NATURAL GAS *brief*

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Methane leakage from oil and gas operations contributes to climate change, even as gas use is increasing around the world and delivering climate benefits by replacing more carbon-intensive fuels, like coal. For the first time, technological innovation and improved awareness have given us tools to eliminate nearly all methane emissions.

Getting to Zero—

Eliminating Methane Emissions from the Oil and Gas Industry

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Natural gas, despite being a fossil fuel, has led to positive environmental outcomes. Cheap natural gas prices in the United States have heralded a shift from coal to gas-based power generation, significantly reducing greenhouse gas and other pollutant emissions from the electricity sector. In developing countries like India, the use of compressed natural gas for transport and cooking has improved indoor air quality and human health outcomes.

Yet, the continued use of natural gas in a climate constrained world is critically dependent on the ability of the industry to collectively reduce methane emissions. Methane is a potent greenhouse gas—a ton of methane emitted today has the same ability to warm the Earth as 80 tons of carbon dioxide in the short term. Indeed, recent studies ▸

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have shown that emitting methane now can contribute to centuries of future sea-level rise.[1] Furthermore, emissions from natural gas production contribute to low-level ozone formation, degrading air quality in gas-producing regions.

The industry cannot credibly claim to be a responsible player in the global sustainability stage if it continues to emit significant quantities of methane through its operations. Even in the United States, with more active denial of climate change, most Americans support government action to address climate change.[2] In this context, methane emissions reductions have practical advantages—they give the operator improved public license to continue operations and a way to monetize the natural gas that would have otherwise been wasted. While this common sense eludes some in the American oil and gas industry, there are encouraging signs. For example, ONE Future, a coalition of natural gas companies that accounts for 25% of U.S. production, has agreed to limit methane emissions across the supply chain to 1% or lower. Yet, much remains to be done.

In this brief, we examine practical limitations to eliminating methane emissions from the oil and gas industry. Technological progress in developing emissions-free process equipment and innovation in leak detection technologies mean that operators can now cost-effectively eliminate nearly all methane emissions, including those that are considered intentional. Natural gas consumption is predicted to rise around the globe, so sustainably developing this resource is in the best interests of all of us.

HOW MUCH METHANE IS THE INDUSTRY EMITTING?

As simple as the question seems, it is one of the most challenging scientific questions to answer. The Environmental Protection Agency (EPA) estimates that the oil and gas industry emitted about 8 million metric tons of methane (~ 200 million metric tons CO_2e) in 2016.[3] This is spread across the entire supply chain from production all the way through distribution pipelines under our homes. That's equivalent in climate impact to the total emissions from 43 million cars for an entire year. However, this top-line number masks significant uncertainty. Here, we discuss three important challenges in accurately accounting for methane emissions.

First, EPA estimates of methane emissions are imperfect. Due to a historical lack of attention and funding, much of the data EPA uses to estimate methane emissions for specific equipment or facilities are either outdated, unavailable, or underestimated. Several recent studies at oil and gas facilities have shown emissions that are significantly higher than EPA estimates.[4] The 2016 U.S. greenhouse gas inventory ▸

1 K. Zichfeld, S. Solomon, and D. Gilford (2017). Centuries of thermal sea-level rise due to anthropogenic emissions of short-lived greenhouse gases. ***Proc. Natl. Acad. Sciences*** **114**, 657.

2 A. Leiserowitz, E. Maibach, C. Roser-Renouf, S. Rosenthal, M. Cutler, and J. Kotcher (2017). Climate change in the American mind: March 2018, Yale University and George Mason University, New Haven, CT: Yale Program on Climate Change Communication.

3 U.S. Environmental Protection Agency (2018). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016, Washington D.C.

4 A.R. Brandt, et al. (2014). Methane leaks from the North American natural gas systems. Science 343, 733. A.R. Brandt, et al. (2014). Methane leaks from the North American natural gas systems. ***Science*** **343**, 733.

and U.S. Energy Information Administration (EIA) production estimates give a leak rate of 1.4% across the natural gas supply chain. However, recent top-down aircraft-based studies of producing regions have shown emissions in the range of 2–10%. While some of this variation can be attributed to the nature of the resource (oil rich vs. gas rich), the root cause of this difference across basins is not entirely clear. Furthermore, top-down measurements (aircraft, satellites, etc.) show emissions that are often higher than estimates from bottom-up data (leak detection surveys, etc.). A few recent studies are beginning to explore the origin for this discrepancy; for example, one recent study[5] in the Marcellus shale in Pennsylvania found that top-down measurements from aircraft preferentially measure one-time events at facilities that occur in the afternoon. Supplementing bottom-up measurements with operator-specific episodic emissions data could help reconcile the differences between these estimates.

Second, every major measurement campaign in the U.S. and Canada has found evidence of super-emitters. A super-emitter is part of a small number of very high-emitting sources at a given facility that are responsible for a majority of the emissions. By analyzing 16 peer-reviewed studies on component-level emissions estimates, we derived the “5–50 rule”: the top 5% of emitters by size contributes to 50% of the total emissions.[6] Combining methane emissions measurements from all available studies, we find that 90% of emissions are from sources emitting more than 61 kg of methane per day; this corresponds to an annual rate of at least 20 tonnes. While some of these super-emitters are known in advance (e.g., large emissions from known operations such as liquids unloading), others are stochastic (e.g., malfunctioning equipment) and intermittent (e.g., pneumatic devices). Eliminating methane emissions cost-effectively means finding and fixing these super-emitters as fast as possible through leak detection and repair programs.

There have been several studies on methane emissions across the natural gas supply chain over the past five years. Our assessment is that total leakage is very likely below 3%, but higher than the EPA’s estimate of 1.4%. Current leakage levels are not high enough to eliminate the climate benefits of natural gas over coal. You can read more about this issue in the August 2018 Natural Gas Brief.

Third, methane emissions vary significantly over space and time. Measurements in the Bakken shale in North Dakota have demonstrated emission ▶

5 S. Schwietzke et al. (2017). Improved mechanistic understanding of natural gas methane emissions from spatially resolved aircraft measurements. ***Environ. Sci. Technol.*** **51**, 7286.

6 A.R. Brandt, G.A. Heath, and D. Cooley (2016). Methane leaks from natural gas systems follow extreme distributions. ***Environ. Sci. Technol.*** **50**, 12512.

rates over 10%,[7] while recent data from the Marcellus shale show emission rates lower than 1%.[8] However, the underlying reasons for this variation are not fully understood. Potential causes include: variable geologic features that require different extraction methods (i.e., reservoir pressure), resource composition (fractions gas, liquids), weather, infrastructure age, regional air quality regulations, and operator management practices. Measurements from one region, in general, cannot be extrapolated to other regions. In addition to spatial variation, methane emissions also vary in time. This arises from components that emit intermittently (e.g., pneumatics), sporadic-time events at the facility that emit large quantities of methane (e.g., liquids unloading and flashing), or maintenance procedures that temporarily increase or decrease emissions.

VENTS VS. LEAKS

Getting to zero emissions means eliminating both unintentional and intentional emissions. Unintentional emissions, or leaks, are emissions that do not occur by design—faulty equipment, operator error, or component wear and tear are all potential reasons. Intentional emissions, or vents, are emissions by design. In addition to leaks and vents, a non-trivial fraction of methane is flared (burnt from a tall stack), especially at remote facilities that lack the infrastructure to collect associated gas; this flaring wastes natural gas and produces carbon dioxide, but is done to prevent direct venting of methane.

Over 40% of methane emissions from the oil and gas industry are intentional emissions or vents—these emissions are present by design and are typically known in advance. These can be large methane releases during sporadic events such as operation of pressure release valves, or liquids unloading where gas dissolved in natural gas liquids under higher pressure is released as it comes to the surface, or one-time emissions such as well completion where methane may be vented to air. Vents can also be intermittent, as typically seen in pneumatic devices that use natural gas as the driving fluid.

THE ROLE OF TECHNOLOGY AND INNOVATION

Innovation in the development of new leak detection technology and platforms will play a critical role in reducing the cost of emissions mitigation. These new technologies range from component-level monitoring systems such as infrared cameras to large-scale, near-continuous systems such as satellite-based detection. Technologies occupy different spatial and temporal regimes as shown in Figure 1, each uniquely suited to various sub-sectors in the natural gas supply chain.

Leak detection technologies and protocols should satisfy three important targets:

1. Rapid detection of super-emitters (“fast screening” mode)
2. Differentiation between a leak and a vent
3. Low cost

Current policy approaches to leak detection and repair programs require the use of ▶

7 A.M. Robertson et al. (2017). Variation in Methane Emission Rates from Well Pads in Four Oil and Gas Basins with Contrasting Production Volumes and Compositions. ***Environ. Sci. Technol.*** **51**, 8832.

8 J. Peischl et al. (2015). Quantifying atmospheric methane emissions from the Haynesville, Fayetteville, and northeastern Marcellus shale gas production regions. ***J. Geophys. Res.: Atmos.*** **120**, 2119.

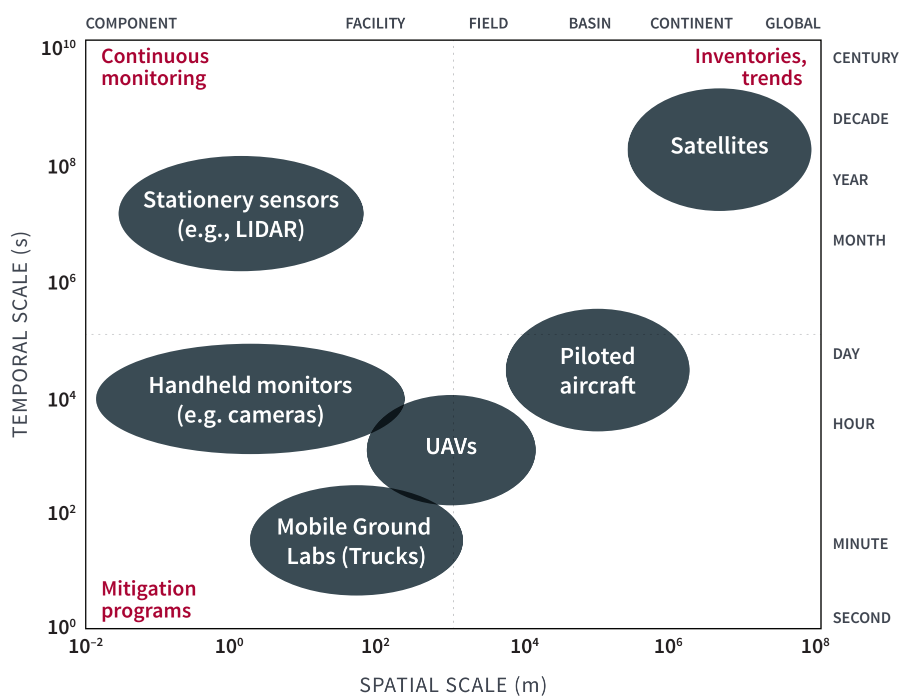
hand-held sensors or optical gas imaging technologies at survey frequencies between one and six times a year.[9] As the number of facilities increases, the cost and logistics of multiple detailed manual leak detection surveys could become prohibitive. Furthermore, the marginal benefits of detailed and frequent surveys have not been scientifically established. More research on this topic is critical to determining the impact of survey frequency on emissions mitigation. Preliminary research by Stanford shows that the number of leaks is greatest during commissioning of a facility, and therefore it would be beneficial to mandate a leak detection survey right after a facility goes into production.

The stochastic nature of super-emitters at natural gas facilities necessitates periodic and frequent leak detection surveys. Such frequent surveys can be made possible only if technologies are low-cost and can screen for super-emitters rapidly. These requirements lend themselves to a hybrid leak detection survey approach—a fast truck- or plane-based system that identifies facilities with anomalous leakage, followed by a more careful component-level survey using a drone or a handheld camera at the selected facilities.

Finally, regulatory agencies should devote resources to develop technology-equivalence metrics so that operators can deploy newer and potentially low-cost options as part of the leak detection and survey process. In this regard, Stanford and the Environmental Defense Fund (EDF) recently organized the Mobile Monitoring Challenge that brought together 11 different mobile technologies promising faster, cheaper, and more robust emissions detection solutions than existing options. Results from this study will be released in summer 2018. ▶

Figure 1

Spatial (x-axis) and temporal (y-axis) space of various methane leak detection technologies and platforms.



9 A.P. Ravikumar, J. Wang, and A.R. Brandt (2016). Are optical gas imaging technologies effective for methane leak detection? *Environ. Sci. Technol.* **51**, 718.

MITIGATION POLICY

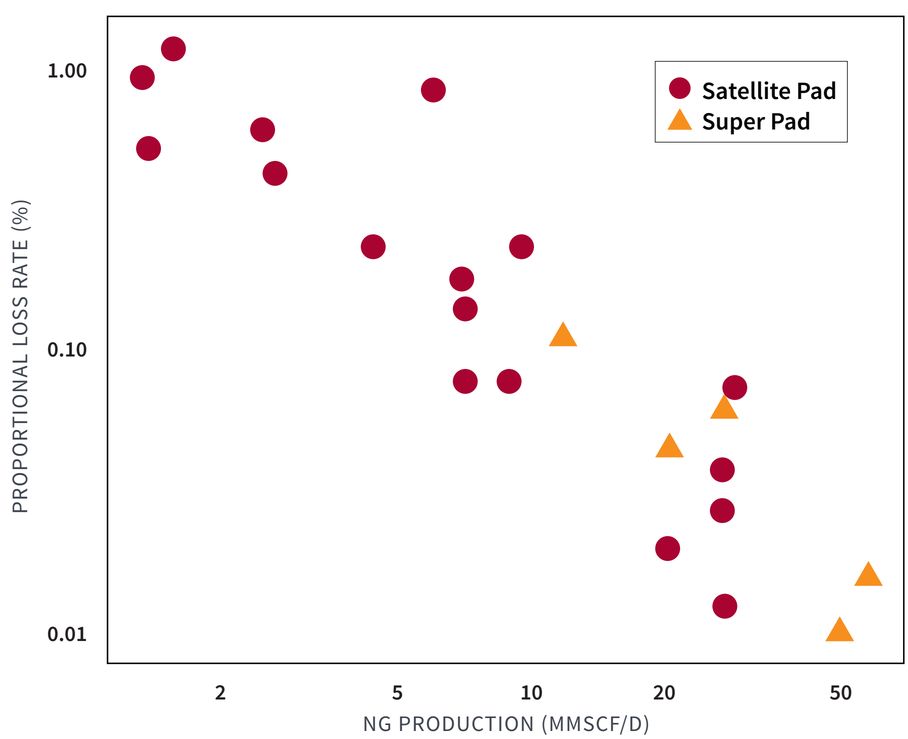
Emissions mitigation policy must proceed on two fronts to be effective—one, leak detection and repair surveys at natural gas facilities to identify and fix unintentional emissions, and two, limits on venting and flaring to reduce intentional emissions. Recent federal regulations in Canada, for example, require tri-annual surveys at processing plants and other large facilities, while specifying annual vent volumes for pneumatic devices.

The issue with most existing methane mitigation regulations is not that they do not have the right framework, but that there are many loopholes. For example, U.S. EPA's 2016 regulations only included facilities that were built (or modified) after 2012—which comprise only a small fraction of all oil and gas facilities.[10] Alberta's proposed regulations do not require tri-annual leak detection and repair surveys at production well-pads, which have been shown to be an important source of emissions.[11] Finally, all regulations specify "acceptable" vent limits, when flaring or converting gas-driven to instrument-air systems or installing vapor-recovery units have become increasingly cost-effective in recent years and can eliminate most vented methane emissions. Closing these policy loopholes would reduce the uncertainty in achieving future mitigation targets.

Prescriptive emissions mitigation policy, or operator best practices, must also incorporate the latest available scientific evidence. For example, we found that there are emissions advantages to aggregating many processes at a single larger site. In a detailed leak detection

Figure 2

Methane emissions (represented as a fraction of production volume) as a function of increasing natural gas production. Pads with > 20 wells and some processing equipment ('Super Pads') emit proportionally less compared to smaller pads ('Satellite pads', <10 wells/pad).



10 A.P. Ravikumar, and A.R. Brandt (2017). Designing better methane mitigation policies: the challenge of distributed small sources in the natural gas sector. *Environ. Res. Lett.* **12**, 044023.

11 Alberta Energy Regulator (2018). Draft Directive 060: Upstream Petroleum Industry Flaring, Incinerating, and Venting

survey in Alberta, Canada, large well-pads (called super-pads) with 20 wells or more and some processing equipment emitted proportionally less than smaller well-pads (called satellite pads) with less than 10 wells/pad (see Figure 2). Tying inproduction from multiple wells to a single large site reduces the geographic spread of equipment and makes maintenance easier. Such operational efficiencies should be targeted for immediate adoption at all facilities.

A commitment to reducing methane emission shouldn't only be about extending the status quo—many of the proposed regulatory requirements are already being implemented by conscientious operators. It involves going beyond a patchwork of mandates and regulatory limits to address the problem comprehensively: What will it take to reduce methane emissions by 80% and beyond?

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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.