Testimony of Dr. Robert L. Kleinberg - Final

Senior Research Scholar, Columbia University Center on Global Energy Policy
Senior Fellow, Boston University Institute for Sustainable Energy
Member of the National Academy of Engineering

House of Representatives Select Committee on the Climate Crisis
"Cutting Methane Pollution: Safeguarding Health, Creating Jobs, and Protecting Our Climate"
24 June 2022

Contents

Introduction

Good day Chair Castor, Ranking Member Graves, and members of the Select Committee. My name is Robert Kleinberg. I am presently affiliated with energy policy research units of Columbia University and Boston University, which I joined after working for four decades in technology development in the oil and gas industry. I have been elected to the National Academy of Engineering in recognition of my contributions to geoscience technology.

The subtitle of today's hearing is "Safeguarding Health, Creating Jobs, and Protecting Our Climate". Some people see creating jobs and protecting our health and environment as mutually exclusive goals, particularly with respect to oil and gas development. I hope to show you today that those goals support each other. Methane emission mitigation is essential to reducing the rate of global warming between now and 2050. It is technically and economically feasible. And it has already generated a constellation of innovative U.S. small businesses exploiting a variety of American designed and built technologies. If we use the technologies we have developed, we will secure the United States' place as the world's premier supplier of fuels while minimizing climate change during the transition to zero-carbon energy.

To understand the importance of minimizing climate change during the transition to low-carbon sources of energy, we must have a clear view of the magnitude and pace of the transition. According to the International Energy Agency, the world consumed four trillion cubic meters of natural gas in 2020. Assuming nations adhere to their announced Nationally Determined Contributions, the world will consume almost exactly the same amount of gas in 2050 [IEA, 2021, Table A.12]. No matter how optimistic you are that nations will respect their Paris Agreement commitments, you must take methane emission reduction seriously.

Moreover, even after the transition from fossil fuels is complete, the methane problem will not go away by itself. Biogas and biomethane production and transport have been found to be increasingly important sources of this climate pollutant [Scheutz, 2019].

Methane as a Greenhouse Gas

We know we must reduce our use of fossil fuels, and we know the transition from fossil fuels to zero carbon sources of energy will take time. One of our chief challenges will be to minimize the damage associated with fossil fuel use during the transition. One of the big questions we face is, who can provide energy with the smallest greenhouse gas (GHG) footprint. The European Union is considering the Carbon Border Adjustment Mechanism, a market-based plan that preferences those countries best able to meet this challenge. Many of us believe the United States should be able to out-compete most everyone else.

You have already learned that control of methane emissions plays an important role in greenhouse gas reduction. Reducing methane is likely the only realistic route to mitigating global temperature increase before 2050, see Figure 1. Unlike carbon dioxide, which is an inevitable by-product of the generation of useful energy from fossil fuels, methane emissions benefit no one. No one makes money sending methane into the atmosphere, no energy is produced as a result of it, no communities are supported by it, no one's job depends on it. Venting methane into the atmosphere is like throwing garbage into the street outside your home. It is worse than that, it is like throwing good food, that could be used elsewhere, into the street outside your home.

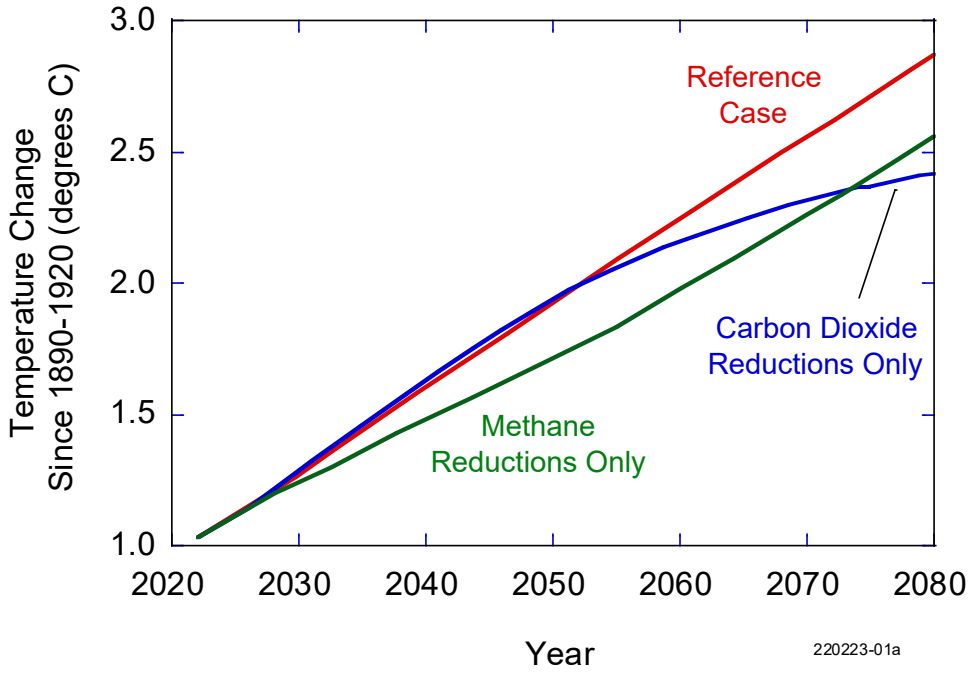

Figure 1. Scenarios for global average temperature change. Updated and redrawn from calculations by Shindell [2012].

Methods for Quantifying Methane Emissions Need to be Improved

We are rapidly refining our understanding of where methane waste is coming from, and therefore how to reduce it. Every year, Annex 1 nations report their methane emissions to the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). The United States submits the Environmental Protection Agency Inventory of U.S. Greenhouse Gas Emissions and Sinks ("GHGI") [UNFCCC, 2022a; EPA, 2022a]. The effort and care EPA invests in this report is extraordinary. EPA tracks 250 methane source types from natural gas and petroleum systems alone [EPA, 2022b].

EPA relies on emission factor methodology, which when it was introduced in the 1990s was the best method of the time, but which is now decidedly outdated. Emissions are calculated from the populations and estimated gas loss rates of each of the 250 source types found in oil and natural gas infrastructure. This is a spreadsheet exercise that requires no measurements of equipment operating in the field and therefore does not represent actual amounts of methane emitted to the atmosphere.

Due to its own extraordinarily restrictive rules on acceptance of alternative means of emission limitation, EPA has to date 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]. Remarkably, over the last seven years, American industry, academia, and non-governmental organizations have moved beyond regulations and worked together to find out how much methane our oil and gas industries are actually emitting. The results have showed that EPA dramatically underestimates methane emissions [see e.g., Alvarez, 2018; Rutherford, 2021].

The Methane Problem is Relatively Easy to Solve

Current regulations to control oil and gas methane emissions are both inefficient and ineffective [Kleinberg, 2021b]. However, this does not imply that solving methane emission problems are economically ruinous or technically difficult. In fact, solutions are not particularly expensive and fall within the range of current engineering practice.

Realizing the limitations of current EPA regulations, the oil and gas industry, competing technology innovators, academics, and non-governmental organizations have cooperated to develop new and better methods to detect and characterize sources of methane emissions. Scientific and technical publications number well above a thousand and a thorough review of this work is beyond the scope of this testimony. I present a few examples that might serve as models for national-scale efforts in the future.

Aircraft Surveillance

The practicality of large scale, quantitative airborne remote sensing is well established. A number of basin-scale campaigns have already been performed in major oil and gas producing regions, by public and private entities using a variety of remote sensing technologies. Here are some examples:

- In the Permian Basin, aircraft-based instrumentation was used to survey areas totaling 55,000 km^2. Methane emission rates were measured at the largest emitters: more than 1000 oil and gas facilities. Updated results are published by the Environmental Defense Fund on maps showing every large emission event, tagged with emission rate and owner/operator identity; see Figure 2 [EDF, 2021b; Cusworth, 2021]. Flare malfunction is the subject of special studies [EDF, 2021a].

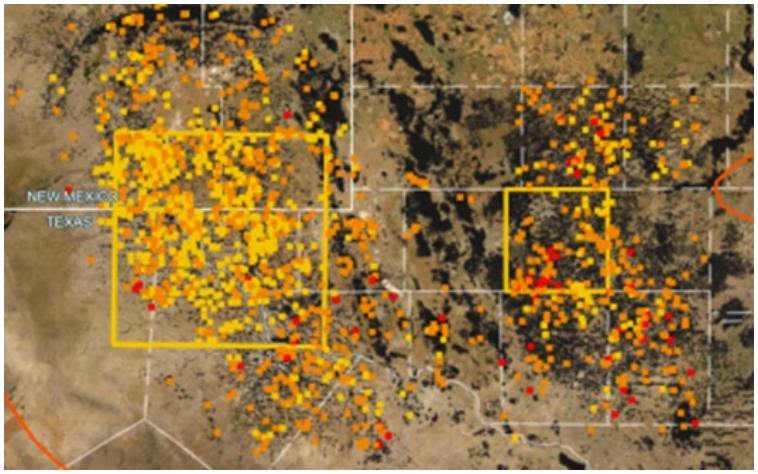

Figure 2. Survey of methane emissions in 55,000 km^2 of the Permian Basin, Fall 2019. White: < 2 kg/h; Yellow: 2-100 kg/h; Orange: 100-1000 kg/h; Red: > 1000 kg/h. Environmental Defense Fund PermianMAP/UArizona/NASA Survey 1 [EDF, 2021b; Cusworth et al., 2021].

- In the Permian Basin of New Mexico, Kairos Aerospace surveyed more than 30,000 active oil and gas wells and more than 10,000 miles of gas gathering pipeline. These comprised 93% of surface facilities and 77% of pipeline length over an area of 10,859 square miles. As a result, 1056 active methane emitters were located, identified, and quantified [Berman & Deiker, 2020; Sridharan, 2020].

- In California, 272,000 infrastructure elements were surveyed over 59,000 km^2. As a result, 564 methane point sources (including those in agricultural and waste sectors) were identified and quantified [Duren, 2019].

Consistent with a modeling study [Rashid, 2020], these surveys have shown that facility-level measurements, even when 100 to 1000 times less sensitive than current EPA mandates, are efficient and effective in finding vented and fugitive methane emissions. Moreover, these surveys are remarkably inexpensive: about $150 per well site in the Permian Basin according to one source [Johnson, 2021]. About 45,000 wells have been drilled in the Permian Basin since January 2011, arranged on a smaller number of pads [EIA, 2021]. These wells can be surveyed for about the cost of drilling and hydraulically fracturing a single well. Note however that service pricing varies with location and other factors.

Continuous Monitoring

Continuous monitoring of oil and gas infrastructure for methane emissions is not yet mature, but I believe it will become an essential element of methane surveillance in the future. The intermittency of super-emitters is a problem that is at the forefront of methane control issues [House Committee on Science, Space, and Technology, 2022]. Continuous monitoring, which is more expensive than occasional aircraft surveys, is best suited for sites with emission-prone infrastructure. These include gas processing plants, refineries, biogas and biomethane production facilities, liquefied natural gas terminals, and well sites or other facilities with storage vessels. By contrast, simple well sites with minimal ancillary hardware are unlikely to need this service. Simple wells account for most of the one million U.S. well sites that the EPA seeks to regulate in its proposed new methane control rules [EPA, 2021]; avoiding the extra expense of monitoring them continuously is desirable. General comments detailing the capabilities and deployment options of continuously monitoring sensors have been submitted to EPA [LongPath, 2022; CleanConnect.AI, 2022].

Remediation

While we have discovered we are emitting much more methane than we thought, we have also discovered that oil and gas methane emissions problems can usually be remediated by known engineering solutions. EPA has already determined that replacing natural-gas-actuated valves with electrical or compressed air systems can reduce methane emissions by a remarkable two million tons per year. Simple combustion sensors can be used to prevent unlit flares from emitting vast amounts of methane. SCADA systems that make sure pressure relief valves on tanks close properly should be universally implemented. Again, note the contrast with carbon dioxide. Reducing our carbon dioxide emissions will entail a multi-decadal, multi-trillion dollar reorganization of our economy. Reducing our oil and gas methane emissions will require some engineering fixes. I compare these to the health and safety improvements I saw over the course of my career in the oilfield. Our highly skilled and inventive workforce has made our workplaces safer while keeping American industry the most efficient and productive in the world. Given smart regulations and incentives, they will do the same with methane.

Economic Benefits of Methane Mitigation

Methane Emission Characterization is Dominated by U.S. Technology and Service Providers.

A rapidly growing, highly competitive, small-business-dominated industry is developing in the absence of regulatory drivers. For example, here is a partial list (in alphabetical order) of U.S. service providers offering commercial aerial surveillance of methane emissions on a fee-for-service basis:

Aerial Production Services	https://www.flyaps.io/oil-gas
Baker Hughes	https://www.bakerhughes.com/emissions-management
Bridger Photonics	https://www.bridgerphotonics.com/
Carbon Mapper	https://carbonmapper.org/
Kairos Aerospace	https://kairosaerospace.com/
LaSen	https://www.lasen.com/
Scientific Aviation	https://www.scientificaviation.com/
SeekOps	https://seekops.com/

Here is a partial alphabetical list of mostly small companies providing continuous monitoring services for oil and gas clients:

Airdar
CleanConnect.ai
Honeywell | Rebellion
IntelliView Technologies
Kuva Systems
LongPath Technologies
Project Canary
Qube Technologies
Scientific Aviation
Sensirion Connected Solutions

These leading-edge companies are a small fraction of the total effort devoted to methane emissions mitigation today. A report written for the Environmental Defense Fund estimates that 215 U.S. companies are engaged in various phases of methane control [EDF, 2021c].

Increasing Interest in Fossil Fuels with Low Greenhouse Gas Footprints

The proposed European Union Carbon Border Adjustment Mechanism (CBAM) – which includes methane as part of the "CO2equivalent" – is the leading example of the trend towards preferencing imports of low-GHG products. CBAM will be meaningless if it is based on spreadsheet exercises unmoored to measurement. If U.S. fossil fuels have lower GHG impact than those from other nations (as plausibly asserted by minority members in a House Committee on Science, Space and Technology hearing last week) certification based on measurement will both immediately benefit U.S. energy exporters and, in the long run, spur other nations to take verifiable actions to reduce their GHG emissions. This will help reduce the rate of climate change during the energy transition.

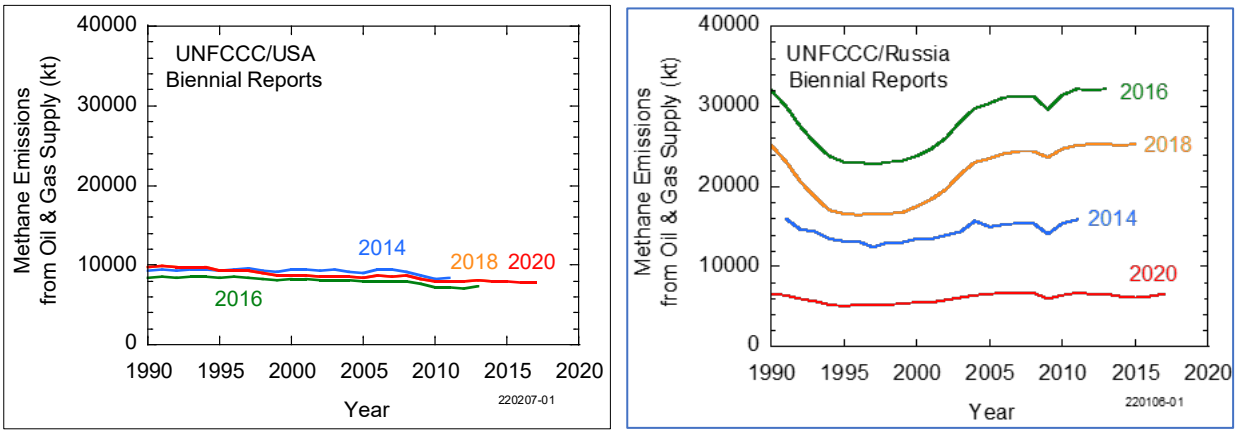

Figure 3. Methane emissions from oil and gas industries, as reported to UNFCCC. Labels are the years of biennial reports. For each report, methane emissions were recalculated from 1990 to two years prior to the date of the report using updated emission factors. Left: United States. Right: Russian Federation. [UNFCCC, 2022b].

Russia Takes Advantage of Inferior Methane Accounting Standards

Like the United States and other Annex 1 countries, Russia uses the emission factor method when reporting its methane emissions to UNFCCC. However, Russia reports on only fourteen source types in their oil and gas industry. And whereas the United States changes its emission factors cautiously, Russian emission factors vary by large amounts from year to year [Kleinberg, 2022]. Figure 3 compares U.S. and Russian reports.

With regard to methane emissions associated with natural gas exports to Europe, the U.S. would today appear to be at a competitive disadvantage relative to Russia. Since 2015, Russia's methane emissions from the oil and gas sector have declined by a factor of eight, according to its National Inventory Reports to UNFCCC. As a result, Russia's reported methane intensity is now less than that of the United States. If left unchallenged, these data weaken the case for reduction of European dependence on Russian natural gas. Although there is broad consensus in U.S. industry and policymaking circles that U.S. natural gas is the cleaner product, UNFCCC data must be challenged, and the only way to do this is with measurements such as those being developed and perfected by American industry and academic groups.

Recommendations

Launch a Methane Census

I draw the Committee's attention to the recently released majority staff report "Seeing CH4 Clearly: Science-Based Approaches to Methane Monitoring in the Oil and Gas Sector" [House Committee on Science, Space and Technology, 2022]. The Recommendations section of this report is worthy of attention. I particularly point to the idea of a Methane Census:

> The Methane Census would utilize commercially-available innovative LDAR [Leak Detection and Repair] technologies to perform large-scale methane detection surveys covering the majority of

> oil and gas infrastructure in each basin and to quantify the size of the detected emissions. The Methane Census would gather data to improve the characterization of oil and gas sector methane emissions in several key aspects, including by segment and by emission source, as well as data regarding the aggregate emissions for each basin. [House Committee on Science, Space and Technology, 2022, page 53]

As documented above, aerial surveys of the Permian Basin and of California have already shown the feasibility of this idea, which can be implemented at relatively low cost. Comprehensive nationwide data would establish the United States as a supplier of verifiably low-GHG fossil fuels for the rest of the world and serve as a baseline for future reduction efforts.

Support the International Methane Emissions Observatory

The International Methane Emissions Observatory (IMEO) is mentioned but not highlighted in the House Committee on Science, Space and Technology majority staff report. The IMEO is a project of the United Nations Environment Programme and supported by the European Commission [European Commission, 2021]. Its mission is to integrate multiple streams of methane emission data to better understand causes and remedies. "A technical study to inform approaches to reconciling the data from the Methane Census with existing EPA data sources" [House Committee on Science, Space and Technology, 2022, page 53] is exactly what IMEO was created to do. The United States has not yet strongly engaged with this effort, which would most certainly benefit from the energy and expertise of U.S. actors in this space. The United States, in turn, would benefit from interaction with European technical experts, particularly in the field of satellite surveillance of oil and gas infrastructure, in which Europe has taken the lead.

Reform the Alternative Means of Emission Limitation Process

Through multiple waves of Environmental Protection Agency rule-making over the last ten years, the EPA has remained an impediment to technical innovation in methane emission control, when it should be a promoter of it. American small business, academics, and NGOs, are enthusiastically innovating in this space, but inflexible EPA rules have discouraged widespread adoption of new technology by oil and gas operators. To put it bluntly, the only two EPA-approved methods, Method 21 and OGI, have been cold dead hands in this horror story.

The Clean Air Act recognizes the role of new technologies in helping to solve our environmental problems:

> If after notice and opportunity for public hearing, any person establishes to the satisfaction of the Administrator that an alternative means of emission limitation will achieve a reduction in emissions of any air pollutant at least equivalent to the reduction in emissions of such air pollutant achieved under the requirements of paragraph (1), the Administrator shall permit the use of such alternative by the source for purposes of compliance with this section with respect to such pollutant. [42 USC 7411(h)(3)]

It has been shown over and over again that basin-wide aircraft overflights have the potential to reduce methane emissions by half or more. This would be outstanding progress compared to the present rate of methane reduction, which averages 0.3% per year [Kleinberg, 2021b].

However, the Alternative Means of Emission Reduction (AMEL) process, as implemented by 40 CFR 60 Subpart OOOO in 2012 and renewed by 40 CFR 60 Subpart OOOOa [40 CFR 60.5398a, 29 August 2017],

was perversely, fiendishly difficult to satisfy. From 2012 to 2020, while American innovators were developing and successfully field testing numerous ground-based, drone-based, aerial, and satellite methods for emission reduction, not a single application for AMEL was filed with EPA. The 2020 Technical Amendments (which were not withdrawn by Public Law 117-23) considerably simplified AMEL application requirements [40 CFR 60.5398a, 15 September 2020]. A single application has been filed, more than a year ago [Bridger, 2021], but to the best of my knowledge, this application has not yet been acted on. For more details on the AMEL issue see [Kleinberg, 2021a, Section 16 and Appendix IV].

Carefully Examine OGMP 2.0 Before Adopting It as U.S. Policy

OGMP 2.0 is a methane emission measurement and reporting protocol for the oil and gas industry that has been embraced by the United Nations Environment Programme, the European Commission, the Government of the United Kingdom, the Environmental Defense Fund, and eighty oil and gas companies [OGMP, 2022a]. Companies that adhere to a subset of its principles are deemed to have attained "gold standard" status. The original OGMP 2.0 Framework [OGMP, 2020] was defective in many respects, but it has recently been replaced by an improved version [OGMP, 2022b] that honors the learnings that have accumulated over the last several years. The range of sponsors has lent momentum to this protocol, and the European Commission seems predisposed to incorporating it into initiatives such as the Carbon Border Adjustment Mechanism. U.S. policymakers should be prepared to respond.

Thank you for giving me the opportunity to share these observations with you.

References

Alvarez, R.A., et al., 2018. Assessment of methane emissions from the U.S. oil and gas supply chain, Science 10.1126/science.aar7204 https://science.sciencemag.org/content/361/6398/186

Berman, E.S.F. & Deiker, S., 2020. Source-attributable, quantitative results from a basin-wide survey of New Mexico Permian methane emissions, MIT A+B Applied Energy Symposium #280. 13-14 August 2020 https://www.youtube.com/watch?v=ySDjZdHMYBA http://kairosaerospace.com/wp-content/uploads/2021/02/Source-Attributable-Quantitative-Results-from-a-Basin-Wide-Airborne-Survey-of-Methane-Emissions.mp4

Bridger, 2021. Why is it Important that ExxonMobil Submitted Gas Mapping LiDAR™ for EPA Approval?, 8 April 2021 https://www.bridgerphotonics.com/blog/why-it-important-exxonmobil-submitted-gas-mapping-lidartm-epa-approval

Chen, Y., et al., 2022. Quantifying Regional Methane Emissions in the New Mexico Permian Basin with a Comprehensive Aerial Survey. Environmental Science and Technology, 56, 4317–4323. https://doi.org/10.1021/acs.est.1c06458

CleanConnect.AI, 2022. https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0317-0762

Cusworth, D.H., et al., 2021. Intermittency of Large Methane Emitters in the Permian Basin, Environmental Science & Technology Letters, 8, 567–573. https://pubs.acs.org/doi/abs/10.1021/acs.estlett.1c00173

Duren, R.M., et al., 2019. California's methane super-emitters, Nature, 575, 180-185. https://www.nature.com/articles/s41586-019-1720-3

EDF, 2021a. PermianMAP, Flaring, Aerial Survey Results, Environmental Defense Fund, Accessed 31 January 2021 https://www.permianmap.org/flaring-emissions/

EDF, 2021b. PermianMAP, Operator Emissions, Environmental Defense Fund, Accessed 3 June 2021. https://data.permianmap.org/pages/operators

EDF, 2021c. Find, Measure, Fix: Jobs in the U.S. Methane Emissions Mitigation Industry. Datu Research. https://www.edf.org/sites/default/files/content/FindMeasureFixReport2021.pdf

EIA, 2021. Drilling and completion improvements support Permian Basin hydrocarbon production. Energy Information Administration, Today in Energy, 19 October 2021. https://www.eia.gov/todayinenergy/detail.php?id=50016

EPA, 2021. Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review, Environmental Protection Agency, 86 Federal Register 63110-63263, 15 November 2021 https://www.federalregister.gov/documents/2021/11/15/2021-24202/standards-of-performance-for-new-reconstructed-and-modified-sources-and-emissions-guidelines-for

EPA, 2022a. Inventory of U.S. Greenhouse Gas Emissions and Sinks. U.S. Environmental Protection Agency, 2022.
https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

EPA, 2022b. Natural Gas and Petroleum Systems in the GHG Inventory: Additional Information on the 1990-2020 GHG Inventory (published April 2022).
https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2020-ghg

European Commission, 2021. International Methane Emissions Observatory launched to boost action on powerful climate-warming gas. Press Release, 31 October 2021.
https://ec.europa.eu/commission/presscorner/detail/en/IP_21_5636

House Committee on Science, Space and Technology, 2022. Seeing CH4 Clearly: Science-Based Approaches to Methane Monitoring in the Oil and Gas Sector. U.S. House of Representatives Committee on Science, Space, and Technology. Majority Staff Report, June 2022.
https://science.house.gov/imo/media/doc/science_committee_majority_staff_report_seeing_ch4_clearly.pdf

IEA, 2021. World Energy Outlook 2021. International Energy Agency.
https://www.iea.org/reports/world-energy-outlook-2021

Johnson, F., et al., 2021. Airborne methane surveys pay for themselves: An economic case study of increased revenue from emissions control. EarthArXiv, 15 July 2021.
https://eartharxiv.org/repository/view/2532/

Kleinberg, R.L. 2021a. EPA Methane Emission Controls, Obama vs Trump vs Biden: What Needs to Be Fixed and What Should be Left Alone, Social Science Research Network, 22 March 2021.
https://ssrn.com/abstract=3810337 or http://dx.doi.org/10.2139/ssrn.3810337

Kleinberg, R.L., 2021b. Reducing Emissions of Methane and Other Air Pollutants from the Oil and Natural Gas Sector: Recommendations to the Environmental Protection Agency. Comment submitted by Robert L. Kleinberg, Posted by the Environmental Protection Agency on July 6, 2021.
https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0295-0035
Data File: Public submission posted by the EPA. August 2, 2021.
https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0295-0071

Kleinberg, R.L., 2022. Methane Emissions from the Fossil Fuel Industries of the Russian Federation. EarthArXiv, 19 May 2022. https://eartharxiv.org/repository/view/3342/

LongPath, 2022. Comment submitted by LongPath Technologies, Inc. et al. Posted by the Environmental Protection Agency on Feb 2, 2022
https://www.regulations.gov/comment/EPA-HQ-OAR-2021-0317-0759

Lyon, D.R., et al., 2021. Concurrent variation in oil and gas methane emissions and oil price during the COVID-19 pandemic. Atmospheric Chemistry and Physics, 21, 6605–6626.
https://doi.org/10.5194/acp-21-6605-2021

OGMP, 2020. Mineral Methane Initiative OGMP 2.0 Framework. Oil and Gas Methane Partnership, 19 November 2020.
https://www.ogmpartnership.com/ogmp-20-reporting-framework

OGMP, 2022a. Oil & Gas Methane Partnership 2.0. Accessed 20 June 2022.
https://www.ogmpartnership.com/

OGMP, 2022b. Oil & Gas Methane Partnership 2.0. Guidance document: Reconciliation and Uncertainty (U&R) in methane emissions estimates for OGMP2.0. Accessed 22 June 2022.
https://www.ogmpartnership.com/uncertainty-and-reconciliation-guidance
https://www.ogmpartnership.com/sites/default/files/files/OGMP%202.0%20U%26R%20Guidance%20document%20-%20SG%20approved.pdf

Rashid, K., et al., 2020. Optimized inspection of upstream oil and gas methane emissions using airborne LiDAR surveillance, Applied Energy 275, 115327.
https://www.sciencedirect.com/science/article/abs/pii/S0306261920308394

Rutherford, J.S., et al., 2021. Closing the gap: Explaining persistent underestimation by U.S. oil and natural gas production-segment methane inventories, Nature Communications, 12: 4715.
https://www.nature.com/articles/s41467-021-25017-4

Scheutz, C. and Fredenslund, A.M., 2019. Total methane emission rates and losses from 23 biogas plants. Waste Management, 97, 38-46.
https://doi.org/10.1016/j.wasman.2019.07.029

Shindell, D., et al., 2012. Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security. Science 335, 183-189
https://www.science.org/doi/abs/10.1126/science.1210026

Sridharan, S., et al., 2020. Long Term, Periodic Aerial Surveys Cost Effectively Mitigate Methane Emissions, Society of Petroleum Engineers Paper SPE 201312.
https://onepetro.org/SPEATCE/proceedings-abstract/20ATCE/3-20ATCE/D031S034R004/449845

UNFCCC, 2022a. United States of America. 2022 National Inventory Report (NIR)
https://unfccc.int/documents/461948

UNFCCC, 2022b. Fourth Biennial Reports - Annex I. Accessed 19 June 2022
https://unfccc.int/BRs