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The Mystery of the Missing Methane

Advances in the scientific understanding of methane emissions highlight the need for improvements to the EPA emissions inventory

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1. Summary

The U.S. Environmental Protection Agency (EPA) recently released a draft of its 1990-2012 greenhouse gas (GHG) emissions inventory. While the EPA is in many ways at the frontier of global best practice, the agency needs to take action to account for the accumulating evidence that the GHG inventory is omitting a significant fraction of methane emissions, the second most prevalent contributor to climate change. The new draft inventory estimates that emissions fell almost two percent in 2012 compared to 2011, and it revises downward previous estimates of methane emissions for the natural gas sector. For example, 2011 emissions are almost 10 percent lower in the 2014 draft inventory than they were in the 2013 inventory. These downward revisions are being made despite increasing scientific evidence that the EPA should be increasing its estimate of emissions.

Just one week before the draft inventory was released, the journal *Science* published a landmark study (Brandt et al., 2014) that concludes that the EPA inventory is undercounting emissions by a significant margin. The study brings together, for the first time, the full body of existing evidence on methane leakage. It estimates that there are 7-21 teragrams (Tg; 10^{12} grams) of methane missing from the EPA inventory and concludes that some of this methane is likely coming from the natural gas system. This quantity, 7-21 Tg, is equivalent to roughly 25–75 percent of the total methane emissions in the inventory and is two to four times the EPA's current estimate of methane emissions from the natural gas system.

The EPA needs to develop a plan to collect and analyze real-world data to narrow the uncertainty ranges and provide a better understanding of methane emissions, especially from the natural gas system. New technologies for detection and measurement of methane emissions can help the EPA achieve this goal. Additional resources should be dedicated to this objective.

2. Bottom-up vs. top-down studies of methane emissions

The EPA emission inventory relies on "bottom-up" studies of methane emissions. Bottom-up studies involve component-level sampling on the ground, at the source. The EPA uses the results from these studies to calculate emission factors for different activities that make up the natural gas system, including production, processing, transmission, and distribution. These emission factors—essentially, typical levels of emissions per unit output for different components of the system—are applied to natural gas production activities to calculate activity-specific emissions, and then are summed to estimate total system-wide emissions. As the EPA inventory for the natural gas system is constructed, uncontrolled emissions are first estimated using the process above (the "potential emissions"), then regulatory initiatives and voluntary information provided by companies are taken into account to produce estimated emissions.

Figure 1. Methane emissions are invisible to the naked eye

Methane emissions from this storage tank are visible not the naked eye but an infrared lens reveals their existence. Photo source: New York Times.

One of challenges with bottom-up studies is that they require the participation of landowners and natural gas companies. Researchers must obtain permission in order to enter a property and directly measure emissions, and have not found it easy to do this. There is some reason to believe that the producers that have voluntarily participated are the cleanest, lowest-emitting operators. This, in combination with the great heterogeneity in types of operations and geology across gas-bearing basins, means that it is difficult for bottom-up studies to collect data from a broad enough array of sources for the sampling to be representative.

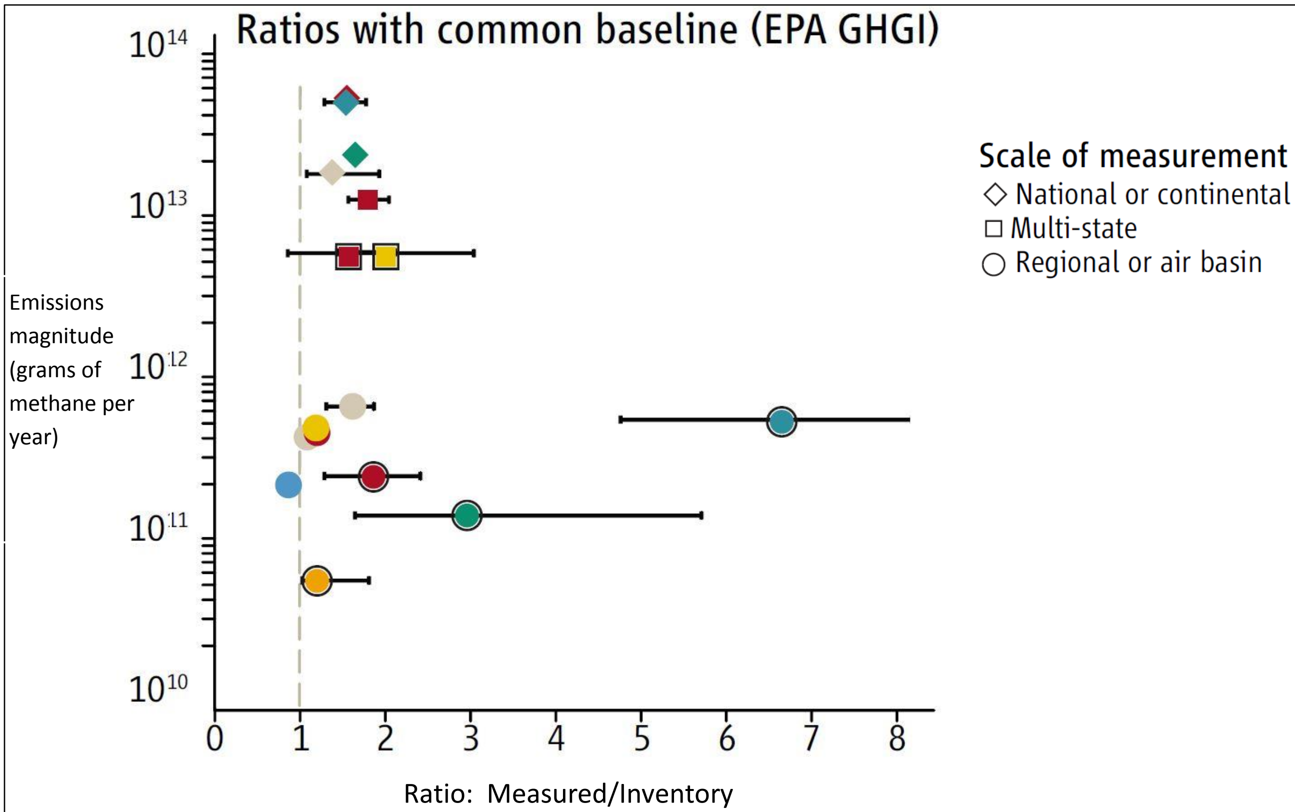
"Top-down" studies are a second, distinct approach for measuring methane emissions. These studies are based on atmospheric sampling from aircraft or tall towers. Top-down studies provide great accuracy with respect to the quantity of total emissions (though some uncertainty is introduced by wind-blown methane that might enter or exit the study area before being sampled). Traditionally, the weakness of top-down studies has been the difficulty of discerning the contribution of different sources the overall level observed level of methane. Many top-down studies have not even attempted to attribute the methane sampled in the atmosphere to particular sources on the ground. However, emerging techniques are making progress in allowing identification of likely sources for atmospherically sampled methane.

3. The missing methane

Brandt et al.'s paper is innovative in two ways. First, they provide a framework for comparison of past studies on methane emissions. In a feat of graphic creativity, Brandt et al. put all of the existing studies, bottom-up (denoted by triangles and dashes) and top-down (denoted by circles, squares, and diamonds), on a single chart. The result helps illuminate how these two threads in the literature relate to each other. Bottom-up studies measure facilities or components: the largest value found by any such study was around 10^9 g of methane emitted per year. In contrast, even the smallest of the top-down studies, which measured the Denver-Julesberg basin, reported over $4*10^{10}$ g of methane.

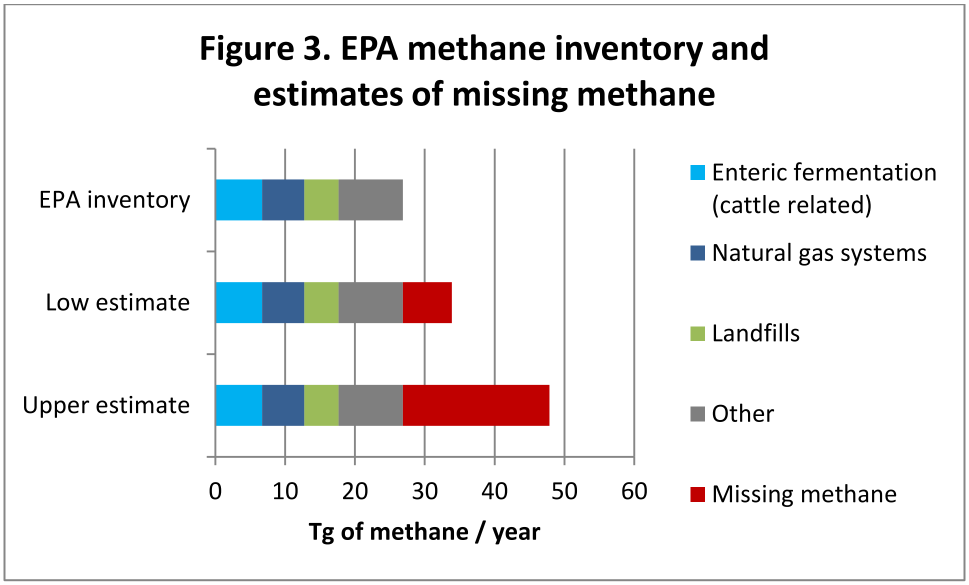
Brandt et al. also conduct a meta-analysis of national-scale, top-down studies of methane emissions. The authors develop a normalization procedure to make the multitude of studies comparable. The result indicates that the most likely range of actual methane emissions is 25–75 percent higher than the EPA inventory indicates. This range of possible emissions is illustrated in the inset panel for Brandt et al.'s principal graphic, which we reproduce as Figure 2. Note that for all of the studies that are national or continental in scale, observations all lie between 1.25 and 1.75—that is 125 percent and 175 percent of the EPA inventory.

Figure 2. Normalized comparison of top-down studies in Brandt et al.



Source: [Brandt et al., 2014]

Figure 3 shows in red the lower and upper estimates (7- 21 Tg) of methane emissions that the EPA did not account for in their inventory, which we are referring to as missing methane. The missing methane is shown on top of the results from the EPA's latest inventory.



Because of the limited ability of top-down studies to trace methane back to specific ground-level sources, it is not possible to determine the origin of the missing methane with great certainty. Still, there is reason to believe that at least *some* of the missing methane is coming from the natural gas system, as there are downward structural biases in the inventory. For example, it would be reasonable to expect that facility operators who believe they may have above-average emissions would be hesitant to join voluntary studies. This may have a large impact on results, as there is accumulating evidence that "super emitters" – a small number of facilities with particularly large leaks – could be a majority or a large fraction of overall emissions. Another downward structural bias is the EPA's choice to reduce the emissions estimated through the bottom-up procedure based on industry assertions that they have taken voluntary actions above and beyond those required by regulations.

The large range of uncertainty remaining about the rate of emissions in the natural gas system is an indicator of the complexity of the situation. The natural gas system is large, complex and heterogeneous, in both engineering and geologic terms. Each natural gas-bearing basin is unique, and there is great variation in how producers operate. Methane emissions come not only from wells producing natural gas, but also from those mainly producing oil. Indeed, 20 percent of the nation's gas is "associated gas" produced at oil wells. Oil wells have different emissions characteristics from wells designed to extract primarily natural gas. The intermingling of the oil and natural gas systems also introduces the question of how to attribute methane emissions. Some of the methane emissions from the petroleum system should be attributed to natural gas, but determining the appropriate fraction is challenging.

4. Computational extensions

The Brandt et al. paper concludes that some of the missing methane is likely coming from the natural gas system. It explores the specific possible sources of methane from the natural gas system beyond the EPA estimates. In the supporting materials for the article, the authors develop what they call a worst-case scenario for emissions from the natural gas system that considers the notion that all of the missing methane is from natural gas. Under such a scenario, if 7-21 Tg of extra methane was being emitted from the natural gas system, that would imply emission rates two to four times higher than the EPA inventory estimate.

While concluding that some of the missing methane almost certainly originates from the natural gas system, the Brandt et al. paper also emphasizes the continued lack of certainty regarding the extent that natural gas emissions are underestimated. To emphasize this uncertainty, the authors consciously chose to refrain from translating missing methane into emission rates. We also find it useful to illustrate the potential magnitude of the problem through some further computation, including implied emission rates for the natural gas system at different levels of missing methane.

Here, we develop four scenarios, translating the missing methane into an emission rate of methane from the natural gas system. The emission rate is calculated by adding a portion of the missing methane (varying by scenario) to the methane emissions assigned to the natural gas industry in the EPA's inventory, then dividing that value by the sum of natural gas production plus total methane emission in that scenario. We also specify the ratio of each scenario's methane emissions attributed to natural gas systems to the corresponding value from the EPA inventory. The scenarios are shown in Table 1.

Table 1. Emission scenarios

Scenario	Implied missing methane from natural gas systems	Ratio of scenario to EPA natural gas system emission	Implied natural gas system emission rate
1.	1.8 Tg	1.25	1.75%
2.	3.5 Tg	1.5	2.1%
3.	7 Tg	2	2.8%
4.	14 Tg	3	4.2%

We chose these scenarios to provide the broadest range of what seems possible in light of the work by Brandt et al. The paper explicitly says that it is not likely that the 21 Tg of methane all comes from natural gas, so that total amount is not considered. The upper bound analyzed is 14 Tg extra from natural gas systems. At the low end of the range of scenarios, we analyze 1.8 Tg of extra methane coming from the natural gas system. This would be the case if, for example, the natural gas system is responsible for 25 percent of the lowest estimate of missing methane. Additionally, we consider two intermediate scenarios, under which 3.5 and 7 Tg of missing methane due to natural gas systems.

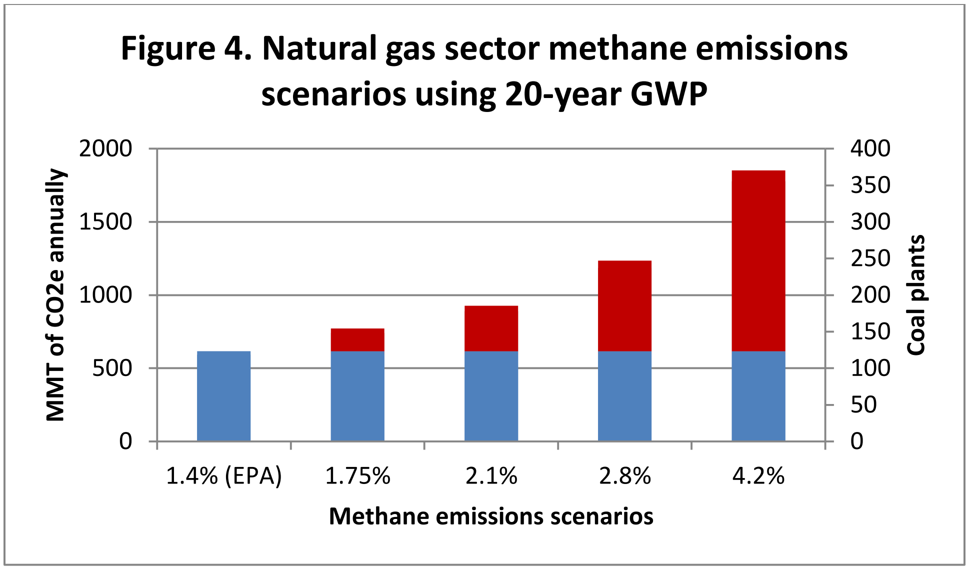
Next, we convert the methane leakage to carbon dioxide equivalent, which we use to compute an equivalency in coal plants. Coal plants comparisons are based on annual emissions using 2012 data for a generator of average efficiency, capacity factor and size for the U.S. fleet (a 543-megawatt generator operating at 85 percent capacity with a heat rate of 10,444 Btu per kilowatt-hour, from the Energy Information Administration 2013).

We use Global Warming Potential (GWP) factors to perform the conversion to CO_2 equivalent. GWP factors represent the relative contribution to global warming from GHGs other than carbon dioxide, which each have different atmospheric residence times and abilities to trap heat. All GHGs are defined in relation to carbon dioxide, the most prevalent GHG, which is assigned a GWP of one for all time periods.

Methane has an especially pronounced effect in the initial years and decades after it is released. Unlike carbon dioxide, which can continue to drive warming for hundreds or thousands of years after it is emitted, methane has an atmospheric residence time of approximately 12 years. However, while it is in the atmosphere, methane is a very potent greenhouse gas. Moreover, atmospheric chemistry transforms methane into carbon dioxide over time. The most recent Intergovernmental Panel on Climate Change (IPCC) reports GWP factors for methane of 34 over 100 years and 86 over 20 years, an increase since the prior IPCC report that reflects improved scientific understanding.

In the past, when climate change seemed like a distant problem, using 100-year GWP values was an accepted convention. The EPA inventory still refers to carbon dioxide equivalent without any reference to the timeframe with the expectation that readers will assume the numbers are on a 100-year scale. Today, with evidence of damages from climate change accumulating, there is increasing attention to near term climate disruptions. Put differently, the value of short-term climate mitigation benefits has been getting more attention from policy-makers. While carbon dioxide emissions will largely determine the extent of global warming in the long run (Harvey et al., 2013), reducing emissions of gases like methane will reduce short-run climate damages and can be used strategically to reduce peak warming (National Research Council 2011). Methane also contributes to the formation of ground-level ozone, so there are local air quality benefits to emission reductions.

This issue brief presents comparisons over both shorter and longer term time periods (20-year and 100-year GWPs). Figure 4 depicts the 20-year values in carbon dioxide equivalent (CO2e) and the comparable number of average coal plants for each of the leakage scenarios detailed in Table 1.



The first bar represents the level of methane emissions from the natural gas sector in the EPA inventory. An emissions rate of 1.4 percent implies emissions equivalent to 124 coal plants using 20-year GWP. A 1.8 percent emissions rate would imply emissions with a carbon dioxide equivalency equal to 31 additional coal plants beyond the basic inventory estimate, for a total of 155. Leakage of 4.2 percent would imply additional emissions with a carbon dioxide equivalency equal to 249 more coal plants, for a total of 373.

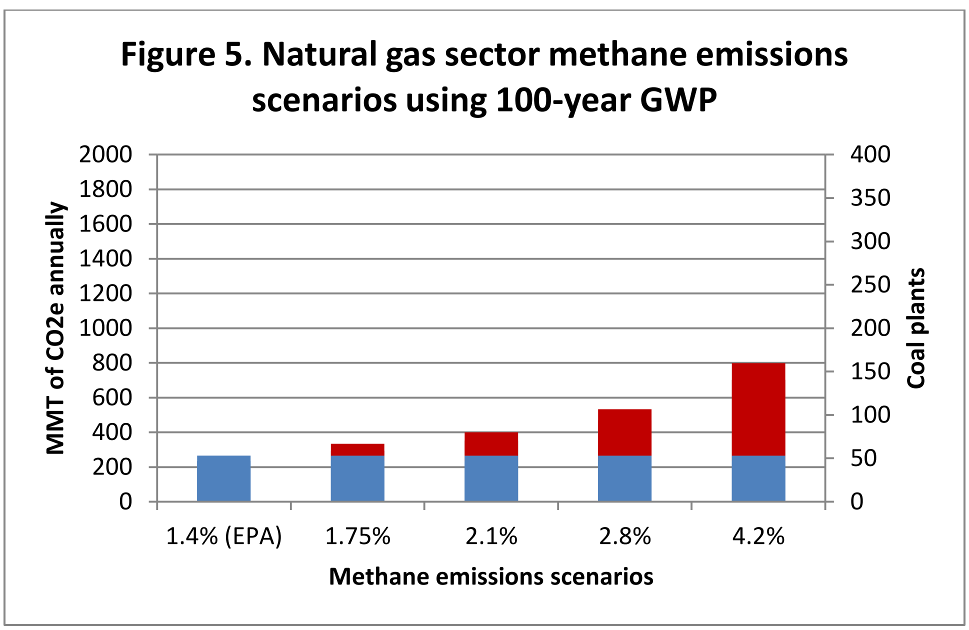


Figure 5 shows that, using 100-year GWP factors, the EPA estimate of methane leakage, 1.4 percent, has a carbon dioxide equivalency equal to 53 coal plants. A leakage rate of 1.8 percent would imply additional emissions with a carbon dioxide equivalency equal to 13 additional coal plants, for a total of

66. Doubling EPA's leakage rate to 2.8 percent results in an additional 53 coal plants, for a total of 106. A tripling of emissions to 4.2 percent would imply additional emissions with a carbon dioxide equivalency equal to 107 more coal plants, for a total of 160.

5. Implications for emissions impacts of electricity from natural gas

Proponents of natural gas have pointed to the lower carbon dioxide pollution emitted from the smokestacks of natural gas-fired electricity generators. Natural gas plants have smokestack emissions that are roughly half those of coal-fired power plants. Yet, methane emissions from the natural gas system significantly reduce this smokestack advantage. One of the reasons it is important to characterize methane emissions from the natural gas system more accurately is to provide a more accurate picture of the environmental impacts of electricity produced with natural gas. (It is worth noting that electricity generation accounted for 39 percent of natural gas consumption in 2012. Therefore, it is only appropriate to attribute that same fraction of the missing methane to electricity generated from natural gas.)

Based on the new understanding of the likely range of methane leakage provided by Brant et al., it seems very likely that substituting natural gas for coal-combustion to produce electricity actually exacerbates climate change over the short run, i.e. 20 years, and lowers greenhouse gas emissions over the long run, i.e. 100 years, (Alvarez et al. 2012). Being somewhat better than coal over a 100-year time horizon is hardly a sufficient condition to conclude that natural gas can serve as the low-carbon bridge to a clean energy future, as it is often called. In a U.S. context, it has been suggested that natural gas use will have to peak by 2030 for the Obama administration's climate goal to be achieved (Banks and Taraska 2013). From a global perspective, even those who extoll the virtues of natural gas have found that if global concentrations of carbon dioxide are to remain below 450 part per million - the level that scientists are targeting to limit the risks of dangerous climate change - then the time is very short for natural gas to serve as a useful bridge fuel (Levi 2012).

6. Conclusion

The EPA should take steps to address clear evidence that its inventory of GHG emissions is undercounting methane. In the short run, as part of finalizing the 2014 inventory, the agency should make the case for a significant effort to improve the inventory of emissions from the natural gas sector. In the longer run, the agency should develop a plan for integrating top-down data as well as new technologies that operate at ground level that can assist in leak detection and measurement. The federal government should be placing more emphasis in and devoting more resources to this effort.

Brandt et al.'s work illustrates the value of top-down measurements to provide evidence of overall emission levels over large areas. The EPA should move to collect airborne measurements into its GHG inventories. By conducting measurement campaigns, EPA will be able to obtain atmospheric data that is more comprehensive across space and time. This will enable the agency to identify aggregate emissions levels with much greater accuracy and will help to improve confidence intervals. Current confidence intervals are much too small in light of uncertainty about the true value.

Emerging technologies can link emissions back to sources, enabling the EPA to conduct an effective ground-level measurement campaign. Infrared cameras are effective at locating leaks, and their use has been required under a recently approved Colorado regulation. Low cost stationary detectors are also under development. The newest detectors can locate leaks and estimate their magnitude from a distance, which reduces the challenge of acquiring property owner permission that bedevils direct on-site measurement.

The current oil and gas boom has been unleashed by a wave of technological innovation (directional drilling, hydraulic fracturing, and other emerging techniques, like "acidizing"). Governments need to keep pace with faster innovation on the regulatory side. New monitoring technologies are an opportunity for greater accuracy, and the EPA should move quickly to use these technologies to transform government monitoring of emissions. Better monitoring of emissions will help the EPA solve the mystery of the missing methane and provide the best objective guidance to policymakers, regulators, and society.

Acknowledgments

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