REPORT TO THE PRESIDENT

Accelerating Effective Reduction of Greenhouse Gas Emissions

Executive Office of the President

President's Council of Advisors on Science and Technology

February 2024

About the President's Council of Advisors on Science and Technology

The President's Council of Advisors on Science and Technology (PCAST) is a federal advisory committee appointed by the President to augment the science and technology advice available to him from inside the White House and from the federal agencies. PCAST is comprised of 28 of the Nation's thought leaders, selected for their distinguished service and accomplishments in academia, government, and the private sector. PCAST advises the President on matters involving science, technology, and innovation policy, as well as on matters involving scientific and technological information that is needed to inform policy affecting the economy, worker empowerment, education, energy, the environment, public health, national and homeland security, racial equity, and other topics.

For more information about PCAST see www.whitehouse.gov/pcast.
https://doi.org/10.2172/2482037

EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

President Joseph R. Biden, Jr.
The White House
Washington, D.C.

Dear Mr. President,

Your Administration has set ambitious and urgently needed goals for national emissions reduction to achieve a Net Zero emissions economy by 2050, with a sustainable balance between the amount of greenhouse gases produced and the amount eliminated or sequestered. Accelerating emissions reduction will ease climate change impacts upon our Nation while also creating jobs and engendering a healthier environment for all Americans. Your Administration's actions and investments, including the Inflation Reduction Act and the Infrastructure Investment and Jobs Act, have already set the wheels to Net Zero in motion, mobilizing the private sector and stimulating greenhouse gas emissions reduction in many sectors.

Achieving Net Zero is an unprecedented endeavor of grand scale that raises a number of challenges not fully addressed by current national strategies or policy. This effort will require the participation by federal and state and local governments, academia, corporations, industry, and citizens. The recommendations in this report will strategically address these key questions: How can we accelerate emissions reduction by identifying the largest sources of emissions in near real-time so that we can act promptly? How can we provide emissions information that can inform and incentivize both voluntary and enforcement-based emissions reduction efforts? How will we know that we are really reducing emissions, or verify that specific investments have produced the needed national emissions reduction? How will we determine which emissions reduction methods are most impactful and cost-effective while boosting jobs and American competitiveness? What can we learn in the next 10 years to guide our national strategy for the following 30 years?

As we are making strides to reduce all greenhouse gas emissions, addressing methane specifically and immediately will be especially impactful. Reducing large localized methane emissions events, or point-source methane, from the oil and gas sector as well as diffuse emissions from agriculture and landfills, offers an early test bed for the data systems we need, while also addressing a particularly harmful greenhouse gas and providing significant health benefits for Americans living near methane sources.

Vetted, validated, and reliable data is essential to tracking our Nation's progress towards the emissions targets you have set forth. Also needed is a data infrastructure that facilitates decision making and course correction. PCAST applauds the ambitious plans agencies have developed to meet your challenge and endorse your Administration's strategy to create an integrated greenhouse gas measurement, monitoring, and information system.[1] The recommendations that follow build upon your Administration's impressive work thus far. The framework and goals described in this report

[1] The White House. (2023 November). *The Biden-Harris Administration National Strategy to Advance an Integrated U.S. Greenhouse Gas Measurement, Monitoring, and Information System*

are essential to establish a system that has the scope and rigor needed to support Administration goals, and that facilitates our understanding of *how* to bring U.S. emissions to Net Zero by midcentury and make the most effective use of IRA funds. Implementing the recommendations in this report will also position the U.S. as the leader in international efforts to quantify emissions reduction and serve as a guide to other countries as they develop their own emissions inventories.

Sincerely,

Your President's Council of Advisors on Science and Technology

The President's Council of Advisors on Science and Technology

Co-Chairs

Frances H. Arnold
Linus Pauling Professor of Chemical Engineering, Bioengineering, and Biochemistry
California Institute of Technology

Maria T. Zuber
Vice President for Research and E. A. Griswold Professor of Geophysics
Massachusetts Institute of Technology

Arati Prabhakar
Director, Office of Science and Technology Policy
Assistant to the President for Science and Technology
The White House

Members

Dan E. Arvizu
Former Chancellor
New Mexico State University System

Dennis Assanis
President
University of Delaware

John Banovetz
Executive Vice President, Chief Technology Officer and Environmental Responsibility
3M Company

Ash Carter (1954–2022)
Director, Belfer Center for Science and International Affairs and Belfer Professor of Technology and Global Affairs
Harvard University

Frances Colón
Senior Director, International Climate
Center for American Progress

Lisa A. Cooper
Bloomberg Distinguished Professor of Equity in Health and Healthcare and Director of the Center for Health Equity
Johns Hopkins University

John O. Dabiri
Centennial Professor of Aeronautics and Mechanical Engineering
California Institute of Technology

William Dally
Chief Scientist and Senior Vice President for Research
NVIDIA

Sue Desmond-Hellmann
Former CEO
Bill & Melinda Gates Foundation

Inez Fung
Professor of Atmospheric Science
University of California, Berkeley

Andrea Goldsmith
Dean of the School of Engineering and Applied Science and the Arthur LeGrand Doty Professor of Electrical and Computer Engineering
Princeton University

Laura H. Greene
Chief Scientist, National High Magnetic Field Laboratory
Florida State University, University of Florida, and Los Alamos National Laboratory
Marie Krafft Professor of Physics
Florida State University

Paula Hammond
Institute Professor, Vice Provost of Faculty and member of the Koch Institute for Integrative Cancer Research
Massachusetts Institute of Technology

Eric Horvitz
Chief Scientific Officer
Microsoft

Joe Kiani
Chairman and CEO
Masimo

Jon Levin
Philip H. Knight Professor and Dean of the Graduate School of Business
Stanford University

Steve Pacala
Frederick D. Petrie Professor Emeritus in the Department of Ecology and Evolutionary Biology
Princeton University

Saul Perlmutter
Franklin W. and Karen Weber Dabby Professor of Physics and Director of the Berkeley Institute for Data Science
University of California, Berkeley
Senior Scientist,
Lawrence Berkeley National Labs

William Press
Leslie Surginer Professor of Computer Science and Integrative Biology
The University of Texas at Austin

Jennifer Richeson
Philip R. Allen Professor of Psychology and Director of the Social Perception and Communication Lab
Yale University

Vicki Sato
Professor of Management Practice (Retired)
Harvard Business School

Lisa Su
Chair and CEO
Advanced Micro Devices (AMD)

Kathryn Sullivan
Former Astronaut
National Aeronautics and Space Administration
Former Administrator
National Oceanic and Atmospheric Administration

Terence Tao
Professor and the James and Carol Collins Chair in the College of Letters and Sciences
University of California, Los Angeles

Phil Venables
Chief Information Security Officer
Google Cloud

Catherine Woteki
Visiting Distinguished Institute Professor in the Biocomplexity Institute
University of Virginia
Professor of Food Science and Human Nutrition
Iowa State University

PCAST Staff

Lara Campbell
Executive Director

Reba Bandyopadhyay
Deputy Executive Director

Melissa Edwards
Assistant Deputy Executive Director

Bich-Thuy (Twee) Sim
Assistant Director for Transformative
Medicine and Health Innovation

Kimberly Lawrence
Administrative Specialist

Riya Dhar
Intern

Anne-Marie Mazza
Former Executive Director

Sarah Domnitz
Former Principal Deputy Executive Director

Kevin Johnstun
Former Policy Analyst

Karin Saoub
Former AAAS Science and Technology Policy Fellow

Alexia Sare
Former Policy Analyst

Jon Judd
Former Intern

Maya Millette
Former Intern

Working Group on Reduction of Greenhouse Gas Emissions

Working Group members participated in the preparation of this report. The full membership of PCAST reviewed and approved the report.

Co-Leads

Inez Fung
Professor of Atmospheric Science
University of California, Berkeley

Saul Perlmutter
Franklin W. and Karen Weber Dabby Professor of Physics and Director of the Berkeley Institute for Data Science
University of California, Berkeley
Senior Scientist
Lawrence Berkeley National Labs

William Press
Leslie Surginer Professor of Computer Science and Integrative Biology
The University of Texas at Austin

Catherine Woteki
Visiting Distinguished Institute Professor in the Biocomplexity Institute
University of Virginia
Professor of Food Science and Human Nutrition
Iowa State University

Working Group Members

Frances Colón
Senior Director, International Climate
Center for American Progress

John O. Dabiri
Centennial Professor of Aeronautics and Mechanical Engineering
California Institute of Technology

Eric Horvitz
Chief Scientific Officer
Microsoft

Steve Pacala
Frederick D. Petrie Professor Emeritus in the Department of Ecology and Evolutionary Biology
Princeton University

Kathryn Sullivan
Former Astronaut
National Aeronautics and Space Administration
Former Administrator
National Oceanic and Atmospheric Administration

Executive Summary

The Biden/Harris Administration has launched an unprecedented revolution in climate and energy policy that will make the Nation healthier, safer, and more prosperous. The Inflation Reduction Act; Innovation, Infrastructure and Jobs Act; CHIPS and Science Act; and the Biden/Harris Administration's suite of climate-related Executive Orders will have set the Nation on a fair and just path toward Net Zero greenhouse gas (GHG) emissions at midcentury, while saving many thousands of people from air pollution deaths, increasing employment in high quality energy-related jobs, revitalizing the Nation's industrial sector, and demonstrating commitment to meeting global climate goals.[2]

The scope and scale of this Administration's revolutionary policies represent exceptional challenges. Achieving Net Zero requires slashing emissions of the suite of climatically important GHGs: carbon dioxide, methane, and nitrous oxide, and others – each with its own diverse set of production sources and sequestration 'sinks.' Currently, the Nation's GHG monitoring capability is distributed across many different agencies, as well as academia, non-governmental organizations, and the private sector. A further challenge is that our national emissions inventory, coordinated by EPA with significant interagency coordination, is compiled from estimates made by individual entities, often with little validation. These estimates are based on targeted emissions measurements that are aggregated and extrapolated across similar emissions sources. There is simply not enough information about all the emissions sources and emissions conditions across the country to evaluate the accuracy of the estimates. With no central system of GHG measuring, monitoring, reporting, and verification (MMRV), our Nation's emissions inventory contains critical gaps, has inconsistent levels of rigor, and sometimes suffers decade-long delays in reporting, as described in more detail in this report. Moreover, the national inventory is not designed to provide sufficiently detailed local data in an understandable format to promote local decision-making around specific emissions.

To track and accelerate our progress towards Net Zero and to maintain public support for these policies, the Nation will need data gathering, analysis, and reporting of GHG emissions that is timely, rigorous, comprehensive, and sustained. Emissions monitoring should be designed to help farmers and entities like cities and corporations that want to voluntarily reduce their emissions. The emissions estimate also needs to be independently verified and validated so that we can trust our understanding of what policies and emissions reduction practices are working best and which need course correction, and so that the public is aware of the benefits.

---

[2] Executive Order 13990, 86 FR 7037 "Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis" (January 25, 2021).
Executive Order 14008, 86 FR 7619 "Tackling the Climate Crisis at Home and Abroad" (February 1, 2021)
Executive Order 14030, 86 FR 27967 "Climate Related Financial Risk" (May 25, 2021)
Executive Order 14017, 86 FR 11849 "America's Supply Chains" (March 1, 2021)
Executive Order 14037, 86 FR 43583 "Strengthening American Leadership in Clean Cars and Trucks" (August 10, 2021)
Executive Order 14057, 86 FR 70935 "Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability" (December 13, 2021)
Executive Order 14081, 87 FR 56849 "Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy" (September 15, 2022)

With decades of investment in basic research, greenhouse gas science has matured, with local activity-based measurements of emissions and emissions rates, process models that allow us to understand the factors that modulate emissions, and airborne and space-borne observations of greenhouse gases from which local or regional emissions can be derived. PCAST has reviewed the Nation's current scientific and technical capabilities and concludes that the U.S. is now ready to move from research to operations and create a system that rigorously assesses the Nation's GHG emissions and guides our transition to Net Zero. In addition to facilitating all of the benefits of the energy transition, such an operational system would provide standards and information to support the Nation's burgeoning ecosystem of private climate service companies and would transform our ability to estimate the emissions of other countries remotely to help them achieve their own emissions goals.

The recently released report by the White House Greenhouse Gas Monitoring and Measurement Interagency Working Group: *National Strategy to Advance an Integrated U.S. GHG Measurement, Monitoring, and Information System* (GHGMMIS) Strategy, reaches these same conclusions.[3] PCAST fully endorses and applauds the recommendations in the National Strategy. Our purpose here is to emphasize the critical attributes of such a system, which PCAST has concluded are essential to deliver on our climate and energy goals.

The Biden/Harris Administration recognizes that quickly reducing methane emissions will slow down warming in the near-term and reduce a health hazard at the same time. While continuing to pursue efforts to reduce all greenhouse gas emissions, PCAST urges immediate and direct work especially on methane, which will provide an excellent test case for an operational system that rigorously assesses overall U.S. emissions.

The agricultural sector is the largest source of methane emissions in the U.S. and its scale and complexity pose unique challenges to comprehensively and accurately monitoring these emissions.[4] Uncertainties in agricultural emissions estimates translate directly into uncertainties in the national methane emissions inventory and less effective mitigation efforts. Currently, emissions estimates from the agriculture and forestry sectors are mostly out-of-date and unverified, as they are estimated from sparse measurements or from decadal surveys and emissions factors that may not capture current conditions in the working fields or advances in agricultural best practice.

Urgent action is needed to accelerate and sustain an integrated GHG MMRV system that achieves the Nation's climate goals.

Recommendations

Recommendation 1. Establish a unified common operating picture for the Nation of emissions measurements, monitoring, reporting, and verification to enable accurate, granular, validated, and timely GHG information at multiple geographic and temporal scales.

Given the urgency of reducing our Nation's GHG emissions, PCAST recommends that the President immediately establish a National GHG Monitoring and Information Office that would further the

[3] The White House. (2023 November). *The Biden-Harris Administration National Strategy to Advance an Integrated U.S. Greenhouse Gas Measurement, Monitoring, and Information System*

[4] Environmental Protection Agency. (2023). Overview of Greenhouse Gases

development and provide oversight of the U.S. GHGMMIS Strategy to 2050 and beyond, as well as host all federal and non-governmental data on GHG concentrations and emissions in the U.S., ensuring a common operating picture and providing actionable information to facilitate emissions reduction.

Recommendation 2. Increase the Nation's capacity to track and accelerate progress toward Net Zero in 2050 and beyond by strengthening research and infrastructure to innovate MMRV of GHG emissions.

To sustain GHG MMRV to 2050 and beyond, we recommend the development of a multi-decadal strategy for satellite observations for GHG MMRV that is coordinated among the agencies, academia, and the private sector. This would maintain U.S. leadership in satellite observations. We also recommend that the National GHG Monitoring and Information Office coordinate interagency research programs to innovate, expand, and sustain GHG MMRV. This would involve, among other things, the innovation of affordable sensors and their calibration, as well as automation of data collection and reporting.

2.1 Develop a multi-decadal strategy for satellite observations for greenhouse gas MMRV.

2.2 Coordinate interagency research programs to accelerate innovation of affordable sensors and their calibration, to develop systems that could automate GHG data collection and reporting, and to expand the GHG monitoring efforts across the country.

Recommendation 3. Expand comprehensive and up-to-date monitoring and reporting of methane emissions from all sectors and incorporate verification using atmospheric approaches.

To quickly advance our Nation's climate and equity goals we recommend expanding and sustaining monitoring and timely reporting of data on methane emissions from the entire supply chain of oil and gas industries and the entire life cycle of methane. We further recommend expanding atmospheric monitoring programs nationwide, to include neighborhoods in the vicinity of large methane sources and other urban areas. Frequent and routine synthesis of atmospheric-based and activity-based emissions estimations is critical to producing coherent and consistent regional and global scale methane emissions estimates. The synthesis would also point to and prioritize next steps for emissions reduction. Although methane is not our only GHG challenge, addressing methane first can provide rapid improvements to help minimize the already dire impacts of climate change as well as improve community health.

3.1 Accelerate and expand the monitoring and timely reporting of data on methane emissions from the entire supply chain of oil and gas industries and the entire life-cycle of fossil methane.

3.2 Expand atmospheric methane monitoring coverage to include neighborhoods in the vicinity of large methane sources, and in urban areas across the country.

3.3. Accelerate the transition from research to operations in order to integrate atmospheric-based and activity-based emissions estimations to produce consistent regional, national, and global scale methane emissions estimates.

Recommendation 4. Accelerate, expand, modernize, and sustain the measuring, monitoring, reporting and verifying of GHG emissions from the agricultural and forestry sectors, focusing first on methane, in order to assess and enhance the effectiveness and implementation of climate-smart agriculture and forestry practices.

The strategy should establish protocols and metrics for direct measurement of methane emissions from systems that are significant but poorly quantified sources, especially methane emissions from rice cultivation, enteric fermentation, waste management systems, and managed and working wetlands. We also recommend accelerating the collection, reporting, and dissemination of data on agricultural practices such as tillage, fertilizer amendments, and animal feed, as well as on the associated methane emissions coefficients. Data latency should be no more than two years.

The recommendations in this report are aimed at supporting and accelerating the U.S. GHGMMIS Strategy and agency efforts towards Net Zero. They would also maintain the U.S. as the international leader in GHG quantification and can serve as a guide to other nations as they develop their own emissions inventories. The actions recommended here can be taken immediately to advance the climate and equity goals of the Biden/Harris Administration.

4.1 Establish protocols and metrics for direct measurement of GHG emissions from sources that are significant but poorly quantified, especially methane emissions from rice cultivation, enteric fermentation, waste management systems, and managed and working wetlands.

4.2 Accelerate the collection, reporting, and dissemination of data on agricultural practices and associated emissions factors relevant for assessing our Nation's annual GHG emissions from agriculture. Data latency should be no more than two years.

Introduction

Climate change is an existential threat. To mitigate the devastating impacts of climate change, the Biden/Harris Administration has set ambitious goals for emissions reduction to achieve Net Zero greenhouse gas (GHG) emissions by 2050. The Build Back Better agenda, Biden/Harris Executive Orders (EOs), the Inflation Reduction Act (IRA), and the Innovation Infrastructure and Jobs Act (IIJA) have been transformative.[5] They have set the wheels in motion for our transition to renewable energy. They will generate climate benefits, create high-quality jobs, boost U.S. competitiveness, and improve air quality and healthy environments for all Americans.

Agencies, academia, and the private sector have stepped up to meet the challenge set forth by the Biden/Harris Administration. PCAST applauds their technological initiatives, proposals, and the implementation of best practices for emissions reduction. PCAST is encouraged by and further endorses the White House Interagency Working Group's *National Strategy to Advance an Integrated U.S. GHG Measurement, Monitoring, and Information System* (GHGMMIS) to support accurate quantification of GHG emissions and removals to support public and private sector climate efforts in the United States at local, state, Tribal, and national levels.[6] As stated in the GHGMMIS Strategy, "The GHGMMIS Strategy will be based upon scientifically validated methods, with sufficient granularity in space and time for acquisition, analysis, and dissemination of trusted, reliable, transparent, and accurate data. The GHGMMIS Strategy will be extensible to international efforts on sustained, coordinated global GHG monitoring."

Nevertheless, Net Zero is an unprecedented challenge of grand scale that raises a number of issues that are not addressed in the Biden/Harris Administration's EOs, the GHGMMIS Strategy, or ongoing GHG reduction activities. It will require the participation by federal and state and local governments, academia, corporations, industry, and citizens. There are key outlying questions that must be addressed with a strategic and coordinated effort: How can we accelerate emissions reduction by identifying the largest sources of emissions in near real-time so that we can act promptly? How can we provide emissions information that can inform and incentivize both voluntary and enforcement-based emissions reduction efforts? How do we assess the relative effectiveness of different reduction approaches? How do we know which practices are most impactful and cost-effective for reducing emissions and boosting jobs and American competitiveness? How do we verify that our investments have produced the maximum possible emissions reduction? How do we confirm that the reductions are sustained over time? How do we determine how best to adjust our course if we veer off the path

[5] Executive Order 13990, 86 FR 7037 "Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis" (January 25, 2021).
Executive Order 14008, 86 FR 7619 "Tackling the Climate Crisis at Home and Abroad" (February 1, 2021)
Executive Order 14030, 86 FR 27967 "Climate Related Financial Risk" (May 25, 2021)
Executive Order 14017, 86 FR 11849 "America's Supply Chains" (March 1, 2021)
Executive Order 14037, 86 FR 43583 "Strengthening American Leadership in Clean Cars and Trucks" (August 10, 2021)
Executive Order 14057, 86 FR 70935 "Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability" (December 13, 2021)
Executive Order 14081, 87 FR 56849 "Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy" (September 15, 2022)
[6] The White House. (2023 November). *The Biden-Harris Administration National Strategy to Advance an Integrated U.S. Greenhouse Gas Measurement, Monitoring, and Information System*

to Net Zero? What can we learn in the next 10 years to guide our national strategy for the next 30 years?

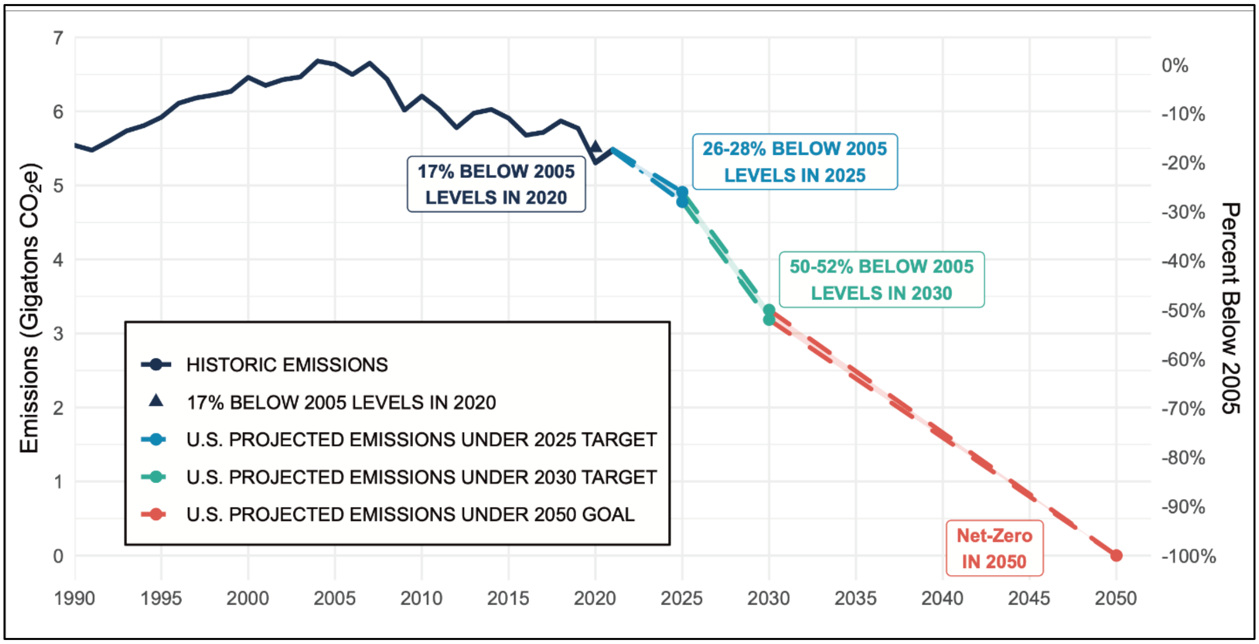

Figure 1. United States historic emissions and projected emissions under the 2050 goal for Net Zero. [7] This figure shows the historical trajectory of U.S. net GHG emissions from 1990 to 2019, the projected pathway to the 2030 Nationally Determined Contributions of 50-52% below 2005 levels, and the 2050 Net Zero goal. The United States has also set a goal for 100% clean electricity in 2035; that goal is not an economy-wide emissions goal so does not appear in this figure, but it will be critical to support decarbonization in the electricity sector, which will in turn help the U.S. reach its 2030 and 2050 goals in combination with broad electrification of end uses.

To know the best way to bring U.S. emissions to Net Zero by midcentury and beyond, and to make the most effective use of IRA funds, the U.S. will need a coherent and integrated Measurement, Monitoring, Reporting, and Verification (MMRV) system that has five components: (1) comprehensive, reliable measurements of GHG emissions across all sectors; (2) sustained monitoring of emissions over time; (3) integrated, standardized, and timely reporting to provide feedback on emissions reduction approaches and guide course corrections; (4) rigorous independent verification to provide confidence in the reported emissions reduction; and (5) ongoing engagement to ensure that data supports the evolving needs of stakeholders who are working to reduce emissions.

[7] The White House. (2021 November). *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*.

The U.S. has the fundamental scientific and technical know-how to meet all these criteria. This optimistic assessment is tempered by several hurdles that must be overcome to meet our national goals: the capabilities are scattered and fragmented across agencies, academia, and the private sector with little coordination or integration; some crucial emissions estimates rely on out-of-date information and do not reflect our current investments in emissions reduction; and there is lack of independent verification of self-reported and self-certified estimates.

Box 1. Acknowledgement of Need for Workforce Growth

A broadly representative and well-prepared workforce is a critical component of our Nation's efforts to effectively accelerate emissions MMRV and achieve Net Zero, and it deserves a more strategic and thorough addressing than is possible in this report. PCAST acknowledges the significant impacts that transitioning to Net Zero will have on the environment as well as communities and individuals. Preparing the workforce needed for the future "green economy" and to support community needs will require engagement from academia, industry, and the non-governmental sectors. We encourage enthusiastic development of educational and training opportunities across the Nation, especially in areas that are close to emissions sources.

We also want to highlight the need to share data, and develop tools that use those data in a way that engages communities in decision-making. Our hope is that the recommendations stated in this report help encourage accessible and usable data for local communities, particularly for those heavily impacted by GHGs and emissions reduction efforts. Substantial growth in a trained workforce is a part of the challenges outlined here and we are encouraged by current efforts, such as in the IRA and IIJA, that will incentivize industry growth and job creation. PCAST encourages efforts to innovatively serve communities and to meet the workforce and infrastructure needs of the coming decades.

A whole-of-country, unified, and complete picture of all activity-based and atmospheric-based estimates of GHG emissions

To accelerate and assess our progress towards Net Zero and the effectiveness of our investments in GHG emissions reduction on the national scale, the U.S. must first be advancing and expanding efforts for emissions reduction across all sectors. The Nation must also have a unified and complete picture of all the individual activity-based emissions measurements and atmospheric-based estimates to generate a comprehensive understanding of emissions from the diverse emissions sources. This comprehensive understanding is necessary to guide the aggregation of local and regional estimates so that we can assess our Nation's path to Net Zero. Developing this unified and complete picture will require breaking down the current siloed approach to emissions estimation. More importantly, this effort will also require a single data center with all emissions and concentration measurements, estimates, as well as meta-data and documentation in common standardized formats. Furthermore, the emissions data, once validated, must be sufficiently disaggregated, downscaled, and localized to inform local mitigation decisions. The sector-specific analytic tools and models must be available to all governmental and non-governmental users to synthesize and check how effective their best practices have been in reducing emissions.

Recommendation 1:

Establish a whole-of-country, unified common working picture of emissions measurements, monitoring, reporting, and verification to enable accurate, verified GHG information at multiple geographic and temporal scales.

PCAST fully endorses the White House Interagency Working Group's *National Strategy to Advance an Integrated U.S. GHG Measurement, Monitoring, and Information System* (GHGMMIS) Strategy and its science-based objectives to advance GHG measurement and monitoring capabilities and to coordinate and focus the significant ongoing activities across federal agencies, academia, and the private and non-governmental sectors. We are further encouraged by the Phase 1 implementation plan in the National GHGMMIS Strategy that outlines tasks with multi-agency collaboration, and by the plan to develop an open access, online portal with timely GHG data products useful to, and readily accessible by, policymakers and stakeholders.

However, as currently articulated, the GHGMMIS Strategy is a coalition of the willing, without clarity of command into the next decades. The U.S. needs a durable entity with administrative authority and budget to sustain measuring and monitoring efforts to 2050 and beyond, to facilitate comprehensive and reliable GHG measurements and their interoperability across all sectors, and to be the one-stop shop for information that is readily accessible and adaptable by stakeholders for their applications.

PCAST recommends that the President immediately establish a National GHG Monitoring and Information Office that would guide and provide oversight for the development of the U.S. GHGMMIS Strategy to 2050 and beyond, as well as host all GHG concentrations and emissions data in the U.S., ensuring a common operating picture and providing actionable information to facilitate emissions reduction.

The National Office would build on the momentum of the U.S. GHGMMIS Strategy and leverage the buy-in among federal agencies. This office should convene the agencies to further the strategy of the GHGMMIS Strategy to sustain and integrate GHG measurement and monitoring through the next several decades. It would also provide oversight and regular assessment of implementation progress for our overall emissions reduction efforts.

PCAST fully supports the U.S. Greenhouse Gas Center articulated in the GHGMMIS Strategy and it should be a core component of the National Office recommended here. The GHG Center is currently led by National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), National Institute of Standards and Technology (NIST), and National Oceanic and Atmospheric Administration (NOAA), but should include, right from the start, the Department of Agriculture (USDA), Department of Energy (DOE), Department of Defense (DoD), Department of the Interior/Bureau of Land Management (DOI/BLM), Department of State (DoS), and other agencies with GHG interests, to avoid divergent development of standards and protocols. The GHG Center should develop protocols for data format, quality (calibration), frequency, and transparency. Submissions of data and metadata adhering to the protocol should be required from federally-funded emissions reduction efforts, and should also be incentivized for the private and non-governmental sectors.

The National Office should be given sufficient bandwidth and increases in personnel and budget capacity to meet its objectives. The office should have a core staff with expertise in GHG observations and inventories as well as in data science and artificial intelligence. Such expertise is crucial to deploying the latest know-how to weave data from the many sources and formats into a coherent and validated picture of emissions.

Tracking and accelerating emissions reduction beyond 2050

The Biden/Harris Administration's investments in emission reduction efforts will accelerate our path to Net Zero. Nevertheless, emissions of all GHGs will continue for decades. Effectively accelerating emissions reduction requires the continued development of new monitoring, measurement, and reporting technologies, as well as new data analysis techniques.

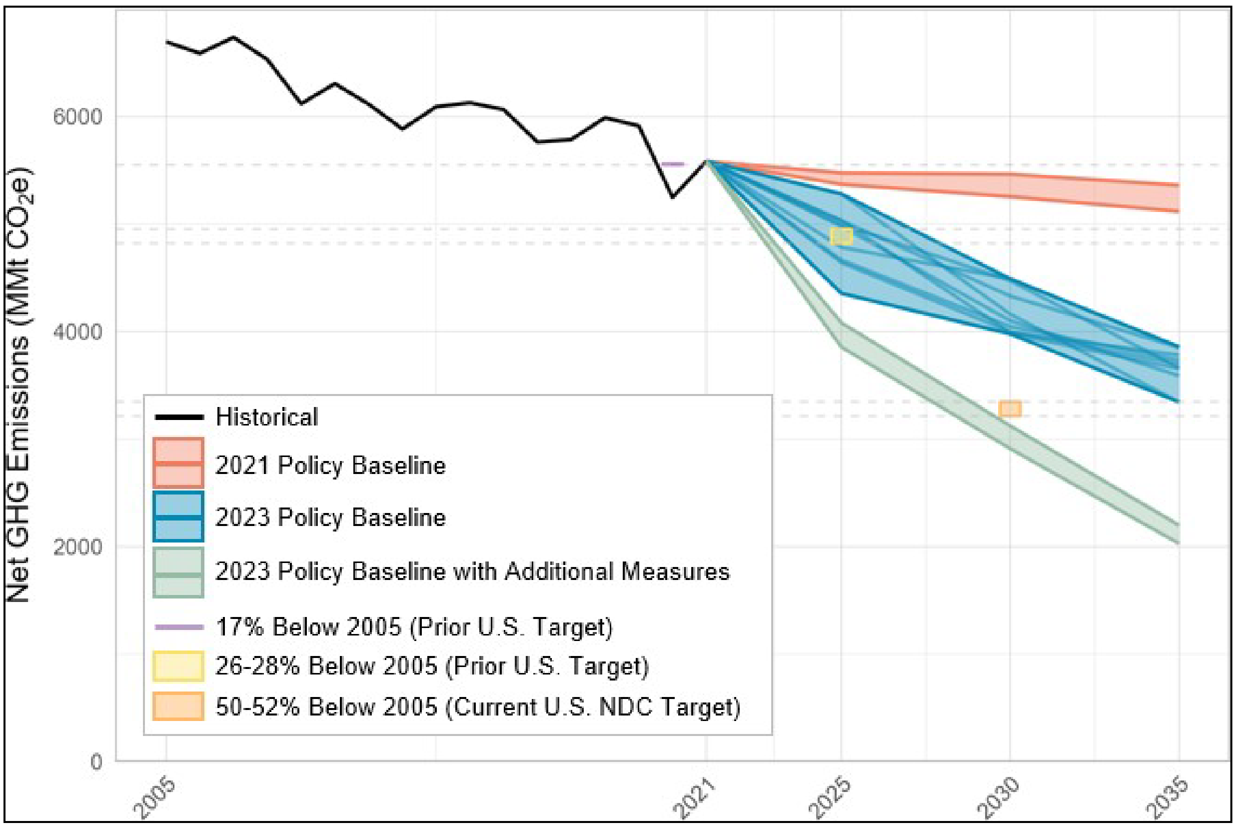

Figure 2. Net greenhouse gas emissions, historical (2005-2020) and modeled (2025, 2030, 2035).[8] The light green shaded range represents the '2023 Policy Baseline with Additional Measures' scenario as modeled and presented in the *U.S. Long Term Strategy (LTS)*. The LTS did not model specific policies but showed a range of possible pathways for meeting the U.S. NDC Target based on 2005 emissions from the 2020 GHGI. The blue shaded area represents the range of model projections with BIL and IRA impacts (i.e., 2023 Policy Baseline). The red shaded area represents the range the 2021 Policy Baseline. (The solid blue lines represent projections from individual models).

[8] United Nations Climate Change. (2023). 2023 Voluntary Supplement to the U.S. Fifth Biennial Report.

Recommendation 2:

Increase the Nation's capacity to track and accelerate progress toward Net Zero in 2050 and beyond by strengthening research and infrastructure to innovate MMRV of GHG emissions.

2.1 Develop a multi-decadal strategy for satellite observations for greenhouse gas MMRV.

Net Zero relies not only on reduction in GHG emissions associated with the energy transition from fossil fuel sources, but also on "negative emissions" such as carbon capture and sequestration as well as direct air capture of CO_2. Currently, the terrestrial biosphere and oceans provide the only effective CO_2 "sinks," absorbing about 50% of all anthropogenic emissions. These critical natural sinks are now changing in response to human activities (e.g., deforestation) and climate change, and some may transition from sinks to sources. Thawing permafrost may release large amounts of methane to the atmosphere. It is important that our Nation has the capability of monitoring and tracking our local, regional, and net emissions to 2050 and beyond.

The 2020 report from the international Committee on Earth Observation Satellites lists the current and planned public and private satellites that measure CO_2 and methane.[9] Of the 17 satellites on the list, only four are from the U.S. (including the now-cancelled GeoCarb). Historically, NASA has been the global pioneer in satellite observations of GHG and other climate variables, and NASA observations are freely accessible and routinely updated and upgraded as remote sensing science advances. However, upcoming NASA missions are focused on new scientific discoveries and are planned according to the Earth Science Decadal Surveys developed by the National Academies of Science and Engineering, and do not extend to 2050, let alone beyond.

It is urgent that U.S. develops a multi-decadal strategy for sustained satellite GHG observing capability that is not subject to the vagaries of market forces or research trends. The strategy could be a part of the plan U.S. Group on Earth Observations (USGEO) is developing for civil Earth observations.[10] The strategy should have inputs not only from the relevant federal agencies, but also from the science community, private, and non-government sectors. The strategy should be multi-tiered, to include, among other things, satellites that provide systematic observations of GHG concentrations at kilometer-scale resolution over the globe as well as high spatial resolution (e.g. <30 meters) satellites that are optimized for measuring intense emissions plumes from point sources. The strategy should also develop the metrics (e.g. data quality, calibration, and transparency) for government purchases of data from non-government entities. This multi-tiered, multi-decadal strategy would stimulate private sector research and development, as well as maintain U.S. leadership in remote sensing of GHG.

2.2 Coordinate interagency research programs to accelerate innovation of affordable sensors and their calibration, to develop systems that could automate GHG data collection and reporting, and to expand the GHG monitoring efforts across the country.

---

[9] Committee on Earth Observation Satellites. (2023). Pilot Top-down Carbon Dioxide and Methane Budgets.
[10] The U.S. Group on Earth Observations (USGEO). (2023). USGEO Overview chaired by OSTP.

Currently, the measurement of GHG concentrations and the monitoring of emissions rely mostly on costly instruments, experienced researchers or operators, and access to facilities, sites, and infrastructure. Most of the work is currently done in research settings. To accelerate our path to Net Zero, GHG measurements need to be useful, specific, and integrated in a timely manner into accessible data that can inform mitigation decisions. Recent innovations in affordable sensors and automation, drones, and small satellites have the capacity to expand measurements of GHG concentrations and emissions from all sources and sinks across the Nation.

The National GHG Monitoring and Information Office should coordinate interagency research programs to expand GHG MMRV to 2050 and beyond. These research programs should advance sensors and instruments for not just concentrations and fluxes of GHG, but also of their isotopes and other co-emitted compounds. The isotopes and co-emitted compounds carry unique signatures of emissions sources and would aid the attribution of emissions to their sources. Equally important are metrics for calibration of data from the new sensors, and protocols for automated reporting. Similarly, the programs should leverage rapid advances in data science and artificial intelligence for the analysis, harmonization, and synthesis of the immense volumes of data into coherent GHG emissions inventories.

Box 2. Focusing on Methane.

Carbon dioxide, methane, and nitrous oxide, the main GHGs, have complex sources and sinks that involve both human activities and natural processes. The Biden/Harris Administration recognizes that even though methane comprises only 10% of human-caused U.S. GHG emissions (in terms of CO_2-equivalents), methane is a very potent GHG, accounting for approximately 30% of today's climate warming.[11] Furthermore, methane is a precursor to tropospheric ozone, which triggers respiratory illnesses and other health problems. Exposure to methane and co-emitted pollutants is thus injurious to human health, especially to those who live and work in the neighborhood of large methane sources. For instance, the Four Corners Methane Hotspot in southwest U.S. has more than 40,000 oil and gas wells.[12] San Juan County, in the southeast corner, emits the second-highest methane amount of any county in New Mexico, and over half the Native American population there live within half-mile of an oil and gas production facility.[13] Agricultural operations such as Concentrated Animal Feeding Operations (CAFO) are large sources of methane emissions, and are more likely to be located near low-income and minority communities. Large-scale application and disposal of manure produced at CAFOs disperse pathogens and contaminants to nearby communities.[14,15] Reducing methane emissions from activities such as these will slow down warming in the near-term and reduce health hazards at the same time.

---

[11] United Nations Environment Programme. (2024). Facts About Methane.
[12] Kort, E. et al. (2014). Four corners: The largest US methane anomaly viewed from space, *Geophys. Res. Lett.*, 41, 6898–6903.
[13] San Juan Citizens. (2024). Methane Hotspot
[14] National Association of Local Boards of Health Understanding. (2010). Concentrated Animal Feeding Operations and Their Impact on Communities.
[15] Son J. et al. (2021). Exposure to concentrated animal feeding operations (CAFOs) and risk of mortality in North Carolina, USA. *Sci Total Environ*.

In 2021, the U.S. led the world with the Global Methane Pledge. The Administration's U.S. Methane Emissions Reduction Action Plan has outlined steps to tackle methane emissions from the oil and gas sector, from landfills, from the agricultural sector, from heavy industry, and from building systems.[16] The White House Methane Summit held in July 2023 underscored the urgency of reducing methane emissions from the oil and gas sector to create good-paying jobs and protect community health.[17]

PCAST is very encouraged that agencies have set out their own ambitious plans and collaborations to reduce methane emissions as well as enhance their measurement and monitoring efforts. EPA, together with DOE's Office of Fossil Energy and Carbon Management (FECM) and the National Energy Technology Laboratory (NETL) have created the Methane Emissions Reduction Program to reduce emissions from the oil and gas sector.[18,19] Furthermore, at COP28 EPA released the final federal rule for sharply reducing methane and other harmful pollutants from oil and gas operations.[20] The Department of Agriculture has found carbon markets to be a potential tool for GHG reduction from the agricultural and forestry sectors, and has outlined protocols for MMRV of GHG emissions by advancing monitoring and measurement technologies as well as process-based models.[21]

Methane emissions from diverse sources are measured and/or estimated using activity-based and atmospheric-based approaches (Appendix B). When the two approaches are employed at the same location, the activity-based emissions are often shown to be underestimates. For example, atmospheric measurement of methane fluxes and emissions derived from satellite-based sensors show that EPA estimates of methane emissions from the Permian Basin and other basins are too low, by a factor of 5 to 9.[22, 23, 24] There may also be gaps in the measurements, such as emissions from natural gas delivery and end use, or methane losses from natural gas infrastructure.[25, 26] As a result, the U.S. lacks the data to quantify uncertainties in the national methane emissions inventory.

---

[16] The White House Office of Domestic Climate Policy. (2021 November). U.S. Methane Emissions Reduction Action Plan.

[17] The White House. (2023 July 26). *The Biden-Harris Administration Hosts White House Methane Summit to Tackle Dangerous Climate Pollution, while Creating Good-Paying Jobs and Protecting Community Health [Fact sheet].*

[18] Environmental Protection Agency. (2024 January). Inflation Reduction Act Methane Emissions Reduction Program.

[19] Department of Energy. (2023 November). Methane Emissions Reduction Program.

[20] Environmental Protection Agency. (2023 December 2). EPA's Final Rule for Oil and Natural Gas Operations Will Sharply Reduce Methane and Other Harmful Pollution.

[21] U.S. Department of Agriculture. (2023 October). A General Assessment of the Role of Agriculture and Forestry in U.S. Carbon Markets [Report to Congress].

[22] Robertson, A. et al. (2020). New Mexico Permian Basin Measured Well Pad Methane Emissions Are a Factor of 5–9 Times Higher Than U.S. EPA Estimates. *Environ. Sci. Technol.* 54, 21, 13926–13934.

[23] Alvarez, R. et al. (2018). Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain. *Science* 361, 186–188.

[24] Cusworth, D. et al. (2022). Strong Methane Point Sources Contribute a Disproportionate Fraction of Total Emissions Across Multiple Basins in the US. *PNAS* 119.

[25] McKain, K. et al. (2015). Methane Emissions from Natural Gas Infrastructure and Use in the Urban Region of Boston, Massachusetts. *PNAS* 112, 1941-1946

[26] Wunch, D. et al. (2016). Quantifying the Loss of Processed Natural Gas within California's South Coast Air Basin Using Long-term Measurements of Ethane and Methane. *Atmos. Chem. Phys.*, 16, 14091–14105, 2016

Reducing methane emissions requires expanded activity-based and atmospheric-based measurements. PCAST emphasizes the critical need for combining these activity-based and atmospheric-based approaches for comprehensive methane emissions estimates. Addressing methane reduction offers an early test bed for the data systems needed, while also addressing a particularly harmful greenhouse gas and providing significant health benefits for Americans living near methane sources.

Expanding MMRV across the nation to track methane emissions reduction and to advance climate and equity goals

The Biden/Harris Administration recognizes that addressing methane specifically and immediately is particularly impactful (Box 2). Current activity-based measurements of methane emissions concentrations are made in selected locations, or are made for specific emissions process (e.g. enteric fermentation). Often not all the emissions sources are covered (e.g., loss from natural gas infrastructure is not measured).[27] Those measurements specific to the operations at a site or process are extrapolated to similar operations or processes using surveys and process models. Verification using atmospheric observations, i.e., confirming that the extrapolated emissions add up and are consistent with the measured atmospheric concentration, would provide confidence in regional and national emissions. Furthermore, methane and its co-emitted pollutants are health hazards. Expansion of atmospheric concentration monitoring to include large methane sources, typically in the vicinity of disadvantaged neighborhoods, would identify, and ultimately reduce, health hazards from methane as well as co-emitted pollutants.

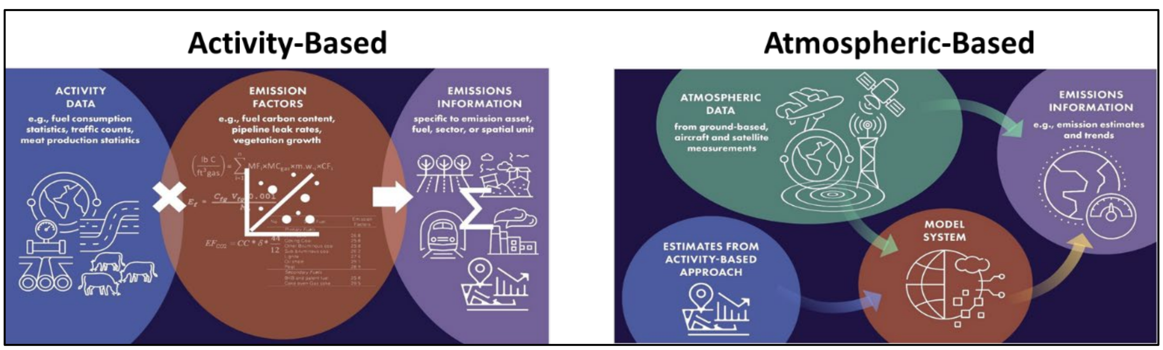

Figure 3. Activity-based versus atmospheric-based approaches.[28] *Activity-based approaches* multiply activity data (representative indicators or drivers of greenhouse gas [GHG] emissions, such as fuel consumption statistics, population, equipment counts, traffic counts) by an emission factor (a coefficient that represents the emission or removal of a GHG per unit of activity) to produce GHG emission totals or emissions by sector. *Atmospheric-based approaches* use atmospheric measurements (green) together with information about atmospheric transport and chemical processes from observations and/or from a model system (red) and/or other prior information from an activity-based inventory (blue) to infer greenhouse gas emissions (purple).

[27] McKain, K. et al. (2015). Methane Emissions from Natural Gas Infrastructure and Use in the Urban Region of Boston, Massachusetts. *PNAS* 112, 1941-1946

[28] National Academies of Sciences, Engineering, and Medicine. (2022). Greenhouse Gas Emissions Information for Decision Making: A Framework Going Forward. Washington, DC: The National Academies Press.

Recommendation 3:

To advance our Nation's climate and equity goals, expand comprehensive and up-to-date monitoring and reporting of emissions from all sectors and incorporate verification using atmospheric approaches.

3.1 Accelerate and expand the monitoring and timely reporting of data on methane emissions from the entire supply chain of oil and gas industries and the entire life-cycle of fossil methane.

The Biden/Harris Administration's Methane Task Force has an emphasis on detecting fugitive emissions using innovative technologies and holding polluters accountable.[29] PCAST is encouraged by the Methane Emissions Reduction Program created by the IRA and implemented through a partnership between EPA, FECM, and NETL to reduce emissions from the oil and gas sector.[30,31] Furthermore, EPA has proposed reporting rules to expand the coverage of emissions from the oil and gas supply chain.[32]

EPA and NASA are already collaborating to identify large anomalous oil and gas emissions events. The recently released gridded methane emissions map would help prioritize locations or operations for expanded monitoring efforts.[33] PCAST recommends that EPA, DOE, NASA, and NOAA enhance their collaboration, as discussed in the National GHGMMIS Strategy, as well as their collaboration with academia and the private sector, to combine activity-based and atmospheric-based data collection efforts. The combined efforts would improve the identification and locations of emissions sources in the oil and gas sector and the quantification of their emissions. The enhanced collaboration would involve also developing data quality standards for both activity-based and atmospheric-based measurements, especially from the new generation of methane satellites. Visual detection of a large plume in the satellite images might be enough to induce operators to voluntarily mitigate, or to motivate regulators to make an emissions estimate using their own technologies, ahead of possible enforcement action. The enhanced collaboration would also involve advancing algorithms to infer local emissions from methane concentrations measured by plume-mapping and other methane satellites in a wide range of meteorological conditions and facility settings. This effort would produce a consistent picture of emissions over time, and would update emissions factors as innovative emissions reduction technologies are implemented. Such an effort would also position the U.S. as a leader in formulating the strategies and protocols of the United Nations Environment Programme (UNEP) International Methane Emissions Observatory (IMEO).[34] The IMEO, launched in 2021, is a

---

[29] The White House. (2023 July 26). *The Biden-Harris Administration Hosts White House Methane Summit to Tackle Dangerous Climate Pollution, while Creating Good-Paying Jobs and Protecting Community Health [Fact sheet].*
[30] Environmental Protection Agency. (2024 January). Inflation Reduction Act Methane Emissions Reduction Program.
[31] Department of Energy. (2023 November). Methane Emissions Reduction Program.
[32] Environmental Protection Agency. (2023 August 1) "Greenhouse Gas Reporting Rule: Revisions and Confidentiality Determinations for Petroleum and Natural Gas Systems (40 CFR Part 98)." *Federal Register.* Vol. 88, No. 146, 50282-50441.
[33] Maasakkers, J. et al. (2023). A Gridded Inventory of Annual 2012–2018 U.S. Anthropogenic Methane Emissions*. Environmental Sci. & Technol.* 2023 *57* (43), 16276-16288.
[34] United Nations Environment Programme. (2024). Methane: UNEP tackles methane emissions from the energy sector to combat near-term global warming.

key implementing partner of the Global Methane Pledge, and its initial phase is focused on tracking methane emissions reduction from the fossil fuels industry.

3.2 Expand atmospheric methane monitoring coverage to include neighborhoods in the vicinity of large methane sources, and in urban areas across the country.

As recognized by the U.S. Methane Emissions Reduction Action Plan, the extraction and production of natural gas exposes the communities in the vicinity of production facilities to particle pollution from fine particulates ($PM_{2.5}$) and a host of toxic chemicals introduced into the atmosphere and into groundwater systems. Currently, NOAA's Global GHG Reference Network measures atmospheric methane concentrations mostly at remote locations. NIST's Urban GHG Measurement Testbed system is focused on Indianapolis, Los Angeles, and the Northeast Corridor, and combines atmospheric-based and activity-based methods to estimate emissions from the cities and identify emissions sources within the cities. The NIST-NOAA urban-scale prototype, as discussed in the U.S. GHGMMIS Strategy Phase 1 implementation, is important for engaging regional and local stakeholders in the development of data products useful for their decision-making.

PCAST recommends that NOAA and NIST work to expand their programs nationwide and include disadvantaged neighborhoods and communities, especially those in the vicinity of large methane sources such as CAFOs and oil and gas extraction and processing facilities, where the hazardous air pollutants accompany upstream oil and natural gas development.[35] Data and continued engagement with stakeholders in these areas are urgently needed to encourage emissions reduction, improve community health, and contribute to equity goals.

3.3. Accelerate the transition from research to operations in order to integrate atmospheric-based and activity-based emissions estimations to produce consistent regional, national, and global scale methane emissions estimates.

Atmospheric-based and activity-based approaches for emissions estimation are complementary, each with its strengths and limitations, see Figure. 3. Atmospheric-based approaches can supplement the often-sparse activity-based emissions estimates by connecting data on emissions locations with knowledge of dispersion and transport of methane in the atmosphere to back out regional source/sink locations and estimates of total emissions.

PCAST supports the National GHGMMIS Strategy's emphasis on improving the atmospheric dispersion and transport models used in measurement approaches. In the pipeline is a new generation of GHG satellites from NASA, the non-governmental sector, and the international community that will produce an unprecedented volume of data on GHG concentrations in the atmosphere. NASA, NOAA, and NIST should develop the protocol and metrics for including these and other atmospheric-based observations into the U.S. GHG Center. The metrics should assess, among other things, data quality (calibration), and transparency.

[35] Garcia-Gonzales, D. et al. (2019). Hazardous Air Pollutants Associated with Upstream Oil and Natural Gas Development: A Critical Synthesis of Current Peer-Reviewed Literature. *Annual Review of Public Health* 2019 40(1), 283-304

Currently, atmospheric-based methane emissions estimation is carried out in research projects by NASA, NOAA, NIST, and academia. For example, NOAA's Carbon Tracker for methane and NASA's GOES-CHEM update gridded monthly methane emissions for the U.S. and around the globe.[36,37,38] EPA is beginning to collaborate with atmospheric scientists to improve emissions quantification. PCAST recommends that this collaboration be prioritized for methane, integrating atmospheric-based and activity-based methane emissions estimation to produce consistent regional, national, and global scale methane emissions. This effort will accelerate the harmonization of methane emissions estimates from different approaches, an objective of the U.S. GHGMMIS Strategy. It will put the emissions from a single location or source into the national and global context, and guide the prioritization of subsequent reduction investments. It will also position the U.S. as a leader in the World Meteorological Organization's (WMO's) Global Greenhouse Gas Watch (GGGW), which aims to deliver, among other things, gridded methane fluxes within one month after the measurements are taken.[39]

Accelerating, expanding, and modernizing the MMRV of GHG emissions from the agricultural sector

The agricultural sector accounts for about 10% of GHG emissions in the U.S., and is the largest source of methane emissions.[40] Its scale and complexity pose unique challenges to comprehensively and accurately monitoring these emissions. Currently, emission estimates from agriculture and forestry (including wetlands and marshes) are mostly out-of-date and unverified, as they are estimated from sparse measurements or from decadal surveys and emissions factors that may not capture current conditions in the working fields or advances in agricultural best practice that have already been implemented. A routine data collection protocol is needed that expands the direct measurement of GHG fluxes and delivers, on a rolling annual basis, statistically valid representations of the practices that impact emissions. Assessing practices such as tillage, fertilizer amendments, and animal feed would assess the effectiveness of GHG emissions reduction efforts and provide the information necessary to inform future course corrections where needed.

GHG emissions from agriculture are highly variable in space and time: the emissions vary not only with year-to-year climate fluctuations, but also with local environmental conditions, infrastructure, technologies, and/or management practices. The U.S. lacks comprehensive measurements, and so cannot quantify the uncertainties of the emissions estimates. The components of the agricultural emissions are thus large and uncertain enough to prevent our ability to verify activity-based measurements with atmospheric-based measurements for the entire country. Not understanding agriculture measures means, for instance, that we do not know how reliable emissions reduction estimates captured in national emissions inventories are.

---

[36] National Oceanic & Atmospheric Administration. Global Monitoring Laboratory. Jacobson et al. (2023 February 17). CarbonTracker CT2022.
[37] National Oceanic & Atmospheric Administration. Global Monitoring Laboratory. Oh et al. (2023 September 30). CarbonTracker-CH_4 2023.
[38] GEOS-Chem. (2023 December). GCClassic 14.2.3 https://geoschem.github.io/
[39] World Meteorological Organization. (2024). Global Greenhouse Gas Watch (G3W).
[40] Environmental Protection Agency. (2023). Overview of Greenhouse Gases.

With funding from the IRA, USDA has initiated, among other things, the Climate-Smart Agricultural and Forestry (CSAF) Strategy to incentivize landowners and producers to identify and adopt effective farming and land use practices that could meet GHG reduction goals, create jobs, and make communities more resilient to climate change. PCAST applauds the ongoing USDA efforts to develop a framework and update technical approaches for quantifying GHG fluxes in agriculture and forestry.[41, 42]

Recommendation 4:

Accelerate, expand, modernize, and sustain the measuring, monitoring, reporting, and verifying of GHG emissions from the agricultural and forestry sector, focusing first on methane, in order to assess and enhance the effectiveness and implementation of climate-smart agriculture and forestry practices.

The accelerated agricultural MMRV efforts should build on the laudable list of demonstration projects outlined in the GHGMMIS Strategy and include developing and validating protocols for monitoring and estimating emissions. It should also advance metrics for assessing the effectiveness of CSAF practices to reduce methane emissions from working lands on timescales of decades and longer. These protocols and metrics would advance U.S. capabilities in emissions reduction and contribute to the Global Research Alliance on Agricultural Greenhouse Gases, of which the U.S. is a founding member. The metrics should also point to course corrections where necessary and guide policy decisions. PCAST supports the plans described in the GHGMMIS Strategy, but urges that the efforts to understand the agriculture and forestry sectors proceed more rapidly than currently planned.

4.1 Establish protocols and metrics for direct measurement of GHG emissions from sources that are significant but poorly quantified, especially methane emissions from rice cultivation, enteric fermentation, waste management systems, and managed and working wetlands.

Accelerated agricultural GHG MMRV efforts should include an implementation plan and protocol to yield GHG emissions data that are representative of the diverse GHG sources across the Nation and that are calibrated against national standards. USDA has ongoing intramural and extramural programs with flux towers that measure CO_2 and methane fluxes at research sites, such as at the Long-term Agroecosystem Research (LTAR) Network and Gracenet. Conditions at working facilities and working lands are different from those at research sites, and emissions are likely different. PCAST applauds ongoing efforts and plans to directly link research and working lands data, and encourages expanding and sustaining flux tower programs in collaboration with DOE, NSF, NOAA, and NIST, to include methane from feedlots and stockyards, waste management systems, rice fields, and working lands where CSAF best practices are being implemented. Accelerated agricultural MMRV efforts should also articulate how the number and types of monitoring sites will be expanded, what approaches will be used to collect data, as well as the frequency of measurements.

---

[41] U.S. Department of Agriculture. Natural Resources Conservation Service. (2023 October). A General Assessment of the Role of Agriculture and Forestry in U.S. Carbon Markets [Report to Congress].

[42] U.S. Department of Agriculture. (2023 July). USDA Investment in Improved GHG Measurement, Monitoring, Reporting and Verification for Agriculture and Forestry through the Inflation Reduction Act.

Accelerated agricultural MMRV efforts will also require concurrent development of metrics that could be used to assess and verify the effectiveness of various agricultural best practices in reducing methane emissions and in sustaining the emissions reduction over decades. These metrics should inform those engaged in emissions reduction how effective their practices are. These metrics should also guide the investment of IRA and other federal monies to practices that produce the maximum reduction in emissions.

4.2 Accelerate the collection, reporting, and dissemination of data on agricultural practices and associated emissions factors relevant for assessing our Nation's annual GHG emissions from agriculture. Data latency should be no more than two years.

Timely data is needed to assess the effectiveness of the emissions mitigation practices incentivized by the Climate Smart Agriculture and Forestry Strategy and to inform future course corrections. Historically, USDA's annual inventory of methane emissions relies on decadal surveys of agricultural management practices such as tillage, irrigation, and animal feed. The surveys conduct personal interviews of farmers and landowners, and include comprehensive anonymized data on conservation and management practices on croplands and the effects of these practices on, among other things, soil health, irrigation, and energy use.[43] The data are not designed for estimating emissions.[44] These disparate data about management practices, together with agricultural statistical data, are inputs to process models used to estimate methane emissions. These data currently are currently based on measurements collected up to ten years earlier, rendering the inventory data significantly out of date.

It is urgent that USDA develop and implement a routine data collection protocol that delivers, on a rolling annual basis, statistically representative data on current agricultural practices that impact GHG emissions, such as tillage, fertilizer amendments, and animal feed. The protocol should improve temporal and spatial coverage of national conservation practice data. The protocol should, where necessary, also protect the confidentiality of business sensitive information for producers in competitive markets. The data on agricultural management practices, emissions models, and their documentation should be delivered to the U.S. GHG Center, following the established protocols. The data latency should be no more than 24 months.

Conclusion

Greenhouse gas emissions in the U.S. will continue at least till mid-century due to current activities requiring fossil fuels and rates of transition to renewable energy. Successful emissions reduction depends on having accurate, granular, timely, and sustained information on GHG emissions, and on this information being made accessible to those driving mitigation actions. A GHG monitoring and information program should therefore be designed to meet the needs of and provide feedback to those driving emissions reduction. Those needs will evolve, so ongoing stakeholder engagement is essential. The information would allow for cost-benefit analysis downstream to advance and design programs around the most cost-effective ways to reduce emissions while creating jobs, enhancing American competitiveness, and improving the health and welfare of all Americans.

---

[43] U.S. Department of Agriculture. Natural Resources Conservation Service. (2022 March). Conservation Practices on Cultivated Cropland: A Comparison of CEAP I and CEAP II Survey Data and Modeling.

[44] U.S. Department of Agriculture. Office of the Chief Economist. (2022 January). U.S. Agriculture and Forestry Greenhouse Gas Inventory 1990 – 2018 [Technical bulletin 1957].

It is essential that Federal monitoring efforts be effectively coordinated with non-Federal (state, municipal, private, non-governmental organization (NGO), academic, and international) efforts. Furthermore, in a resource-limited environment, it is important to carefully prioritize targets for monitoring. For example, one might prioritize large or potentially large sources which are poorly characterized, or sources where monitoring could enable voluntary or regulatory mitigation actions. Methane is a high value target for monitoring and mitigation, and experience gained monitoring both point sources of methane from the oil and gas industry and urban areas, and diffuse sources from agriculture, will aid CO_2 monitoring efforts.

An accelerated and sustained monitoring effort is needed, and EOP should create an appropriate and enduring administrative structure that has the authority and budget capacity to marshal all to action, and to provide oversight and guide the development of the GHG Measurement and Monitoring System to 2050 and beyond.

The recommendations in this report are aimed at supporting and accelerating the U.S. GHGMMIS Strategy. They would also maintain the U.S. as the international leader in GHG quantification and serve as a guide to other nations as they develop their own emissions inventories. The actions recommended here can be taken immediately to advance the climate and equity goals of the Biden/Harris Administration.

Acknowledgements

The members of PCAST wish to thank Daniel Jacob and Steve Wofsy of Harvard and staff in the White House Office of Science and Technology Policy (OSTP), especially Jane Lubchenco, for helpful conversations. We also wish to thank the Greenhouse Gas Monitoring and Measurement interagency Working Group, especially Phil Duffy, Grace Hu, and Sonia Wang for informative and clarifying discussions. We also wish to thank the staff at the Department of Energy, particularly Karen Talamini and Natalia Melcer, who have worked tirelessly in administering PCAST.

Appendix A: Complementary Approaches: Advances in activity-based and atmospheric-based estimates of methane emissions

Methane emitted into the atmosphere is either fossil methane resulting from the fossil fuels used by the energy sector, or biological methane produced by microbes in anaerobic (oxygen-free) environments, such as landfills, stomachs of cattle, waste management systems, flooded rice fields, and wetlands.

Activity-based Approach. Currently, the emissions estimates reported to the EPA are activity-based, or "bottom-up," synthesis reports. For example, owners and operators of the large oil and gas facilities estimate and report their fossil methane emissions following protocols in EPA's Mandatory GHG Reporting Program. These reports are "self-certified." Biological methane emissions from animals are based on surveys of animal populations, animal feed, and associated emissions factors. An example of an emissions factor is the average amount of methane produced by dairy cows as a function of body weight, feed, and exercise. The emission factors, often measured under optimal conditions or in research settings, are typically decades-old and may no longer be accurate due to changes in emissions technologies and best practices. The most accurate—and thus ideal—way to estimate emissions in a "bottom-up" manner is by directly measuring the flux (amount emitted per unit of time) or methane in the air produced by an emitting entity. This measurement can be accomplished by installing instrumented flux towers at select facilities such as a rice field, dairy farm, or landfill. The flux measurements would be useful for updating emissions coefficients and checking if emissions are actually reduced based on improved practices. However, it is impractical to install instruments everywhere. Therefore, the emissions factors are used in the process methods for corresponding emitting entities to yield regional or sector-wide emissions estimates.

Atmospheric-based Approach. The atmospheric-based, or "top-down," approach measures the GHG concentration (mass per unit volume) in the atmosphere, which is an integration of all emissions across space and time. This approach may be done by directly collecting air samples at various locations, or via remote-sensing instruments mounted on airplanes, drones, or satellites. NOAA's Global Greenhouse Gas Reference Network regularly collects air samples from locations around the globe (e.g., the Mauna Loa Observatory, Hawaii), and calibrates these high-precision measurements against international standards established by the World Meteorological Organization. In a similar vein, NIST has an Urban Dome Test Bed System in Indianapolis, Los Angeles, and the Northeast Corridor. In these urban areas, GHG concentrations are measured by instruments on networks of tall towers. Satellites are an effective way to independently identify emissions regions and continuously measure methane concentrations for many significant emissions sources. NASA and other international space agencies have orbiting satellites (e.g., EMIT, TROPOMI) that continuously update atmospheric methane concentrations around the globe, with resolutions at the scale of municipalities or counties. Winds disperse and spread the emitted GHG over larger regions. Scientists working at NASA, NOAA, NIST, and in academia have demonstrated the ability to merge atmospheric methane concentration measurements, activity-based measurements, and information about the locations of emission sources and sinks in a numerical weather forecast model to infer regional methane sources and sinks. This atmospheric-based approach should produce verification of activity-based emission estimates.

Emissions estimates based on atmospheric concentration measurements have the capability to span local to regional to global scales. NIST's GHG Measurement Program has the capability to measure fine-scale (e.g., city street) GHG concentrations.[45] In addition to satellite observations by NASA and international space agencies, a new generation of small satellites from the private sector (e.g., GHGsat, CarbonMapper, MethaneSat) have the capability to map methane plumes and hotspots and estimate emissions from individual onshore and offshore oil and gas facilities, coal mines, and landfills.[46, 47, 48] They can be used in a "surveillance mode," in which operators or regulatory entities are notified when previously unknown large plumes are detected. Visual detection of a large plume in the satellite images might be enough to induce operators to voluntarily mitigate, or to motivate regulators to make an emissions estimate using their own technologies, ahead of possible enforcement action. Together with academic, non-profit, and other stakeholders, these atmospheric concentration data can be translated into local or regional emissions data that can help improve emissions reduction efforts by clarifying where emissions originate and what processes effectively reduce those emissions.

[45] National Institute of Standards and Technology. (2024). Greenhouse Gas Measurements (GHG) Program.
[46] Greenhouse Gas Emissions Monitoring. (2024).
[47] Carbon Mapper. (2024). Accelerating Local Climate Action, Globally Locating, Quantifying and Tracking Methane and CO_2 Point-Source Emissions from Air And Space.
[48] MethaneSAT. (2024).

Appendix B: External Experts Consulted

PCAST sought input from a diverse group of additional experts and stakeholders. PCAST expresses its gratitude to those listed here who shared their expertise. They did not review drafts of the report, and their willingness to engage with PCAST on specific points does not imply endorsement of the views expressed herein. Responsibility for the opinions, findings, and recommendations in this report and for any errors of fact or interpretation rests solely with PCAST.

Lori Bruhwiler
Physical Scientist, Earth System Research Laboratory
National Oceanic and Atmospheric Administration

Alyssa Charney
Director, Lands and Climate-Smart Agriculture
The White House

Deirdra Chester
Director, Office of the Chief Scientist
U.S. Department of Agriculture

Jared Ciferno
Technology Manager, Existing Plants Research Program
Department of Energy

David Crisp
Senior Research Scientist (Retired)
Earth and Space Sciences
Jet Propulsion Laboratory
National Aeronautics and Space Administration

Tom Curry
Director of Policy and Analysis, Office of Resource Sustainability
Department of Energy

Phillip Duffy
Climate Science Advisor
The White House Office of Science and Technology Policy

Riley Duran
CEO
Carbon Mapper

Marlen Eve
Deputy Administrator, Natural Resources and Sustainable Agricultural Systems
U.S. Department of Agriculture

Justina Gallegos
Deputy Director, Industrial Innovation
The White House Office of Science and Technology Policy

Gary Geernaert
Director, Earth and Environmental Systems Sciences Division
Department of Energy

Jeff Guido
Mission Director
Planet Labs

Kevin Gurney
Professor, School of Informatics, Computing and Cyber Systems
North Arizona University

Steve Hamburg
Senior Vice President and Chief Scientist
Environmental Defense Fund

Linsey Haram
Climate Fellow, Office of the Chief Scientist
U.S. Department of Agriculture

Mark Hazelgreen
Program Examiner
The White House Office of Management and Budget

William Hohenstein
Director, Office of Energy and Environmental Policy Office of Chief Economist
U.S. Department of Agriculture

Soloman Hsiang
Chief Environmental Economist
The White House Office of Science and Technology Policy

Grace Hu
Program Examiner
The White House Office of Management and Budget

Bill Irving
Chief, Climate Policy Branch
Environmental Protection Agency

Argyro Kavvada
Program Manager
U.S. Greenhouse Gas Center
National Aeronautics and Space Administration

David Knaebel
National Program Leader (Soil Biology)
National Resources and Sustainable Agricultural Systems
U.S. Department of Agriculture

Gretchen Kroh
AAAS Science and Technology Policy Fellow
U.S. Department of Agriculture

J. Michael Kuperberg
Director, U.S. Global Change Research Program
The White House Office of Science and Technology Policy

Sharyn Lie
Director, U.S. Global Change Research Program
Department of Energy

Jane Lubchenko
Deputy Director
Environment and Climate
The White House Office of Science and Technology Policy

Will Marshall
CEO, Co-Founder
Planet Labs

Yasjka Meijer
Mission Scientist, CO2M
European Space Agency

Joe Montoni
Senior Program Analyst, Agricultural Branch
The White House Office of Management and Budget

Mary Nichols
Chairwoman (Retired)
California Air Resources Board

Jeff O'Neill
Government Affairs Director
Planet Labs

Lesley Ott
Research Assistant, Meteorological Studies
Global Modeling and Assimilation
National Aeronautics and Space Administration

Ryan Peay
Deputy Assistant Secretary
Office of Resource Sustainability
Office of Fossil Energy and Carbon Management
Department of Energy

Timothy Reinhardt
Program Manager, System Analysis and Low Temperature and Coproduced Resources Programs
Department of Energy

Daniel Roberts
Research Leader
Sustainable Agricultural Systems Laboratory
Agricultural Research Service
U.S. Department of Agriculture

Hannah Safford
Senior Policy Advisor, Climate Policy Office
The White House

James Stock
Vice Provost, Climate and Sustainability
Harvard University

Daniel Stover
Program Manager, Office of Biological and
Environmental Research, Earth and
Environmental
Systems Sciences Division
Department of Energy

Colm Sweeney
Associate Director of Science
Global Monitoring Laboratory
National Oceanic and Atmospheric Administration

Emily Sylak-Glassman
Deputy Associate Director
Earth Action
National Aeronautics and Space Administration

Thomas Wagner
Program Scientist
Planetary Science Division
National Aeronautics and Space Administration

Sonia Wang
Policy Fellow
The White House Office of Management and
Budget

Melissa Weitz
Physical Scientist
Office of Atmospheric Programs
Environmental Protection Agency