Methane Measurement and Monitoring

Reconciling Estimation Approaches

Background

The Climate Solutions Now Act of 2022 (CSNA) requires that, "In developing and implementing the plan the Department [of the Environment] shall: Incorporate top–down methane emissions data acquired through aircraft observations" (Environment Article §2–1206). Top-down and bottom-up are two distinct approaches to estimating emissions.

The top-down approach involves measurement or observation of atmospheric methane concentrations, for example by aircraft fitted with measurement equipment, observation tower stations, or methane detecting satellites. Emissions are then estimated from the observed concentrations with techniques such as atmospheric transport modeling. The bottom-up approach extensively used for greenhouse gas (GHG) emissions inventories, including Maryland's GHG inventory, uses monitoring at individual point sources where available, and widely accepted emissions factors that are developed from representative samples.

Top-down monitoring studies, both nationally and internationally, have generally pointed to the underestimating of methane emissions by bottom-up methods. This report provides a comparison of recent top-down estimates to Maryland's GHG inventory and an update on the current state of research.

Comparison to Maryland GHG Inventory Emissions

For the Maryland area, The Ren et al. study of 2018 continues to be the most recent published analysis of methane measurements collected by aircraft that is spatially comprehensive of the Maryland area and provides estimated fluxes (as opposed to concentration observations alone) for comparison to bottom-up emission inventories. The Maryland Department of the Environment (MDE) worked with the lead researchers of the Fluxes of Atmospheric Greenhouse Gases in Maryland (FLAGG-MD) research team in 2020-2021 to evaluate opportunities for reconciling the two methodologies.

Flights for this study were conducted during February & March of 2015 and February of 2016, representing two consecutive winter periods. The study used a mass balance technique to quantify methane emissions from the Baltimore-Washington area during this period. For comparison to the Maryland GHG inventory, the study results were apportioned to the Maryland portion of the study area and extrapolated statewide by scaling to population (6.01 million Maryland population : 8.50 million in the combined Baltimore-DC-VA urban area).

Table 1 provides a comparison of the statewide methane emissions from Maryland's GHG inventory to the estimates derived from the study results. Results are presented here in both kg/s, the units used in the research studies representing the momentary nature of individual measurements, and MMTCO2e/yr, the units used in inventories representing annual emissions. As Maryland's GHG inventory is updated triennially, the 2014 and 2017 inventory data is presented for the nearest comparison to the study's 2015 and 2016 flight periods. The inventory emissions are 14% lower than the flight estimate, but within the confidence interval of the study results.

Table 1. Statewide methane emissions comparison between flight data and inventory estimates.

Units	2015/16 Flights (Ren et al., 2018)	2014 Inventory (MDE, 2022)	2017 Inventory (MDE, 2022)
kg-CH4/s	6.24	5.56	5.13
MMTCO2e/yr*	5.51	4.91	4.53

*all MMTCO2e values using AR5 100-yr GWP of 28

Landfills

Ren et al. (2018) surveyed methane emissions at 8 Maryland landfills using downwind transect flights and a mass-balance approach. Table 2 provides a comparison of landfill methane emissions from Maryland's GHG inventory to the estimates from the study results. Note that the flight study result reported here is only for the surveyed landfills, while the inventory emissions cover all landfills in the state. The results compare well statewide but there are differences at the site level. However, the uncertainty at the site-level in some cases is as much as the mean emission rate reported for the site. This evaluation points to a need for more targeted site-specific monitoring. Two opportunities that will provide greater understanding of landfill methane emissions are discussed below.

Table 2. Landfill methane emissions comparison between flight data and inventory estimates.

Units	2015/16 Flights (Ren et al., 2018)	2014 Inventory (MDE, 2022)	2017 Inventory (MDE, 2022)
kg-CH4/s	1.50	2.19	1.85
MMTCO2e/yr*	1.32	1.93	1.64

*all MMTCO2e values using AR5 100-yr GWP of 28

Maryland Landfill Methane Regulation

In 2023, Maryland adopted a regulation for the Control of Methane Emissions from Municipal Solid Waste Landfills. The new regulation implements regulatory requirements for owners and operators of new and existing Municipal Solid Waste (MSW) landfills, which include surface emission monitoring, detecting and repairing landfill gas leaks, recordkeeping and reporting requirements, and installing and operating emission control systems based upon the regulatory applicability. Applicable landfills are required to perform quarterly surface emissions monitoring for one year. MDE will begin assessing results of this monitoring in 2024.

Site-Specific Landfill Study

Researchers at the University of Maryland (UMD) Department of Atmospheric and Oceanic Science and National Institute of Standards and Technology (NIST) Greenhouse Gas Measurements Program, with support from MDE, are pursuing a targeted site-specific study to monitor methane emissions from an active landfill site in Maryland. The study is currently in the planning stages. Goals are to better understand landfill methane emissions under a range of operations and conditions, refine emissions models, and identify strategies for abatement.

Natural Gas Distribution and Transmission

Methane emissions estimated from the flight study are able to be attributed to the natural gas system using techniques based on ethane-to-methane ratios. The study found 39-55% of the methane emissions in the study area to be attributable to the natural gas system (Ren et al., 2018). Table 3 provides a comparison of methane emissions from the natural gas system from Maryland's GHG inventory to the estimates from the study results.

Table 3. Natural gas system methane emissions comparison between flight data and inventory estimates.

Units	2015/16 Flights (Ren et al., 2018)	2014 Inventory (MDE, 2022)	2017 Inventory (MDE, 2022)
kg-CH4/s	2.78	1.22	1.20
MMTCO2e/yr*	2.45	1.08	1.06

*all MMTCO2e values using AR5 100-yr GWP of 28

The emission rate of the flight study is more than double that of the inventory estimate. It is important to note that the flights were conducted during the winter period. A recent study of tower-based methane observations in the Baltimore-DC area found seasonal variability in methane emissions correlated with increased natural gas use in the winter (Karion et al., 2023). The study found winter methane emissions to be 44% (or 1.44 times) higher than in the summer. Seasonal variability however does not explain the entire gap seen in the flight study comparison, as carrying this factor over to the flight study results gives a summer emission rate (1.93 kg/s) that is still higher than the annual rate reported in the inventory. Persistent discrepancies between top-down and bottom-up accounting approaches for the natural gas sector could have several reasons. Two are discussed here:

Pipeline Accidents

Emission factors used in bottom-up inventories are typically based on average operating conditions. They are unable to account for occurrences outside of the conditions under which the factors were developed, such as pipeline accidents. Pipeline incident data is published by the United States Pipeline and Hazardous Materials Safety Administration (PHMSA)[1], but only includes events that exceed property damage and gas loss reporting requirements. PHMSA also tracks amounts of lost and unaccounted for (LAUF) natural gas as reported by natural gas distribution utilities. LAUF could be one source of accounting for discrepancies; however in a report to Congress, PHMSA determined that the metric "is not a valid proxy for either unknown leak volume or methane emissions" (PHMSA, 2017). An in-depth study commissioned by the Massachusetts Department of Public Utilities also found LAUF not to be an accurate surrogate for methane emissions (ICF, 2014).

Post-Meter Emissions

Bottom-up inventories can only account for emissions sources for which either direct monitoring is reported or emissions factors have been developed and activity data is gathered. One source not previously accounted for had been post-meter leak emissions from natural gas end-uses beyond the meter. After reviewing multiple data sources, the U.S. Environmental Protection Agency (EPA) recently added this category to the national level GHG emissions inventory in 2022[2]. In the U.S. in 2021, post-meter methane emissions made up 7% of methane emissions from the natural gas systems sector, and were nearly (85%) as much as distribution system methane emissions (EPA, 2023). MDE will add post-meter emissions to the Maryland GHG inventory when it has been added to EPA's State Inventory Tool (SIT).

Other Studies

While the law specifically requires consideration of measurements taken from airplanes, there are other monitoring techniques available and advancing. Several are highlighted here:

Northeast Corridor Tower Network

The National Institute of Standards and Technology (NIST) has deployed networks of tower-based observation stations as part of the NIST Greenhouse Gas Measurements Program. NIST has established three urban test beds, including one for the Northeast Corridor which began in 2015 with a dense network in the Baltimore-D.C. region. The tower-based monitoring features continuous measurements of carbon dioxide and methane and extensive modeling of transport and dispersion. The most recent study analyzing these observations was published in November 2023. It finds that annual methane emissions from 2018 to 2021 averaged 0.05 million metric tons (or 1.33 MMTCO2e/yr, using AR5 100-yr GWP of 28) in the Baltimore urban area, and 0.08 million metric tons (2.24 MMTCO2e/yr) in the D.C. urban area, and decreased 4-5% annually in both areas. (Karion et al., 2023). Maryland's GHG inventory for 2020 puts statewide methane emissions

[1] https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-20-year-trends

[2] https://www.epa.gov/system/files/documents/2022-04/2022_ghgi_update_-_meter.pdf

at 4.52 MMTCO2e/yr (AR5 100-yr GWP of 28) and shows only a 0.1% decrease annually from the inventory year of 2017. This suggests that the activity data used for bottom-up inventories are not sensitive to the same factors that drive the annual trend and variability captured in top-down observations.

Mobile-Based Monitoring

A vehicle-based surface measurement program has been operated by scientists at the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL) and is referred to as NOAA's Air Resources Car (NOAA's ARC).[3] Mobile measurement surveys have been conducted in the Baltimore-D.C. area, collecting measurements of greenhouse gas concentrations and meteorological parameters, and can be useful in identifying localized hotspots for targeted remediation.

Methane-Detecting Satellites

There are a number of satellite missions currently existing for methane monitoring and more expected in the near future. As these technologies expand they will offer opportunities to align bottom-up inventories and address hotspots. Individual point sources in Maryland have generally been under the detection limit of existing satellites. Table 4 provides details on spatial coverage, resolution, detection limits, and data availability of many existing and upcoming methane-detecting satellites and is adapted from the EPA Science Advisory Board (SAB) report on the scientific and technical basis of EPA's rule for oil and natural gas operations, which was made final in December 2023 (EPA SAB, 2023).

Table 4. Characteristics of existing and upcoming methane-detecting satellites (EPA SAB, 2023).

Spatial Coverage	Satellite	Data Available	Pixel Size	Detection Limit (kg/h)
Global	GOSAT/GOSAT-2	2009- /2018-	10 x 10 km	7000 / 4000
Global and regional	TROPOMI	2017-	7 x 5.5 km	4000
	Sentinel-5	Expected 2024	7.5 x 5.5 km	4000
Regional	MethaneSAT	Expected 2024	130 x 400 m	1000
Individual point-sources	Landsat 8 and 9	2013 - / 2021 -	30 x 30 m	900
	Sentinel-2 (A+B)	2015 -	20 x 20 m	900
	PRISMA	2019 -	30 x 30 m	500
	EnMAP	2022 -	30 x 30 m	500
	EMIT	2022 -	60 x 60 m	500
	WorldView-3	2014 -	3.7 x 3.7 m	<100
	GHGSat	2016 -	25 x 25 m	200

[3] https://www.arl.noaa.gov/

Carbon Mapper	Expected 2024	30 x 30 m	100

Recent Federal Action

The Federal government has taken recent actions to advance the utilization of emissions measurements and monitoring.

U.S. GHGMMIS & U.S. GHG Center

In November 2023, "the Office of Management and Budget, the White House Office of Science and Technology Policy, and White House Office of Domestic Climate Policy announced the release of the National Strategy to Advance an Integrated U.S. Greenhouse Gas Measurement, Monitoring, and Information System [GHGMMIS], a Strategy developed by the Greenhouse Gas Monitoring and Measurement Interagency Working Group to enhance coordination and integration of greenhouse gas measurement, monitoring, and information efforts across the Federal government". The strategy identifies five objectives to focus and integrate efforts by federal and non-federal entities: 1) "Improve activity-based ("bottom up") GHG quantification approaches; 2) Improve atmospheric-based ("top down") GHG quantification approaches; 3) Coordinate the use of activity- and atmospheric-based approaches to move towards convergence of GHG estimates; 4) Improve latency, completeness, interoperability, and accessibility of GHG data; and 5) Support development of science-based standards to ensure consistent and accurate GHG measurements (GHG IWG, 2023).

Additionally, the U.S. Greenhouse Gas Center was launched, which will serve as a hub for collaboration between agencies across the U.S. government as well as non-profit and private sector partners. Data, information, and computer models from observations from the International Space Station, various satellite and airborne missions, and ground stations are available online. The center's data catalog includes a curated collection of data sets that provide insights into greenhouse gas sources, sinks, emissions, and fluxes.

EPA's Final Rule for Oil and Natural Gas Operations

In December 2023, EPA issued a final rule regulating methane from oil and natural gas operations. The final rule includes a Super Emitter Program that will allow third parties to report large methane releases detected by approved remote-sensing technologies. EPA will receive and evaluate the third-party data, notify owners and operators mitigate emissions, and make data publicly available.

Conclusions

As the science and technology of top-down greenhouse gas measurements develops, MDE will continue to evaluate robust accounting protocols, guided by emerging research, while maintaining consistency with national and international inventory standards. Brief conclusions regarding current limitations and the potential role for utilizing top-down measurements are provided below. For a comprehensive discussion of bottom-up and top-down approaches to methane emissions see the National Academies of Sciences, Engineering, and Medicine (NASEM) Consensus Study Report on Improving Characterization of Anthropogenic Methane Emissions in the United States (2018).

Limitations in Developing an Inventory From Top-Down Measurements

- The conversion of concentrations to emissions
  - Aircraft and tower stations record observations as concentration measurements. Atmospheric inverse analyses, using transport and dispersion models, are required to estimate fluxes of emissions and can add uncertainty.
- Limited seasonal sampling versus the need for inventories to quantify annual emissions
  - Tower station observations in the Baltimore and Washington, DC region have shown seasonal cycles in methane concentrations, with higher concentrations in the winter associated in part with natural gas use. (Karion et al., 2020)
- Attribution to sources
- The need for repeated surveys every inventory year

Potential Role for Top-Down Monitoring

- Targeted studies that inform inventory emissions factors and bottom-up models
- Geographical representation of emissions sources and revealing unknown sources
- Confirming reduction trends
  - Decarbonization measures in the buildings and industry sectors lead to reduced natural gas consumption. For the economywide modeling of Maryland's Climate Pollution Reduction Plan, the University of Maryland (UMD) Center for Global Sustainability (CGS) projects lowers methane emissions from the natural gas distribution and transmission system correlated to the reduced gas throughput. Current inventory methane emissions from natural gas infrastructure are calculated with emission factors that are based on average leak rates per length of pipeline and vary only based on pipe material. The emission factors do not vary with throughput. Top-down monitoring of methane can be used to confirm the expected reduction trends.

Additional Resources

- National Academies of Sciences, Engineering, and Medicine. 2018. Improving Characterization of Anthropogenic Methane Emissions in the United States. https://nap.nationalacademies.org/catalog/24987/improving-characterization-of-anthropogenic-methane-emissions-in-the-united-states
- University of Maryland, Fluxes of Atmospheric Greenhouse Gases in Maryland (FLAGG-MD): https://www2.atmos.umd.edu/~flaggmd/

- National Institute of Standards and Technology (NIST), Greenhouse Gas Measurements Program: https://www.nist.gov/greenhouse-gas-measurements
    - Northeast Corridor Urban Test Bed: https://www.nist.gov/programs-projects/northeast-corridor-urban-test-bed-greenhouse-gas-emissions
    - Greenhouse gas observations from the Northeast Corridor tower network: https://essd.copernicus.org/articles/12/699/2020/
- National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL): https://www.arl.noaa.gov/
- National Strategy to Advance an Integrated U.S. Greenhouse Gas Measurement, Monitoring, and Information System (U.S. GHGMMIS): https://www.whitehouse.gov/omb/briefing-room/2023/11/29/interagency-working-group-releases-national-strategy-enhance-nation-greenhouse-gas-measurement-monitoring-capabilities/
- U.S. Greenhouse Gas Center: https://earth.gov/ghgcenter
- Clean Energy 101: Methane-Detecting Satellites: https://rmi.org/clean-energy-101-methane-detecting-satellites/
- Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2020: Updates for Post-Meter Emissions: https://www.epa.gov/system/files/documents/2022-04/2022_ghgi_update_-_meter.pdf
- Large Fugitive Methane Emissions From Urban Centers Along the U.S. East Coast: https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019GL082635

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Maryland Department of the Environment (MDE). 2022. Technical Support Document for COMAR 26.11.42 – Control of Methane Emissions from Municipal Solid Waste Landfills. https://mde.maryland.gov/programs/regulations/air/Documents/Technical%20Support%20Document%20-%20Control%20of%20Methane%20Emissions%20from%20MSW%20Landfills%20-%20Final%20w%20appendices.pdf

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The Greenhouse Gas Measurement and Monitoring Interagency Working Group (GHG IWG). National Strategy to Advance an Integrated U.S. Greenhouse Gas Measurement, Monitoring, and Information System, 2023. https://www.whitehouse.gov/wp-content/uploads/2023/11/NationalGHGMMISStrategy-2023.pdf

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U.S. Environmental Protection Agency (EPA) Science Advisory Board (SAB). 2023. Science Advisory Board Review of the Scientific and Technical Basis of the Proposed Rule: Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review. EPA-SAB-23-005.