Center on Global Energy Policy

METHANE EMISSION CONTROLS: REDESIGNING EPA REGULATIONS FOR GREATER EFFICACY

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1. Introduction

Natural gas holds a critical role in the US energy economy, providing 32 percent of primary energy evenly distributed among electric power generation, industrial use, and residential and commercial consumption (LLNL 2020). As countries set targets to minimize climate change, however, widespread reliance on fossil fuels, with their attendant greenhouse gas emissions, is being scrutinized. Methane, the main constituent of natural gas, is second only to carbon dioxide in its contribution to greenhouse gas warming (Kleinberg 2020). It holds the potential to be a primary driver of global average temperature change between now and 2050—no matter what progress is made in controlling increases of atmospheric carbon dioxide over the next thirty years (Shindell et al. 2012).

Half of global methane emissions come from natural sources, such as swamps and seeps, and half from anthropogenic sources, such as agriculture and fossil fuels. Regulations curbing methane emissions from the oil and gas industry are essential to mitigating global climate change over the next three decades. In the United States, current regulations were devised at a time when the technology for the measurement of natural gas emissions was relatively immature. Comprehensive performance-based regulations were not an option, and because of this, many regulations put in place were highly prescriptive. Data show these regulations have been largely ineffective.

This commentary examines the potential to reduce emissions of methane from oil and natural gas infrastructure. It begins with a brief history of natural gas regulations and the effectiveness of rulemaking, before exploring unregulated and underregulated sources of methane. This is followed by a discussion about improvements in measurement capabilities and how regulations could be used to more effectively address methane emissions.

This work shows the complexities of oil and gas production do not lend themselves to prescriptive regulation. Performance-based regulation, including quantitative compliance monitoring, would engage the talents of thousands of engineers, encouraging them to solve problems using locally appropriate solutions rather than relying on a prescriptive checklist approach that cannot anticipate every eventuality.

The key to performance-based regulation is accurate measurement, and this capability has improved rapidly in recent years. Aircraft-based, facility-scale measurements encompassing tens of thousands of facilities spread over tens of thousands of square kilometers are economically viable and increasingly common. Permanently installed continuously monitoring sensors show promise in detecting intermittent sources; oil field pilot studies are underway. However, aircraft- and ground-based facility-scale measurements are not compliant with the current regulatory regime, which focuses on individual components. Therefore, the current regulatory regime must be completely rethought. (A comprehensive exposition of this topic, with evidentiary support, has been submitted to the Environmental Protection Agency [Kleinberg 2021b].)

2. Regulatory History

In the United States, regulation of gas processing plants under the Clean Air Act dates from 1985 (40 CFR 60 Subpart KKK). More comprehensive regulation of air pollutants from upstream and midstream crude oil and natural gas segments, including emissions of volatile organic compounds (VOC) (40 USC 51.100(s)) from production, processing, transmission, and storage operations, were regulated in 2012 with the New Source Performance Standards (NSPS) (40 CFR 60 Subpart OOOO). Because VOC and methane are often emitted together, methane reduction was notionally a co-benefit of this regulation. In 2016, the regulatory regime was expanded to explicitly include greenhouse gases and methane, in particular (40 CFR 60 Subpart OOOOa). Subparts OOOO and OOOOa imposed similar, though not identical, limits on natural gas emissions (Kentucky, 2016).

On August 13, 2020, the Environmental Protection Agency (EPA), now under a different administration, promulgated its final rules amending the 2012 and 2016 NSPS (EPA 2020). Policy amendments deregulated methane emissions in the production and processing segments and deregulated both methane and volatile organic compound emissions in the transmission and storage segments. On June 20, 2021, the new president signed Senate Joint Resolution 14, repealing these provisions (Public Law 117-23).

3. Rulemaking and Its Effectiveness

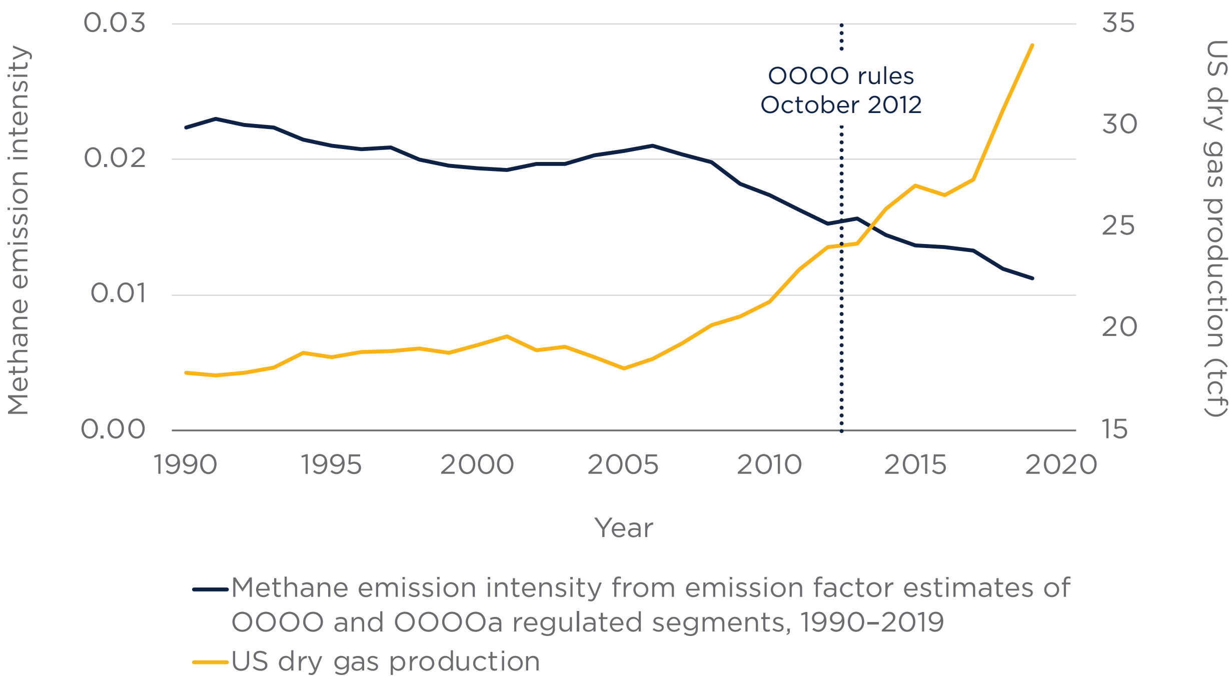
Each year since 1997, the Environmental Protection Agency has published the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHGI) (EPA 2021b). The inventory is based on emission factors, which are engineering estimates calculated from the populations and gas-loss rates of each component or assembly type found in oil and natural gas infrastructure. This is an accounting exercise that does not require measurements of actual equipment operating in the field. Emission factors for methane were first compiled in a fifteen-volume series of studies—a monumental effort—describing what were thought to be the most important sources of emissions in the oil and natural gas industry (EPA 1996). Emission factors continue to be refined and are the product of considerable, serious, ongoing effort (see, e.g., EPA 2021a).

The emission-factor method was a logical approach to a problem about which there was very little *a priori* knowledge. Prior to the formulation of the 2012 EPA regulations on pollutant emissions into the atmosphere from upstream and midstream oil and gas infrastructure, emissions measurements were rare. The EPA itself has approved only two methods for natural gas leak detection, neither of which are quantitative (40 CFR 60 Appendix A-7 Method 21; 73 Fed. Reg. 78199-78219).

The effectiveness of OOOO and OOOOa regulations are assessed using EPA data issued in conjunction with the Inventory of *U.S. Greenhouse Gas Emissions and Sinks* (GHGI) (EPA 2021b; EPA 2021c). These data, which are submitted to the Secretariat of the United Nations Framework Convention on Climate Change, are estimates of greenhouse gas emissions from 1990 to sixteen months prior to the date of issuance. The report uses emission-factor methodology, the estimates from which are known to be considerably in error but which constitute a meticulously curated data set that is consistent over the long term and is the only way to track emission trends over decades.

The methane emission intensity shown in Figure 1 is the annual methane emissions from US upstream and midstream crude oil and natural gas activities, divided by annual US dry gas production (EPA 2021b; EPA 2021c; EIA 2021). The emission intensity decreased by a factor of two between 2006 and 2019. This period coincided with a rapid increase of dry gas production due to the introduction of massive hydraulic fracturing.

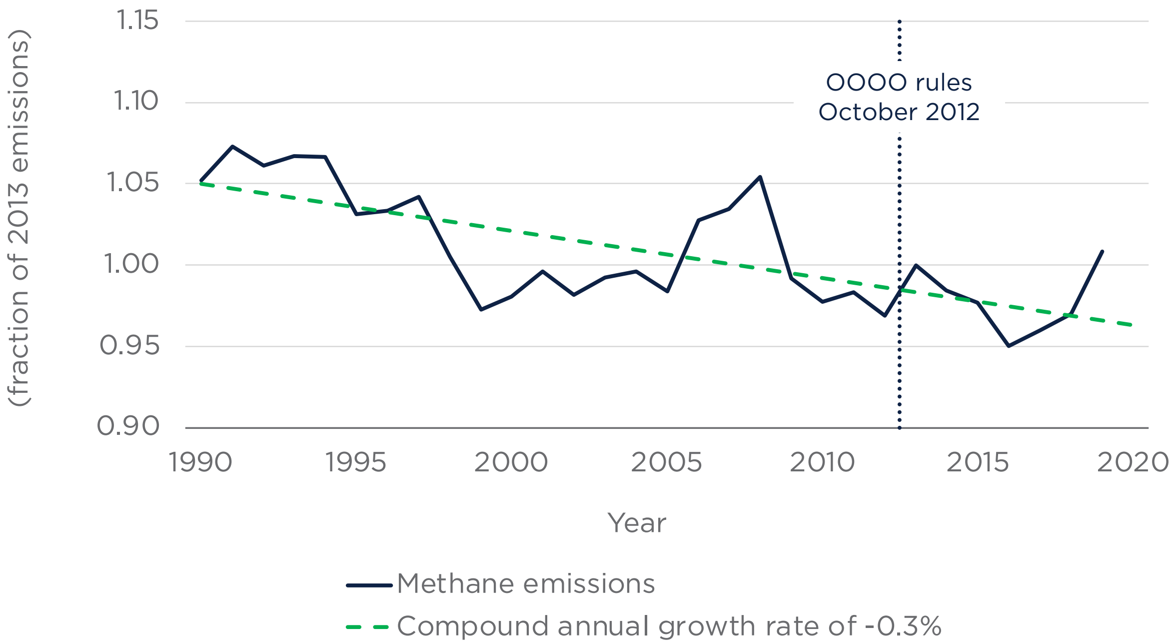
Figure 1: Methane emission intensity and US dry gas production



Source: EPA 2021c, EIA 2021.

Figure 2 is a more detailed view of the same data and shows methane emissions normalized to emissions in 2013. The data look noisy due to the small range of the vertical scale. Emissions changed little over the years following the promulgation of OOOO rules meant to control VOC emissions, with methane emission control as a co-benefit.

Figure 2: Methane emissions normalized to emissions in 2013



Source: EPA 2021c.

Figures 1 and 2 can be interpreted optimistically or pessimistically in relation to efforts to reduce greenhouse gas emissions. Optimistically, methane emission intensity has declined steeply since 2005: emissions have remained relatively constant as gas and oil production increased rapidly. Pessimistically, natural gas emission control efforts started in October 2012 have had no perceptible effect on this trend. In 2016, the Obama administration pledged to reduce methane emissions from the oil and gas sector by 40 to 45 percent by 2025 (White House 2016), representing a compound annual decline rate of roughly 6 percent. However, methane emissions have changed little over the years following the promulgation of the OOOO rules, consistent with a long-term compound annual decline rate of about 0.3 percent. Clearly, the 2016 goal will not be achieved if present trends persist.

It should be noted that the 2012 regulations only applied to "new sources," meaning those for which construction, modification, or reconstruction commenced after August 23, 2011. The 2016 regulations only applied to sources for which construction, modification, or reconstruction commenced after September 18, 2015. Therefore, the effects of regulation might have been muted by a relatively slow turnover of oil field equipment. To understand the effect of this limitation, the EPA under the Obama administration initiated an information collection request. The request was withdrawn in March 2017 by the Trump administration, with then–EPA Administrator Pruitt stating the agency was assessing the need for the information (82 Fed. Reg. 12817). Consequently, the EPA lacks data that could help it understand why methane emissions are not decreasing faster.

4. Unregulated and Underregulated Sources

The EPA tracks about 250 distinct sources of methane emissions in petroleum and natural gas production, transmission, and distribution systems (EPA 2021c). Of these, only some are subject to regulatory controls prescribed by the NSPS. In past rulemaking, the EPA aimed to regulate the most significant sources identified by 1990s-era studies (EPA 1996), while minimizing the burdens placed on generally accepted oil field practices. In the intervening decades, methane-emission measurements in the field have become much more accurate and widespread and the environmental costs of accepted practices have become evident. Sources that had been overlooked or inadequately assessed are now regarded as inadequately regulated for environmental protection. This section presents a selection of problems inherent in the current regulations. A more complete survey can be found elsewhere (Kleinberg 2021a).

4.1 Older Facilities

The New Source Performance Standards promulgated in 2016 applied to a limited list of crude oil and natural gas facilities for which construction, modification, or reconstruction commenced after September 18, 2015. Once it promulgated the revised NSPS in 2016, the EPA was legally required to extend regulation of methane emissions to facilities constructed prior to September 2015 (Clean Air Act Section 111(d); 42 USC 7411(d)). However, it failed to do so before the Trump administration took office and deregulated methane in the oil and gas industry, temporarily blocking the possibility of regulating methane emissions from older facilities (Agri and Kleinberg 2021). Reregulation of methane emissions on June 30, 2021, by Public Law 117-23 restored the mandate to supervise older facilities.

The contribution of older production and processing facilities to total methane emissions is a matter of controversy, which the EPA reports at length in the Federal Register (85 Fed. Reg. 57063-57065). Gas well production declines with age, suggesting that methane emissions from wells and associated facilities decline too. This is only partially true, as shown in Table 1, which presents the results of a 2019 aerial survey of 32,500 wells in the New Mexico sector of the Permian Basin, the most important oil and gas producing province in the United States. Sites less than six years old and sites six to ten years old displayed a comparable incidence of high-volume leaks. Older sites showed a lower but hardly insignificant incidence of large leaks. Moreover, there are a large number of older sites, so emissions from this category are significant. It is not known how many of these sites were modified or reconstructed since September 2015 and are, therefore, regulated as new sources.

Table 1: Incidence of high leak rates at facilities in various age ranges

Age of well sites	0–5 years	6–10 years	>10 years
Detected emitters > 20kg CH_4/h	63	56	78
Wells surveyed (approx.)	5,200	4,400	22,900

Source: Kairos Aerospace data 2019.

4.2 Low Production Facilities

The 2016 New Source Performance Standards specified that all new facilities were subject to regulation (81 Fed. Reg. 35856). The 2020 NSPS Technical Amendments, which were not changed by Public Law 117-23, withdrew regulation of fugitive emissions from well sites—defined as a collection of individual wells and related facilities (40 CFR 60.5410a(k); 40 CFR 60.5430a)—producing less than 15 barrels of oil equivalent (BOE) per day (85 Fed. Reg. 57400). This production rate is equivalent to 90,000 standard cubic feet of natural gas per day.

Fugitive and vented emissions from a component or assembly can depend on the quantity of gas it handles, the length of time it is in service, the number of operations it performs, or a combination of these factors (Heydarzadeh et al. 2020). Therefore, low reported gas production is not necessarily correlated with negligible methane emissions (Brantley et al. 2014). One study found that methane intensity (emission rate divided by gas production) of new high-producing wells was much smaller than for old low-producing wells (Omara et al. 2016). The causes were plausibly hypothesized as due to inadequate maintenance of old equipment and emission sources whose emissions were independent of gas throughput.

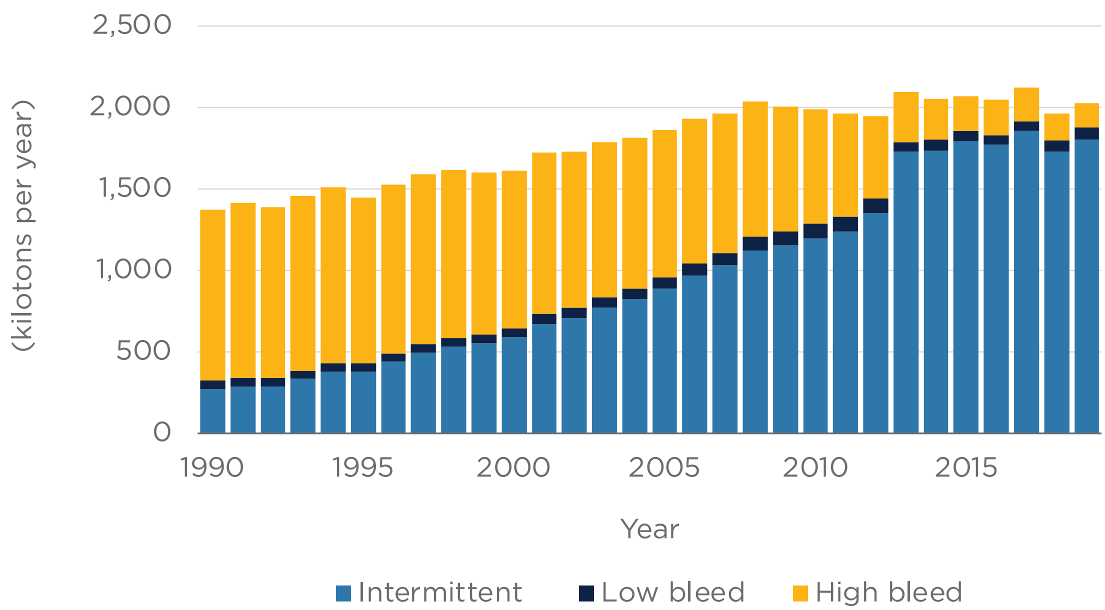
Another study found that while 85 percent of sites produce less than 100,000 standard cubic feet of natural gas per day (equivalent to 17 BOE per day), they account for only 9.6 percent of natural gas production but 63 percent of methane emissions (Omara et al. 2018). Equally important, 23 percent of well site methane emissions come from readily detectable (greater than 7.2 kilogram per hour) sources at these low production sites.

4.3 Pneumatic Controllers

The oil and gas industry relies on automated controls to ensure the safety and efficiency of its operations by maintaining tank pressures or liquid levels within design limits. However, each year more than two million tons of methane are lost to the atmosphere from pneumatic controllers. This amounts to a quarter of all emissions from petroleum and natural gas systems as estimated by the EPA. In remote locations electric power may not be available, so valves and similar devices are actuated by a readily available source of energy: the pressure of produced gas, which is primarily methane and volatile organic compounds. A pneumatic controller will vent ("bleed") gas continuously or only when the valve is opened or closed, i.e., intermittently (EPA 2006a).

The prescriptive rules of the NSPS restrict pneumatic valves of facilities built or modified after October 15, 2013, to bleed rates less than 6 standard cubic feet per hour. Generally speaking, high-bleed valves have been replaced by intermittent-bleed pneumatic valves. Although the average intermittent-bleed controller emits less gas than the average high-bleed controller, it emits more than the average low-bleed controller by a factor of ten (EPA 2021c). As a result, this poorly designed regulation has produced no net improvement in environmental performance, see Figure 3.

Figure 3: Methane emissions from pneumatic controllers in the oil and natural gas sector



Source: EPA 2021c.

4.4 Tanks

The primary sources of natural gas emissions from tanks are not leaking components, which are inspected per regulation and require repairs, but in unregulated pressure relief valves operating intermittently (normally and abnormally) and unregulated open inspection hatches (Lyon et al. 2016; Rutherford et al. 2021). Some two million tons of methane are lost to the atmosphere each year in the United States from tanks. Vapor recovery units can be used to collect the gas for injection into the reservoir, a sales line, or a flare (EPA 2006b; EPA 2009), but in practice, vapor recovery units are only practical at larger facilities.

4.5 Malfunctioning and Unlit Flares

The EPA estimates oil field flares combust waste gas with an efficiency of 98 percent (EPA Undated); this means 2 percent of the gas—much of it methane—sent to the flare escapes uncombusted to the atmosphere. But aerial surveys in North Dakota have found weighted average efficiencies to be lower than the EPA estimates (Gvakharia et al. 2017), implying they are emitting significantly more natural gas into the atmosphere (Kleinberg 2019).

Methane emissions from Permian Basin flares alone amount to more than 300,000 tons per year, according to Environmental Defense Fund measurements, almost four times greater than the EPA estimate (see Table 2).

Table 2: Methane emissions from flaring in the Permian Basin, 2020

	Methane emissions (metric tons per year)			
Flare status	**Functioning**	**Malfunctioning**	**Unlit**	**Total**
EDF estimate	75,000	30,000	200,000	305,000
EPA estimate	80,000			80,000

Source: EDF 2021.

Excess emissions are due to unlit and malfunctioning flares, comprising 4.6 percent and 10.3 percent, respectively, of flares in use (EDF 2021). About 10 to 20 percent of total methane emissions in the Permian Basin are due to malfunctioning and unlit flares (Duren et al. 2020), and unlit oil field flares are some of the largest point sources of methane on earth (Bloomberg 2019).

Regulation of flare operation (40 CFR 60.18) specifies a pilot light that is on and monitored, an upper limit on the exit velocity of flared gas, and a lower limit on the flammability of the gas. These provisions are meant to ensure that the flare automatically ignites and will not self-extinguish. However, there is no rule stipulating that the flare actually be lit. As the ultimate safety system to prevent system overpressures, flares can never be simply shut off. One solution is a requirement for combustion sensors that can trigger remedial action or notify operators of fault conditions. In the absence of regulation, these simple sensors are not routinely installed. This is an example of how even a minor oversight in prescriptive regulations can compromise the effectiveness of environmental protection.

4.6 Gas-Gathering Pipelines

Gas-gathering pipelines transport natural gas from production to processing sites. Although NSPS rules regulate gathering-system compressors, gathering-system pipelines have never been regulated by the EPA. The Pipeline and Hazardous Materials Safety Administration (PHMSA) has primary responsibility for regulating pipelines in the United States (49 USC 601). The agency's priority has been on safety; environmental concerns have been largely neglected (Webb 2015).

Aircraft surveys have found that gathering pipeline leaks are responsible for 30 percent of large methane emissions (those that are more than about 30 kilograms per hour) in the Permian Basin of southeast New Mexico (Berman et al. 2019; Berman and Deiker 2020), suggesting a significant gap in greenhouse gas control measures.

The Consolidated Appropriations Act of 2021, Division R, gave the Pipeline and Hazardous Materials Safety Administration the responsibility for leak detection and repair of pipelines to protect the environment. However, PHMSA has not given itself the authority to protect the environment by mandating comprehensive leak detection and repair surveys outside of areas where the safety of people can be affected (PHMSA 2018).

5. Recently Developed and Improved Measurement Capabilities

Technology that can monitor methane emissions has advanced dramatically in recent years, and independent assessments of methane emissions from oil and natural gas facilities have multiplied over the last ten years. Environmental advocacy groups (principally the Environmental Defense Fund), academic groups, and technology developers have conducted thorough and widespread surveys of sites and facilities, employing increasingly sophisticated quantitative methods. These studies have repeatedly shown that the actual methane emissions determined by various remote sensing methods consistently exceed the EPA's emission-factor estimates by wide margins (see, e.g., Alvarez et al. 2018; Zhang et al. 2020; Robertson et al. 2020).

The central problem of the emission-factor method is that it tends to miss what researchers have come to understand are among the dominant contributors to natural gas emissions: abnormal conditions and equipment malfunctions, which are characterized by intermittent superemitters (Zavala-Araiza et al. 2017; Allen et al. 2017; Alden et al. 2020). Moreover, methane sensing satellites have discovered enormous superemitters, emitting methane at rates greater than ten tons per hour each (see, e.g., Varon et al. 2019; IEA 2021; Lauvaux et al. 2021). Normally functioning sites emit zero to 10 kilograms per hour.

The difference in results between emission-factor estimates and remote-sensing methods can be stark. For example, the EPA's emission-factor estimates of US oil and gas industry methane emissions in 2015 was 8.1 million tons, whereas EDF's assessment was 13 million tons (Alvarez et al. 2018; EPA 2017). Although the EPA inventory is far more detailed, the Alvarez data compilation is informed by facility-level field studies, which are generally believed to more likely represent actual emissions.

6. Effective and Efficient Regulation

Advancements in survey technology have exposed weaknesses in methane regulations. Methane emissions regulations that are too prescriptive have discouraged technological advances. Performance-based regulation on the other hand, aligns the interests of asset managers and engineers with societal goals. Characteristics of prescriptive and performance-based regulations for methane emission control are outlined in Table 3.

Table 3: Characteristics of prescriptive and performance-based regulations for methane emission control

Prescriptive regulation	Performance-based regulation
Focus on components	Focus on facilities or companies
Separate rules for leaks, vents, flares	Unified target for all emissions
Regulators write rules	Facility engineers figure out how to hit target
Measurements not required	Accurate measurements essential
Compliance unverified (honor system)	Compliance verified by validated third-party measurements
Owners and operators rated pass/fail	Owners and operators rated quantitatively

6.1 Prescriptive Regulation

Prescriptive (sometimes called "command-and-control") regulation directs regulated entities to take specific actions. For example, the NSPS is prescriptive in its leak detection and repair mandates, even specifying the meter resolution and probe diameter of certain instruments (40 CFR 60 Appendix A-7 Method 21). Prescriptive regulation is generally well tolerated by risk-averse regulated entities because they lay out clear, unvarying mandates that can often be reduced to checklists. The owner or operator and its employees need show no initiative to avoid sanctions. The author has found that the oil and gas industry places a premium on compliance with rules of all kinds, many of them essential for safe operations in what can be hazardous conditions. Thus, prescriptive regulation can blend well with the corporate cultures of oil and gas companies.

If prescriptive regulations are perfectly designed, mandated actions will produce the desired environmental benefit. However, if these regulations are imperfect, regulated entities can comply with all mandates without achieving the desired environmental outcome, as documented in Section 4.

Another widespread aspect of oil field corporate culture (and, for that matter, most corporations) is the drive to reduce costs. Asset managers are evaluated on their ability to deliver profits to the organization. A dutiful facility engineer or technician will comply with the letter of relevant regulations at the lowest possible cost. This can lead to situations in which the regulations do not drive the desired outcomes. For example, if EPA regulations command retirement of high-bleed pneumatic controllers, those controllers can be replaced with the most economical alternative that complies with the regulation, without regard to whether total methane emissions are reduced.

6.2 Performance-Based Regulation

Performance-based regulations are an option that could potentially prove more effective in combatting methane emission. These regulations mandate an outcome and encourage regulated entities to innovate to find efficient solutions that regulators may not have anticipated. To be effective, a performance-based regulation must include a measurement requirement to verify compliance (Coglianese 2017).

Oil field problems are diverse and highly technical. In the author's experience, local engineers often are far more capable of finding and fixing the most important problems at their sites than are rule makers working elsewhere. Performance-based regulation, when implemented correctly, offers the potential to engage the ingenuity of thousands of engineers in their area of expertise.

Effective regulation can align the interests of asset managers and facility engineers with broad societal interests. The broader society has no interest in the kinds of controllers used in the oil field, for example, but is very concerned with how much methane is being emitted by the oil and gas industry. Current EPA regulations command finding methane leaks as small as thirty grams per hour but ignore unlit flares that can emit thirty tons per hour. If punishments or rewards are meted out to owners and operators based on environmental performance, they will have an incentive to improve environmental performance.

7. Observations and Recommendations

Because methane regulations were devised at a time when the technology for the measurement of natural gas emissions was relatively immature, comprehensive performance-based regulations were not an option. Some OOOO and OOOOa regulations are highly prescriptive, while performance-based previsions lack mechanisms to verify compliance. Unfortunately, methane reductions resulting from these regulations have been much lower than targeted. In 2016, the Obama administration pledged to reduce methane emissions from the oil and gas sector by 40 to 45 percent by 2025, representing a compound annual decline rate of roughly 6 percent. However, methane emissions have changed little following the promulgation of the OOOO and OOOOa rules meant to control natural gas emissions. At a compound annual decline rate of about 0.3 percent, the results are indistinguishable from trends observed since 1990.

Another obstacle to greater progress in reducing emissions is that low-production facilities are no longer required to comply with these methane emission control regulations, despite being responsible for substantial fractions of total upstream methane emissions. Further, gathering pipelines, which are not regulated by the EPA and inadequately regulated for environmental purposes by the Pipeline and Hazardous Materials Safety Administration, are the origin of many of the largest leaks associated with oil and gas production and processing segments.

Some very important sources of vented methane also have not been adequately mitigated by the Obama- and Trump-era EPA or by industry. These include routine emissions associated with normal and abnormal operations of pneumatic controllers and oil storage tanks as well as malfunctioning and unlit flares. These sources collectively account for roughly a third of the methane emitted by the entire US oil and gas industry, as estimated by the Environmental Defense Fund.

Finally, the complexities of oil and gas production do not lend themselves to prescriptive regulation. Performance-based regulation, including quantitative compliance monitoring, would engage the talents of thousands of engineers, encouraging them to solve problems using locally appropriate solutions rather than relying on a prescriptive checklist approach that cannot anticipate every eventuality.

The key to performance-based regulation is accurate measurement, and this capability has improved rapidly in recent years. But although aircraft-based, facility-scale measurements encompassing tens of thousands of facilities spread over tens of thousands of square kilometers are economically viable—and permanently installed continuously monitoring sensors also show great promise—such measurements are not compliant with the current regulatory regime, which focuses on individual components. To allow for such technological advances to improve the effectiveness of emissions regulations, the current regulatory regime must be completely rethought.

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Dr. Robert L. Kleinberg is an adjunct senior research scholar at the Center on Global Energy Policy of the Columbia University School of International and Public Affairs. From 1980 to 2018, he was employed by Schlumberger, attaining the rank of Schlumberger Fellow, one of about a dozen who held this rank in a workforce of 100,000. He has served on or advised numerous government and academic committees on energy policy. Dr. Kleinberg was educated at the University of California, Berkeley (BS chemistry, 1971) and the University of California, San Diego (PhD physics, 1978). He is a member of the National Academy of Engineering.

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