Mapping, Measuring, and Managing Methane: The Critical Role of a Potent Climate Pollutant

Deborah Gordon and Frances Reuland
Watson Institute for International and Public Affairs, Brown University
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Why Methane?

Earth's temperature is rising to dangerous levels. Cutting greenhouse gas emissions is increasingly urgent. Although carbon dioxide is the major climate pollutant, from the moment it is emitted, a ton of methane is at least 120 times more potent than a ton of carbon dioxide. While methane may not last long in the atmosphere, new research suggests that its potential to warm the planet may be 25 percent greater than previously believed.[1]

Methane's rapid multiplier effect accelerates global warming. To avoid an emissions overshoot that destabilizes the climate past 1.5 degrees Celsius, policymakers, industry, and civil society should focus their attention on short-lived climate pollutants, like methane.

Methane is a stealthy gas—invisible, odorless, minute, and forceful. Monitoring methane to chart its release into the atmosphere is an ongoing challenge. Measurement systems are continually improving to detect and quantify methane using hybrid monitoring approaches that entail top-down satellite systems, bottom-up engineering calculations, and regional (basin-level) detection and reconciliation. Taken together, these methods can create a comprehensive view of methane from various sources.

The petroleum industry is a principal source of methane emissions, as methane is the main component of natural gas. Methane can escape through different routes in the petroleum value chain, wherever oil and gas are extracted, processed, shipped, stored, or combusted. Preventing the leakage of methane can be profitable for petroleum companies who sell non-leaked gas. In fact, an estimated one-half of methane currently escaping from natural gas systems could return a profit, even after considering costs of installing leak prevention measures.

In today's market, crude oil is much more valuable than natural gas. This creates a perverse incentive to maximize oil production over gas. Overcoming these economic barriers will require direct government action, in addition to voluntary industry efforts, to prevent leakage of unwanted methane throughout the petroleum supply chain. Increased transparency and data collection, improved oversight through monitoring, reporting, and verification, regulations and binding agreements, research and development (R&D) and technology transfer, and financial incentives and penalties each has a role to play. In order to offer durable climate solutions, efforts to mitigate methane must be designed to withstand future political pressures.

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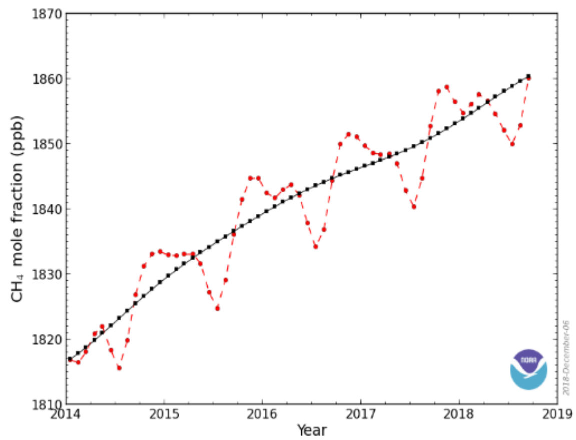
[1] The potency of a greenhouse gas is currently quantified by its Global Warming Potential (GWP) — the "time-integrated radiative forcing in the atmosphere due to a pulse emission of a given component, relative to a pulse emission of an equal mass of carbon dioxide." See Box 2 for more details on methane multipliers compared to CO_2, depending on the timeframe.

Rising Short-lived Climate Pollutant Concerns

Carbon dioxide (CO_2) has historically driven climate policy—and for good reason. This principal greenhouse gas (GHG) is emitted in massive volumes and lingers in the atmosphere, warming the earth for a century or longer. Recent studies show that global fossil fuel energy growth, which accounts for nearly 90 percent of all CO_2 emissions, is outpacing efforts to decarbonize the economy. Redoubled efforts to cut CO_2 emissions are needed.

But reducing CO_2 will not be enough to protect the climate from significant disruption. Short-lived climate pollutants (SLCPs) are accelerating climate change in the near term. Methane is a prime SLCP concern, and its atmospheric concentration is on the rise (Figure 1).

Figure 1. Rising mean concentrations of global monthly mean methane



Source: https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/

Oil and gas companies in the U.S. currently self-report their direct corporate methane emissions, which they submit are at least 15 times greater than their CO_2 emissions.[2] Yet studies find that methane emitted by the petroleum industry is significantly under-reported. These disparities, along with the rapid growth in U.S. shale production over the past decade and the rise in global liquefied natural gas trade, underscore the need to more accurately map, measure, and manage methane.

Global Petroleum Sector's Methane Burden

Methane is emitted from natural sources such as wetlands, rice paddies, and other biogenic causes, but the oil and gas supply chain is the primary manmade emission driver. Methane is the principal ingredient in natural gas and is contained in all petroleum resources in differing amounts. Crude oils vary widely, averaging 38 percent methane content. Light oil and condensates have a methane content ranging from 40 to 80 percent. Oil with associated gas mixed in averages 67 percent methane. Wet gas that contains hydrocarbon liquids averages 60 percent, and dry gas averages 97 percent methane. Knowing the composition of gas as it moves through the system is necessary to estimate the amount of methane emitted in the event of gas released anywhere in the supply chain.

Oil and gas supply 54 percent of primary energy demand worldwide. That is twice as much as coal according to the International Energy Agency. Considering both the industry's direct (Scope 1), indirect (Scope 2), and end users' (Scope 3) methane and CO_2 emissions, petroleum use accounts for one-half of the short-term GHG climate burden (Figure 2).

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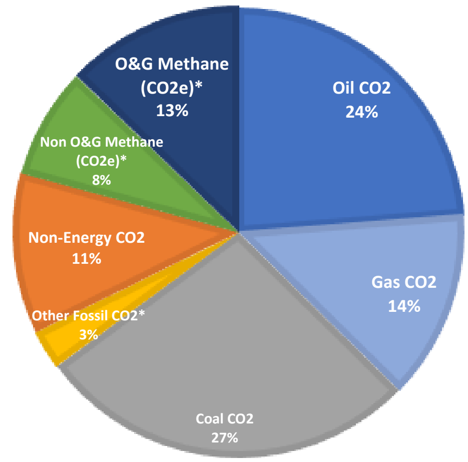
[2] See Table 3.1 for the industry's direct methane to CO_2 emissions from natural gas systems, petroleum systems, and abandoned oil and gas wells. Note that EPA uses Global Warming Potential (GWP) for methane from the Intergovernmental Panel on Climate Change (*IPCC) Fourth Assessment Report,* AR4 (2007). This calculation updates GWPs using the *IPCC Fifth Assessment Report,* AR5 (2014). See Footnote 3.

Tallying 2017 global oil and gas sector methane emissions amounts to short-term climate forcing of seven gigatons CO_2 equivalent (Gt CO_{2eq}).[3] The methane emitted annually from global oil and gas sources is estimated to have at least as much short-term global warming potential as the CO_2 emitted by the entire global transport sector.

All the more concerning, methane emitted from the petroleum sector is a growing problem. According to a team of scientists from NASA's Jet Propulsion Lab, 17 million metric tons (Mt) of the recently observed 25-Mt-per-year increase in methane emissions were due to fossil fuels.

Figure 2. Carbon Dioxide and Methane Emissions for Energy and Non-Energy Sources (2017)



Sources: IEA World Energy Outlook 2018 and Global Carbon Project
Notes: Total 2017 CO_2 and methane budget = 53 Gt; assume 20-year GWP; Other fossil fuel CO_2 from cement production

Powerful Escape Artist

Methane is as tiny as it is forceful. It readily leaks through numerous different routes in production, processing, storage, and transport. With only one carbon and four hydrogen atoms, gaseous methane travels in pressurized vessels and escapes unnoticed from oil and gas equipment. It seeps from old wells long after they are abandoned. Additional methane is even being expelled from beneath the ground as permafrost thaws and from underwater as oceans warm.[4]

The relative ease with which methane escapes unnoticed raises the stakes for tracing its source. Leakages can be unintentional. Releases can be intentional, for example during venting and blow downs when operational controls are bypassed. Methane can also escape as a fugitive gas due to foregone maintenance or improper equipment design. These venting, fugitive, and flaring (VFF) episodes—along with unanticipated accidents—are the main anthropogenic escape routes for methane emissions from the oil and gas supply chain.

Measuring Methane

Methane emissions are generally quantified in one of two ways: "bottom-up" or "top-down" accounting. However, other approaches—such as site-level measurements and regional assessments (sometimes referred to as "basin-level" measurements)—are also being used. No single method is entirely decisive. Multiple scales of measurement are necessary to monitor, report, and verify (MRV) methane (and other) emissions.

[3] IEA, World Energy Outlook 2018, Tables 2.2 and 2.3; Assumes methane GWP of 86 (20 year), according to the IPCC AR5 with climate-carbon cycle feedbacks. The long-term climate forcing of methane from oil and gas sources amounts to 3 Gt CO_{2eq}, using a methane GWP of 34 (100 year) AR5 value.

[4] While fossil fuel emissions are currently the largest source of greenhouse gases to the atmosphere, new sources of methane are expected over the longer term as the gas trapped in permafrost and methane hydrates (gas frozen in oceans) is released as global temperatures rise due to climate change. Current methane emissions from thawing permafrost are estimated at one percent of the global methane budget, according to NASA. By mid- to end-century, the permafrost-carbon feedback could be the second largest anthropogenic source of greenhouse gases. Permafrost-derived methane emissions are not included in climate projections.

Bottom-Up Measurements

Bottom-up methods construct ground-based inventories of emissions by conducting equipment counts, noting equipment specifications, applying standard emission factors, reporting resource characteristics, and projecting operating conditions. Climate policymakers, including the United Nations Framework Convention on Climate Change (UNFCCC), require nations to submit countrywide GHG emission inventories annually under the Kyoto Protocol.

However, data collection and accounting procedures are inconsistent, varying from site to site, person to person, and over time. These multiple scales of measurements that survey individual equipment, one-by-one, can overlook leakages. Operators may not be in the right place at the right time to catch and quantify methane released using a bottom-up approach. Therefore, bottom-up modeling is not the best way to assess real-time methane emissions or accidents. Other approaches are often far better indicators of methane emitted in non-routine situations.

Bottom-up estimates are also plagued by small sample sizes that can overlook steady emission streams and miss super-emitter sites altogether. Super emitters are infrequent sites that have an outsize proportion of emissions relative to their frequency. One study found that, in a given region, five percent of sites contributed over half the leakage volume.[5] In addition to sampling a sufficiently large number of sites when using bottom-up methods, other top-down measurements are needed to ensure these emissions do not go undetected.

Top-Down Measurements

Top-down methods record emissions via tower-based measuring stations, drive-by detection, and fly-over techniques, including satellites, aircraft, and drones. A growing line of past, present, and future remote sensing missions continue to be used to measure and attribute methane emissions. For example, the Tropospheric Monitoring Instrument (TROPOMI), a new monitoring instrument developed jointly by the Dutch and the European Space Agency, began reporting global methane data in 2019.[6] Other examples are listed in Table 1.

Table 1. Tranche of past, present, and future methane-capable satellites

Actor	Asset	Launch Year
NASA Jet Propulsion Lab	Hyperion, EO-1	2000
European Space Agency	SCIAMACHY	2002
NASA Jet Propulsion Lab	TES-Aura	2004
Japanese Government	GOSAT, GOSAT2	2009, 2018
NASA Jet Propulsion Lab	OCO-2, OCO-3	2014, 2019
GHGSat	GHGSat-D Claire	2015
European Space Agency-Copernicus	TROPOMI	2017
Bluefield	Satellite 1	2020
Environmental Defense Fund	MethaneSat	2022
NASA	GeoCARB	2022
Planet Lab/California	TBD	2023

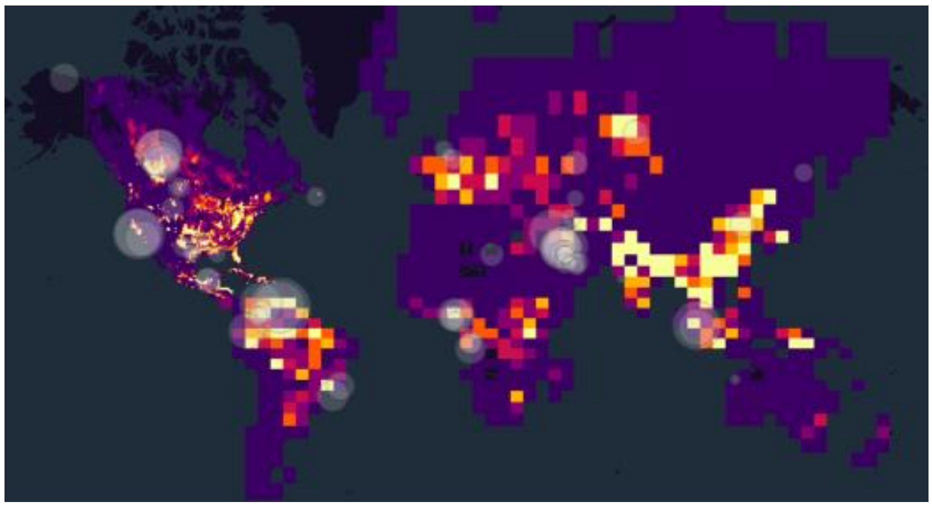
Source: Authors' summary of numerous public and private methane-capable satellites. Note: Updated August 2020.

[5] This phenomenon has been repeatedly identified among studies across U.S. shale plays.

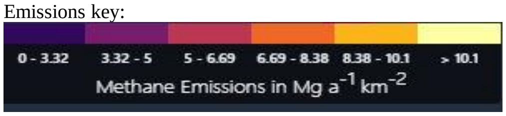
[6] TROPOMI is on board the Copernicus Sentinel-5 Precursor (S5P) satellite, a European Space Agency (ESA) satellite. The S5P was launched in 2017 as part of a series of Sentinels that will measure atmospheric composition over a seven-year mission.

Top-down measurements employ inversion models along with satellite readings to approximate transport-prone, rapidly dispersed ground-level methane sources. U.S. and international agencies, along with their academic partners, are creating global visualizations of methane emissions using both top-down satellite data and bottom-up inventory data. For example, a team of NASA scientists led by Harvard researchers have constructed comprehensive methane data analytics. Using an inversion model and five-year average of measurements from the GOSAT instrument, the Harvard team has produced a map that reveals methane hot spots around the globe (Figure 3).

Figure 3. Map of Global Methane Hotspots



Notes: Circles represent estimated oil and gas field lifecycle GHGs using the OCI+ Preview model under development; Map recolored from its original publication by Maasakkers, et. al.
Emissions key:



Source: Joannes D. Maasakkers et al. 2019, https://www.atmos-chem-phys-discuss.net/acp-2018-1365/

Top-down measurements can successfully capture "fat tail" events that would not otherwise be recorded by bottom-up approaches, therefore revealing significant volumes of methane pumped into the atmosphere. This approach is valuable in detecting operators intentionally bypassing equipment or when equipment fails. Top-down measurements work well when systems are forced to operate under unusual, unplanned conditions releasing more methane than normal.

Other Measurement Methods

Regional estimates, sometimes referred to as "basin-level" measurements, are yet another approach. These too can involve regional or field-level equipment surveys, satellite measurements, ground-based campaigns, or aerial measurements. In the latter, aircraft transects are gathered upwind and downwind of the study region, resulting in flux estimates for the region. New methane observation techniques are constantly evolving. Downwind measurements, such as the EPA's OTM33a, spiral flight assessments over a specific facility, and Differential Absorption Light Detection and Ranging (DIAL), a laser-based method, remotely measure the concentration of a specific gas type, or "species".

Regional methods can utilize basin-wide metadata along with data from processes employed, operator reports, and industry algorithms. Emissions are then modeled using best engineering practices for designing oil and gas systems. This regional perspective offers opportunities to predict where in the system the greatest likelihood of GHGs may arise. Scenarios can also be run to compare the CO_2 and methane impacts of different oil and gas resources side by side. Moreover, this method can be used to estimate methane emissions from future projects before they are approved, built, and started up. (See Box 1).

Box 1: Estimating Field-Level Emissions with the Oil Climate Index

The Oil Climate Index (OCI) is an open-source tool that is used to model lifecycle GHG emissions from global oil and gas resources. The OCI has three underlying, peer-reviewed engineering models—OPGEE (production), PRELIM (refining), and OPEM (product transport and end uses). The tool is equipped to handle smart data inputs to improve its bottom-up estimations.

The International Energy Agency (IEA) used the OCI in its 2018 World Energy Outlook to estimate methane emissions from global oil resource production and refining. The IEA developed analytics to estimate methane from gas resources and these emission factors have been incorporated into the Oil Climate Index + Gas (OCI+), a model currently under development. The results show that methane emissions vary considerably from one oil and gas resource to another (Figures 4a and 4b).

Figure 4a. Share of Methane Emissions from Global Oil Systems

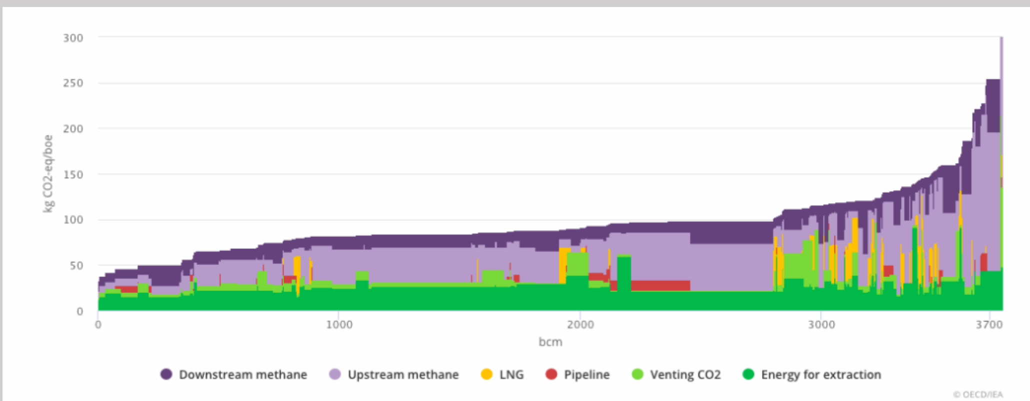
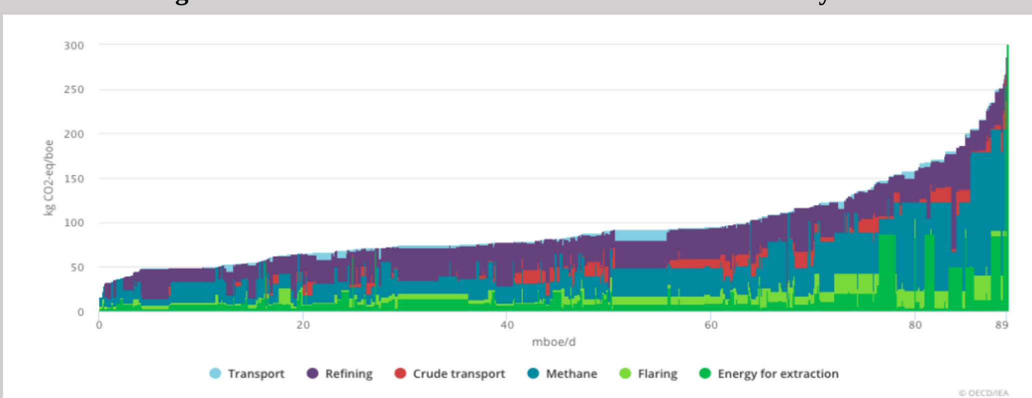


Figure 4b. Share of Methane Emissions from Global Gas Systems



Source: International Energy Agency, 2018 World Energy Outlook, Chapter 11, pp. 487 and 489.

While governments, NGOs, and companies continue to improve their methods to measure and monitor methane, difficulties remain. These include: quantifying actual amounts leaked, annualizing intermittent sources, deciphering methane over water due to poor surface reflectivity, attributing methane emissions to responsible parties, identifying intermittent venting practices, and countering incentives for industry to game MRV detection. A range of actors continue to pursue new technologies and improve accounting methods to more effectively manage methane, as discussed below.

Ounce of Prevention, Pound of Cure

Policymakers who have long focused on mitigating carbon dioxide emissions are now endeavoring to manage methane. What started in 2016 with President Obama's efforts to "plug leaky equipment" have since been rolled back by the Trump Administration. Despite the U.S.'s backtracking, states and other countries are stepping up. California, for example, adopted legislation to conduct research on methane hot spots and develop a tiered observation system. New Mexico is developing a regulatory framework to prevent methane waste from new and existing oil and gas sources. And Mexico published ambitious regulations in 2018 to curb methane.

The Climate & Clean Air Coalition (CCAC) is calling on governments to double down on their Paris Climate Commitments by reducing absolute oil and gas methane emissions by 45 percent by 2025 and 60 to 75 percent by 2030. At the 2019 UN Climate Summit, countries committing to these targets joined the Global Alliance, an effort supported by international organizations, NGOs, and industry leaders. Other global methane efforts include the Global Methane Initiative, a multilateral public-private partnership that aims to reduce methane emissions across sectors in partner countries. Related efforts by corporations and countries have also been underway to reduce flaring methane, including the World Bank's "Zero Routine Flaring by 2030" initiative. Since unwanted gas that is not flared is potentially vented, it is important to track flaring, which is reported to be on the rise.

The Global Alliance's call to action complements other coalition efforts that target the methane problem from multiple dimensions. For example, the United Nations Economic Commission of Europe is working to develop a set of norms for methane management. CCAC is collaborating with the Environmental Defense Fund (EDF) and the Oil and Gas Climate Initiative (OGCI) on a series of scientific studies to measure methane from the petroleum sector.[7] CCAC, through its Oil and Gas Methane Partnership, is focused on upstream oil and gas methane emissions and has released guiding documents with methodologies to quantify and mitigate emissions for key methane sources. And at least eleven companies have signed onto CCAC's Methane Guiding Principles to reduce methane emissions by advancing strong performance across gas value chains, improving accuracy of methane emissions data, advocating sound policies and regulations on methane emissions, and increasing corporate transparency.

In 2019, several major petroleum companies announced their support for "impactful" methane programs, federal methane standards on new U.S. oil and gas wells, and annual inspections at sites to demonstrate methane controls. BP, Shell, and Exxon (under the OGCI and individually) set emission intensity or absolute reduction targets on methane emissions and flaring. Notably, BP

[7] The OGCI companies are BP, CNPC, Eni, Pemex, Reliance Industries Limited, Repsol, Saudi Aramco, Shell, Statoil, and Total.

recently stated its commitment to deploy continuous methane monitoring at future oil and gas processing projects.

Continuously increasing cooperation from industry and non-industry groups is essential to reduce methane emissions. Still, it is important to keep in mind most global efforts remain voluntary. As more countries, companies and industry associations sign onto these initiatives, it will be important to convert these commitments into actual reduction pledges that can be quantified and independently verified with tangible incentives or repercussions.

What is more, industry support at this juncture remains limited. Current company commitments focus on U.S. onshore production and overlook major methane sources in the U.S. and around the world, including other onshore facilities, offshore production, storage, shipping sources, refineries, petrochemical facilities, LNG terminals, and transport infrastructure such as pipelines. With gas, condensate, and light oil production, processing, and long-distance trade on the rise worldwide, a more comprehensive approach throughout the oil and gas value chain is crucial for durably reducing methane emissions.

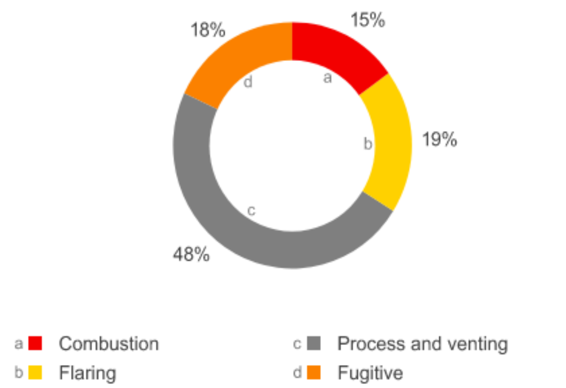
Additionally, current methane inventories remain unreliable. The EPA's methane measurements are projected using general emission factors from oil field equipment rather than actual field-level measurements. Despite the IPCC's issuance of good practice guidelines for inventorying, recent scientific studies show that ground-based inventories may underestimate methane emissions by as much as 60 percent. When substantial emissions are "missing" from inventories, this distorts the problem and ups the ante on tactical reporting and mitigating climate change.

In Search of Missing Methane

When oil and gas systems are designed, the overriding goals should be to gather gas and carefully contain it for three possible outcomes: for sale in the market, for reinjection back into the formation where extracted, or for on-site power and heat if cleaner renewable sources are not available.

At a systems level, the release of methane through venting, fugitives, and flaring (VFF) can be lumped together. However, VFF problems differ by intent, frequency, volume, and source. When it comes to reducing emissions from the petroleum sector, methane sources require disaggregation, as illustrated in Figure 5, and tailored solutions to detect and fix.

Figure 5. Reporting Methane Emissions by Source (Shell, 2018)



Source: Shell Sustainability Report 2018, https://reports.shell.com/sustainability-report/2018/sustainable-energy-future/managing-greenhouse-gas-emissions/methane-emissions.html

Lessons can be learned from existing efforts to estimate methane emissions. The more consistently and granularly reported, the better. Overall averages do not provide sufficient specificity. And when different bases are used, it can be difficult to reconcile findings.

EPA assumes a leakage rate of 1.4 percent per unit gas produced. EDF and academics report an estimated 2.3 percent leakage rate on the same basis. Averaged globally, IEA estimates that 1.7 percent of the gas produced is lost to the atmosphere before it reaches the consumer. IEA also disaggregates methane emission intensities for various U.S. oil and gas systems. These estimates range from 0.2 to 0.7 percent (for oil) and 0.6 to 1.5 percent (for gas), depending on where emissions reside (onshore vs. offshore) and the resource type (conventional vs. unconventional). U.S. methane leakage rates can then be scaled using country multipliers that range from 0.8 to 7.4 for other global locations.

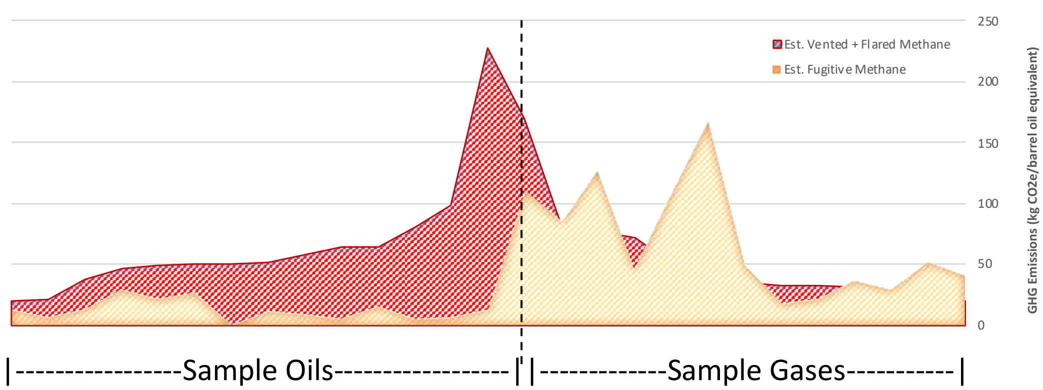
What are the correct assumptions for the methane leakage rate? The jury is still out. But a significant amount of research is underway to answer these questions.

In April 2015, scientists at the National Oceanic and Atmospheric Administration performed fly-overs of U.S. oil and gas producing regions. Data were recorded calculating per-hour emission rates. Remote sensing research is continuing as part of NASA's Carbon Monitoring Systems program.

Methane math can be tricky. Numerators need to measure methane and not all gases released. Denominators must be on the same basis in order to add up emission rates. Recorded emission rates cannot be simply annualized. Methane releases and their durations can vary markedly from place to place, season to season, and over time. Temporal and seasonal measurements are needed to construct more accurate methane inventories. Top-down measurements may not capture minute sources from routine operating procedures, while bottom-up measurements can miss non-routine operations, such as venting and accidents. Direct comparison of estimates from widely different timescales can be misleading. This points to a larger need to be realistic about how to balance different methane measurement techniques to quantify and control venting, fugitive, and flaring emissions.

A smart VFF mitigation system benefits from knowing where to look. The next phase of the OCI model (Box 1) is under development—the OCI + Gas (OCI+)—estimates that oil operations are at greater risk for venting and flaring, while gas operations pose a greater risk of fugitive emissions (Figure 6). The ability to focus detection and controls on those who bear significant responsibilities holds out the highest prospects for meaningful methane reductions worldwide.

Figure 6. Sources of Venting and Flaring versus Fugitive Methane



Source: Oil Climate Index + Gas (OCI+) Preview Web Tool, Accessed September 13, 2019
Notes: Calculated based on 20-year GWP (86 multiplier for methane compared to CO_2)

Preventing Venting

Emissions of methane can result from the purposeful venting of gas. By nature, vented emissions tend to be episodic, but they can also be voluminous and recurrent. This makes it difficult to simply annualize venting sources, which include storage tank vents, gas dehydrators, depressurizing equipment before maintenance and wells after hydraulic fracturing, liquid unloading, and misuse of flares.[8,9] Pneumatic valves, by design, also vent small quantities of natural gas during routine operations.

The decision to vent gas can be triggered by operational constraints, safety considerations, or economic circumstances. When oil and gas systems are improperly designed or unusual situations occur, gas may need to be bled out. Venting can also occur when operations optimize liquid production and operators are willing to forego gas gathering in order to recoup greater economic returns.

Some oil companies include data on venting practices in their corporate climate reports (see Shell, for example, in Figure 5). The push for increased emissions transparency is growing. Investors are calling on petroleum majors to report regular inventories of their emissions and to set targets that align corporate practices with goals set in the Paris Climate Agreement. But efforts to prevent venting must focus not only on international petroleum companies that face mounting public pressure to take action, but also on independent operators and national oil companies (NOCs). NOCs hold the lion's share of oil and gas production. And independent producers, albethey smaller in size, account for over half of oil production and 85 percent of gas production in the U.S. While methane sits squarely the purview of these operators, public accounting is sparse. Sector-wide reporting solutions need to be considered.

It will be important, however, that methane policy solutions not encourage companies to "game" the system. For example, relying solely on monitoring from satellite flyover could allow companies to evade detection by strategically timing their venting operations.

One potential solution is a zero-tolerance initiative for venting, similar to the World Bank's Zero Flaring Initiative that helps remove technical and regulatory barriers to flaring reduction, conducts research, disseminates best practices, and develops country-specific flaring reduction programs. While it remains to be seen whether or not the initiative to eliminate routine flaring by 2030 is successful[10], extending this effort or replicating it to cover venting could prove fruitful given that the same international and national oil companies, governments, and institutions are collaborating on flaring reduction. Additionally, the fact that flare mismanagement and maintenance problems result in excess methane leakage provides another justification to incorporate venting into the World Bank's initiative.

Another option is to impose high fines for venting when it is detected. The combination of a high fine plus a verifiable accounting system may work best. Similar to the U.S. Oil Spill Liability Trust fund established in 1990, a methane liability trust fund could impose a small fee

8 Environmental Protection Agency, "Replacing Glycol Dehydrators with Desiccant Dehydrators," June 29, 2004, https://slideplayer.com/slide/8281927/

9 Environmental Defense Fund, "Methane Leakage from Natural Gas Operations," n.d., https://www.edf.org/sites/default/files/methaneLeakageFactsheet0612.pdf

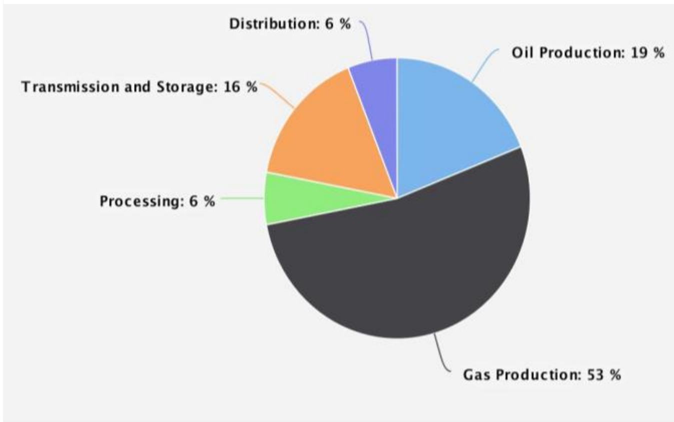
10 Despite efforts to monitor flaring using the VIIRS satellite to curtail this wasteful practice, in 2018, global gas flaring was up 3 percent to 145 bcm with the U.S., Russia, Iraq, and Iran accounting for the greatest natural gas volumes going up in smoke.

on oil and gas operators to conduct routine methane MRV and to identify and collect fines from those who discharge methane. The system could operate with a warning upon first detection; low fine on second detection; and high fines on repeat offenders. Whatever organization is selected as the arbiter of imposing fines for venting, it is important that it be thoroughly independent of industry to maintain legitimacy.

Reducing Fugitives

Fugitive emissions comprise gas or vapor that unintentionally leaks from any source. Methane is released along all segments of the oil and gas supply chain, as shown in Figure 7, through various components such as valves, flanges, and connectors. Current U.S. inventories assign three-quarters of fugitive methane emissions to gas and oil production. Common oil and gas fugitive methane emission sources include: gathering and boosting stations (37 percent) and pneumatic controllers (31 percent). Offshore platforms, chemical injection pumps, tanks, completions and workovers, and liquids uploading make up the rest.

Figure 7: Methane Emissions, by Supply Chain Segment



Source: U.S. EPA, 2016 Methane Emissions by Segment, from Inventory of U.S. Greenhouse Gas Emissions and Sinks

In many ways, fugitive methane emission detection is simpler and more fruitful than tracking methane venting. When a petroleum company repairs one leaky area, another may spring up elsewhere in the system. Therefore, it is more reasonable to assume a constant and relatively low fugitive rate, especially in gas systems, where methane is the principal commodity. Bottom-up emission inventories are more likely to be accurate, and top-down measurements are more likely to pick up on continuous fugitive emissions, especially when they are large. The Oil Climate Index + Gas (OCI+), which models fugitive emissions through its underlying Oil Production Greenhouse Gas Emissions Estimator (OPGEE) model that is based on thousands of data points, is likely the best available estimator for U.S. fugitives.

Unlike venting, which is a matter of economic optimization, fugitives concern equipment and operating procedure optimization. When it comes to better equipment design, producers could look to refineries and petrochemical plants. Increased risk of fires in refineries and gas plants calls for tighter gas leakage specifications for their operating equipment. Here, even small fugitive methane emissions are not tolerated. Redesigning equipment and tightening operational standards at the wellhead in line with refinery specifications could help minimize upstream fugitive methane emissions.

A reasonable regulatory environment also has a role to play in mitigating fugitive emissions. As the American Petroleum Institute pressures President Trump to follow through with his rollbacks of Obama-era methane leakage regulations and monitoring, oil majors like Exxon and Shell are publicly opposing efforts to relax or abolish methane mitigation mandates for strategies like leak detection and repair and pneumatic device standards. Just how seriously individual companies are pursuing methane mitigation measures remains to be seen, however. Nevertheless, corporate support for initial regulations sends a strong message that rules on methane are essential to keep industry practices in line with climate responsibility.

Operating Safely and Avoiding Accidents

Safe operations require frequent maintenance and equipment upgrading. Because methane is highly flammable, its leakage can result in fires and explosions.

Flares are a prime example. They are used to burn off combustible gases when a production site lacks the capacity to capture or use the gas. Flaring is both harmful and wasteful, but the process can also be dangerous. If flares are not carefully maintained, unburned methane and other hazardous gases (such as formaldehyde) can escape through incomplete combustion.

Operators should aim to capture or reuse all of a field's associated gas. There are several available technologies that avoid the need for flaring by reinjecting associated gas underground. While burning excess gas by flare will remain part of a facility's safety regime, investing and deploying highly efficient flares is also essential.

While flaring contributes CO_2 emissions, from a climate perspective (if efficiently operated and accurately reported), it is preferred to the direct venting of methane and other volatile organic compounds. From a recent study over the Bakken region, incomplete combustion may contribute nearly one-fifth of total field methane and ethane emissions. Methane detection is needed to pick up on inefficient flares, or worse, increased venting in the face of tightened flaring practices, especially offshore where methane releases can quickly disperse.

Detection strategies are also needed to identify equipment that is no longer working correctly. In the case of liquids storage tanks, methane and other vapors rise, increasing the tank's pressure. In order to avoid explosions, tanks and other closed systems are equipped with pressure relief devices that automatically open a valve and release the gas into the atmosphere. If tanks, for example, are not sized properly, or processing equipment is not removing enough gas prior to storage, they can continuously vent methane when the pressure sensor keeps the valve open. Therefore, replacing old or outmoded equipment is critical for methane management.

Even in a best-case scenario—near-zero venting, attentive fugitive monitoring, and efficient flaring—emissions will occur through misfortunes. Notable is the case of Aliso Canyon, California, where in 2015, a groundwater-corroded gas pipe ruptured and spewed about 100,000 metric tons of methane in what became the largest methane leak in U.S. history. A broad range of hazardous air pollutants were co-emitted with the methane, including mercaptans, hydrogen sulfide, and miscellaneous oil residues.

Notwithstanding later analyses that revealed preemptive measures that may have lessened the accident's scale, future accidents are not altogether avoidable. Emissions from these types of events need to be included in national and global methane climate inventories, even if they are unavoidable mistakes.

Among other important takeaways from the event is continued advancement in the ability to identify methane emissions from space, especially from accidents. In the case of Aliso, NASA's Hyperion instrument onboard an orbiting spacecraft detected methane leaking from the underground storage facility. Likewise, SCIAMACHY satellite detected a large, enduring methane hot spot in New Mexico from 2002 to 2012. Such detections were breakthroughs for aerial scientific monitoring of methane, and there are signs that monitoring capabilities will progress. Most recently, the new Dutch TROPOMI instrument was able to spot leakage from a gas well blowout in Ohio in early 2018, and in tandem with a tracer transport simulation, quantify the emission rate and total methane release from the accident. These occurrences enhance the argument for tight on-site monitoring and real-time satellite reporting.

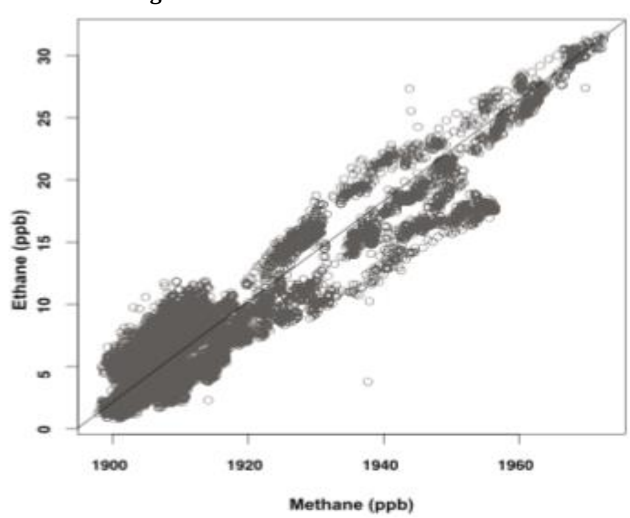
Overcoming Methane Hurdles

Attributing Methane Sources

Attributing methane to the responsible operator and aggregating emissions among sectors is challenging. Some regions are home to several methane-emitting sectors—for example, cattle ranching and oil production, or gas production near wetlands. This can confound the emissions attributed to oil and gas. With the exception of a few studies, which attribute methane by sector-specific methane isotopes, attribution has mostly been done based on sector attribution ratios from ground-based inventories, which, for reasons mentioned above, are less than ideal.

Experts are hopeful that a possible solution lies in ethane, another short-lived GHG that is co-emitted in oil and gas production but not in other sectors (Figure 8). Alarmed by a recent uptick in ethane emissions, researchers found that the increase could be pinned to oil and gas production, especially production in the U.S. Other studies examine how ethane is uniquely associated with methane from the petroleum sector and may be used as a tracer to distinguish petroleum-responsible methane from, say, agricultural sources. As scientific understanding grows, ethane gas may be critical in assigning responsibility to methane from oil and gas.

Figure 8. Methane and ethane co-emission



Source: http://dels.nas.edu/resources/static-assets/basc/miscellaneous/ch4-6-1/4-gordon.pdf

Measuring Methane Offshore

Offshore oil and gas production present another obstacle to monitoring methane. In 2015, offshore operations represented 30 percent of all production. This proportion is expected to increase with expansion in areas like the Gulf of Mexico, the Persian Gulf, the North Sea, and Brazil. The rise of liquefied natural gas (LNG) production and global transport also increases the risk of methane releases taking place offshore worldwide.

The IEA World Energy Model estimates methane emission intensity from offshore venting and fugitives to be about half of its onshore counterpart. However, monitoring and verifying offshore emissions is a big challenge. Methane-measuring instruments on the best-available global satellites rely on light reflecting off earth’s surface. Observing and detecting methane over water is difficult since the ocean absorbs sunlight. Low-flying, highly resolved instruments will be required to verify emissions from offshore production. This could prove challenging in certain regions where public air access is limited.

Glint observations may be a work around. Some satellites are equipped with an additional functionality, glint mode, which points sensors to the bright spots over oceans where solar radiation is directly reflected off the water's surface. This technique, however, is not yet up to par with measurement capabilities over land.

Scaling Satellites

There are tradeoffs between global and localized methane monitoring. Researchers who examine emissions on a global scale are limited by quality of satellite data, spatial resolution, and time to accessing data. Methane emissions data from the European Space Agency's Tropospheric Monitoring Instrument (TROPOMI) satellite came online in 2019. Once fully validated, TROPOMI data will have the best global coverage at a high spatial resolution (7 by 7 kilometers) available to date.[11] Researchers expect that the enhanced satellite imagery will inform more accurate global emissions and an updated methane map.

Other researchers take a more localized approach and reconcile top-down with bottom-up estimations. They pair aircraft flyovers and bottom-up measurements at specific oil production sites. One benefit of this approach is improved source attribution. This type of monitoring also allows for the policing of specific fields or production regions. However, time and resource constraints limit the ability to locally examine (or self-report) all areas of production. Conflict, political tensions, and other reasons may prevent these methods from being deployed in some regions that contribute most heavily to emissions. Given the global nature of the methane problem, the ability to look big picture is a must.

Real-Time Observations

TROPOMI and previous satellites to date have required a lengthy period of reconciliation and validation before methane data is released. However, any future scenario that best abates methane venting, fugitives, and accidents will rest on real-time data. The Environmental Defense Fund (EDF), through the use of intelligent machines, expects to significantly reduce latency and allow for faster production of methane imagery from its MethaneSat satellite that is slated to launch in 2022.

In the meantime, there are other barriers to confront in addition to long turn-around time for satellite data—one being costs of data access. Some of the best high-resolution methane data available today, particularly those collected through private-led efforts, live behind steep paywalls. Several actors who are capable of and motivated towards reducing methane emissions, including some state governments, face financial limitations to acquiring best-available methane data that could be used to leverage current knowledge for the greatest social benefit.

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[11] Monitoring satellite instruments are designed for different scales of measurement. Some higher-resolution instruments such as GHGSat (<50m) target point source detection at the facility level. Researchers expect TROPOMI data to improve the global coverage and monitor large point sources and regional trends, as compared to the previous GOSAT record.

Moving Forward on Methane

The IPCC [1.5 degree report](#) warns of imminent consequences of continued atmospheric warming. This presses near-term action to limit the rise in global average temperature to below 2 ^{o}C.

Using Short-term Global Warming Potentials

It is critical that industries, governments, and policymakers reflect this urgency by considering methane's impact in the relative short term, when the IPCC's adverse warming scenarios could play out. Today's inventories use a 100-year timeframe; this global warming potential (GWP) is inappropriate for SLCPs. A wholesale revision will be necessary to base inventories, mitigation efforts, and policy decisions on updated calculations that use methane's short-term (20-year or similar) GWP with climate-carbon cycle feedbacks (CCF).

The calculated contributions of CO_2 equivalent emissions by component, sector, and country vary significantly with the GWP timeframe selected. Many national and corporate GHG inventories use outdated GWP values and base calculations only on a 100-year timeframe. In fact, guidelines from the United Nations Framework Convention on Climate Change still mandate the use of GWP values from the IPCC's Fourth Assessment Report (AR4), from 2007. The AR4 100-year GWP_{100} value for methane is 25, but the IPCC's fifth and most recent Assessment Report (AR5) from 2014 reports methane's 20-year GWP_{20} with CCF to be 86. And as soon as methane is emitted, its GWP is estimated as high as 120, as discussed in Box 2.

Box 2: Using a 20-Year Versus 100-year GWP

The IPCC defines the Global Warming Potential (GWP) as the "time-integrated radiative forcing in the atmosphere due to a pulse emission of a given component, relative to a pulse emission of an equal mass of carbon dioxide." A direct interpretation is that the GWP is an index of the total energy added to the climate system by the source in question, relative to what carbon dioxide adds. The GWP has become the default metric for transferring emissions of different gases to a common scale, known as "CO_2 equivalent emissions." The GWP is usually integrated over 20-, 100-, or 500-year timeframes.

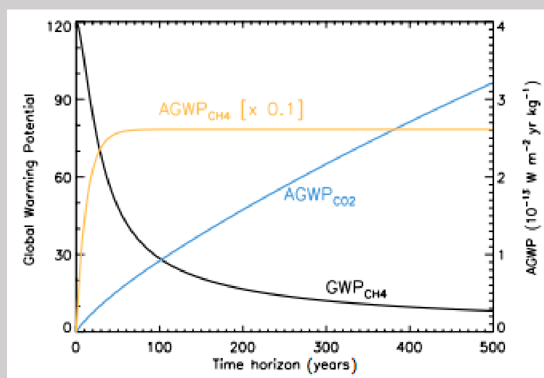


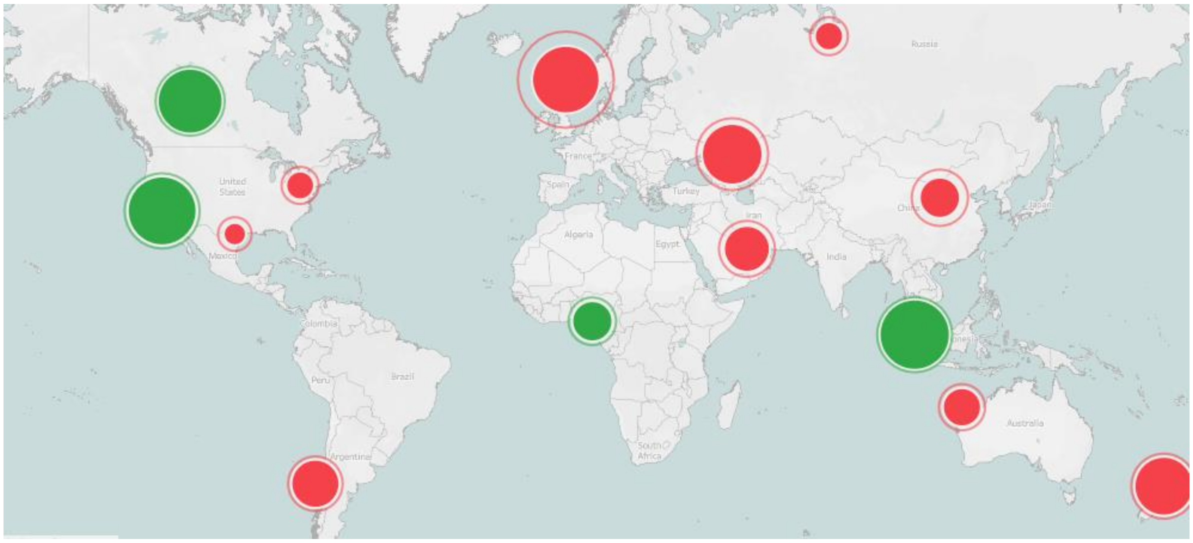
Figure 8.29 | Development of AGWP-CO_2, AGWP-CH_4 and GWP-CH_4 with time horizon. The yellow and blue curves show how the AGWPs changes with increasing time horizon. Because of the integrative nature the AGWP for CH_4 (yellow curve) reaches a constant level after about five decades. The AGWP for CO_2 continues to increase for centuries. Thus the ratio which is the GWP (black curve) falls with increasing time horizon.

The GWP of 100 years was adopted as a metric to implement the multi-gas approach embedded in the United Nations Framework Convention on Climate Change (UNFCCC) and was made operational in the 1997 Kyoto Protocol. There is no scientific argument for selecting 100 years compared with other choices. The choice of time horizon has a strong effect on the GWP values, as plotted above.

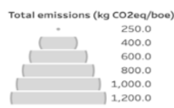
Source: IPCC, *Anthropogenic and Natural Radiative Forcing*.

An analysis using the OCI_+ model under development to assess methane emissions demonstrates the significance of using the 20- versus 100-year GWPs in estimating industry-responsible emissions from oil and gas production and refining. As shown in Figure 9, all emission footprints for global petroleum resources increase in the 20-year term compared to 100-year, and some bubbles swell to nearly twice in size.

Figure 9. Effect of 20- versus 100-year Global Warming Potentials on Petroleum Sector Emissions



Source: Authors' analysis using OCI+, Preview Web Tool, Accessed September 13, 2019
Key for total oil and gas GHG footprints:



Notes: Oil and gas resources are represented by green and red bubbles, respectively. Inner circles represent 100-year GWOs and outer circles represent 20-yar GWPs.

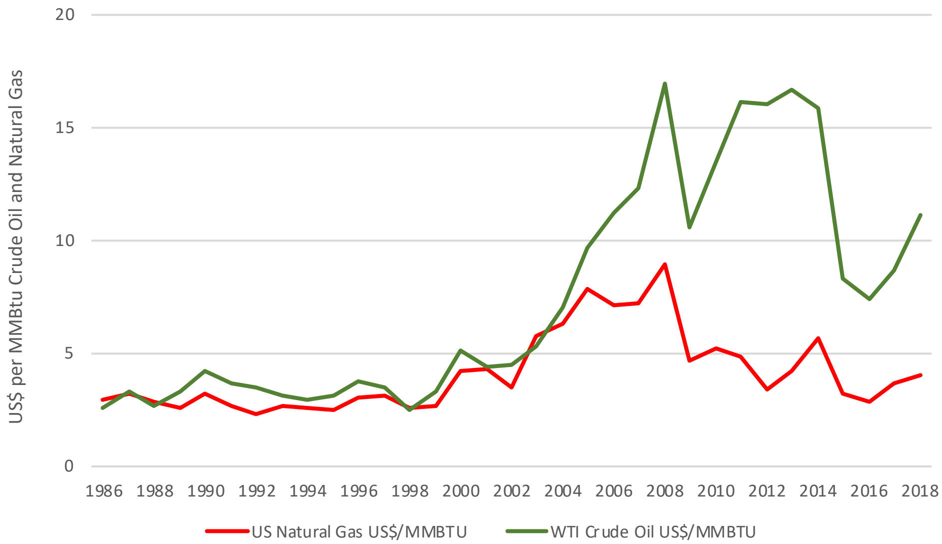
Scientific understanding of methane's role in global warming is not static. A 2016 study shows that methane's radiative forcing could be 25 percent higher than the IPCC's most recent value. The IPCC's Sixth Assessment is due out in 2021/2022 and is expected to be updated with this new knowledge. This year, a refinement to the IPCC's *2006 Guidelines for National Greenhouse Gas Inventories* was released. Development work will continue in creating methodologies to calculate emissions from SLCPs beyond methane—tropospheric ozone, particulate matter, and additional hydrofluorocarbons.

Addressing Market Hurdles

The marketplace presents barriers for effectively managing methane. Oil is much more valuable than gas (especially in the U.S., where fracking has taken off to extract light oil with high levels of associated gas). As such, it can be economically rational for a petroleum company to dispose of unwanted natural gas in the pursuit of maximizing oil production and profits.

Prior to 2000, crude oil and natural gas prices hovered around parity (1:1), when compared based on their heating values. However, in recent years, crude oil captured up to five times more market value than the equivalent energy unit of natural gas (Figure 10). This recent economic inequality favors oil production over gas production under most circumstances. When coupled with inadequate gas infrastructure, undue pressures can set up to mismanage methane and release gas into the atmosphere instead of marketing it.

Figure 10. U.S. Oil versus Gas Prices, 1986 to Present



Sources: U.S. Energy Information Administration, Accessed September 9, 2019, https://www.eia.gov/dnav/ng/hist/n9130us3a.htm and https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RWTC&f=A
Note: Assumes that 1 Mcf gas = 1.036 MMBtu; 0.17 barrels crude = 1 MMBtu.

Analysts are touting the economic benefits associated with preventing methane leakage. For example, the IEA estimates that it is possible to reduce current oil and gas methane emissions by some 50 percent at **no net cost**, offering a financial profits for companies that do so. Furthermore, by maximizing technical ability, up to three-fourths of current emissions could be avoided. Regardless of potential gains from selling gas, operators may still choose to flare or vent their gas due to overriding economic pressures that favor oil.

Implementing Effective Mitigation Policies

In addition to market impediments, the regulatory environment for methane may also be suboptimal, delaying rapid deployment of promising methane-reducing technologies. The technology approval system is disjointed, opaque, and slow. Pathways for technology approval differ state-by-state, and in some cases, the process can extend over a year. These barriers discourage entrepreneurs from bringing new technologies to market.

Durable policymaking is essential to correct such market asymmetries by encouraging innovative management practices, new infrastructure, equipment replacement, and better technologies. Policies could include: increased data collection combined with enhanced transparency; improved oversight through MRV; regulations and binding agreements; R&D and technology transfer to spur innovation; and market mechanisms, financial incentives, and penalties.

Improved MRV is underway. For example, EDF's new methane satellite promises to monitor fifty major petroleum producing regions, accounting for over 80 percent of global production. And an array of government and private satellites are in various stages of deployment (see Table 1). New measurement methods, digitization techniques, and other strategies are also under development around the world to further enhance transparency and boost corporate reporting.

For example, some companies are beginning to deploy internet-connected lasers that can detect methane to warn remote operators. Still more methane R&D is underway. The national laboratories have identified 76 innovative technologies that involve a range of options—equipment, operating procedures, and cooperative actions—which can be applied to reduce venting and flaring emissions.

Beyond monitoring and technology deployment, government rules on methane need to be revisited. Just a handful of jurisdictions worldwide have methane rules in place. And in the U.S., previously adopted methane controls are being relaxed. It will be important for policymakers in other nations to learn from past issues and to avoid fits and starts to durably manage methane.

Some are calling for a shift from prescriptive to outcomes-based rules that would allow companies to adopt innovative technologies that equivalently lower emissions. As long as these rules do not create loopholes, an outcomes-based system paired with faster approval processes for alternative technologies could provide greater flexibility in problem solving and encourage innovation. However, each company's outcomes are different because resource portfolios and operations can vary significantly.

Important questions remain about how best to incentivize better methane management and technology uptake in order to overcome market barriers. One promising idea revolves around pricing methane emissions. Efforts underway to price carbon (carbon taxes or fees) have been slow to gain traction around the globe. Pricing methane could be a first step. Methane emissions are smaller in volume yet more immediately impactful than carbon dioxide. A small subset of sectors is implicated by methane pricing, centering on oil and gas, ranching, and waste management. Yet other creative market mechanisms to manage methane could entail establishing a certification program for low-methane oil and gas operations.

In sum, effective policymaking that encourages innovation while also slashing methane emissions might have the following elements: (1) a digitized global data set of methane measurements; (2) market mechanisms that reward low methane emissions or penalize high emissions; (3) companies voluntarily tailor to their operations to tightly manage methane in line with IPCC GHG reduction targets; (4) companies that fail to reduce methane are subject to prescriptive MRV measures; (5) companies that do not demonstrate measured progress towards meeting goals are subject to stringent regulations.

The Necessity of Ambitious Industry Emission Reductions

Natural climate solutions, such as forestry projects, are critical to preserve and grow sinks for carbon dioxide. However, climate-forest feedbacks are still not well understood. Scientists recently showed that some trees release methane, undermining their methane-removal capacity. Several oil majors include forestation in their emissions equation. So, while forest conservation should be encouraged, it is no substitute for prompt, ambitious goals for methane mitigation backed by corporate action.

Moreover, global dialogue is broadening from climate mitigation to climate engineering (or geoengineering). Already, efforts are underway to apply engineering techniques to remove carbon dioxide on a planetary scale or mask warming underway. Climate engineering conversations are shifting to include techniques and technologies to cut methane levels in the atmosphere. While such interventions will become a necessary next step if catastrophic consequences from warming increase, we must continue to spur action for emission reductions that are driving climate change in the first place.

Looking Beyond Global Impacts

Reducing methane leakage will not only significantly slow global warming, it will also benefit the local environment. Natural gas comprises a hazardous brew of benzene, hexane and other alkanes, hydrogen sulfide, oil residues, and more, which pollutes the air and water and threatens public health. A recent Colorado School of Public Health study found that people who live within 500 feet of a natural gas well in the state are eight times more likely to develop cancer.

On top of pressing climate change concerns and local health impacts, methane leakage raises public safety considerations. Methane is flammable and thus poses a hazard as experienced in the 2010 Deepwater Horizon spill from the blow out of BP's Macondo platform offshore in the Gulf of Mexico, an event that killed 11 workers and severely damaged the region's ecosystem and economy. More recently, explosions of pipelines and well pads in Ohio caused fires and forced evacuations of residents. In 2019, leaking gas killed 64 and seriously injured nearly 100 people in a Chinese petrochemical facility in Jiangsu Province. And evidence is mounting that oil and gas drilling and extraction can cause earthquakes that damages buildings, stresses residents, and devastates communities. The list of methane's hazards goes on.

Clearly, both global and local welfare call for more effective methane management. This simplest of organic compounds that is classified technically as non-toxic and is not considered a criteria or hazardous air pollutant has been historically overlooked and under-controlled by industry, environmentalists, and policymakers. Methane is a pressing concern in need of heightened attention. Its fast and powerful climate forcing abilities, along with the potential to create dangerous warming feedback loops, underscore the importance of effective methane mitigation.

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