | 5769.1 | 2.3 |
| 2470 | 0.0005 | 3252.7 | 3.2 |
| 2471 | 0.0003 | 5371.1 | 3.8 |
| 2472 | 0.0004 | 8277.9 | 7.7 |
| 2473 | 0.0044 | 8562.8 | 83.4 |
| 2474 | 0.0014 | 7375.0 | 23.1 |
| 2475 | 0.0001 | 11447.6 | 1.6 |
| 2518 | 0.0015 | 0.0 | 0.0 |
| 2519 | 0.0030 | 0.0 | 0.0 |
| 2523 | 0.0018 | 0.0 | 0.0 |
| 2528 | 0.0024 | 0.0 | 0.0 |
| 2529 | 0.0035 | 172.9 | 1.3 |
| 2530 | 0.1009 | 62.1 | 13.7 |
| 2531 | 0.0013 | 92.7 | 0.3 |
| 2532 | 0.0083 | 175.9 | 3.2 |
| 2533 | 0.0041 | 1192.0 | 10.6 |
| 2534 | 0.0612 | 1996.6 | 267.8 |
| 2535 | 0.0018 | 1807.3 | 7.0 |
| 2536 | 0.0028 | 68.1 | 0.4 |
| 2537 | 0.0019 | 4417.0 | 18.8 |
| 2538 | 0.0007 | 4278.0 | 6.4 |
| 2539 | 0.0009 | 1728.6 | 3.2 |
| 2540 | 0.0003 | 2645.9 | 1.7 |
| 2541 | 0.0003 | 2398.5 | 1.4 |
| 2542 | 0.0000 | 6492.0 | 0.2 |
| 2543 | 0.0003 | 4700.0 | 2.7 |
| 2544 | 0.0007 | 1867.6 | 2.7 |
| 2545 | 0.0003 | 3416.3 | 2.3 |
| 2546 | 0.0005 | 11781.1 | 14.1 |
| 2548 | 0.0001 | 3880.7 | 0.8 |
| 2549 | 0.0002 | 5678.8 | 2.2 |
| 2593 | 0.0281 | 0.0 | 0.0 |
| 2599 | 0.0038 | 0.0 | 0.0 |
| 2603 | 0.0118 | 105.4 | 2.7 |
| 2604 | NA | NA | NA |
| 2605 | 0.0069 | 148.5 | 2.2 |
| 2606 | 0.0019 | 382.2 | 1.6 |
| 2607 | 0.0098 | 140.4 | 3.0 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 2608 | 0.0112 | 0.0 | 0.0 |
| 2609 | 0.0044 | 136.2 | 1.3 |
| 2610 | 0.0043 | 350.8 | 3.3 |
| 2611 | 0.0020 | 2078.0 | 9.3 |
| 2612 | 0.0008 | 6389.2 | 11.3 |
| 2613 | 0.0007 | 4352.1 | 6.6 |
| 2614 | 0.0003 | 2364.1 | 1.4 |
| 2615 | 0.0000 | 2391.5 | 0.0 |
| 2616 | 0.0014 | 13083.2 | 38.7 |
| 2617 | 0.0003 | 6755.4 | 4.9 |
| 2618 | 0.0009 | 5039.0 | 10.2 |
| 2619 | 0.0004 | 9985.5 | 7.8 |
| 2620 | 0.0001 | 1454.7 | 0.4 |
| 2622 | 0.0000 | 3618.8 | 0.1 |
| 2623 | NA | 5260.0 | NA |
| 2666 | NA | 0.0 | NA |
| 2669 | NA | 0.0 | NA |
| 2673 | NA | 0.0 | NA |
| 2674 | 0.0047 | 0.0 | 0.0 |
| 2676 | 0.0123 | 0.0 | 0.0 |
| 2677 | 0.0196 | 0.0 | 0.0 |
| 2678 | 0.0048 | 107.3 | 1.1 |
| 2679 | 0.0074 | 0.0 | 0.0 |
| 2680 | 0.0044 | 51.3 | 0.5 |
| 2681 | 0.0045 | 61.4 | 0.6 |
| 2682 | 0.0056 | 3593.2 | 43.7 |
| 2684 | 0.0016 | 208.2 | 0.7 |
| 2685 | 0.0015 | 278.2 | 0.9 |
| 2686 | 0.0022 | 939.4 | 4.5 |
| 2687 | 0.0005 | 5032.5 | 5.5 |
| 2688 | 0.0001 | 5338.1 | 1.6 |
| 2690 | 0.0000 | 4456.4 | 0.1 |
| 2691 | 0.0003 | 4241.4 | 2.9 |
| 2692 | 0.0010 | 7433.9 | 15.9 |
| 2743 | NA | 0.0 | NA |
| 2748 | 0.0069 | 0.0 | 0.0 |
| 2749 | 0.0100 | 0.0 | 0.0 |
| 2750 | 0.0061 | 0.0 | 0.0 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 2751 | 0.0029 | 10.9 | 0.1 |
| 2752 | 0.0064 | 0.0 | 0.0 |
| 2753 | 0.0086 | 86.0 | 1.6 |
| 2754 | 0.0051 | 170.5 | 1.9 |
| 2755 | 0.0041 | 0.0 | 0.0 |
| 2756 | 0.0007 | 83.3 | 0.1 |
| 2757 | 0.0028 | 20.2 | 0.1 |
| 2758 | 0.0049 | 0.0 | 0.0 |
| 2759 | 0.0018 | 2166.6 | 8.4 |
| 2760 | 0.0034 | 3762.1 | 28.1 |
| 2761 | 0.0008 | 739.5 | 1.2 |
| 2762 | 0.0007 | 1602.7 | 2.5 |
| 2765 | 0.0001 | 12140.2 | 2.4 |
| 2766 | 0.0017 | 8721.1 | 33.0 |
| 2767 | 0.0003 | 8946.0 | 6.1 |
| 2768 | 0.0000 | 4379.4 | 0.2 |
| 2816 | 0.0081 | 0.0 | 0.0 |
| 2818 | NA | 0.0 | NA |
| 2821 | NA | 46.0 | NA |
| 2822 | 0.0036 | 99.7 | 0.8 |
| 2824 | 0.0026 | 0.0 | 0.0 |
| 2825 | 0.0035 | 159.3 | 1.2 |
| 2826 | 0.0039 | 48.7 | 0.4 |
| 2827 | 0.0043 | 0.4 | 0.0 |
| 2829 | 0.0044 | 0.0 | 0.0 |
| 2830 | 0.0081 | 82.1 | 1.5 |
| 2831 | 0.0057 | 1526.4 | 19.1 |
| 2832 | 0.0069 | 373.0 | 5.6 |
| 2833 | 0.0034 | 1122.1 | 8.3 |
| 2834 | 0.0027 | 2012.5 | 11.9 |
| 2835 | 0.0000 | 1973.9 | 0.1 |
| 2837 | NA | 5808.7 | NA |
| 2839 | 0.0000 | 5.3 | 0.0 |
| 2841 | 0.0006 | 354.1 | 0.5 |
| 2842 | 0.0006 | 9411.3 | 12.0 |
| 2843 | 0.0000 | 2570.0 | 0.0 |
| 2897 | NA | 21.6 | NA |
| 2898 | 0.0120 | 0.0 | 0.0 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 2899 | 0.0012 | 156.3 | 0.4 |
| 2900 | 0.0006 | 799.8 | 1.1 |
| 2902 | 0.0044 | 62.3 | 0.6 |
| 2903 | 0.0016 | 156.7 | 0.5 |
| 2904 | 0.0047 | 0.0 | 0.0 |
| 2905 | 0.0031 | 10.2 | 0.1 |
| 2906 | 0.0027 | 39.6 | 0.2 |
| 2907 | 0.0038 | 113.9 | 0.9 |
| 2908 | 0.0011 | 338.5 | 0.8 |
| 2909 | 0.0000 | 2752.0 | 0.2 |
| 2910 | 0.0003 | 4269.4 | 2.8 |
| 2912 | 0.0000 | 5881.9 | 0.3 |
| 2913 | 0.0001 | 2027.0 | 0.4 |
| 2914 | 0.0000 | 260.1 | 0.0 |
| 2915 | 0.0001 | 0.0 | 0.0 |
| 2916 | 0.0003 | 1707.7 | 1.1 |
| 2962 | 0.0196 | 0.0 | 0.0 |
| 2966 | 0.0081 | 140.8 | 2.5 |
| 2971 | 0.0003 | 326.4 | 0.2 |
| 2973 | 0.0030 | 0.0 | 0.0 |
| 2974 | 0.0094 | 42.7 | 0.9 |
| 2975 | 0.0032 | 0.0 | 0.0 |
| 2976 | 0.0154 | 52.5 | 1.8 |
| 2977 | 0.0007 | 0.0 | 0.0 |
| 2978 | 0.0004 | 153.3 | 0.1 |
| 2979 | 0.0011 | 210.4 | 0.5 |
| 2980 | 0.0044 | 30.5 | 0.3 |
| 2981 | 0.0025 | 627.1 | 3.4 |
| 2982 | 0.0014 | 562.0 | 1.7 |
| 2984 | 0.0004 | 9109.6 | 8.3 |
| 2985 | 0.0004 | 9458.9 | 8.6 |
| 2986 | 0.0004 | 7916.4 | 6.9 |
| 2987 | 0.0009 | 7337.1 | 14.8 |
| 2989 | 0.0006 | 11.2 | 0.0 |
| 2990 | 0.0000 | 121.1 | 0.0 |
| 2991 | 0.0003 | 0.0 | 0.0 |
| 2992 | 0.0017 | 0.0 | 0.0 |
| 3038 | 0.0060 | 0.0 | 0.0 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 3040 | 0.0121 | 0.0 | 0.0 |
| 3041 | 0.0047 | 30.8 | 0.3 |
| 3043 | 0.7531 | 1237.8 | 2043.2 |
| 3045 | NA | 177.2 | NA |
| 3046 | 0.0060 | 56.7 | 0.7 |
| 3047 | 0.0090 | 191.5 | 3.8 |
| 3048 | 0.0392 | 88.5 | 7.6 |
| 3050 | 0.0178 | 54.6 | 2.1 |
| 3051 | 0.0002 | 119.6 | 0.0 |
| 3052 | 0.0001 | 846.0 | 0.2 |
| 3053 | 0.0022 | 157.1 | 0.8 |
| 3054 | 0.0018 | 938.9 | 3.8 |
| 3055 | 0.0005 | 3823.5 | 4.4 |
| 3056 | 0.0020 | 3186.2 | 14.1 |
| 3057 | 0.0006 | 7047.0 | 9.0 |
| 3058 | 0.0027 | 8680.5 | 52.2 |
| 3059 | 0.0012 | 12467.1 | 33.0 |
| 3060 | 0.0027 | 7954.4 | 46.6 |
| 3061 | 0.0007 | 10338.9 | 15.4 |
| 3062 | 0.0000 | 14513.1 | 0.6 |
| 3067 | 0.0001 | 0.0 | 0.0 |
| 3113 | 0.0064 | 0.0 | 0.0 |
| 3117 | 0.0077 | 525.7 | 8.8 |
| 3119 | NA | 94.0 | NA |
| 3120 | 0.0025 | 0.0 | 0.0 |
| 3121 | 0.0025 | 2.6 | 0.0 |
| 3123 | 0.0003 | 0.0 | 0.0 |
| 3124 | 0.0001 | 0.0 | 0.0 |
| 3125 | NA | 246.0 | NA |
| 3126 | 0.0001 | 304.3 | 0.1 |
| 3127 | 0.0002 | 152.4 | 0.1 |
| 3128 | 0.0005 | 704.2 | 0.8 |
| 3129 | 0.0005 | 3491.7 | 4.1 |
| 3130 | 0.0009 | 1717.9 | 3.6 |
| 3131 | 0.0002 | 4692.2 | 2.1 |
| 3132 | 0.0003 | 3202.2 | 2.4 |
| 3133 | 0.0004 | 11896.9 | 10.3 |
| 3134 | 0.0045 | 9962.0 | 99.1 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 3136 | 0.0004 | 7622.1 | 7.2 |
| 3140 | 0.0000 | 0.0 | 0.0 |
| 3188 | 0.0145 | 0.0 | 0.0 |
| 3189 | 0.0270 | 0.0 | 0.0 |
| 3191 | 0.0022 | 0.0 | 0.0 |
| 3192 | 0.0069 | 14.8 | 0.2 |
| 3196 | 0.0076 | 93.2 | 1.6 |
| 3198 | 0.0009 | 0.0 | 0.0 |
| 3199 | 0.0168 | 390.2 | 14.3 |
| 3200 | 0.0018 | 326.2 | 1.3 |
| 3201 | 0.0087 | 81.1 | 1.6 |
| 3202 | 0.0001 | 55.9 | 0.0 |
| 3203 | 0.0004 | 641.0 | 0.5 |
| 3204 | 0.0003 | 2903.3 | 1.8 |
| 3205 | 0.0004 | 5358.9 | 4.5 |
| 3206 | 0.0002 | 1681.2 | 0.9 |
| 3207 | 0.0004 | 2691.7 | 2.6 |
| 3208 | 0.0020 | 7661.8 | 34.4 |
| 3213 | 0.0000 | 58.1 | 0.0 |
| 3214 | 0.0000 | 478.4 | 0.0 |
| 3215 | 0.0000 | 4775.3 | 0.2 |
| 3261 | 0.0102 | 0.0 | 0.0 |
| 3262 | 0.0040 | 0.0 | 0.0 |
| 3263 | 0.0018 | 0.0 | 0.0 |
| 3264 | 0.0114 | 43.7 | 1.1 |
| 3265 | 0.0040 | 17.0 | 0.1 |
| 3266 | 0.0047 | 200.7 | 2.1 |
| 3267 | 0.0102 | 139.5 | 3.1 |
| 3268 | 0.0039 | 284.3 | 2.5 |
| 3269 | 0.0029 | 195.3 | 1.3 |
| 3270 | 0.0007 | 297.3 | 0.5 |
| 3273 | 0.0024 | 210.5 | 1.1 |
| 3274 | 0.0107 | 184.0 | 4.3 |
| 3275 | 0.0269 | 1183.7 | 69.7 |
| 3276 | 0.0010 | 1763.7 | 4.0 |
| 3277 | 0.0024 | 1863.1 | 9.9 |
| 3278 | 0.0003 | 7540.9 | 4.6 |
| 3279 | 0.0007 | 8897.8 | 13.8 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 3280 | 0.0002 | 8355.0 | 3.9 |
| 3281 | 0.0001 | 11859.2 | 2.7 |
| 3282 | 0.0007 | 7826.1 | 12.2 |
| 3283 | 0.0008 | 5267.1 | 8.7 |
| 3284 | 0.0009 | 3410.0 | 7.0 |
| 3288 | 0.0000 | 1545.6 | 0.0 |
| 3289 | 0.0000 | 487.9 | 0.0 |
| 3337 | 0.0562 | 188.1 | 23.2 |
| 3338 | NA | 44.5 | NA |
| 3339 | 0.0092 | 0.0 | 0.0 |
| 3340 | 0.0051 | 137.4 | 1.5 |
| 3343 | 0.0036 | 0.0 | 0.0 |
| 3344 | 0.1379 | 10.6 | 3.2 |
| 3345 | 0.0093 | 0.0 | 0.0 |
| 3346 | 0.0210 | 0.0 | 0.0 |
| 3347 | 0.0022 | 148.6 | 0.7 |
| 3348 | 0.0220 | 471.2 | 22.7 |
| 3349 | 0.0007 | 668.3 | 1.0 |
| 3350 | 0.0044 | 949.0 | 9.1 |
| 3351 | 0.0049 | 1312.5 | 14.1 |
| 3352 | 0.0028 | 7787.8 | 47.0 |
| 3353 | 0.0011 | 7452.3 | 18.1 |
| 3354 | 0.0009 | 8293.6 | 16.0 |
| 3355 | 0.0000 | 8180.1 | 0.6 |
| 3356 | 0.0002 | 9300.6 | 4.4 |
| 3357 | 0.0005 | 8640.2 | 10.1 |
| 3358 | 0.0007 | 10648.4 | 16.3 |
| 3410 | NA | 25.2 | NA |
| 3412 | NA | 0.0 | NA |
| 3413 | 0.0010 | 26.7 | 0.1 |
| 3414 | 0.0022 | 205.5 | 1.0 |
| 3415 | 0.0115 | 218.7 | 5.5 |
| 3416 | 0.0045 | 44.0 | 0.4 |
| 3420 | 0.0014 | 88.9 | 0.3 |
| 3421 | 0.0008 | 272.6 | 0.5 |
| 3422 | 0.0062 | 911.4 | 12.4 |
| 3423 | 0.0135 | 445.3 | 13.2 |
| 3424 | 0.0041 | 849.1 | 7.6 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 3425 | 0.0040 | 3064.2 | 26.7 |
| 3426 | 0.0046 | 2194.7 | 22.3 |
| 3427 | 0.0015 | 5007.7 | 16.8 |
| 3428 | 0.0001 | 10343.6 | 1.8 |
| 3429 | 0.0003 | 5301.5 | 3.7 |
| 3430 | 0.0001 | 6859.9 | 1.1 |
| 3431 | 0.0003 | 8700.8 | 6.4 |
| 3432 | 0.0016 | 9597.9 | 32.6 |
| 3433 | 0.0011 | 9841.2 | 23.5 |
| 3435 | 0.0002 | 943.2 | 0.5 |
| 3485 | 0.0071 | 137.2 | 2.1 |
| 3486 | 0.0037 | 53.3 | 0.4 |
| 3487 | 0.0014 | 190.8 | 0.6 |
| 3488 | 0.0033 | 186.0 | 1.4 |
| 3489 | 0.0079 | 306.7 | 5.3 |
| 3490 | 0.0026 | 68.3 | 0.4 |
| 3492 | 0.0010 | 11.7 | 0.0 |
| 3493 | 0.0001 | 0.0 | 0.0 |
| 3494 | 0.0002 | 0.0 | 0.0 |
| 3495 | 0.0056 | 0.0 | 0.0 |
| 3496 | 0.0062 | 447.6 | 6.1 |
| 3497 | 0.0576 | 1663.5 | 210.0 |
| 3498 | 0.0051 | 1627.4 | 18.3 |
| 3499 | 0.0002 | 1083.8 | 0.4 |
| 3500 | 0.0000 | 3173.0 | 0.3 |
| 3501 | 0.0001 | 4120.8 | 1.2 |
| 3502 | 0.0004 | 2499.6 | 2.2 |
| 3503 | 0.0002 | 1604.0 | 0.8 |
| 3504 | 0.0016 | 2918.5 | 10.5 |
| 3505 | 0.0014 | 2731.0 | 8.1 |
| 3506 | 0.0041 | 4351.0 | 38.7 |
| 3507 | 0.0003 | 7266.2 | 5.4 |
| 3508 | 0.0005 | 6861.3 | 8.1 |
| 3509 | 0.0031 | 5871.2 | 40.0 |
| 3559 | 0.0170 | 0.0 | 0.0 |
| 3560 | 0.0381 | 0.0 | 0.0 |
| 3561 | 0.0009 | 15.9 | 0.0 |
| 3562 | 0.0014 | 0.0 | 0.0 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 3563 | 0.0027 | 30.1 | 0.2 |
| 3564 | 0.0343 | 0.0 | 0.0 |
| 3568 | 0.0034 | 24.9 | 0.2 |
| 3569 | 0.0028 | 61.9 | 0.4 |
| 3570 | 0.0031 | 120.2 | 0.8 |
| 3571 | 0.0026 | 2309.9 | 13.1 |
| 3572 | 0.0026 | 894.8 | 5.2 |
| 3573 | 0.0011 | 1358.3 | 3.2 |
| 3574 | 0.0001 | 2327.5 | 0.7 |
| 3575 | 0.0000 | 4968.6 | 0.4 |
| 3576 | 0.0003 | 315.1 | 0.2 |
| 3577 | 0.0002 | 423.9 | 0.2 |
| 3578 | 0.0002 | 2626.9 | 1.0 |
| 3579 | 0.0014 | 2021.9 | 6.3 |
| 3580 | 0.0010 | 2751.8 | 6.2 |
| 3581 | 0.0012 | 2060.7 | 5.4 |
| 3582 | 0.0006 | 1587.1 | 2.1 |
| 3583 | 0.0005 | 6391.8 | 7.2 |
| 3633 | 0.0053 | 0.0 | 0.0 |
| 3634 | 0.0033 | 0.0 | 0.0 |
| 3635 | 0.0033 | 0.0 | 0.0 |
| 3636 | 0.0071 | 0.0 | 0.0 |
| 3637 | 0.0291 | 0.7 | 0.0 |
| 3640 | 0.0023 | 0.0 | 0.0 |
| 3641 | 0.0028 | 0.0 | 0.0 |
| 3642 | 0.0012 | 55.8 | 0.2 |
| 3644 | 0.0001 | 86.7 | 0.0 |
| 3645 | 0.0044 | 2753.3 | 26.8 |
| 3646 | 0.0014 | 3186.0 | 10.0 |
| 3647 | 0.0025 | 314.1 | 1.7 |
| 3648 | 0.0013 | 536.3 | 1.5 |
| 3649 | 0.0008 | 734.0 | 1.3 |
| 3650 | 0.0007 | 147.8 | 0.2 |
| 3651 | 0.0001 | 976.0 | 0.2 |
| 3652 | 0.0001 | 4403.5 | 1.1 |
| 3653 | 0.0005 | 2432.1 | 2.6 |
| 3654 | 0.0004 | 2604.8 | 2.2 |
| 3655 | 0.0008 | 2588.4 | 4.3 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 3656 | 0.0012 | 1852.2 | 4.8 |
| 3657 | 0.0009 | 465.8 | 0.9 |
| 3658 | 0.0000 | 115.2 | 0.0 |
| 3659 | 0.0000 | 0.0 | 0.0 |
| 3707 | NA | 0.0 | NA |
| 3708 | 0.0006 | 0.0 | 0.0 |
| 3709 | 0.0012 | 0.0 | 0.0 |
| 3710 | 0.0010 | 0.0 | 0.0 |
| 3711 | 0.0485 | 0.0 | 0.0 |
| 3712 | 0.0281 | 0.0 | 0.0 |
| 3713 | 0.0028 | 0.0 | 0.0 |
| 3717 | 0.0022 | 0.0 | 0.0 |
| 3718 | 0.0026 | 857.0 | 4.8 |
| 3719 | 0.0092 | 2600.7 | 52.2 |
| 3720 | 0.0026 | 3112.7 | 17.9 |
| 3721 | 0.0044 | 175.2 | 1.7 |
| 3722 | 0.0008 | 361.0 | 0.6 |
| 3723 | 0.0046 | 159.7 | 1.6 |
| 3724 | 0.0023 | 3.8 | 0.0 |
| 3725 | 0.0018 | 147.1 | 0.6 |
| 3726 | 0.0005 | 490.3 | 0.5 |
| 3727 | 0.0001 | 1224.8 | 0.2 |
| 3728 | 0.0000 | 1710.1 | 0.1 |
| 3729 | 0.0004 | 1375.1 | 1.1 |
| 3730 | 0.0010 | 281.3 | 0.6 |
| 3731 | 0.0011 | 0.0 | 0.0 |
| 3780 | NA | 0.0 | NA |
| 3783 | 0.0054 | 0.0 | 0.0 |
| 3786 | 0.0046 | 0.0 | 0.0 |
| 3787 | 0.0057 | 0.0 | 0.0 |
| 3789 | NA | NA | NA |
| 3791 | 0.0064 | 168.7 | 2.3 |
| 3792 | 0.0021 | 1303.9 | 5.9 |
| 3793 | 0.0018 | 1844.7 | 7.4 |
| 3794 | 0.0034 | 107.9 | 0.8 |
| 3795 | 0.0055 | 238.6 | 2.9 |
| 3796 | 0.0034 | 289.8 | 2.1 |
| 3797 | 0.0029 | 376.3 | 2.4 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 3798 | 0.0034 | 1138.0 | 8.6 |
| 3799 | 0.0031 | 742.8 | 5.1 |
| 3800 | 0.0046 | 99.4 | 1.0 |
| 3801 | 0.0041 | 744.2 | 6.6 |
| 3802 | 0.0014 | 766.4 | 2.4 |
| 3803 | 0.0005 | 62.1 | 0.1 |
| 3804 | 0.0006 | 0.0 | 0.0 |
| 3805 | 0.0020 | 0.0 | 0.0 |
| 3855 | NA | NA | NA |
| 3864 | 0.0094 | 161.2 | 3.3 |
| 3865 | 0.0019 | 423.8 | 1.8 |
| 3866 | 0.0019 | 316.8 | 1.3 |
| 3867 | 0.0020 | 492.9 | 2.2 |
| 3868 | 0.0096 | 177.7 | 3.7 |
| 3869 | 0.0049 | 931.3 | 9.9 |
| 3870 | 0.0096 | 0.0 | 0.0 |
| 3871 | 0.0060 | 686.5 | 9.1 |
| 3872 | 0.0084 | 318.3 | 5.8 |
| 3873 | 0.0099 | 326.2 | 7.1 |
| 3874 | 0.0141 | 1236.7 | 38.3 |
| 3875 | 0.0137 | 2156.8 | 64.9 |
| 3876 | 0.0068 | 37.2 | 0.5 |
| 3877 | 0.0063 | 0.0 | 0.0 |
| 3878 | 0.0006 | 0.0 | 0.0 |
| 3936 | 0.1930 | 0.0 | 0.0 |
| 3938 | NA | NA | NA |
| 3939 | 0.0006 | 183.3 | 0.2 |
| 3940 | 0.0009 | 845.6 | 1.7 |
| 3941 | 0.0022 | 1397.5 | 6.6 |
| 3944 | 0.1145 | 1094.8 | 274.9 |
| 3945 | 0.0162 | 793.7 | 28.2 |
| 3946 | 0.0073 | 812.2 | 13.1 |
| 3947 | 0.0129 | 3622.5 | 102.1 |
| 3948 | 0.0136 | 1103.0 | 33.0 |
| 3949 | 0.0104 | 66.4 | 1.5 |
| 3950 | 0.0100 | 0.0 | 0.0 |
| 4000 | NA | 0.0 | NA |
| 4004 | NA | NA | NA |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 4008 | NA | 0.0 | NA |
| 4012 | 0.0009 | 151.8 | 0.3 |
| 4014 | 0.0011 | 0.0 | 0.0 |
| 4018 | 0.0100 | 787.9 | 17.2 |
| 4019 | 0.0121 | 590.7 | 15.6 |
| 4020 | 0.0523 | 120.8 | 13.8 |
| 4021 | 0.0080 | 2371.2 | 41.4 |
| 4022 | 0.0074 | 776.1 | 12.7 |
| 4023 | 0.0039 | 117.4 | 1.0 |
| 4024 | 0.0047 | 0.0 | 0.0 |
| 4081 | 0.0228 | 0.0 | 0.0 |
| 4085 | 0.5632 | 0.0 | 0.0 |
| 4087 | 0.1044 | 237.3 | 54.3 |
| 4088 | 0.0565 | 1127.2 | 139.5 |
| 4092 | 0.0673 | 392.9 | 58.0 |
| 4093 | 0.0471 | 1806.7 | 186.5 |
| 4094 | 0.0058 | 1301.3 | 16.7 |
| 4095 | 0.0093 | 2507.1 | 51.0 |
| 4096 | 0.0138 | 1519.6 | 45.9 |
| 4158 | NA | NA | NA |
| 4159 | NA | 0.0 | NA |
| 4160 | 0.0072 | 46.7 | 0.7 |
| 4162 | 0.1151 | 3091.5 | 779.9 |
| 4163 | 0.0332 | 3324.5 | 241.6 |
| 4164 | 0.0176 | 2153.5 | 83.1 |
| 4165 | 0.0400 | 1811.2 | 158.9 |
| 4166 | 0.0567 | 2052.0 | 255.1 |
| 4167 | 0.0038 | 1135.8 | 9.4 |
| 4168 | 0.0050 | 5486.1 | 60.7 |
| 4169 | 0.0101 | 8869.7 | 197.0 |
| 4228 | 0.0100 | 0.0 | 0.0 |
| 4229 | NA | 0.0 | NA |
| 4235 | 0.0885 | 2049.4 | 397.4 |
| 4236 | 0.0593 | 2294.4 | 298.4 |
| 4237 | 0.0095 | 3918.1 | 81.2 |
| 4238 | 0.0184 | 1181.5 | 47.8 |
| 4240 | NA | 450.3 | NA |
| 4241 | 0.0130 | 3907.9 | 111.4 |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 4242 | 0.0065 | 2339.7 | 33.3 |
| 4302 | 0.0082 | 0.0 | 0.0 |
| 4306 | 0.0256 | 415.0 | 23.3 |
| 4307 | 0.0158 | 256.7 | 8.9 |
| 4311 | 0.0211 | 118.9 | 5.5 |
| 4313 | 0.0423 | 70.9 | 6.6 |
| 4314 | 0.1690 | 1327.3 | 491.6 |
| 4315 | 0.0528 | 2445.4 | 283.0 |
| 4376 | NA | 3.4 | NA |
| 4382 | NA | 200.0 | NA |
| 4383 | 0.0437 | 1202.3 | 115.0 |
| 4384 | 0.0028 | 95.5 | 0.6 |
| 4385 | NA | 122.8 | NA |
| 4386 | NA | 241.6 | NA |
| 4387 | NA | 3317.8 | NA |
| 4388 | NA | 3667.0 | NA |
| 4389 | NA | NA | NA |
| 4442 | 0.7577 | 0.0 | 0.0 |
| 4443 | NA | 0.0 | NA |
| 4458 | NA | 0.0 | NA |
| 4459 | NA | 30.1 | NA |
| 4460 | NA | 58.0 | NA |
| 4461 | NA | 2149.7 | NA |
| 4462 | NA | 332.0 | NA |
| 4463 | NA | 780.2 | NA |
| 4516 | NA | 0.0 | NA |
| 4522 | NA | 0.0 | NA |
| 4527 | NA | 6.6 | NA |
| 4528 | NA | 3.5 | NA |
| 4529 | NA | 0.0 | NA |
| 4531 | NA | 0.0 | NA |
| 4532 | NA | 0.0 | NA |
| 4533 | NA | 0.0 | NA |
| 4534 | NA | 147.7 | NA |
| 4535 | NA | 562.9 | NA |
| 4536 | 0.4018 | 260.3 | 229.2 |
| 4537 | NA | 291.4 | NA |
| 4543 | NA | 0.0 | NA |

**Table E-3** (continued).

| Grid Cell ID | Methane EF | AF (MMscf/yr) | Methane Emissions (2013) (kg/h) |
|---|---|---|---|
| 4590 | NA | 0.0 | NA |
| 4594 | NA | 0.0 | NA |
| 4595 | NA | 0.0 | NA |
| 4597 | NA | 0.0 | NA |
| 4599 | NA | 0.0 | NA |
| 4600 | NA | 123.8 | NA |
| 4605 | NA | 0.0 | NA |
| 4606 | NA | 0.0 | NA |
| 4607 | NA | 0.0 | NA |
| 4608 | NA | 136.0 | NA |
| 4609 | 0.0101 | 83.6 | 1.9 |
| 4610 | NA | 79.8 | NA |
| 4672 | NA | 0.0 | NA |
| 4674 | NA | NA | NA |
| 4679 | NA | 0.0 | NA |
| 4680 | NA | 0.0 | NA |
| 4682 | NA | 0.0 | NA |
| 4683 | 0.2531 | 0.0 | 0.0 |
| 4684 | 0.0137 | 0.0 | 0.0 |
| 4753 | NA | 0.0 | NA |
| 4756 | NA | 0.0 | NA |
| 4757 | NA | 0.0 | NA |
| 4758 | NA | 0.0 | NA |

### *E.4 Per grid cell scaling factors*

Another way of looking at the scaling of emissions per grid cell, is to calculate a scaling factor; where the ratio of *[Natural Gas Production 2013]/[Natural Gas Production 2009]* is determined for each individual grid cell (instead of a single average ratio for the Barnett Shale Region) and then used to scale 2009 methane emissions for each particular grid cell; which is equivalent to multiplying the emission factor times the activity factor for each grid cell, and then summing up all the emissions. Total estimated methane emissions would be 46,745 kg/h; with the results showing significant spatial differences that cause emissions to grow by a factor of three.

The increase of emissions points to a skewed spatial distribution of production changes from 2009 to 2013 within the Barnett Shale. Production decreases in some sections of the region, while others show increases that are considerably higher than 8%. From the initial (baseline year) dataset, 30% of the grid cells had a 2013 production of zero, a subset of grid cells with non-zero 2013 production is used for the remaining analyses in this section.

Figure E-3 bins the grid cells by the magnitude of the scaling factors (*the ratio of 2013 production divided by 2009 production*), showing the percent of methane emissions (for the baseline year) falling into each scaling factor bin. The map in the right side of Figure E-3 shows the scaling factor of each grid cell, highlighting the heterogeneous shifts in production. Roughly 37% of the emissions occur in grid cells that have a scaling factor between 1.0 and 10, and 6% of the emissions would be multiplied by a scaling factor greater than 10. In terms of grid cells, roughly 10% of them have a scaling factor greater than 10.

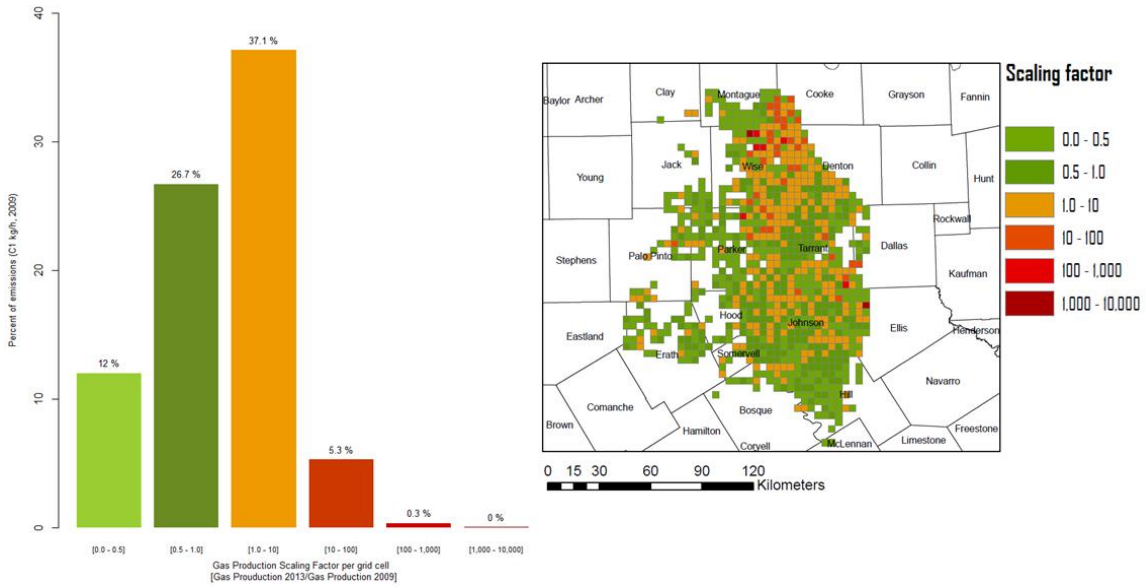


**Figure E-3.** Distribution of estimated methane emissions for the baseline year, categorized by grid cell scaling factors (*left*), and their spatial distribution (*right*).

## *E.5 References*

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