Methane Emissions from the Production and Use of Natural Gas

by Robert W. Howarth

An analysis of methane emissions from the production and use of natural gas in the United States.

Methane is a major driver of global warming and climate disruption, and scientists now recognize that human-controlled methane emissions are responsible for 0.5 °C of the warming observed since the 1800s, compared to 0.75 °C for carbon dioxide.[1] Reducing methane emissions is critical and is perhaps the easiest way to slow the rate of global warming.[2] Unfortunately, atmospheric methane has been rising rapidly over the past decade after emissions were steady at the start of the 20th Century.[3] Many studies suggest that much of this rise may have come from increased production of natural gas, and particularly shale gas development in North America.[4]

Before this century, the technologies for developing shale gas did not exist, but since 2005 or so shale gas production has driven dramatically. Today, most natural gas production in the United States is from shale, and shale-gas production has accounted for most of the increase in all-natural gas production globally since 2010.3 I and others published the first analysis of how methane emissions contribute to the greenhouse gas footprint of shale gas in 2011. We used the best available data but noted the urgent need for improved measurements on methane emissions made by independent scientists.[5]

How Large Are Methane Emissions from Natural Gas?

Since our 2011 paper, there has been an explosion of new measurements on methane emissions, primarily in the United States. Table 1 summarizes the data collected from aircraft flyover and satellite studies that estimate emissions at the regional scale, so called "top-down" studies. These include emissions that occur at gas well sites plus those from the processing, storage, and transport of gas in high-pressure pipelines ("upstream and midstream" emissions). As a percentage of the natural gas produced, studies report between 0.2% and 40% released unburned to the atmosphere. Both spatial and temporal variation likely contribute to this rather large range. The median emission rate is 3.7% of the rate of gas production and omitting the two highest satellite-based estimates as possible outliers, the mean weighted by the volume of production in the different gas fields is 2.6%.[4] These values are remarkably similar to what we estimated based on very preliminary data in our original 2011 paper: 3.2%.[5]

Unburned methane is also emitted from the distribution pipeline systems that run under virtually all streets in cities and towns, and even from within buildings. These "downstream" emissions are less studied, but recent top-down measurements in several studies[6-9] shows emissions of between 1.7% and 3.5% of natural gas consumption (see Table 2), in addition to the upstream and midstream emissions shown in Table 1. The emissions for Boston (see Figure 1)[10] are often attributed to the old cast-iron distribution pipelines still in use in much of that city, but of interest, emissions from Indianapolis are also high even though that city has a much more modern distribution system dominated by plastic piping with some steel.[8] The mean for the five downstream urban emission estimates shown in Table 2 is 2.5% of consumption. Note that gas consumption is always less than gas production, both because of the emission losses and due to some use of gas for powering the compressors in pipelines that deliver the gas to market. In the United States, consumption is approximately 12% less than production,[11] so an emission rate of 2.5% of consumption is equivalent to 2.2% of production. Combining 2.2% of production for downstream emissions with the volume-weighted mean value of 2.6% emitted from upstream and midstream sources, overall average methane emissions in the United States are approximately 4.8% of natural gas production.

Climate Effects of Emissions from Natural Gas

Even though carbon dioxide emissions from burning natural gas are less than from burning coal and oil products, unburned methane emissions of 4.8% contribute to an overall greater greenhouse gas footprint for natural gas than for any other fossil fuel when the fuels are burned.[4,12] The details on how the fuels are used matter, so for example natural gas has no immediate climate advantage over coal for generating electricity if methane emissions are greater than 3.2%, or over diesel for powering large trucks if emissions are greater than 1%.[13] When used for heat energy, natural gas with methane emissions of 4.8% are far worse for the climate than either coal or oil for at least the first 20 years after the fuel is burned.[12] Note that while methane is also released from using coal and oil, methane is simply a contaminant of these fuels, while natural gas is composed overwhelmingly of methane. Methane emissions per unit of heat energy are far greater for natural gas than for coal or oil.[12]

Reducing methane emissions is critical and is perhaps the easiest way to slow the rate of global warming.

Across the globe, governments have systematically underestimated methane emissions from the oil and gas industry for decades, on average by at least 1.7-fold according to a recent analysis by the International Energy Agency.[14] In the United States, a large number of independent scientific studies have concluded that the U.S. Environmental Protection Agency (EPA) has severely underestimated these methane emissions.[4,12] Perhaps surprisingly, while the science showing high emissions has grown stronger in recent years, the official estimates from EPA have gone down (see Table 3). These official values show a decrease in total emissions of one third from 2015 to 2019, from 1.48% of production to 0.93%, driven by assumed decreases in upstream and midstream emissions only slightly countered by increased emissions downstream (Table 3). This decrease reflects the emissions estimates that the oil and gas industry report to EPA. These reported emissions are not independently verified, and are clearly too low when compared to objective, verifiable data from the peer-reviewed literature (Table 3). It seems unlikely that the emissions from the gas industry have

Table 1. Top-down estimates for upstream and midstream emissions of methane from natural gas systems, including studies based on aircraft flyovers and satellite data, listed chronologically. Estimates are the percentage of the methane in natural gas that is produced. Reprinted from Howarth (2022).[4]

Aircraft Data		
Peischl et al. (2013)	Los Angeles Basin, CA	17.0%
Karion et al. (2013)	Uintah Shale, UT	9.0%
Caulton et al. (2014)	Marcellus Shale, PA	10.0%
Karion et al. (2015)	Barnett Shale, TX	1.6%
Peischl et al. (2015)	Marcellus Shale, PA	0.2%
Peischl et al. (2016)	Bakken Shale, ND	6.3%
Barkley et al. (2017)	Marcellus Shale, PA	0.4%
Peischl et al. (2018)	Bakken Shale, ND	5.4%
	Eagle Ford Shale, TX	3.2%
	Barnett Shale, TX	1.5%
	Haynesville Shale, LA	1.0%
Ren et al. (2019)	Marcellus Shale, PA & WV	1.1%
Satellite Data		
Schneising et al. (2014)	Eagle Ford Shale, TX	20.0%*
	Bakken Shale, ND	40.0%*
Zhang et al. (2020)	Permian Basin Shale, NM	3.7%
Schneising et al. (2020)	Permian Basin Shale, NM	3.7%
	Appalachia (Marcellus + Utica), PA	1.2%
	Eagle Ford Shale, TX	3.5%
	Bakken Shale, MD	5.2%
	Anadarko Shale, OK	5.8%

*Schneising et al. (2014) reported emissions as percentage of combined production of oil and gas. Here these are converted to percentage of just gas production using data on relative production of oil and gas from Schneising et al. (2020).

Table 2. Downstream emissions of methane found in several studies.[6-9]

Tower Data		
McKain et al. (2015)[6]	Boston, MA	2.7 %
Wunch et al. (2016)[7]	Los Angeles, CA	1.7 %
Lamb et al. (2016)[8]	Indianapolis, IN	3.5 %[a]
Sargent et al. (2021)[9]	Boston, MA	2.5 %
Aircraft Data		
Lamb et al. (2016)[8]	Indianapolis, IN	1.9 %[a]

Notes:

a. Lamb et al. report gas consumption as 28 Gg/month in the summer and 140 Gg/month in the winter, which suggests annual gas consumption of 1,000 Gg/year. They report natural gas emissions from tower data as 34.8 Gg/year, or 3.5% of consumption, and from aircraft flyovers as 17.8 Gg/year, or 1.8% of consumption.

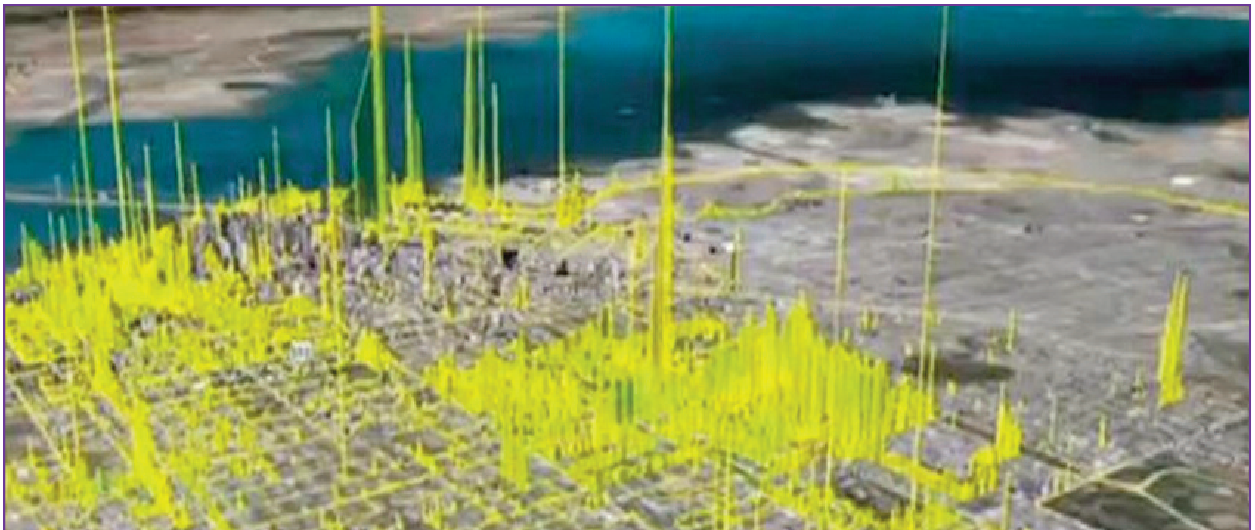

Figure 1. Methane concentrations along city streets in Boston, Massachusetts measured by a special instrument in a car that was driven along the streets by Prof. Nathaniel Phillips of Boston University.[10] The heights of the yellow bars are proportional to the concentrations. Methane leaks are widespread across much of the city.

Table 3. Comparison of estimates for average methane emissions in the United States from the natural gas industry based on the preponderance of top-down studies in the peer-reviewed literature and values assumed by EPA for 2015 and for 2019 (as a percentage of the methane in natural gas that is produced).

	Average from peer-reviewed literature	EPA (2015)	EPA (2019)
Upstream and midstream emissions[a]	2.6%[c]	1.4%[e]	0.79%[g]
Downstream emissions[b]	2.2%[d]	0.08%[f]	0.14%[h]
Total emissions	**4.8%**	**1.48%**	**0.93%**

Notes:

a. Upstream and midstream emissions include those from production, processing, storing, and transmission of gas.

b. Downstream emissions include those from distribution gas pipelines, as well as emissions that occur within buildings from leaks and incomplete combustion.

c. Volume-weighted mean from 18 top-down studies, excluding two other very high estimates from satellites which may be outliers, as presented in Table 1.[4]

d. Mean from 5 studies for U.S. cities presented in Table 2.

e. Based on emissions of 7.64 Tg/year,[15] assuming natural gas production of 28.8 trillion cubic feet for 2015,[16] and assuming gas is 93% methane.[17]

f. Based on emissions of 0.44 Tg/year,[15] assuming natural gas production of 28.8 trillion cubic feet for 2015,[16] and assuming gas is 93% methane.[17]

g. Calculated from the mean estimate for shale and conventional gas of 152 g methane per million BTU reported.[18]

h. Calculated from the value for distribution of 26.8 g methane per million BTU.[18]

actually decreased to any majo extent in recent years.[4] What has changed is a growing awareness by the public and press that methane is dangerous to the climate, and therefore an increasing motivation by industry to downplay their contribution.

Can Methane Emissions from Natural Gas Be Reduced?

Absolutely, although there are limits as how great these reductions can be. Importantly, methane emissions are not simply a result of unintended leaks and accidents: some

Figure 2. Natural gas storage tanks at the Haynseville, Texas, shale fields. Picture on left taken with a normal camera. Picture on right was taken with forward-looking infrared (FLIR) camera tuned to the infrared spectrum of methane, which allows visualization of methane emissions. Photo courtesy of Sharon Wilson. Reprinted from Howarth (2019).[3]

emissions are the result of routine, purposeful release of methane to the atmosphere, for instance to control pressure in tanks and pipelines for safety and for maintenance of pipelines. Methane is a colorless, invisible gas so routine emissions cannot be observed without special equipment, but the use of special forward-looking infrared radar (FLIR) cameras tuned to the infra-red absorption spectrum of methane allows visualization.

Figure 2 compares what the naked eye and a FLIR camera see when looking at a storage tank for natural gas, with the "smoke" seen in the infra-red imagery actually methane vented from the tank. In 2019, *The New York Times* ran a great interactive visual highlighting FLIR imagery of methane emissions from natural gas facilities.[19] For maintenance on pipelines, the methane in the pipeline is generally released to the atmosphere, to reduce the explosion risk when welding the pipeline. This "blow-down" of gas, when it occurs rapidly, causes cooling of the air around the release, which can condense water vapor and make the release highly visible, even though the methane itself remains invisible (see Figure 3).

Particularly important emissions upstream and midstream include those during the initial drilling of gas wells, leaks from the "gathering lines" that connect wells to storage and processing centers, emissions from incomplete combustion of flared gas, release from blow-downs for pipeline maintenance, and emissions from incomplete combustion of natural gas used to power compressors that drive gas through pipelines.[15,20,21] The methane that is released during drilling apparently occurs when drillers encounter old gas wells or coal mines. When drilling in regions with a lot of prior fossil-fuel history, drillers use "under balanced" techniques for safety reasons, and this apparently results in methane releases to the air. There is no known technology for reducing these emissions if wells are to be safely drilling in areas with large numbers of old gas wells or coal mines.[4,20] With regard to flaring, this purposeful burning of released gas is required in many regions, rather than venting unburned methane. However, combustion of methane in the flares is never 100% effective, and flares go out, with the unlit flares then venting completely unburned methane. Enforcement of flaring requirements by federal and state authorities is often poor, and a recent study documents that methane emissions from flares are on average five-fold greater than has previously been estimated by EPA.[21]

Should We Let Distribution Systems Leak Methane?

As noted above, roughly half of the total methane emissions from producing and using natural gas occur downstream. These emissions include leaks from medium and low-pressure pipelines that occur under the streets of most cities and towns, as well as leaks within homes and buildings and incomplete combustion of the gas burned in furnaces, water heaters, and stoves. Gas delivery systems are managed to keep leaks below levels likely to lead to explosions but leaks below this level are expensive to fix and are generally ignored by gas utilities. These leaks could presumably be reduced by replacing the gas distribution system, but this is both expensive and disruptive, requiring widespread ripping up of pavement.

I believe that rather than spending funds to reduce these distribution-pipeline leaks, society should move as quickly as

Figure 3. Blowdown for maintenance of a natural gas pipeline in Yates County, New York. Methane is an invisible gas, but the cooling from the rapid blowdown condenses water vapor, leading to the obvious cloud. Phot courtesy of Jack Ossont. Reprinted from Howarth (2019).[3]

possible away from using natural gas in building and homes. A climate law passed by the State of New York in 2019 requires that all greenhouse gas emissions from all economic sectors in the State be reduced by 40% by 2030 and by at least 85% by 2050.[22] The use of fossil fuels in homes and commercial buildings is the single largest source of greenhouse emissions in New York, and the implementation plan for the state to reach its climate goals calls for reducing the use of natural gas by 25% by 2030, by 50% by 2035, and completely by 2050.[22] Given this, the priority for funding for energy should be on moving away from fossil fuels rather than on rebuilding the gas infrastructure. **em**

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