NATURAL GAS *brief*

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Methane emissions from the U.S. natural gas value chain are likely more than 2% of production. Understanding how this can be estimated improves our ability to manage the leakage problem and maintain the greenhouse gas advantage of using natural gas.


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Seeing Across Scales—

Understanding methane emissions from the U.S. gas industry by integrating a variety of real-world measurements

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In the past five years, numerous studies have been published examining methane emissions from the U.S. natural gas industry. These studies take many different experimental approaches, from large regional-scale flight campaigns with instrumented aircraft to ground-level methane leakage studies looking at components across hundreds of facilities. These are often called "top-down" and "bottom-up" approaches to measuring emissions. Top-down studies have the advantage of including all potential sources in a region, but cannot tell operators or regulators much about ground-level causes of emissions. In contrast, bottom-up ▸

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studies give great detail on sources of methane but are labor intensive, typically have small sample sizes, and face challenges with potential sampling bias.

In the past, it has been hard to reconcile the emissions figures obtained by top-down studies with those generated from bottom-up studies. In 2014, Brandt et al.[1] noted that top-down studies tended to be consistently higher in estimated emissions than bottom-up studies, at least when compared using U.S. Greenhouse Gas Inventory methods. As the number of studies has grown, this divergence has been reaffirmed.

A new paper by Alvarez et al., "Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain" published recently in Science, makes the most progress to date in resolving this divergence[2]. Alvarez found that they could reconcile top-down and bottom-up results and that the resulting estimated emissions amount to 2.3% of gross gas production in the U.S., or about 60% higher than current U.S. Environmental Protection Agency (EPA) inventory estimates.

This result of 2.3% total system loss has mixed implications for the climate benefits of fuel switching. First, it is well below levels commonly thought to render natural gas a poor substitute for coal. However, 2.3% loss is much higher than levels that make natural gas a good substitute for gasoline or diesel in the transportation sector.

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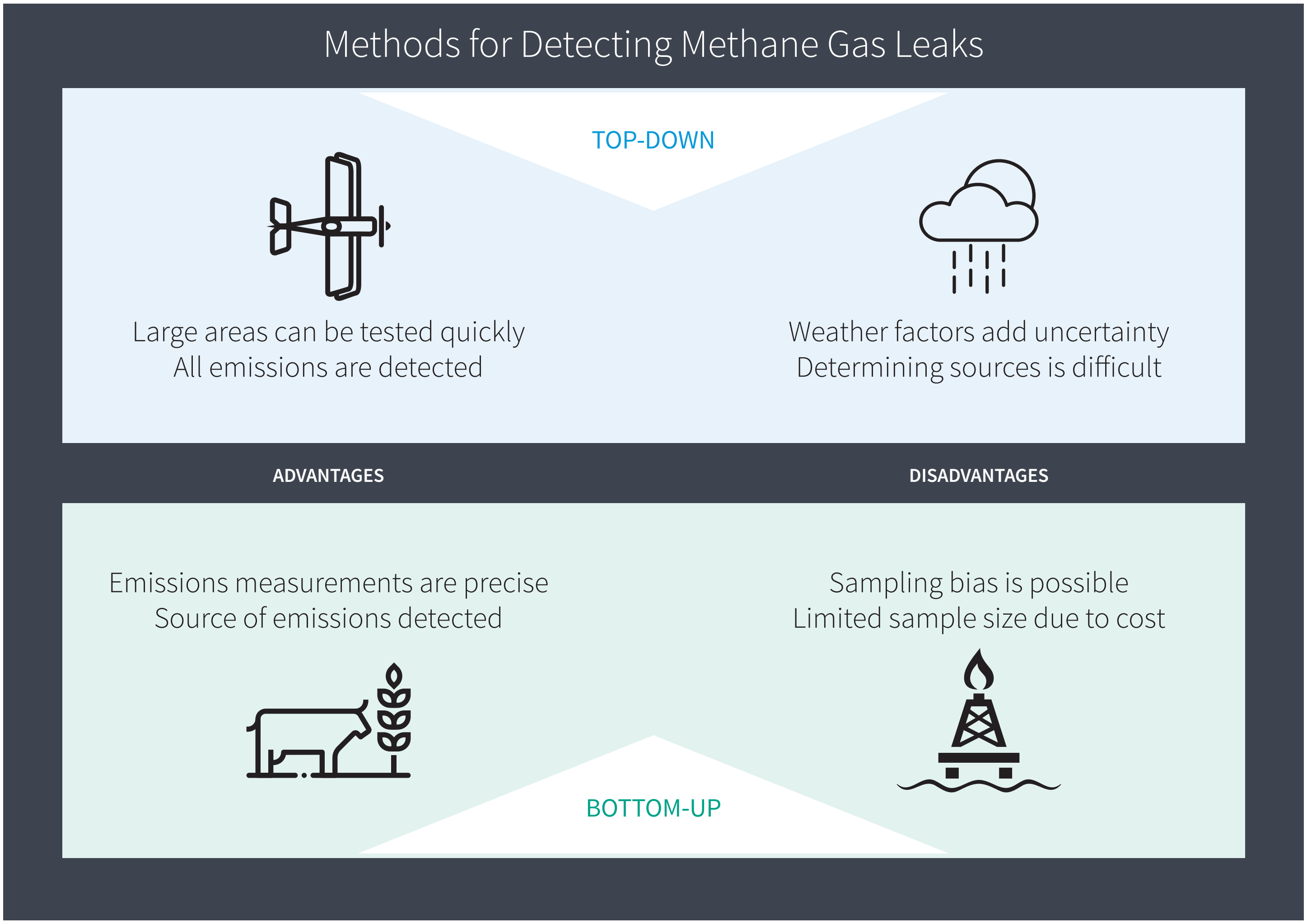
More concretely: A 2012 paper in Proceedings of the National Academy of Sciences[3] noted that to derive benefits from natural gas fuel switching over all time periods, leakage rates must be held to about 1% for diesel vehicle substitution, 1.5% for gasoline vehicle substitution, and 3% for coal substitution. If a longer "break even" period is allowed (i.e., the switch would have benefits over an integrated 20- or 100-year period), then much higher loss rates are acceptable.

While that "headline" result is certainly intriguing and provides support for continuing efforts to reduce greenhouse gas emissions by coal to natural gas fuel switching, from a scientific perspective another key result of the study is even more interesting: Which bottom-up studies you use matters greatly in your ability to accurately re-create the emissions observed in top-down studies. What Alvarez et al. find is that when you sum emissions from a "conventional" component-by-component inventory (i.e., number of leaking valves times the leakage per valve), you tend to find emissions smaller than top-down studies. But, if you instead estimate emissions extrapolated from "facility-scale" bottom-up studies, the bottom-up results line up well with top-down results. In fact, they find that top-down and bottom-up results align across nine different oil and natural gas producing regions, within expected estimation and extrapolation error. ▶

1 Brandt, A.R., G.A. Heath, et al. (2014). Methane Leaks from North American Natural Gas Systems. Science. DOI: 10.1126/science.1247045

2 R.A. Alvarez, D. Zavala-Araiza, et al. (2018). Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain. Science.

3 R.A. Alvarez et al. (2012). Greater focus needed on methane leakage from natural gas infrastructure. Proceedings of the National Academy of Sciences. DOI: 10.1073/pnas.1202407109



Why would these "facility-scale" bottom-up estimates be able to more accurately recreate the remote top-down studies? A few factors come into play. The simplest possible factor is missing sources; for example, component-level surveys have to date neglected tank emissions due to safety and practicality concerns. Another possible cause is that emissions tend to be dominated by so-called super-emitters. A 2017 paper by Brandt et al.[4] found that the largest 5% of methane emissions sources will contribute over 50% of total methane emitted (they deemed this the "5 – 50 rule"). If a survey method performed at the component level misses such large emissions sources, or even undersamples them by a relatively small amount, the computed emissions factors will undercount emissions as a whole when scaled up. A visited site can suddenly become unrepresentative if a problematic valve—representing, say, 25% of site emissions on its own—is repaired before the ▸

4 Brandt, A.R., G.A. Heath, D. Cooley (2016). Methane leaks from natural gas systems follow extreme distributions. Environmental Science & Technology. DOI: 10.1021/acs.est.6b04303

site is visited for measurement. What seems like small differences in equipment can add up significantly in emissions when emissions are so strongly driven by a few problem sources.

A second factor, perhaps even more important than the above, has to do with study design and participation in voluntary studies. Most site-level measurements of methane emissions are performed with operator participation. Active participation by the operator is desirable for a number of very practical reasons: logistics, survey safety, and avoiding interference with operations. This has led to criticism that the results may be biased by companies "fixing up" sites before the field visits begin. Scientists designing field campaigns have taken care to attempt to avoid this bias by, for example, giving operators a list of sites that may be visited, then not providing forewarning about which of the sites will actually be visited on any given day or even in the entire measurement campaign.

However, one persistent source of possible bias is difficult or impossible to remove when performing such site visits: participation bias. On average, one could easily imagine that companies that are willing to host scientists affiliated with the EPA, universities, or the Environmental Defense Fund are somewhat different from companies that are unwilling to host such visits. For example, participating companies may be larger companies with more sophisticated and well-staffed environmental health and safety divisions. If this were the case, even if the companies themselves did absolutely nothing to bias the results at any of their facilities, the study results still might not be representative of the entire industry.

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Such participation bias is challenging to avoid and difficult to detect, and can affect many kinds of study designs across the scientific world. For example, in the world of medicine you might design a study on a new weight loss treatment. If the study design only looked at volunteers, your study may overly select for those who are more motivated than average to lose weight, thus overestimating how effective the treatment will be when applied across a larger group of people. Or, such a study may continue to follow the progress of those who remain in the treatment program, biasing observed results by losing participation unevenly across different groups of people.

In the case of methane emissions, participation bias can only be avoided by sampling natural gas production, processing, and transmissions sites completely randomly with no requirement for participation. For example, if a given shale play contains 1000 well-pads managed by 17 different operators, you may visit 10% of the sites, regardless of which operator runs the facility. In this kind of study design, on-site access is often impossible due to lack of permission or safety clearance to visit a facility. Thus, these study designs are typically performed remotely, in so-called "fence-line" fashion. For example, emissions might be measured by driving by the facility with an instrumented vehicle and estimating the natural gas loss rate using data on winds and gas concentrations across the facility fence.

One can rightly criticize such fence-line studies in a number of ways. For example, fence-line emissions estimates tend to have wider uncertainty ranges than those derived from direct quantification of leaks on site ▸

(i.e., +/- 30% compared to +/- 10% in estimated leakage volume). And fence-line studies make attribution of emissions to sources or causes difficult. However, such studies have a distinct advantage: They trade increased uncertainty in any given measurement for the potential for much lower participation bias in the study as a whole. This is in general a good trade-off, as increasing sample size will help to counteract the noise in any one measurement, which is not the case for a more fundamental and one-sided effect like participation bias.

Thus, by moving scales from truly bottom-up measurements to what might be called "meso-scale" facility measurements, Alvarez et al. help to increase our understanding of methane emissions and for the first time resolved a challenge that has perplexed scientists for years. ▲

THE NATURAL GAS INITIATIVE AT STANFORD

Major advances in natural gas production and growth of natural gas resources and infrastructure globally have fundamentally changed the energy outlook in the United States and much of the world. These changes have impacted U.S. and global energy markets, and influenced decisions about energy systems and the use of natural gas, coal, and other fuels. This natural gas revolution has led to beneficial outcomes, like falling U.S. carbon dioxide emissions as a result of coal to gas fuel switching in electrical generation, opportunities for lower-cost energy, rejuvenated manufacturing, and environmental benefits worldwide, but has also raised concerns about global energy, the world economy, and the environment.

The Natural Gas Initiative (NGI) at Stanford brings together the university's scientists, engineers, and social scientists to advance research, discussion, and understanding of natural gas. The initiative spans from the development of natural gas resources to the ultimate uses of natural gas, and includes focus on the environmental, climate, and social impacts of natural gas use and development, as well as work on energy markets, commercial structures, and policies that influence choices about natural gas.

The objective of the Stanford Natural Gas Initiative is to ensure that natural gas is developed and used in ways that are economically, environmentally, and socially optimal. In the context of Stanford's innovative and entrepreneurial culture, the initiative supports, improves, and extends the university's ongoing efforts related to energy and the environment.

Join NGI

The Stanford Natural Gas Initiative develops relationships with other organizations to ensure that the work of the university's researchers is focused on important problems and has immediate impact. Organizations that are interested in supporting the initiative and cooperating with Stanford University in this area are invited to join the corporate affiliates program of the Natural Gas Initiative or contact us to discuss other ways to become involved. More information about NGI is available at ngi.stanford.edu or by contacting the managing director of the initiative, Bradley Ritts, at ritts@stanford.edu.