# ASSESSING FEDERAL PROGRAMS FOR MEASURING GREENHOUSE GAS SOURCES AND SINKS

## JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY
SUBCOMMITTEE ON ENVIRONMENT

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

OF THE

HOUSE OF REPRESENTATIVES

ONE HUNDRED SEVENTEENTH CONGRESS

SECOND SESSION

JUNE 23, 2022

**Serial No. 117–62**

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE
47–809PDF WASHINGTON : 2023

## COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HON. EDDIE BERNICE JOHNSON, Texas, *Chairwoman*

ZOE LOFGREN, California
SUZANNE BONAMICI, Oregon
AMI BERA, California
HALEY STEVENS, Michigan, *Vice Chair*
MIKIE SHERRILL, New Jersey
JAMAAL BOWMAN, New York
MELANIE A. STANSBURY, New Mexico
BRAD SHERMAN, California
ED PERLMUTTER, Colorado
JERRY MCNERNEY, California
PAUL TONKO, New York
BILL FOSTER, Illinois
DONALD NORCROSS, New Jersey
DON BEYER, Virginia
CHARLIE CRIST, Florida
SEAN CASTEN, Illinois
CONOR LAMB, Pennsylvania
DEBORAH ROSS, North Carolina
GWEN MOORE, Wisconsin
DAN KILDEE, Michigan
SUSAN WILD, Pennsylvania
LIZZIE FLETCHER, Texas

FRANK LUCAS, Oklahoma, *Ranking Member*
MO BROOKS, Alabama
BILL POSEY, Florida
RANDY WEBER, Texas
BRIAN BABIN, Texas
ANTHONY GONZALEZ, Ohio
MICHAEL WALTZ, Florida
JAMES R. BAIRD, Indiana
DANIEL WEBSTER, Florida
MIKE GARCIA, California
STEPHANIE I. BICE, Oklahoma
YOUNG KIM, California
RANDY FEENSTRA, Iowa
JAKE LATURNER, Kansas
CARLOS A. GIMENEZ, Florida
JAY OBERNOLTE, California
PETER MEIJER, Michigan
JAKE ELLZEY, TEXAS
MIKE CAREY, OHIO

---

### SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

HON. HALEY STEVENS, Michigan, *Chairwoman*

MELANIE A. STANSBURY, New Mexico
PAUL TONKO, New York
GWEN MOORE, Wisconsin
SUSAN WILD, Pennsylvania
BILL FOSTER, Illinois
CONOR LAMB, Pennsylvania
DEBORAH ROSS, North Carolina

RANDY FEENSTRA, Iowa, *Ranking Member*
ANTHONY GONZALEZ, Ohio
JAMES R. BAIRD, Indiana
JAKE LATURNER, Kansas
PETER MEIJER, Michigan
JAKE ELLZEY, TEXAS

---

### SUBCOMMITTEE ON ENVIRONMENT

HON. MIKIE SHERRILL, New Jersey, *Chairwoman*

SUZANNE BONAMICI, Oregon
DAN KILDEE, Michigan
LIZZIE FLETCHER, Texas
CHARLIE CRIST, Florida
SEAN CASTEN, Illinois

STEPHANIE I. BICE, Oklahoma, *Ranking Member*
ANTHONY GONZALEZ, Ohio
RANDY FEENSTRA, Iowa
CARLOS A. GIMENEZ, Florida

# C O N T E N T S

**June 23, 2022**

# ASSESSING FEDERAL PROGRAMS FOR MEASURING GREENHOUSE GAS SOURCES AND SINKS

**THURSDAY, JUNE 23, 2022**

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY,
JOINT WITH THE SUBCOMMITTEE ON ENVIRONMENT,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
*Washington, D.C.*

The Subcommittees met, pursuant to notice, at 10 a.m., in room 2318 of the Rayburn House Office Building, Hon. Haley Stevens [Chairwoman of the Subcommittee on Research and Technology] presiding.

**COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY**
**SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY**
**SUBCOMMITTEE ON ENVIRONMENT**
**U.S. HOUSE OF REPRESENTATIVES**

**HEARING CHARTER**

***Assessing Federal Programs for Measuring Greenhouse Gas Sources and Sinks***

Thursday, June 23, 2022
10:00 a.m.
2318 Rayburn House Office Building and Online via Zoom

**Purpose**

The purpose of this hearing to explore Federal programs focused on monitoring, measuring, and verifying sources and sinks of greenhouse gas emissions (GHGs). The Committee will examine data and measurement challenges as well as research gaps related to improving GHG monitoring, measurement, and verification. Finally, the Committee will discuss the measurement tools, methods, and standards that can enable industries and governments to have the information they need to manage emissions effectively and where Congress should focus efforts to improve GHG monitoring, measurement, and verification.

**Witnesses**

- **Dr. Eric K. Lin**, Director, Material Measurement Laboratory, National Institute of Standards and Technology
- **Dr. Ariel Stein**, Acting Director, Global Monitoring Laboratory and Director, Air Resources Laboratory, National Oceanic and Atmospheric Administration
- **Dr. Karen M. St. Germain**, Earth Science Division Director, Science Mission Directorate, National Aeronautics and Space Administration
- **Dr. Bryan Hubbell**, National Program Director for Air, Climate, and Energy, Office of Research and Development, United States Environmental Protection Agency

**Overarching Questions**

- What are the ongoing research and development (R&D) efforts related to GHG monitoring, measuring, and verification within and outside of the Federal Government?
- What are the current gaps in GHG monitoring, measuring, and verification research?
- What are opportunities for further federal investment in GHG monitoring, measuring, and verification efforts?
- What is the role of collaboration and coordination within the Federal Government and with non-federal entities in advancing GHG monitoring, measuring, and verification?

**Background**

Greenhouse gases (GHG) are gases which trap heat in the atmosphere and are a driving force of climate change. These gases can be emitted through anthropogenic and natural sources, and include carbon dioxide, methane, nitrous oxide, and other fluorinated gases. Of these gases, carbon dioxide is the most prevalent, making up 79% of 2020 U.S. emissions. GHGs are emitted from the combustion of fossil fuels, livestock and agricultural practices, manufacturing processes, and industrial activities. [1]

Greenhouse gas emissions are measured via several technologies, including observational tower, aircraft, and satellite measurements.[2] GHG measurements are broadly undertaken in two ways. One is through a ground source, or bottom-up approach, where the data is collected near the source of the emitter. Alternatively, a top-down approach collects data on a broad atmospheric level. This data can be utilized to determine an emitter, although the data is not collected directly from the emissions source.[3] Different measurement strategies are employed by federal agencies to collect various types of GHG data, further discussed in each agency section below.

The measurements of greenhouse gases can be used for a number of different activities and the method, scale, and type of measurement can affect how those measurements are used. Measurements that are conducted at a larger scale, such as atmospheric measurements or measurements at a regional level, can be used to constrain GHG emissions at the level of nation states. In turn, this information can be used to test and evaluate greenhouse gas inventories. This information can also be used to support compliance with international agreements and frameworks regarding greenhouse gas emissions. Measurements that are conducted at a smaller scale, such as measuring the emissions of individual wellheads, can be used to drive mitigation efforts such as fixing leaks or informing regulatory work. There can be overlap between these two types of measurements and they often are used in complementary ways.

The Global Warming Potential (GWP) compares the global warming impact of different gases.[4] Carbon dioxide is used as the reference for GWP and thus, has a GWP of 1.[5] Methane, nitrous oxides, and fluorinated gases all have significant GWP's, with fluorinated gases being the most substantial. GWP provides a common unit of measurement, which is essential for compiling national GHG inventories and comparison between emissions.[6]

Due to the harmful impacts of anthropogenic GHG emissions, there have been agreements at the international level to help curtail and regulate GHG emissions. The United States Nationally Determined Contribution (NDC) as part of the Paris Agreement, the most recent international agreement, sets an economy-wide target of reducing its net GHG emissions by 50-52 percent below 2005 levels in 2030.[7] The U.S. uses the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, produced by the EPA, as the quantifiable information.[8] The quantifiable information is used as the

[1] https://www.epa.gov/ghgemissions/overview-greenhouse-gases
[2] https://www.nist.gov/greenhouse-gas-measurements
[3] https://www.fs.fed.us/pnw/pubs/pnw_gtr906.pdf
[4]https://www.epa.gov/ghgemissions/understanding-global-warming-potentials
[5] Ibid.
[6] Ibid.
[7] https://unfccc.int/sites/default/files/NDC/2022-06/United%20States%20NDC%20April%2021%202021%20Final.pdf
[8] Ibid.

starting point, or baseline, and as part of the accounting mechanism for the U.S. NDC.[9]

**Federal GHG Research and Development Activities[10]**

*Environmental Protection Agency (EPA)*
The Environmental Protection Agency's Office of Research and Development (ORD) provides scientific and technical information on GHG measurements with a research focus on improving source emissions measurements for sources with uncertain or little GHG emissions data. ORD research supports EPA's regulatory and voluntary emissions reductions programs with ORD working closely with the Office of Air and Radiation (EPA OAR). EPA focuses on a bottom-up approach, analyzing ground-level sources of GHG emission. EPA OAR utilizes the data provided by ORD to contribute toward the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.[11] ORD collaborates with a variety of stakeholders including industry, state and local regulators, and communities as part of their Next Generation Emissions Measurement (NGEM) research team. These research approaches include novel mobile and remotely operated sensor technologies for GHG detections.[12] The EPA's *Greenhouse Gas Reporting Program* (GHGRP) collects further GHG emissions data from industries including power plants, refineries, waste companies, and chemical manufacturers. It requires that large GHG emissions sources report their GHG emissions data, and approximately 8,000 facilities report data which is compiled and released as an annual report.[13] EPA also has strong collaborations with other federal agencies to improve the understanding of GHG emissions from sources with uncertainties by closing the gap between bottom-up and top-down emissions estimates.

*National Institutes of Standards and Technology (NIST)*
The NIST Greenhouse Gas Measurement Program works to develop tools and standards for accurately measuring GHG emissions. A key component of this work is the measurement science research done at NIST. NIST has developed a greenhouse gas measurement framework to measure and map urban GHG emissions, using independent top-down and bottom-up measurements to calibrate each other. The top-down measurements are captured in coordination with NSF, NOAA, and the National Center for Atmospheric Research (NCAR) using ground-based observing networks and airborne measurements of atmospheric greenhouse gas concentrations. The bottom-up measurements are advanced greenhouse gas accounting methods focused on urban locations. To test this framework, NIST established Urban Test Beds throughout the United States in 2010. The agency currently operates three testbeds in the United States: one in Indianapolis, IN; one in the Los Angeles Air Basin; and one in Northeast Corridor, which starts in the Washington, DC/Baltimore regions.[14] The Northeast Corridor test bed will be extended up to Boston. These testbeds allow NIST to develop and evaluate the performance of advanced GHG measurement capabilities. NIST's observation networks allow for measurements at a finer scale, at the city level and sometimes down to the street level. This complements the observation done at larger scales by other federal agencies. NIST measurement science research can be used by a variety of

[9] https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks
[10] Note: Several federal agencies are involved in GHG R&D activities, including many outside of the Science Committee's jurisdiction. The information in this charter should not be considered an exhaustive list of all federal GHG R&D efforts.
[11] https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks
[12] https://www.epa.gov/air-research/next-generation-emission-measurement-ngem-research-fugitive-air-pollution
[13] https://www.epa.gov/ghgreporting
[14] https://www.nist.gov/greenhouse-gas-measurements/urban-test-beds_

stakeholders including other federal agencies, state and local governments, and the private sector. By improving the accuracy of GHG emissions measurement and monitoring, this work will help stakeholders identify the best ways to reduce their GHG emissions.

In addition to the measurement science research, NIST's expertise in international standards is an important aspect of their GHG measurement work.[15] NIST has initiated the development of technical standards that will help support accuracy and transparency in GHG emissions measurements. NIST is also supporting the development of certified measurement standards, in collaboration with a number of partners, to ensure the consistency and accuracy of global GHG measurements. NIST also provides linkage traceable to the International System of Units to NOAA as the World Meteorological Organization's (WMO) Central Calibration Laboratory for GHG concentration measurements.

*National Oceanic and Atmospheric Administration (NOAA)*
The National Oceanic and Atmospheric Administration primarily conducts GHG emissions research activities through its Office of Oceanic and Atmospheric Research (NOAA OAR). NOAA's research laboratories conduct an integrated program of research, technology development, and services to improve the understanding of Earth's atmosphere, oceans, and inland waters, and to describe and predict changes occurring to them.[16] Within NOAA OAR, the Global Monitoring Laboratory (GML) provides high-precision measurements of the abundance and distribution of long-lived GHGs that are used to calculate global average concentrations.[17]

GML produces the Annual Greenhouse Gas Index (AGGI), which is a measure of the climate-warming influence of long-lived trace gases in the atmosphere and how that influence has changed since the onset of the industrial revolution.[18] Air samples are collected through the NOAA Global Greenhouse Gas Reference Network (GGRN), which provides samples from up to 80 global background air sites.[19] The GGRN also provides measurements of the atmospheric distribution and trends of the three main long-term drivers of climate change: carbon dioxide, methane, and nitrous oxide.[20] GML also performs reference measurements and research, maintains calibration scales and provides calibration services, top-down emission quantification, and satellite and model data evaluation. GML has observation facilities at the South Pole, the Artic Circle, American Samoa, and Mauna Loa. NOAA's Mauna Loa Atmospheric Baseline Observatory has collected carbon dioxide emissions since 1958 and has been essential in tracking global emissions. In 2021, carbon dioxide at Mauna Loa eclipsed 420 parts per million for the first time in human history.[21]

NOAA's Office of National Environmental Satellite Data and Information Service (NESDIS) collects raw data, including GHG emissions, from its constellation of weather and environment-monitoring satellites.[22] As part of NESDIS' data mission, the National Centers for Environmental Information (NCEI) host and provide access to comprehensive oceanic, atmospheric, and

[15] https://www.nist.gov/greenhouse-gas-measurements/international-activities_
[16] https://gml.noaa.gov/
[17] Ibid.
[18] https://gml.noaa.gov/aggi/aggi.html
[19] Ibid.
[20] https://gml.noaa.gov/ccgg/ggrn.php
[21] https://keelingcurve.ucsd.edu/2022/05/31/2114/
[22] https://www.nesdis.noaa.gov/about/what-we-do

geophysical data.[23] NCEI manages the world's largest archive of climate and palaeoclimatological data, which was essential in providing the GHG emissions measurements prior to the inception of modern instrumental measurements.[24]

*National Aeronautics and Space Administration (NASA)*

NASA conducts GHG research activities through its Earth Science Division and the management of space-based, airborne, and ground-based measurement platforms. This work focuses on observation, measurement, and foundational science. The Orbiting Carbon Observatory 2 (OCO-2) is a remote sensing satellite that collects daily space-based global measurements of atmospheric carbon dioxide from a polar Earth orbit. These measurements allow for the characterization of sources and sinks on regional scales.[25] The Orbiting Carbon Observatory 3 (OCO-3), externally mounted on the International Space Station, consists of an identical instrument as OCO-2, that measures variations through the day in the release and uptake of carbon dioxide by plants and trees in mid-latitude urban areas and major tropical rainforests. These measurements help explain global variations in atmospheric carbon dioxide levels.[26] NASA's Carbon Monitoring System, which was initiated in 2010, sponsors project opportunities for research focused on developing carbon monitoring, reporting, and verification systems.[27] NASA is also planning future work to support GHG research activities. In May 2021, NASA announced the Earth System Observatory, a planned set of Earth-focused missions based on top-priority observations recommended by the decadal survey to provide information to guide efforts related to climate change, disaster mitigation, fighting forest fires, and improving real-time agricultural processes. This project is in the formulation phase.[28] NASA is also planning the Geostationary Carbon Cycle Observatory (GeoCarb), which would place an instrument on a satellite in geostationary orbit. GeoCarb, which is due to launch by the end of 2024, will collect 10 million daily observations of the concentrations of carbon dioxide, methane, carbon monoxide and solar-induced fluorescence (SIF)over North and South America.[29] In addition to the space-based and airborne observations, NASA also sponsors ground-based networks, such as the Advanced Global Atmospheric Gases Experiment (AGAGE). AGAGE is a network of 15 ground sensors supported by NASA, NOAA, and agencies in Europe and Asia that have measured greenhouse gases and other trace gases, like the types that contribute to ozone depletion, since 1978.[30] The Earth Science Division also engages in technology development work to make sensors smaller, cheaper, and easier to deploy.

*Department of Energy (DOE)*

DOE's Advanced Research Projects Agency-Energy's (ARPA-E) Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR) program, which started in 2014, provided funding for the development of low-cost technologies to accurately locate and measure methane emissions associated with natural gas production.[31] Within DOE's Office of Fossil Energy

[23] https://www.ncei.noaa.gov/about
[24] For more information on palaeoclimatological practices, principles, and perspectives see here: https://www.ncei.noaa.gov/products/paleoclimatology/paleo-perspectives
[25] https://www.nasa.gov/mission_pages/oco2/overview
[26] https://ocov3.jpl.nasa.gov/mission/
[27] https://carbon.nasa.gov/pdfs/CMS_Phase-2_Report.pdf
[28] https://www.nasa.gov/press-release/new-nasa-earth-system-observatory-to-help-address-mitigate-climate-change
[29] https://eospso.nasa.gov/missions/geostationary-carbon-cycle-observatory-evm-2
[30] https://agage.mit.edu/about/our-mission
[31] https://arpa-e.energy.gov/technologies/programs/monitor_

and Carbon Management, the Methane Mitigation Technologies Division works to eliminate non-trivial methane emissions from the oil and gas supply chain by 2030.[32] The National Energy Technology Laboratory at DOE supports research to address mitigation and quantification of methane emissions from fossil energy supply chains.[33] DOE's Methane Reduction Infrastructure Initiative provides technical assistance to Federal agencies, states, and tribes to assist with the clean-up of orphaned wells.[34]

*Interagency Coordination*
In January 2022, the White House announced the formation of a Greenhouse Gas Monitoring and Measurement Interagency Working Group. The IWG will help identify and develop tools and data systems to measure, monitor, report and verify carbon dioxide, methane, and other GHG emissions and removals. The IWG will work to develop a national GHG system to measure, monitor, report, and verify GHG emissions that will facilitate the dissemination of GHG data to end users. The IWG is co-led by the White House Office of Science and Technology Policy (OSTP), the Office of Management and Budget (OMB), and the White House Climate Policy Office.[35]

A number of other Federal agencies outside the Committee's jurisdiction also engage in GHG measurement research activities. The U.S. Department of Agriculture's Agricultural Research Service, the U.S. Geological Survey, the Department of Transportation, and the Federal Aviation Administration all contribute to this work though they are not the subject of this hearing.

**Research Gaps and Opportunities**
There are several areas of research underway to address some of the outstanding questions related to greenhouse gas measurement. One focus of research to improve GHG measurement and observation involves work to make sensors smaller, more accurate and more cost-effective. Work to improve the accuracy of sensors used for observations must also balance the cost and size of these instruments to ensure they can be used effectively. Additional research gaps include reducing data contamination between GHG sources and sinks, especially from sources difficult to pinpoint such as shipping and aviation.[36] Further, there are opportunities for increasing research related to reducing the emission gap, or the gap between recorded and reported GHG emissions. Streamlining best practices for researching natural carbon sinks like forests and bodies of water is another area for improvement. Improved standards can improve reporting of GHG emissions in the context of international agreements and provide a pathway for reduced emissions.[37]In increased collaboration and data sharing between federal agencies and the private sector could also help improve the quality of measurements. Pilot programs such as the collaboration between NOAA and Boeing to evaluate GHGs on commercial jets are an example of such collaboration.[38]

---

[32] https://www.energy.gov/fecm/mission

[33]https://www.energy.gov/sites/default/files/202206/June%208%2C%202022%20HSST%20NETL%20Dr.%20Anderson%20Testimony%20on%20Methane%20Research%20Hearing.pdf

[34] https://www.whitehouse.gov/briefing-room/statements-releases/2022/01/31/fact-sheet-biden-administration-tackles-super-polluting-methane-emissions/

[35] https://www.whitehouse.gov/briefing-room/statements-releases/2022/01/31/fact-sheet-biden-administration-tackles-super-polluting-methane-emissions/

[36] https://www.washingtonpost.com/climate-environment/interactive/2021/greenhouse-gas-emissions-pledges-data/

[37] https://www.unep.org/resources/emissions-gap-report-2021

[38] https://research.noaa.gov/article/ArtMID/587/ArticleID/2763/NOAA-Boeing-team-up-to-test-greenhouse-gas-measuring-technology

Chairwoman STEVENS. This hearing will come to order. My colleague, Congressman Feenstra, we're both running from meetings, but this is an exciting and important topic. So without objection, the Chair is authorized to declare recess at any time.

Before I deliver my opening remarks, I wanted to note that today's Committee hearing is meeting both in person and virtually. Just a couple of reminders to Members about the conduct of this hearing. First, Members and staff who are attending in person may choose to be masked. It's not a requirement. However, any individuals with symptoms, a positive test, or exposure to somebody with COVID–19 should wear a mask while present.

Members who are attending virtually should keep their video feed on as long as they are present in the hearing. Members are responsible for their own microphones. Please keep your microphones muted unless you're speaking.

Finally, if Members have documents they wish to submit for the record, please email them to the Committee Clerk, whose email address was circulated prior to the hearing.

So, good morning, and welcome to today's joint hearing to examine Federal programs for measuring greenhouse gas sources and sinks. I really want to thank our distinguished panel of witnesses. It's just so great to be with so many of you in person today.

The vast majority of American adults, 78 percent, now say that they have been personally affected by extreme weather events in the last 5 years. This is according to a nationwide survey released this week by the Harvard School of Public Health, NPR (National Public Radio), and the Robert Wood Johnson Foundation. Americans report these events caused serious health problems, severe financial woes, and property damage. I know just yesterday I was talking to a Michigander who said she is still getting her house in order from floods she experienced last year. No State in our Nation is untouched by the damaging physical and emotional impacts of climate change.

As the hottest part of the year now gets underway, families across the country are bracing themselves for another season of devastating hurricanes, storms, floods, fires, and heat waves all while we're just trying to enjoy the Fourth of July. So it is timely that on the brink of this summer season we are holding this hearing to examine the tools the government has to properly track our greenhouse gas emissions and where our data is falling short.

Greenhouse gases act like a blanket. The gases trap heat in the atmosphere. These gases include carbon dioxide, methane, nitrous oxide, and other fluorinated gases. And they are drive—they are a driving force of climate change. Since the start of the Industrial Revolution, human activities have vastly increased the volume of greenhouse gases emitted into the atmosphere. Reducing greenhouse gas emissions is essential to mitigating the effects of climate change. I hope that that is no longer a controversial statement in Congress or one that requires further explanation. It is the year 2022, and we have been talking about this since mid-last century. Yet we seem to be arguing about whether or not we should do anything.

And so I can only hope that this Nation's leaders are able to come together soon to enact real policy to reduce emissions and ad-

dress the threats that are already at our door because it is not too late for us to respond. And in fact, this can be an opportunity for us. I come from an industrial State. I come from the heart of automotive land in Michigan, and our industry leaders are also environmental leaders because our industry leaders are our manufacturers. They are the people who work in manufacturing facilities who love to go up north. They love to access our Great Lakes. They like a regular temperature over the summer. And they certainly don't want to experience flooding in their home and incurring the costs.

So when we don't enact real policy, we need the tools to track progress and guide evidence-based decisionmaking. That's what this Science Committee is all about. We will want the most accurate tools to ensure that we are reaching our goals, but also importantly, ensure that we are able to hold other nations to accountable measurements to be global leaders. We need accurate and consistent greenhouse gas data.

And that is where our Federal science agencies come in. Many of our agencies, including those represented by the experts before us today, are engaged in tremendous research and development (R&D) work to improve our measurements of greenhouse gas emissions. This work spans the whole range of greenhouse gas measurement activities, from fundamental measurement science and technology development to operation of science-based airborne and ground-based sensors and observation platforms to maintaining greenhouse gas emissions inventories.

These agencies do not do this work in a vacuum. Each of these agencies represented here today cooperate on vital interagency work to improve greenhouse gas measurement, both on individual projects and as part of an interagency working group. Hurray, government coming together for a productive outcome for the public good. This cooperation is essential to the success of our greenhouse gas measurements. So much can be accomplished when our Federal science agencies leverage their respective expertise in support of a common goal.

I am looking forward to this hearing, and I'm looking forward to hearing more about the work that our witnesses are here today to discuss with us to support and improve the programs underway. So thank you again for joining us.

[The prepared statement of Chairwoman Stevens follows:]

Good morning and welcome to today's joint hearing to examine federal programs for measuring greenhouse gas sources and sinks. I thank our distinguished panel of witnesses—it is great to be with so many of you in person today.

The vast majority of U.S. adults—78 percent—say they have been personally affected by extreme weather events in the past five years. This is according to a nationwide survey released this week by the Harvard School of Public Health, NPR, and the Robert Wood Johnson Foundation. Americans report these events caused serious health problems, severe financial woes, and property damage. No state in our nation is untouched by the damaging physical and emotional impacts of climate change.

As the hottest part of the year now gets underway, families across the country are bracing themselves for another season of devastating hurricanes, storms, floods, fires, and heat waves. So, it is timely, that on the brink of this summer season, we are holding this hearing to examine the tools the government has to properly track our greenhouse gas emissions and where our data is falling short.

Greenhouse gases act like a blanket—the gases trap heat in the atmosphere. These gases include carbon dioxide, methane, nitrous oxide, and other fluorinated gases, and they are a driving force of climate change. Since the start of the Indus-

trial Revolution, human activities have vastly increased the volume of greenhouse gases emitted into the atmosphere.

Reducing greenhouse gas emissions is essential to mitigating the effects of climate change. I hope that is no longer a controversial statement in Congress, or one that requires further explanation. Yet we still seem to be arguing about whether to do anything about it.

I can only hope that this nation's leaders are able to come together soon to enact real policy to reduce emissions and address to the threats that are already at our door.

Because it isn't too late for us to respond.

When we do enact real policy, we will need the tools to track progress and guide evidence-based decision-making. We will want the most accurate tools to ensure we are reaching our goals, but also importantly, ensure we are able to hold other nations to accountable measurements. To be global leaders, we need accurate and consistent greenhouse gas data.

And that is where our Federal science agencies come in. Many of our agencies, including those represented by the experts before us today, are engaged in tremendous research and development work to improve our measurements of greenhouse gas emissions. This work spans the whole range of greenhouse gas measurement activities from fundamental measurement science and technology development, to operation of space-based, airborne, and ground-based sensors and observation platforms, to maintaining greenhouse gas emissions inventories.

These agencies do not do this work in a vacuum. Each of the agencies represented here today cooperate on vital interagency work to improve greenhouse gas measurement, both on individual projects and as part of an interagency working group. This cooperation is essential to the success of our greenhouse gas measurements. So much can be accomplished when our federal science agencies leverage their respective expertise in support of a common goal.

I'm looking forward to hearing more about this work from our witnesses today and to discussing what we here in Congress can do to support and improve these programs. I'd like to again thank our witnesses for joining us today.

Chairwoman STEVENS. The Chair is now going to recognize Ranking Member Feenstra for an opening statement.

Mr. FEENSTRA. Well, thank you, Chairwoman Stevens, and thank you for your passion. And thank you to our witnesses for your participation today. I'm very grateful to have you here and to hear from you.

We're here to discuss the measurement and monitoring of greenhouse gases, which can improve the tools we have available to reduce and capture emissions. Importantly, we're not just going to discuss emissions but also sinks and the processes that remove greenhouse gases from our atmosphere. One example is the land use and forestry sector, which offset total U.S. greenhouse gas emissions by 13 percent in 2020. This is an important contribution to emission reductions, and Federal R&D can help us make even this further—go further. For example, we now know the potential to improve carbon sequestration in cropland through conservation, tillage, and other practices.

Without accurate data, however, it's difficult to make significant progress in any greenhouse gas reduction efforts. So Federal science agencies are working with academia and industry to improve the monitoring, measuring, and verifying of the sources and sinks of greenhouse gas emissions. Better monitoring and measurement technologies give us the ability to implement more efficient and cost-effective practices to reduce greenhouse gases and its concentrations.

I'm encouraged by the work being done today, and I see great potential. For instance, the National Institute for Standards and Technology, NIST, is using an innovative approach through its Greenhouse Gas Measurement Program. While most cities estimate

greenhouse gas emissions indirectly through economic data such as the number of miles that vehicles drive within the city, NIST has developed atmospheric observational tools to measure emissions directly. By combining the indirect and direct observations, scientists can make better estimates for emissions and provide more useful information to its stakeholders.

NIST also operates an Urban Greenhouse Gas Measurement Testbed System, which develops and evaluates the performance of emission measurement capabilities in Indianapolis, the Los Angeles Air Basin, and the Northeast Corridor. In order to help measure, monitor, and report greenhouse gas emissions in an accurate, standardized, and transparent manner, NIST has also initiated a documentary standard effort. This work will help develop best practices that improve industry's ability to use measurement tools and quantification methods to reduce greenhouse gases in the environment. Eventually, the hope is that we will lead to the development of technical standards to improve the data quality of greenhouse gas emission reports.

NIST also works with other Federal agencies through Greenhouse Gas Monitoring and Measurement Interagency Working Groups to coordinate existing efforts. The coordination is so critical. We can't afford to have agencies duplicating work or, worse, providing conflicting information.

So I'd like to emphasize to our witnesses today how important it is that we continue to coordinate research activities moving forward to maximize our resources. In addition to learning more about the work being done to better understand lifecycle greenhouse gas emissions, I hope to learn more today about where measurement and data challenges exist and where research gaps remain. I look forward to hearing your perspectives on that. And I want to thank our witnesses again.

Madam Chair, thank you for putting this hearing on, and I yield back.

[The prepared statement of Mr. Feenstra follows:]

Thank you, Chairwoman Stevens and Chairwoman Sherrill for holding today's hearing. And thank you to our witnesses for your participation here today.

We're here to discuss measurement and monitoring of greenhouse gases, which can improve the tools we have available to reduce and capture emissions.

Importantly, we're not just going to discuss emissions, but also sinks, or the processes that remove greenhouse gases from the atmosphere.

Once such example is the land use and forestry sector, which offset total U.S. greenhouse gas emissions by 13% in 2020.

This is an important contribution to emissions reductions, and federal R&D can help us make it even better.

For example, we know there's potential to improve carbon sequestration in cropland through conservation tillage and other practices.

Without accurate data, however, it's difficult to make significant progress in any greenhouse gas reduction efforts.

So federal science agencies are working with academia and industry to improve the monitoring, measuring, and verifying of sources and sinks of greenhouse gas emissions.

Better monitoring and measurement technologies give us the ability to implement more efficient and cost-effective practices to reduce greenhouse gas concentrations.

I'm encouraged by the work being done today and I see great potential.

For instance, the National Institute of Standards and Technology (NIST) is using an innovative approach through its Greenhouse Gas Measurement Program.

While most cities estimate greenhouse gas emissions indirectly through economic data, such as the number of miles that vehicles travel within a city, NIST has developed atmospheric observational tools to measure emissions directly.

By combining the indirect and direct observations, scientists can make better estimates for emissions and provide more useful information to stakeholders.

NIST also operates an Urban Greenhouse Gas Measurements Testbed System, which develops and evaluates the performance of emissions measurement capabilities in Indianapolis, the Los Angeles Air Basin, and the Northeast Corridor.

In order to help measure, monitor, and report greenhouse gas emissions in an accurate, standardized, and transparent manner, NIST has also initiated a documentary standards effort.

This work will help develop best practices that improve industry's ability to use measurement tools and quantification methods to reduce greenhouse gases in the environment.

Eventually, the hope is that they will lead to the development of technical standards to improve the data quality of greenhouse gas emissions reports.

NIST also works with other Federal agencies through the Greenhouse Gas Monitoring and Measurement Interagency Working Group to coordinate existing efforts.

That coordination is critical. We can't afford to have agencies duplicating work or worse—providing conflicting information.

So I'd like to emphasize to our witnesses today how important it is that you continue to coordinate research activities moving forward to maximize our resources.

In addition to learning more about the work being done to better understand lifecycle greenhouse gas emissions, I hope to learn more today about where measurement and data challenges exist, and where research gaps remain.

I look forward to hearing your perspectives on that. I want to thank our witnesses again.

And Madam Chair, I yield back.

[The prepared statement of Chairwoman Sherrill follows:]

Good morning, everyone. I am pleased to welcome you, alongside Chairwoman Stevens, to today's joint subcommittee hearing. And thank you to our witnesses for joining us today to provide their expertise on programs at their agencies responsible for measuring greenhouse gas emissions and sinks. I'm looking forward to your testimonies.

Greenhouse gases, such as carbon dioxide, methane, nitrous oxide, and fluorinated gases, trap heat within the Earth's atmosphere causing our planet to become warmer. These greenhouse gases can be emitted naturally and through human activities. The scientific consensus points to the increasing emissions of anthropogenic greenhouse gases as the leading cause of climate change. We have often talked on this Committee how communities across the nation are already experiencing the effects of climate change through record rainfall amounts, bigger wildfires, longer droughts, and rising sea levels.

Every day, many Americans take individual action towards curbing their excess greenhouse gas emissions. This includes but is not limited to, buying electric vehicles, using public transportation, and purchasing carbon offsets. Governments at all levels are also supporting these efforts through developing energy efficiency standards and the rapid deployment of renewable energy infrastructure. This shift in our behavior is spurring the growth of the economy through the development of new markets and the competitiveness of those markets, as well as through innovation. Reducing carbon and other greenhouse gas emissions will not only create a healthier environment for all communities but will also encourage economic growth.

My home state of New Jersey has set an ambitious but achievable goal of 50 percent reduction of the state's greenhouse gas emissions by the end of this decade, and an 80 percent reduction by 2050. New Jersey also releases a comprehensive statewide greenhouse gas emissions inventory report every two years. This report is consistent with national and international standards for inventory practices. Other states and local communities publish similar reports to track their efforts to reduce their greenhouse gas emissions. While these efforts are imperative to monitor our greenhouse gas emissions, and reductions, the New York Times reported last year that cities across the nation are under reporting their emissions by nearly 20 percent. Accurate emissions data is essential to understanding where our communities currently stand and how the mitigation efforts are progressing.

That is what brings us here today. While we are working to curb excess greenhouse gas emissions to reduce the impacts of climate change and protect public health, we do not know exactly how much we are emitting and if our efforts to reduce these emissions are effective. The federal science agencies that we are fortunate to hear from today are some of the leaders in cutting-edge research to accurately track greenhouse gas emissions globally and domestically. To address this challenge immediately, we need to understand the current state of observation, measurement, and verification processes of the sources and sinks of greenhouse

gases, and how to improve those processes. We also need to address any challenges there may be in monitoring or collecting this valuable data.

Achieving our emissions reduction goals and meeting our commitment to the Paris Agreement requires accurate accounting of the sources and sinks of greenhouse gas emissions. We cannot mitigate what we cannot measure. The U.S. can continue to lead the world in advancing research and technology innovation to help tackle this global issue.

I look forward to the witnesses' testimony today on the ongoing federal efforts on the measurements of greenhouse gas emission data, as well as any recommendations to the Committee on how we can address research gaps related to this important issue. Thank you again for being here. I yield back.

[The prepared statement of Mrs. Bice follows:]

Thank you, Chairwoman Stevens.

Last week we had a hearing on methane emissions from the oil and gas sector. The overall message we heard was that monitoring technologies are out there, but federal regulations can hinder their widespread deployment.

Today's hearing is broader than that, as we look at the whole suite of greenhouse gases and how they are monitored, measured, and verified, no matter where they come from.

But the overarching message is likely the same: we have the ability to improve the most helpful technologies, but we need to make sure the path to deployment isn't blocked by burdensome federal regulations.

The United States already has a tremendous story to tell when it comes to environmental stewardship and reducing greenhouse gas emissions. That is largely due to industry taking the lead and acting without being forced to change—or outright stop—their productivity.

We've been the world leader in lowering carbon emissions since 2005, reducing more than the next 7 emissions reducing countries combined. Methane emissions in our country have also decreased by 17% since 1990. And as Mr. Feenstra pointed out, our land use and forestry sector continues to be a carbon sink, reducing the overall amount of greenhouse gases in the atmosphere from all sectors.

All of this has taken place while the energy and agriculture industries increased production and lowered energy costs for American households during that time.

So with in mind, I sincerely hope that today's hearing is not an attempt to villainize the energy producers like those in Oklahoma, which are producing three times more energy than the state consumes.

What I am hopeful we can talk about today is how our federal agencies are collaborating with each other when it comes to quantifying and reporting greenhouse gas emissions. Because the simple fact of the matter is that if we don't know how much or what kind of gas is in the atmosphere, we have no hope of preventing its release in the future.

Make no mistake, this is a whole-of-government approach. NASA and NOAA have satellites with global monitoring tools. NIST evaluates the performance of measurement and quantification technologies. EPA prepares the Inventory of U.S. Greenhouse Gas Emissions and Sinks, the premier collection of data related to greenhouse gases.

Each agency has a role to play, but we must ensure that federal resources are not being wasted on duplicative efforts.

With energy prices at record highs, now is not the time for virtue-signaling. If there are ways to better monitor and quantify greenhouse gases, we don't need to play the blame game. We need to understand what is impeding their deployment and work to enable their commercialization as soon as possible.

We must also remember we are talking about a global problem in need of global solutions. For every ton of greenhouse gas emissions reduced by the United States, China has increased their emissions by nearly 4 tons. We can do our part here at home, but if monitoring doesn't extend to a global reach, we have no hope of real change.

I want to thank all of our witnesses for taking the time to testify today. I look forward to your testimonies and—given that you each works for a federal agency—how you are collaborating on these efforts. I also hope to hear how each agency is incorporating a global outlook when it comes to greenhouse gases.

Thank you Madam Chair and I yield back the balance of my time.

[The prepared statement of Chairwoman Johnson follows:]

Good morning. Thank you everyone for joining us for this joint subcommittee hearing. I especially want to thank Chairs Stevens and Sherrill for holding today's hearing. This is an important and timely topic.

Last November, I attended the 26th U.N. Conference of Parties, or COP 26, in Glasgow with Speaker Pelosi and many of my colleagues. Throughout the conference, we consistently heard about the need to keep within 1.5 degrees of warming. This Committee has worked tirelessly to pass legislation that ensures we develop the tools and technologies to address climate change and its worst impacts.

Ultimately, however, we will need to enact policy to regulate greenhouse gas emissions. And for any such policy to be successful, we must have high-quality and accurate measurements of these emissions. Measurement, reporting, and verification will be the backbone of meeting obligations and holding parties accountable at the local, national, and international level, including under the Paris Climate Agreement.

But ensuring the accuracy of these measurements is a difficult challenge. Earlier this month, this Committee had a hearing about methane, during which witnesses testified that oil and gas companies are failing to measure and mitigate methane leaks. A 2021 study showed that many U.S. cities were dramatically undercounting their greenhouse gas emissions. Failing to accurately measure our emissions will undermine our ability to achieve effective climate solutions.

Fortunately, many of our Federal science agencies are working together to address this challenge. Some of our agencies, like the EPA, focus on a bottom-up approach, analyzing ground-level sources of greenhouse gases. Others, in particular NASA and NOAA, collect data top-down through the atmosphere. NIST has developed a greenhouse gas measurement framework for urban emissions, using both top-down and bottom-up measurements to calibrate one another.

In order to reach our goal of trusted measurement frameworks, new technologies will be needed to improve the accuracy of greenhouse gas measurements while bringing down their associated costs. Creating novel measurement capabilities will in turn require a workforce with the skills to operate them. And finally, we must continue to support and improve domestic and international partnerships toward our common goal of addressing climate change.

Today's discussion will rightfully focus on the science and technology needs to advance this field. However, we mustn't forget the public health impacts of greenhouse gas emissions. Communities of color are disproportionately vulnerable to the impacts of climate change caused by increased greenhouse gas emissions. Improving our ability to accurately measure greenhouse gases will in turn improve public health outcomes in these communities. The most vulnerable communities must be prioritized when improving our greenhouse measurement programs

I am excited to hear testimony from expert witnesses representing each of these agencies about their unique roles and activities related to greenhouse gas measurement. I am particularly interested to hear if the agencies need any new authorities or funding to support their important work.

Thank you, Chairs Stevens and Sherrill. I yield back the balance of my time.

Chairwoman STEVENS. And at this time, I would like to introduce our witnesses. Our first witness is Dr. Eric Lin. Dr. Lin is the Director of NIST Material Measurement Laboratory, MML. MML has more than 900 staff members and visiting scientists and serves as the Nation's reference laboratory for measurements in the chemical, biological, and materials sciences, another best kept secret at NIST. Dr. Lin has also served as the Acting Associate Director for Laboratory Programs at NIST, during which time he provided direction and operational guidance for all of NIST's scientific and technical laboratories.

Our next witness is Dr. Ariel Stein. Dr. Stein is the Director of NOAA's (National Oceanic and Atmospheric Administration's) Air Resources Laboratory and Acting Director of NOAA's Global Monitoring Laboratory. He has extensive expertise and experience working with atmospheric transport, dispersion, and photochemical models. Prior to his current role, Dr. Stein served as a Supervisory Physical Scientist at the Air Resources lab.

Our third witness is Dr. Karen St. Germain. Dr. St. Germain is the Division Director of the Earth Science Division in NASA's (Na-

tional Aeronautics and Space Administration's) Science Mission Directorate. In this role, she provides executive leadership, strategic direction, and overall management for the entire agency's Earth science portfolio. Prior to coming to NASA, she served as the Deputy Assistant Administrator systems for NOAA's Satellite and Information Service. She has also previously served in positions at the Department of Defense.

Our third—our final witness is Dr. Bryan Hubbell. Dr. Hubbell is the National Program Director for the Air, Climate, and Energy (ACE) Research Program in EPA's (Environmental Protection Agency's) Office of Research and Development, ORD. Dr. Hubbell has worked for EPA for 24 years as an expert on the health and environmental impacts of air pollution. He led the EPA project team that developed the Environmental Benefits Mapping and Analysis Program, which is used around the world to estimate the benefits of clean air.

As our witnesses should know, you'll have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. And when you've all completed your spoken testimony. We will begin with questions, and each Member will have 5 minutes to question the panel. We're going to start with Dr. Lin.

**TESTIMONY OF DR. ERIC K. LIN,**
**DIRECTOR, MATERIAL MEASUREMENT LABORATORY,**
**NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY**

Dr. LIN. Chairwoman Stevens, Chairwoman Sherrill, Ranking Members Feenstra and Bice, and Members of the Subcommittees, I'm Dr. Eric Lin, Director of the Material Measurement Laboratory at the Department of Commerce's National Institute of Standards and Technology, NIST. Thank you for the opportunity to appear before you today to discuss NIST's role in greenhouse gas measurements. NIST's laboratory programs work at the frontiers of measurement science to ensure that the U.S. system of measurements is firmly grounded in sound scientific and technical principles.

For this hearing, the NIST Greenhouse Gas Measurements Program helps businesses and governments at all levels measure, monitor, authenticate, and report greenhouse gas emissions in an accurate, transparent, and standardized manner. This measurement program will help cities demonstrate that they are contributing to the Administration's national greenhouse gas emissions reduction targets for the next 20 to 30 years.

NIST provides a system of observation networks for measuring greenhouse gases at the city level and even down to the street and block. Our work complements that of our partner agencies with their expertise in quantifying greenhouse gases on larger scales, our regions and continents.

To demonstrate the feasibility and validity of NIST's granular approach, NIST established the Urban Greenhouse Gas Measurements Testbed System. This so-called Urban Dome Project provides the measurements and accuracy that businesses and governments need for mitigation actions and science-based policy decisions. The Urban Dome Project can measure and map emissions at any level needed, down to an individual building and over a range of time

resolutions, from annual variations to seasons, weeks, days, and hours.

NIST operates measurement testbeds in Indianapolis, the Los Angeles Air Basin, and the Washington D.C./Baltimore region with plans to extend through the Northeast Corridor to Boston. These testbeds encompass a range of conditions that represent the span of U.S. urban areas. The NIST Urban Dome Project is a partnership with members of government, business, academic, and non-governmental organizations. The Urban Dome Project develops and provides mature measurements-based scientific tools, methods, and data to better estimate greenhouse gas emissions. These validated tools will enable the identification of the most economically viable emission-reduction opportunities in urban areas. Application of these tools before and after the deployment of energy efficiency where alternative energy solutions can authenticate their effectiveness.

This toolkit will soon include international documentary standards to which NIST provides technical expertise that will improve data quality in national greenhouse gas emission reports. High-quality data will help the community judge progress toward national emissions reduction targets.

NIST works closely with our Federal partners in the Greenhouse Gas Monitoring and Measurement Interagency Working Group. Coordination through this group is essential to continue to maximize the impact of agency resources; enhance the Nation's ability to measure, quantify, and monitor greenhouse gas emissions and removals; and accelerate the transition of relevant research to operational use.

Interagency and additional collaborations can enhance our understanding of greenhouse gas emissions by linking surface emission measurements to satellite and airborne observations for even more robust domestic measurement and monitoring capabilities; modeling fossil fuel and biogenic emissions and uptake to better understand the effects of vegetation, wetlands, and similar urban features on emissions measurements; developing measurements and models to relate atmospheric greenhouse gas concentrations to emissions.

For more than a century, NIST has conducted measurement science that is impartial, accurate, and consistent so that decisions in the business and policy realms are made on sound scientific footing. NIST helps to provide the measurements and data that the United States and other nations need as they monitor and choose ways to reduce greenhouse gas emissions.

We greatly appreciate the Members of these Committees and others in Congress for their support of Federal research and services that support greenhouse gas mitigation efforts, and I'll be pleased to answer any questions that you have. Thank you.

[The prepared statement of Dr. Lin follows:]

17

Testimony of

Eric K. Lin, Ph.D.
Director
Material Measurement Laboratory
National Institute of Standards and Technology
United States Department of Commerce

Before the

Committee on Science, Space, and Technology
Subcommittee on Environment
Subcommittee on Research and Technology

United States House of Representatives

*"Assessing Federal Programs for Measuring Greenhouse Gas Sources and Sinks"*

June 23, 2022

**Introduction**

Chairwoman Stevens, Chairwoman Sherrill, Ranking Members Feenstra and Bice, and Members of the subcommittees, I am Dr. Eric Lin, Director of the Material Measurement Laboratory (MML) at the Department of Commerce's National Institute of Standards and Technology (NIST). Thank you for the opportunity to appear before you today to discuss NIST's role in greenhouse gas measurements. The NIST laboratory programs work at the frontiers of measurement science to ensure that the U.S. system of measurements is firmly grounded in sound scientific and technical principles. The NIST laboratories address complex measurement challenges ranging from the very small (nanoscale devices) to the very large (vehicles and cities), and from the physical (renewable energy sources and fossil fuel emissions) to the virtual (cybersecurity and cloud computing). As new technologies are developed and evolve, NIST's measurement research, standards, and services remain central to innovation, manufacturing, productivity, trade, and public safety.

**NIST and Greenhouse Gas Measurements**

NIST works with our federal partners through the Greenhouse Gas Monitoring & Measurement Interagency Working Group to coordinate existing capabilities and opportunities for enhancing measurement and quantification of greenhouse gas emissions and removals, with a goal of developing an operational greenhouse gas monitoring system that informs local to national-scale greenhouse gas emission mitigation efforts and assesses the effectiveness of greenhouse gas reduction policies. Coordination through this interagency working group is essential to maximize the impact of agency resources, enhance the Nation's ability to measure and monitor greenhouse gas emissions and removals, and accelerate the transition of relevant research capabilities to operational use.

As a global-scale example, NIST provides linkage for high-quality data that is traceable to the International System of Units (SI units; the international standard for measurement) to the National Oceanic and Atmospheric Administration (NOAA) as the World Meteorological Organization's Central Calibration Laboratory for greenhouse gas concentration measurements. NOAA disseminates standards to support ground, tower, and aircraft measurements of greenhouse gases (GHGs). These measurements are critical to keep track of sources (emissions into the atmosphere) and sinks (removal from the atmosphere) of GHGs around the world. The NOAA GHG network is also used to provide a direct link to remote measurements made by satellites such as NASA's Orbiting Carbon Observatories (OCOs). NIST works with NOAA to provide traceability of NOAA's primary greenhouse concentration standards to the International System of Units to strengthen global consistency of greenhouse gas measurements. NIST recently launched an ambitious project to develop a next-generation, continuous calibration system capable of extending SI traceability to both global satellite remote sensing and ground-based remote sensing platforms. If successful, this work will reduce the cost and complexity of satellite calibrations while improving accuracy and precision to 0.1 percent or better—a step on the path toward the World Meteorological Organization's ambitious goal of improving remote sensing of GHGs by a factor of 400.

On the ground, a portable frequency comb laser system developed as a research project by scientists and engineers from NIST and the University of Colorado Boulder detects minute methane emissions from oil and gas fields. The technology was commercialized by LongPath Technologies and is used by oil and gas producers to monitor their facilities for leaks. This project was originally funded by the Department of Energy's Advanced Research Projects Agency-Energy Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR) program.

Among our federal partners, NIST is unique in its operation of dense observation networks for measuring greenhouse gases at the city level, and even down to the street and block. Our work complements that of our partner agencies with expertise in quantifying GHGs at the continental to regional scale.

NIST's work supports the Biden Administration's emphasis on transitioning demonstrated, key research capabilities to operational use, in order to generate and disseminate data and information on greenhouse gas emissions for use by mitigation policymakers and to inform local, regional and private-sector greenhouse gas mitigation efforts.

**Support for Local Climate Action**

The NIST mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life. It is fitting, therefore, that NIST's work supports the private sector and public-private partnerships working to mitigate climate change.

The Paris Agreement[1] recognized that locally implemented policies by cities and businesses are required to reduce greenhouse gas emissions. Occupying two to four percent of earth's land area, representing about 55 percent of domestic and global populations, and aggregating businesses, cities account for about 70 percent of greenhouse gas emissions.[2] Businesses play key roles at the local level as the main financiers, developers, implementers, and operators of specific mitigation, clean energy, and energy efficiency targets. Many national, state, local governments and businesses have stated yearly emissions reduction goals. Currently, U.S. cities are challenged to confidently determine whether those targets were being met. A recent NIST-funded study[3] compared results from urban inventory protocol implementation in 48 U.S. cities with an atmospherically calibrated, U.S. emissions data product. The study showed differences ranging from about 60 percent over-reporting to about 140 percent under-reporting. This disparity illustrates the need for accurate and consistent methods of reporting. NIST is developing and

---

[1] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

[2] IEA (2016), Energy Technology Perspectives 2016, OECD Publishing, Paris, https://doi.org/10.1787/energy_tech-2016-en.

[3] Gurney, K.R. et al, "Under-reporting of greenhouse gas emissions in U.S. cities," *Nature Communications*, 12, Article number: 553 (2021). http://dx.doi.org/10.1038/s41467-020-20871-0

Schwartz, John, "U.S. Cities Are Vastly Undercounting Emissions, Researchers Find," *The New York Times*, Feb. 2, 2021. Accessed June 9, 2022: https://www.nytimes.com/2021/02/02/climate/cities-greenhouse-gas-emissions.html

demonstrating urban greenhouse gas emissions measurement methods to help improve existing goal tracking systems for states and local governments.

There is a need for equitable access to high-quality greenhouse gas monitoring systems to standardize the measurements—and, therefore, the data—that inform decision-making. NIST responds to that need with internationally recognized measurement capabilities and technical expertise to inform the development of new standards and has initiated efforts to establish technical international documentary standards.

The NIST Greenhouse Gas Measurements Program addresses the needs of businesses and governments at all levels, helping them measure, monitor, authenticate, and report greenhouse gas emissions in an accurate, transparent, and standardized manner. The methods developed by the program will help cities to demonstrate that their reductions are contributing to the Biden Administration's national greenhouse gas emissions reduction targets for the next 20 to 30 years.

**An Innovative Measurement Framework**

The NIST greenhouse gas measurement framework approach combines two independent methods to measure and map urban greenhouse gas emissions and removals, using one method to calibrate the other.

The top-down or atmospheric method measures and maps urban greenhouse gas emissions, in collaboration with the National Science Foundation and the National Center for Atmospheric Research, academia, and NOAA, by coupling highly accurate data from ground-based observing networks and airborne measurements of atmospheric greenhouse gas concentrations with numerical weather simulation and statistical optimization methods.

The bottom-up method uses advanced greenhouse gas accounting methods to provide fine-scale determination of urban greenhouse gas emissions locations. These maps account for fossil fuel emissions, biogenic sinks, and emissions associated with urban vegetation and agricultural and forested areas surrounding cities.

**Urban Dome Testbeds**

NIST established the Urban Greenhouse Gas Measurements Testbed System to demonstrate the feasibility and validity of this new measurement framework for cities. NIST operates testbeds in Indianapolis, the Los Angeles Air Basin, and the U.S. Northeast Corridor (beginning in the Washington, DC/Baltimore regions and extending to Boston over time). These testbeds encompass a range of meteorological, climatic, and emissions profiles meant to span U.S. urban typographic and meteorological conditions.

Recent measurements in the Indianapolis testbed demonstrated a better than 10 percent consistency between the top-down and bottom-up methods.[4] Recent results in the Los Angeles and Northeast Corridor testbeds, using similar methods, detected and accurately quantified greenhouse gas reductions before and during the early months of the 2020 pandemic.

---

[4] Lauvaux, T., et al., "Policy-relevant assessment of urban greenhouse gas emissions," *Environ. Sci. Technol.* 2020, 54, 16, 10237–10245: https://doi.org/10.1021/acs.est.0c00343.

Many governments and businesses have stated emissions reduction goals of 1 percent to 3 percent yearly. NIST's approach is to develop validated measurements and standards that are at least 10 times more accurate than the stated need, in this case 10 times less than 1 percent. The Urban Dome project measures and maps emissions at the street, block, or building level and at a time resolution of hours, days, weeks, seasons, and annual variations. Businesses and governments will then have the improved information they need for advancing timely and effective mitigation actions and science-based policy decisions.

NIST is working in partnership with government stakeholders at various levels and with the business, academic, and non-governmental organization communities to develop and provide mature, measurements-based scientific tools, methods, and data to estimate greenhouse gas emissions with high accuracy. These methods improve the means to track progress with the space and time resolutions required to guide evidence-based decision-making.

The validated tools, methods, and data disseminated will enable the identification of the most efficient and economically viable emission reduction opportunities in urban areas. Application of these tools before and after deployment of energy efficiency or alternative energy solutions can authenticate their effectiveness. Their application also has the potential for improved monitoring tools to enable validation and verification of the impacts of measures and policies that have historically been difficult to measure.

They also will provide a means of assessing the effectiveness of mitigation actions taken by other nations.

**International Documentary Standards Development**

The climate research community concerned with greenhouse gas measurements has advanced elements of measurement and emissions estimation capabilities to a level of maturity sufficient to support widespread usage. NIST has initiated a documentary standards effort aimed at advancing the implementation of mature, measurements-based, scientific tools and methods, together with associated data, based on the research community's best practices. New greenhouse gas technical documentary standards will support existing greenhouse gas emissions management standards promulgated by the International Organization for Standardization (ISO), specifically ISO 14064-1 to 3.[5] NIST has initiated development of technical standards via the American National Standards Institute (ANSI) and ISO Technical Committee (TC) 207 – Environmental Management, Sub-committee (SC) 7 on Greenhouse Gas Management and Related Activities.

The effort will lead to the development of a series of technical measurement standards supporting transparency and accuracy for users globally. These technical standards—based on research community best practices currently nearing publication by the Integrated Global Greenhouse Gas Information System of the World Meteorological Organization's[6] (WMO) Global Atmospheric Watch—are anticipated to improve data quality assurance of national

[5] ISO TC 207, SC 7 Standards https://www.iso.org/committee/546318/x/catalogue/.

[6] Integrated Global Greenhouse Gas Information System (IG$^3$IS), An Integrated Global Greenhouse Gas Information System (IG3 IS) Science Implementation Plan, GAW Report No. 245, 2019: https://library.wmo.int/doc_num.php?explnum_id=10034.

greenhouse gas emissions reports from which all can judge progress toward national reduction targets.

A foundational element of worldwide atmospheric greenhouse gas observing strategies are the gas mixture concentration standards that are key to data accuracy in atmospheric greenhouse gas emissions estimation methods. Expanded development of certified measurement standards will be undertaken, in collaboration with the BIPM [7] and the international metrology community, NOAA, the WMO, and the specialty gas industry, to ensure the consistency and accuracy of atmospheric greenhouse gas measurements globally.

Other areas in which collaboration with other agencies and partners can enhance GHG measurements and monitoring include:

**Linking Surface Emissions Measurements to Satellite Observations**

To address the complexities of integrating greenhouse gas concentration data with that observed from low Earth orbiting and geosynchronous Earth orbiting satellites, NIST will utilize its Urban Dome Testbeds. Successful linkage of atmospheric greenhouse gas concentration data obtained from testbed surface and aircraft networks to airborne and satellite remote sensing data can enhance comprehensive measurement and monitoring coverage domestically. Observations of atmospheric GHG concentrations through the entire atmospheric depth by satellite instruments linked to surface-determined emissions would enhance U.S. coverage using atmospheric methods. Completion of NIST's Northeast Corridor testbed in a region with multiple overpasses by U.S. satellites and those of other nations will extend U.S. measurement capacity over a range of emissions and socioeconomic conditions. Collaborating with the satellite and associated research communities to advance such measurements will provide the means to achieve domestic coverage and will provide an independent means of assessing bottom-up emissions data.

**Fossil Fuel and Biogenic Emissions/Uptake Modeling for Bottom-Up Estimation**

Urban climate change mitigation efforts are focused on reducing methane and fossil fuel $CO_2$ combustion emissions. However, vegetation and wetlands in cities complicate measurements of urban methane and $CO_2$ emissions and make it difficult to identify their sources. In addition, these biospheric processes add complexity to quantification of anthropogenic $CO_2$ emissions at the urban scale. Vegetative $CO_2$ emission can be as strong as fossil fuel emission, especially during the growing season. Similarly, methane emissions from biogenic sources like landfills and urban wetlands are significant contributors to urban emissions. To more confidently attribute urban and regional methane and $CO_2$ emissions to specific sources, the community needs advances in biospheric modeling.

NIST will expand its capabilities in both fossil fuel and biogenic emission modeling and partner with leading experts to improve modeling tool performance and assess results in NIST testbeds and those of others. NIST will strengthen its data science capabilities to harmonize currently disparate fossil fuel emissions estimation methodologies and advance modeling tools by establishing standards and guidelines. Expanded urban vegetation measurements will be used to improve modeling of vegetative processes and improve the calibration of satellite instruments.

---

[7] The International Bureau of Weights and Measures (BIPM): https://www.bipm.org/en/about-us/.

**Measurements and Models for Top-Down Methods**

Measurement and modeling advances will also improve greenhouse gas emissions mapping and accuracy. For example, measuring atmospheric greenhouse gas concentration change with altitude due to dispersal and mixing in and above the atmospheric boundary layer will fill a measurement and modeling gap. By better describing vertical atmospheric concentration gradients, the accuracy of path averaged concentration data from satellite instruments will improve. These, coupled with advances in statistical inference methods, bottom-up emission analyses, and radiocarbon measurements will improve spatial resolution for local and urban applications.

Concentration Gradient Measurement: Atmospheric greenhouse gas concentrations change substantially from the surface to the top of the atmosphere and vary with local meteorological conditions. Satellites sense greenhouse gases through the entire atmospheric column and use analyses resulting in path averaged concentrations that employ initial gradient estimates from global models. Periodic instrumented aircraft flights sampling from the surface to near the atmospheric center provide data for these models. Surface observing networks sample the atmosphere from communication towers and building roofs at fixed altitudes and locations. Accurate means to relate the point measurements of surface networks to averaged values from aircraft and particularly satellites will improve emissions measurement accuracy. In concert with the next-generation, continuous calibration system mentioned above to extend SI traceability to both global satellite remote sensing and ground-based remote sensing platforms, NIST is developing methods to measure atmospheric greenhouse gas gradients from the surface to near the top of the atmosphere using a near-vertical beam[8]. Acceleration of this research will result in real-time gradient measurement capabilities that can be operationalized. Along with solar viewing spectrometers and Doppler Lidars located across the U.S. at overpass locations, path averaged data accuracy will be improved.

Radiocarbon Measurements: It is challenging to differentiate $CO_2$ emitted from fossil fuel combustion from $CO_2$ emitted by live vegetation as part of the growth process. Radiocarbon dating and modelling of biogenic processes are helpful, but the availability of data from these methods is currently severely limited due to sample measurement expense and scarcity. Recent NIST research has demonstrated bench-scale optical methods of absolute radiocarbon measurement that is much less costly than the current mainstay method, accelerator mass spectrometry. Advancing development and demonstration of these technologies will aid in transferring them to private sector providers of radiocarbon data, significantly expanding availability to the atmospheric greenhouse gas measurement community, as well as to other user sectors, such as those measuring carbon footprints.

**Conclusion**

Accurate and consistent greenhouse gas emissions data is essential for the success of climate actions and mitigation decisions as the United States and other nations around the world seek to achieve ambitious goals to reduce the impacts of climate change. Ensuring measurement

---

[8] Wagner, GA and Plusquellic, DF, "Multi-frequency differential absorption LIDAR system for remote sensing of CO2 and H2O near 1.6 μm," Optics Express, Vol. 26, Issue 15, pp. 19420-19434 (2018). https://doi.org/10.1364/OE.26.019420

accuracy and consistency is a fundamental challenge on par with that of economic data. NIST continues to build on its world-leading scientific achievements to secure for the U.S. a position of international leadership in this vitally important global effort. NIST's statutory role as the U.S. National Metrology Institute, and its role to promote accurate national and international standards, are fully aligned with the Biden Administration's priority to achieve net-zero global emissions by 2050, and advance the means needed for all nations to provide scientifically based emissions data and reports to measure progress toward reducing the impacts of the climate crisis.

Thank you for the opportunity to testify today. I would be happy to answer any questions you may have.

25

Eric K. Lin

*Director, Material Measurement Laboratory*

Dr. Eric K. Lin serves as the Director of the Material Measurement Laboratory (MML) at the National Institute of Standards and Technology (NIST). MML has more than 900 staff members and visiting scientists and serves as the nation's reference laboratory for measurements in the chemical, biological and materials sciences. MML activities include fundamental research in the composition, structure and properties of industrial, biological, and environmental materials and processes, to the development and dissemination of certified reference materials, critically evaluated data and other measurement quality assurance programs. MML serves a broad range of industry sectors ranging from transportation to biotechnology, and provides research, measurement services and quality assurance tools for addressing problems of national importance ranging from developing tools to shorten the time-to-discovery of new materials, to the investigation of new sources of renewable energy, to improved diagnostics and therapies for health care.

Lin received a B.S.E. from Princeton University, and Masters and Ph.D. degrees in chemical engineering from Stanford University.

Chairwoman STEVENS. And now, we'll move to Dr. Stein.

**TESTIMONY OF DR. ARIEL STEIN,**
**ACTING DIRECTOR, GLOBAL MONITORING LABORATORY**
**AND DIRECTOR, AIR RESOURCES LABORATORY,**
**NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION**

Dr. STEIN. Chairs and Ranking Members and Members of the Subcommittee, thank you for the opportunity to testify today regarding Federal programs focused on monitoring, measuring, and verifying sources and sinks of greenhouse gases. NOAA's mission is to understand and predict changes in climate, weather, the oceans, and coasts. To achieve this, we must continuously monitor and detect changes as they occur. The primary focus of my work is to monitor and detect changes in the atmosphere that impact climate. This is something NOAA has a long history of doing. With $CO_2$ measurement dating back to 1958, NOAA's Mauna Loa Observatory in Hawaii is the global benchmark location for monitoring atmospheric composition and was key in determining the connection between rising atmospheric $CO_2$ levels and climate change.

Building off this historic accomplishment, NOAA's long-term, continuous atmospheric observations serve as a baseline and record which can be used to monitor natural and anthropogenic emissions and greenhouse gases, as well as their uptake by the natural land and ocean-based processes and the effectiveness of efforts to reduce climate change through greenhouse gas mitigation.

The Mauna Loa Observatory continues today as a cornerstone of NOAA's Global Greenhouse Gas Reference Network. This network has grown to a global scale, with more than 70 sites around the world measuring over 60 gases. These high-quality data serve as the backbone of NOAA's climate mission by providing vital environmental intelligence for monitoring the steadily changing composition of Earth's atmosphere and understanding global weather and climate.

NOAA uses this foundational climate information to develop products and tools to help inform decisionmaking. NOAA's greenhouse gas data feed models to predict long-term changes in climate that have the potential to impact long-term planning needed for industries like shipping, fishing, forest management, agriculture, construction, finance, and water resources. For instance, NOAA has developed a system based on measurements and models to detect long-term changes in sources and sinks at the global, national, and regional levels.

NOAA is also working to better understand changes in greenhouse gas emissions and air quality in our Nation's cities in partnership with other agencies. In particular, NOAA conducted research on how greenhouse gas emissions coming from urban environments may not have changed much during the lockdown period of COVID–19, while significant changes were simultaneously observed in air quality.

NOAA has also conducted research with the oil and gas industry to pinpoint fugitive emissions to realize efficiencies while ensuring the safety of these sites and preventing the loss of valuable fuel that could be captured and sold.

These are just a few examples of NOAA's boots-on-the-ground approach to providing climate services. Just as with our other climate services, by connecting with communities and leverage our Greenhouse Gas Network, NOAA helps local decisionmakers strengthen our resilience and adaptation to climate change, which will help protect lives, lifestyles, and livelihoods.

NOAA's work on understanding sources and changing greenhouse gas emissions and sinks requires cooperation with numerous agencies. Each agency represented here today brings to the table core capabilities that complement each other and will help us advance this field.

NOAA is also looking toward expanding the Greenhouse Observational Network by using new technologies to allow the detection of greenhouse gases at higher temporal and spatial resolutions. For example, NOAA is working with the airline industry to help expand our agency observing network by putting instruments on commercial aircrafts to acquire data as planes ascend and descend. Much like how the National Weather Service already partners with commercial airlines to gather meteorological data, these new capabilities have the potential to provide orders of magnitude more observation of the atmosphere in climate-sensitive regions like the Arctic and the tropics, as well as high-emitting regions surrounding many metropolitan airports. These data may allow NOAA to detect greenhouse gases changes at finer resolutions, which will improve the climate information available to decisionmakers at the regional and local scales.

Thank you, and I look forward for your questions.

[The prepared statement of Dr. Stein follows:]

**WRITTEN STATEMENT OF**
**DR. ARIEL STEIN**
**DIRECTOR OF NOAA'S AIR RESOURCES LABORATORY**
**ACTING DIRECTOR OF NOAA'S GLOBAL MONITORING LABORATORY**

**ON THE**
**ASSESSING FEDERAL PROGRAMS FOR MEASURING GREENHOUSE GAS SOURCES AND SINKS**

**BEFORE THE**
**HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY**
**SUBCOMMITTEE ON ENVIRONMENT**
**SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY**

## 1. INTRODUCTION

Chairwomen Sherrill and Stevens, Ranking Members Bice and Feenstra, and Members of the Subcommittees, thank you for the opportunity to testify today regarding Federal programs focused on monitoring, measuring, and verifying sources (emissions to the atmosphere) and sinks (removal from the atmosphere) of greenhouse gases (GHGs).

NOAA's mission is science, service, and stewardship. Our reach goes from the surface of the sun to the depths of the ocean floor as we work to keep the public informed of the changing environment around them. We know that major elements of our Earth's life support system are changing in ways never before observed in recorded history. Foundational environmental parameters – atmospheric composition, water and land surface temperatures, ocean chemical balance, global sea levels, polar sea-ice cover, and global land use distribution – are all changing at unprecedented rates.

## 2. LEGACY OF GREENHOUSE GAS MONITORING AT NOAA

NOAA's long-term atmospheric observations serve as a baseline and record, which can be used to monitor natural and anthropogenic emissions of GHGs as well as their uptake by natural land- and ocean-based processes and the effectiveness of efforts to reduce climate change through GHG mitigation or other means.

NOAA's Mauna Loa Observatory is the global benchmark location for monitoring atmospheric composition. With $CO_2$ measurements dating back to 1958, the Mauna Loa Observatory offers a unique location 11,135 feet above sea level and far from most human influences to monitor sunlight and air. The NOAA observatory continues today as a cornerstone of NOAA's Global

Greenhouse Gas Reference Network, measuring a range of GHGs, ozone depleting gases, air pollutants, and the sun's radiation. NOAA scientists take continuous measurements from Mauna Loa and more than 70 sites around the world.

NOAA's GHG data feed models to predict long-term changes in climate that have the potential to impact long-term planning needed for industries like shipping, fishing, agriculture, construction, finance, and water resources. Other federal agencies, states and local governments, communities, U.S. industry, and international partners depend on measurements we collect through our Global Greenhouse Gas Reference Network.

**3. NOAA'S ROLE**

Building on this legacy, NOAA is a trusted source for monitoring the long-term trends of concentrations of $CO_2$ and other GHGs in the atmosphere. We are the World Meteorological Organization's Central Calibration Laboratory for GHG concentration measurements, and we disseminate field standards for GHG measurements. More than 60 years of recorded measurements at NOAA's Mauna Loa Observatory and other remote sites - such as the South Pole and the northernmost point of Alaska - represent some of the most important and fundamental sources of information to understand and demonstrate how humans have changed the atmosphere.

Observations at these remote sites also provide NOAA with a measure of the cumulative direct impact of rising GHG levels on Earth's climate. NOAA uses this foundational climate information to develop products and tools to help understand the human contributions to warming from long-lived GHGs and inform decision-making. In 2006, NOAA developed the Annual Greenhouse Gas Index (AGGI) as a way to help policymakers, educators and the public appreciate how changes in atmospheric composition change the amount of heat trapped in our atmosphere. The AGGI has shown that the human contribution to warming from long-lived GHGs in the atmosphere was 49 percent higher in 2021 than in 1990.

As the global leader in monitoring long-term trends of atmospheric concentrations of $CO_2$, methane, and other potent GHGs, NOAA plays a vital role in attributing and understanding emissions of these gases that are critical to Earth's radiative balance (the balance of incoming solar energy and outgoing energy reflected from the Earth's surface). For example, in 2018, observations and analyses from NOAA's Global Greenhouse Gas Reference Network and international partners indicated that atmospheric concentrations of an ozone-destroying Chlorofluorocarbon (CFC-11) were not declining as fast as expected, providing evidence of increasing emissions arising from unreported production of CFC-11, which is a violation of the Montreal Protocol.[1] This discovery led to international pressure and eventually renewed

[1] See Emissions of an ozone-destroying chemical are rising again and Two additional regions of Asia were sources of banned ozone-destroying chemicals

enforcement and inspection measures. NOAA is also conducting research to understand various natural sinks, including monitoring and quantifying the natural GHG uptake of ocean- and land-based processes, carbon sequestration in coastal ecosystems, and the critical role of the ocean in removing $CO_2$.

By measuring atmospheric concentrations of over 60 different species of gases, NOAA's global network is essential for detecting not only changes in human-made emissions of GHGs over time but also how human-made emissions and human activities increase natural sources of GHGs (e.g., through what are referred to as feedbacks). This is important because warming-induced changes in the natural sources and sinks of $CO_2$ could in turn impact our collective ability to meet any desired climate target, such as keeping the global temperature increase to well below 2°C relative to pre-industrial times. With this robust global monitoring network, NOAA is capable of distinguishing, for example, between relative concentrations of $CO_2$ coming from fossil fuels versus those coming from natural sources, such as the decay of organic matter. NOAA's research has shown that it is unlikely that fossil fuels are the largest contributor on a global basis to the rapid rise in methane that we have detected over the last decade. Instead, this methane is coming from microbes, indicating that agriculture, wetlands or landfills are more likely sources of the methane rise.

NOAA has recently built up technology that enables balloons to be launched and retrieved in the same location and that allows full profiles up to 100,000 feet to be captured and measured, providing an important touchstone to integrate satellite measurements into our observational network. NOAA is working with the airline industry to help expand the agency's GHG observing network by putting instruments on commercial aircraft to capture data as the planes ascend and descend. This new capability has the potential to provide orders of magnitude more observations of the atmosphere in climate-sensitive regions like the Arctic and the tropics as well as high-emitting regions surrounding many metropolitan airports. Not only will this provide NOAA with more high quality data, but these data may allow NOAA to detect GHG changes at higher temporal and spatial resolutions.

Accurate estimates of GHG concentrations allows scientists to better estimate emissions and removals essential for informing and evaluating specific measures and broader policy decisions to mitigate climate change impacts. NOAA plays a key role in delivering this information to policymakers and the public through the communication of our data and the development of tools and methods to quantify GHG sources and sinks. For example, NOAA's CarbonTracker is a modeling system that uses the global reference network and other data to model sources and sinks of carbon dioxide around the world. On a global scale, NOAA's CarbonTracker model uses data from approximately 150 sites across the globe to provide a 4-D picture of the two most important GHGs ($CO_2$ and methane) emitted by human activities at 3-hour intervals from January 2000 to the present. This tool is one baseline of comparison for atmospheric based

estimates of GHG emissions and removals across the globe, providing ground truth for satellites and emissions estimates. As I speak, NOAA is in the process of merging its CarbonTracker data assimilation system with its high-resolution Unified Forecast System to enable users to assess emissions at various scales and for different sectors. NOAA aims to contribute with new tools to provide reliable and timely estimates of GHG emissions and removals to support regional, national and global climate mitigation efforts.

Under the Infrastructure Investment and Jobs Act (IIJA), signed by President Biden on November 15, 2021, NOAA received funding to support efforts including integrated understanding of linkages between fires, drought, air quality, and land surface sensitivity in a post-fire environment; advancements in smoke emissions and air quality modeling; experimental improvement to climate and Earth system models to integrate fire dynamics and drivers more explicitly into model simulations in support of modeling and forecasting efforts. NOAA also received funding in the FY22 Disaster Supplemental to support work including short-range fire weather prediction, observations to support fire weather and emissions modeling and research, and weather to seasonal-to-subseasonal to climate fire weather research.

Lastly, the Joint Polar Satellite System (JPSS) and the advanced Geostationary Operational Environmental Satellite (GOES)-R series satellites host instruments capable of providing near real-time operational and long-term climate data records of many land and ocean properties related to GHG cycles, including land cover, land cover change, vegetation biophysical characteristics, wildfire information, and ocean color. In fact, NOAA provides unified and consistent multi-decadal climate data records (CDRs). CDRs are a time series of data sets generated by reprocessing data from the complete series of NOAA operational satellites (the 1970s- to the present) in a consistent, transparent, and authoritative manner. CDRs are used in industry, research, and environmental modeling. For example, the U.S. energy sector uses CDR radiation patterns over the Pacific to predict continental-scale temperature deviations up to two weeks ahead, informing early business decisions on large-scale production, transportation, and market trades. CDRs are also used in agriculture and food-security applications to assess drought extent and in developing crop yield against historical patterns to pre-positioning food relief in developing countries.

NOAA continues to be a leader and trusted partner in delivering world-class science on greenhouse gases and translating that science into actionable information. NOAA's FY23 budget requests funding for the investments needed to enable NOAA to maintain and enhance our long-term atmospheric observations, which support research on future climate scenarios. The request includes $16,100,000 in new investments to support and enhance our atmospheric observing systems, which will allow NOAA to support a Global Stocktake, an essential process of the Paris Agreement. This funding would create an independent, transparent evaluation of GHG emissions

and changes in emissions at various scales and examine the biogeochemical-climate feedbacks and the resulting climate sensitivity. It would also provide a robust understanding of the allowable cumulative GHG emissions to limit global warming at different future levels by taking into account likely changes in natural GHG sinks and sources in the ocean, land, and atmosphere. As a climate steward, NOAA partners with other federal agencies, states, local communities, tribes, territories, and private industry to expand knowledge and enable capabilities to deliver results for the American people.

**4. PARTNERSHIPS WITH OTHER AGENCIES**

To understand the sources of and changes occurring in GHG emissions and atmospheric levels, accurate, precise, and expansive measurements of GHGs are necessary. This work requires cooperation with numerous agencies. NOAA's frequent collaborators and friends include DOE, EPA, NIST, and NASA, among many others in this mission space.

NOAA and DOE have a long relationship of collaboration on atmospheric monitoring and measurements including leveraging DOE's Southern Great Plains (SGP) atmospheric observatory for aerosol, radiation, and GHG measurements both from the ground and from aircraft. This relationship extends to the Arctic where NOAA and DOE have a multi-decade effort of collaborating on atmospheric observations at NOAA's Barrow Observatory and many other sites across Alaska.

NOAA and the EPA have worked together on the bottom-up GHG emissions inventories by comparing inventories with direct observations of the atmosphere downwind of reported emission sources. For example, NOAA has used aircraft-based observations to identify discrepancies in bottom-up GHG emissions inventories of methane from the nation's oil and natural gas production basins and the downstream supply chain. NOAA's measurements are now part of EPA's quality assurance and verification process for the hydrofluorocarbon (HFC) estimates in the annual GHG Inventory. This innovative contribution is helping EPA and NOAA to identify areas where the estimates can be improved. NOAA also supports the integration of coastal wetlands data into the EPA-led U.S. National GHG Inventory. Through this joint effort the United States was the first country to incorporate coastal wetlands into its National GHG Inventory; now NOAA is working with EPA and the Department of State, among others, to assist other nations to include blue carbon associated with coastal wetlands in their official GHG inventories.

Over the last decade, NIST and NOAA have collaborated closely to better understand how to integrate models and atmospheric measurements in urban settings to better estimate GHG

emissions. This collaboration has consisted of information exchange, sharing of technical expertise, and modeling and tool development leading to vastly improved monitoring and understanding of GHGs emissions in urban settings.

NOAA has extensive collaborations with NASA including the development of products like the CarbonTracker described earlier. NOAA has provided critical atmospheric measurements to support several NASA experiments in the Arctic as well as those made in oil and gas regions where remote sensing technologies were being tested and compared to NOAA measurements. NOAA also played a key role in NASA's Atmospheric Tomography Mission (ATom) by providing expertise to make GHG, aerosol, and reactive gas measurements which culminated in the development of a critical dataset for evaluating satellite observations for years to come. Starting in 2023, an interagency agreement between NASA and NOAA will allow NOAA to take in-situ observations of GHGs emitted by the North American urban areas onboard a NASA research aircraft. NOAA is also planning to work with NASA on evaluating and utilizing NASA's new GeoCarb mission, which will provide the first observations of GHGs from geostationary orbit starting in 2025. These measurements will provide better daily and spatial coverage of GHG levels, and NOAA's global network will be used in the calibration of these new space-based measurements.

NOAA also participates in the Greenhouse Gas Monitoring & Measurement Interagency Working Group to coordinate on existing capabilities and opportunities for enhancing the measurement and quantification of GHG emissions and removals. Our goals include informing local to national-scale GHG emission mitigation efforts and assessing the effectiveness of GHG reduction policies over time. Coordination through this interagency working group is essential to maximize the impact of agency resources, enhance the Nation's ability to measure and monitor GHG emissions and removals and accelerate the transition of relevant research capabilities to operational use.

**6. CONCLUSION**

In partnership and collaboration with our Federal partners, NOAA a leader in providing global and regional observations, science, and prediction. We deliver trusted climate information, forecasts, and services to our Nation's decision-makers at all levels of government, in all U.S. regions, across geographic scales from national to local, and in all economic sectors. Underpinning NOAA's leadership in this field is our foundational GHG concentrations measurement and analysis systems that monitor and understand present trends and prepare for the future. NOAA is building on our legacy through its contribution to an integrated GHG observing system through collaborative interagency and private partnerships to meet the growing demand for accessible and accurate climate data, tools, and services that help protect the American public, economy, and natural ecosystems in the face of changing conditions.

Dr. Ariel Stein is currently ARL Director and Acting Director of the Global Monitoring Laboratory. Dr. Stein has extensive experience working with atmospheric transport, dispersion, and photochemical models. Previously, Ariel was a Supervisory Physical Scientist before becoming Acting Deputy Director of NOAA's Air Resources Laboratory. Ariel has an in-depth understanding of hybrid dispersion modeling techniques including ARL's HYSPLIT model. His research interests cover a wide range of topics dealing with atmospheric transport and dispersion modeling including the simulation of atmospheric tracer release experiments, radionuclides, smoke originated from wildfires, volcanic ash, and wind-blown dust. He has several peer-reviewed papers in these topics in prestigious international journals. He holds a B.Sc. in Chemistry from the University of Cordoba, Argentina, a M.Sc. in Environmental Pollution Control and PhD in Meteorology from Penn State University.

Chairwoman STEVENS. Great. And now, we'll hear from Dr. St. Germain.

**TESTIMONY OF DR. KAREN M. ST. GERMAIN,**
**EARTH SCIENCE DIVISION DIRECTOR,**
**SCIENCE MISSION DIRECTORATE,**
**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

Dr. ST. GERMAIN. Chairwoman Stevens, Ranking Member Feenstra, Chairwoman Sherrill, and Ranking Member Bice, and Members of the Subcommittee and Committee, I'm Dr. Karen St. Germain, Director of NASA's Earth Science Division, and I'm very pleased to appear before you to share NASA's role in measuring, monitoring, and understanding the role of greenhouse gases in our warming climate.

NASA's mission is to provide the observations and foundational science that underpin our understanding of the Earth as a system. We're working to bring cutting-edge space-based and airborne instruments and observations, advanced modeling, new technologies, and analytic techniques to deliver world-class scientific understanding of the Earth system. In doing so, we support the broad range of efforts across the agencies you see here and many others in the Federal Government and beyond. We're committed to open science and collaborating with our colleagues here to offer policymakers and Americans actionable information in support of their efforts to mitigate greenhouse gases and respond to the wide-ranging—the wide range of impacts of the climate change.

We're moving out today to build the Earth System Observatory that will consist of five major missions augmented by several competed missions. The Earth System Observatory will give us an even better overall understanding of the Earth system and the interplay between greenhouse gases and the carbon and water cycles.

Today, our instruments that measure greenhouse gases include OCO–2, the Orbiting Carbon Observatory, and OCO–3, its sibling on the International Space Station. NASA airborne campaigns obtain high-resolution temporal and spatial measurements of complex local processes, which give us an even clearer understanding of what our global satellite observations are telling us. For example, the MOOSE (Michigan-Ontario Ozone Source Experiment) campaign in Michigan lets us better understand why we're seeing elevated ozone levels in the—at the Michigan-Ontario border region, while other campaigns have been critical in documenting methane super sources.

NASA continues to advance technology for new space-based and airborne measurement capabilities, and in developing these tools, NASA strives to make these technologies reliable, affordable, and deployable. And when there's opportunity, we transition these technologies to the private sector, as is the case with NASA's Jet Propulsion Laboratory partnership with Carbon Mapper Inc. Our technology efforts will enable better measurements of carbon dioxide and methane fluxes and trends in varying conditions.

The Carbon Monitoring System, or CMS, has allowed us to combine observations of greenhouse gases in the atmosphere with other types of measurements to give us a better understanding of the Earth system processes such as the carbon cycle. CMS projects

have provided insight into the role of forest and cropland in greenhouse gas fluxes, including whether certain lands under agricultural use are carbon sinks, sources, or both under varying conditions. For example, Midwestern cornfields are carbon sinks during most years, while during years of water stress, they release carbon, even as Oklahoma winter wheat might show no notable change under similar environmental conditions.

CMS-funded scientists built a new series of maps detailing the global geography of methane emissions from coal, oil, gas, and other sources. Using publicly available data reported, the research team plotted fuel exploitation emissions that arise before the fuels are ever consumed.

NASA's greenhouse gas research and its applications depend also on partners and their assets from NOAA's Suomi-NPP (National Polar-orbiting Partnership) to the European TROPOMI (TROPOspheric Monitoring Instrument) and the Japanese GOSAT (Greenhouse Gases Observing Satellite), and we work with partners at NOAA, EPA, and NIST to assimilate many sources of data to help understand the nature of greenhouse gas emissions.

NASA is working with other agencies through the new Greenhouse Gas Monitoring and Measurement Interagency Working Group to maximize the impact of agency resources, enhance the Nation's ability to measure and monitor emissions and removals, and accelerate the transition of relevant research capabilities to operational use. And we at NASA are building on these efforts toward an Earth Information Center with an initial focus on prototyping capabilities for greenhouse gas monitoring information that will integrate the data from these variety of sources with the goal of making that data more accessible and usable to Federal, State, local, and tribal governments, as well as researchers, the public, and other users.

NASA's $2.4 billion request for Earth science in the ' 23 President's budget will allow us to continue to make this strong progress in observing and understanding the Earth as a system, including greenhouse gas emissions and, just as importantly, understand how the widely varying impacts of the changing climate are affecting our communities from the coasts to the heartland.

NASA stands ready to work with our Federal, State, tribal, local, and commercial partners to address the challenges posed by greenhouse gases and their effects. And I want to thank this Committee and Congress for its support of Earth science and the entire Federal Government's efforts to tackle the challenges we're discussing today. And I welcome your questions.

[The prepared statement of Dr. St. Germain follows:]

National Aeronautics and
Space Administration

Hold for Release Until
Presented by Witness

June 23, 2022

# Committee on Science, Space, and Technology Subcommittee on the Environment and Subcommittee on Research and Technology

# U.S. House of Representatives

Statement of:
Dr. Karen M. St. Germain
Director, Earth Science Division
Science Mission Directorate
National Aeronautics and Space Administration

117th Congress

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
June 23, 2022

**Statement of**
**Dr. Karen M. St. Germain**
**Earth Science Division Director**
**Science Mission Directorate**
**National Aeronautics and Space Administration**

**before the**

**Subcommittee on the Environment and the**
**Subcommittee on Research and Technology**

**Committee on Science, Space, and Technology**
**U.S. House of Representatives**

Chairwoman Stevens, Ranking Member Feenstra, Chairwoman Sherrill, Ranking Member Bice, and Members of the Subcommittee and Committee:

I am Dr. Karen St. Germain, Director of NASA's Earth Science Division, and I am pleased to appear before you to share NASA's role in measuring, monitoring, and understanding the role of greenhouse gases in our warming climate.

My testimony will highlight how we intend to bring Federal capabilities like NASA's cutting-edge space-based instruments, airborne observations, climate modeling, and technology development together in support of an integrated national greenhouse gas emission monitoring and information system. Working with its Federal partners, NASA intends to bring demonstrated research capabilities into operational use, the kind of pathfinding role NASA has played since its founding. We recognize that Congress and other policymakers are eager for actionable information in support of efforts to mitigate greenhouse gases and respond to a changing climate.

Defining the Challenge

Since the 1980s, each decade has been warmer than the previous decade, with the past eight years the warmest collectively since modern record keeping began. It is unequivocal that our planet's climate is changing, that, these changes are driven by greenhouse gas emissions from human activity, and that future warming depends on future emissions. NASA's scientists, engineers, researchers, and innovators are working to understand the challenge and expand society's capacity to respond based on the best available information.

Efforts to decrease greenhouse gas emissions require a whole-of-government approach which you see reflected in the panel before you. Understanding the effects of greenhouse gases on the Earth as a system requires ongoing scientific inquiry; further translating what we know into

actionable information will require a sustained Federal effort. NASA, NOAA, EPA, NIST, and many other Federal, international, and private partners are expanding efforts to cooperate in measuring, monitoring, reporting, and verifying the sources and sinks of greenhouse gases in our country and around the world.

Assessments of progress, like the 2023 Global Stocktake of Greenhouse Gas emissions and reductions, will require reliable, accurate, and prompt reporting. NASA's space-based and aerial capabilities, commitment to transparency and open data, world-class research in Earth science, sophisticated modeling, and applications can improve accuracy, support increased accountability and broaden the range of informed responses.

As NASA also works with our colleagues across the Federal government to address global and local effects of climate change like rising temperatures and the threat of wildfire, rising sea levels, inland flooding, and drought, we stand ready to assist decisionmakers as they face the challenges before us.

How We See it at NASA

NASA's mission is to provide the observations and foundational science that underpins our understanding of Earth as a system. This is essential in the context of greenhouse gases and climate change because the processes that drive climate change depend not only on human influences such as greenhouse gas and aerosol emissions, but also how the land biosphere and ocean respond to and absorb these emissions.

We use the unique vantage point of space to observe the Earth from our fleet of Earth observing satellites, the International Space Station, suborbital aircraft, and other assets to understand these feedback mechanisms and refine our ability to project future change. These feedback mechanisms represent a highly complex set of interlocking science challenges and a compelling basis for strategic partnerships with Europe, Japan, Canada, and a host of other international and domestic commercial partners.

NASA develops and operates several satellites and instruments that measure atmospheric carbon dioxide. Aura, one of the satellites in the multinational partnership of closely synchronized Earth observing satellites known colloquially as the 'A-Train,' observes carbon dioxide, methane, nitrogen dioxide, ozone, and water using several different instruments. The Orbiting Carbon Observatory 2 (OCO-2) measures atmospheric carbon dioxide. OCO-3, mounted on the International Space Station (ISS), provides carbon dioxide data like its sibling OCO-2.

NASA's Global Ecosystem Dynamics Investigation (GEDI), whose high-resolution surface and forest measurements have contributed significantly to understanding of the carbon cycle, is also currently mounted on the ISS. The Earth Surface Mineral Dust Source Investigation (EMIT), which will aid our understanding of how mineral dust affects the warming of our planet, will arrive at ISS later this summer. NASA also collaborates with other federal entities and international space organizations, including NOAA and the European Space Agency (ESA), to collect and distribute greenhouse gas data.

Pursuant to the 2017 National Academies of Sciences, Engineering, and Medicine Decadal Survey on Earth Science and Applications, NASA intends to launch five Earth System Observatory (ESO) missions to capture observations on aerosols, clouds, convection, and precipitation, mass change, surface biology and geology, and surface deformation and change. NASA is currently initiating the formulation phase of several of these missions. These combined capabilities will give us a better understanding of the Earth system as a whole and how it interacts with greenhouse gases.

NASA will augment the core of the ESO with a new class of mission, the Earth System Explorers (ESE), to make additional high-priority observations and encourage innovative solutions through competitive selection at the mission level. The Decadal Survey recommended that this competitive program include proposals related to greenhouse gases. These missions will conduct scientific investigations of modest and focused programmatic scope and can be developed relatively quickly, and NASA expects to release the first ESE Announcement of Opportunity late this year.

NASA conducts airborne and ground campaigns to obtain high-resolution temporal and spatial measurements of complex local processes, which can be coupled to global satellite observations for a better understanding of Earth system processes. These include airborne science campaigns like the Michigan-Ontario Ozone Source Experiment (MOOSE), to better understand ozone levels in southeast Michigan. Analyses of data from past airborne campaigns like the NASA Atmospheric Tomography (ATom) mission, focused on the distribution and atmospheric fate of short-lived climate forcers, and the Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) mission, aimed at Arctic carbon cycling, continue to contribute to our understanding of the roles played by greenhouse gases in the Earth system.

NASA surface-based measurements like the Advanced Global Atmospheric Gases Experiment (AGAGE) network are critical to documenting long-term changes in greenhouse gas concentrations, not just carbon dioxide and methane, but nitrous oxide, chlorofluorocarbons, hydrochlorofluorocarbons, and similar compounds, and are closely coordinated with related measurements by NOAA and our international partners.

Advancing Technology

Our goals for monitoring, measurement, and verification must be commensurate with our technical capabilities. NASA continues to advance technology for new measurement capabilities that can advance future generations of airborne and satellite-based measurements of greenhouse gases. The High Altitude LIDAR Observatory (HALO) instrument is an example of a technology already in development that uses active remote sensing/light detection and ranging (LIDAR) that can allow NASA airborne campaigns to detect methane enhancements up to 20 kilometers downwind of a point source.

In the FY23 President's Budget Request NASA is asking for funding for a focused activity using competitive approaches to advance the development and testing of new technologies for space-based greenhouse gas measurement.

Technologies NASA is investing in include photonic systems on a chip for LIDAR and radio frequency applications and spectrometers, detectors, and readout integrated circuits for focal plane arrays. A key effort will be in making these technologies reliable, affordable, and deployable everywhere from space-based telescopes to small aerial platforms.

Increased capabilities hold the prospect of improved measurements of carbon dioxide and methane fluxes and trends, global and regional quantification of point sources and identification of source types, better spectral and spatial coverage to understand carbon fluxes. New work will allow us to better assess greenhouse gas emissions in varying conditions of illumination, for example, measuring emissions in the Arctic during wintertime and methane emissions from tropical wetlands.

Science Supporting Mitigation

Through its Carbon Monitoring System (CMS), NASA supports prototyping of new data capabilities and product-oriented overlays to our existing programs that aid in the monitoring, reporting, and verification of carbon stocks and fluxes. CMS is an Earth system science approach that combines observations of greenhouse gases in the atmosphere with measurements of the biological processes responsible for surface emission and uptake, or absorption, of carbon dioxide. CMS looks at land and water along with critical markers of the transformation of vegetation like evapotranspiration and solar-induced fluorescence. By producing top-down and bottom-up greenhouse gas emissions estimates and comparing them, CMS can point towards what we are missing.

CMS projects have provided insight into the role of forests and cropland in greenhouse gas fluxes, including whether certain lands under agricultural use are carbon sinks, sources, or both, and under what conditions. For example, Midwestern cornfields have shown to be carbon sinks during certain years, while years of water stress, they have been shown to release carbon, even as Oklahoma winter wheat might show no notable change under the same conditions. Analyses of forest canopy height and above ground biomass can reveal carbon sequestration potential in Northeastern forests.

NASA research has also supported more advanced quality assurance and verification of methane estimates. Colorless and odorless, methane leaks are hard to detect without scientific instruments. CMS-funded research has used atmospheric observations to assess national inventories for the U.S., Canada, and Mexico. NASA airborne campaigns, especially those using AVIRIS-NG (the Airborne Visible InfraRed Imaging Spectrometer - Next Generation) and HyTES (the Hyperspectral Thermal Emission Spectrometer) have been critical to documenting methane emissions including 'super sources' and serve as precursors for future measurements.

A recent month-long NASA Jet Propulsion Laboratory (JPL) airborne study with partners from the University of Arizona and Arizona State University has shown that about half of the largest sources of methane in the Permian Basin oilfield in New Mexico and Texas are likely to be malfunctioning oilfield equipment.

CMS-funded scientists also built a new series of maps detailing the global geography of methane emissions from coal, oil, and gas, and other sources. Using publicly available data reported in 2016, the research team plotted fuel exploitation emissions that arise before the fuels are ever consumed, showing areas where further reductions in emissions might be possible.

NASA's greenhouse gas research and its applications depend significantly on open science and partnerships. In addition to assets like Aura, OCO-2, and OCO-3, NASA relies on information from NOAA's Suomi NPP, the Japan Aerospace Exploration Agency (JAXA)'s Greenhouse gases Observing Satellite (GOSAT), the European Space Agency (ESA)'s Tropospheric Monitoring Instrument (TROPOMI), and a host of other data sources, past and present.

NASA compares data between programs (including algorithm intercomparisons and mutual calibration/validation efforts) and combines data from these interagency and international sources, as well as others, to help understand the nature of greenhouse gas emissions, including the balance between biologically-emitted greenhouse gases and those from fossil fuel development and combustion.

NASA coordination with international partners includes the joint Committee on Earth Observation Satellites (CEOS))/Coordination Group for Meteorological Satellite (CGMS) working group on climate and its subgroup on carbon as well as bilateral approaches like work with ESA on a future Sentinel mission for monitoring carbon dioxide.

NASA also provides support for American scientific leadership of the World Meteorological Organization's Integrated Global Greenhouse Gas Information System, along with NIST and NOAA, and jointly supports the Arctic Methane and Permafrost Challenge with ESA. Relevant NASA data are routinely and freely shared with all of NASA's partners, and our commitment to open science is a scientific beacon to the entire world.

An important part of our open approach is to make our science available, understandable, and useable by the public. NASA's Applied Remote Sensing Training Program (ARSET) and similar training programs allow all communities, including those most affected by greenhouse gases and our changing climate, to participate in our science. In fact, NASA just concluded an ARSET training module on how combining bottom-up and top-down methods for tracking emissions and removals of carbon dioxide and methane can make the 2023 Global Stocktake more complete and transparent. We hope to tell you more about our plans as we work to make next year - 2023 - a Year of Open Science at NASA.

The ability to compare, combine, and analyze all available data involving multiple, complex, and coupled processes that occur on a continuum of spatial and temporal scales and affect our entire Earth system is at the core of what NASA does. NASA's modeling capabilities, especially data assimilation, are critical to the development and sharing of observation-informed model products. In addition to all the data sources cited above and in collaboration with NOAA, NASA has shown that there are ways to assimilate everything from nighttime lights, fire radiative power, vegetation greenness, to atmospheric circulation, and fill in information that satellites cannot observe directly.

Understanding climate sensitivity is also key to mitigation and adaptation. NASA scientists and our partners are working to improve climate models over time. We know from studies of the past that Earth's climate can change dramatically, and NASA scientists working at the Goddard Institute for Space Studies studied records from periods millions of years ago when carbon dioxide levels, global temperatures, and sea level were much higher, to help understand the range of possible futures. Quantifying climate sensitivity and narrowing the uncertainties can have big implications for understanding human mitigation and adaptation choices.

Collaboration Going Forward

NASA greenhouse gas work can be enhanced increasingly by higher spatial and temporal resolution data available from companies that image the Earth from space by way of our Commercial Smallsat Data Acquisition Program. We have used that Program to on-ramp new and innovative Earth observation data providers like Planet, Spire Global, and Maxar. We expect to on-ramp additional providers later this year.

We eagerly look forward to new greenhouse gas data providers like GHGSat of Canada and the public-private partnership Carbon Mapper from California, expected to launch in 2023. NASA JPL has contributed a state-of-the-art imaging spectrometer to the Carbon Mapper project similar to ones used to identify major methane emitters in California and the Four Corners region. NASA experience has shown that where new data providers have arrived, science users are eager to validate and use whatever information they can offer.

In addition to the host of collaborations in observations, modeling, research, and other areas, NASA is working with other agencies through the new Greenhouse Gas Monitoring and Measurement Interagency Working Group. Coordination through this interagency working group will be essential to maximize the impact of agency resources, enhance the Nation's ability to measure and monitor GHG emissions and removals, and accelerate the transition of relevant research capabilities to operational use. NASA also just initiated Cycle 3 of the interagency Satellite Needs Working Group process to determine what measurement or data products needed by our interagency partners can be provided by NASA.

As part of a renewed emphasis on providing actionable data and information to a broad range of users, NASA is planning an Earth Information Center with an initial focus on prototyping capabilities for a greenhouse gas monitoring and information system that will integrate data from a variety of sources with a goal of making data more accessible and usable to Federal, state, and local governments, researchers, the public, and other users. These efforts will be implemented in coordination with other agencies and partners.

With $2.4 billion requested for NASA Earth Science in the fiscal year 2023 President's Budget, NASA will continue to make strong progress in observing and understanding the Earth as a system, including greenhouse gas emissions. NASA stands ready to work with our federal, state, tribal, local, and commercial partners to address the challenges posed by greenhouse gases and their effects. I want to thank this Committee and the Congress for its support for Earth science and the entire Federal government's efforts to tackle the challenges we discuss today, and I welcome your questions.

# Dr. Karen M. St. Germain

Dr. St. Germain is the Division Director of the Earth Science Division, in the Science Mission Directorate at the National Aeronautics and Space Administration (NASA) Headquarters. She provides executive leadership, strategic direction, and overall management for the entire agency's Earth Science portfolio, from technology development, applied science, research, mission implementation and operation.

Prior to coming to NASA, Dr. St. Germain was the Deputy Assistant Administrator, Systems (DAAS), for NOAA's Satellite and Information Service. She guided the ongoing development and deployment of NOAA's two major satellite programs (the Joint Polar Satellite System and Geostationary Operational Environment Satellite – R series), the COSMIC-2 mission, and the Space Weather Follow-On. She also led the development of the next-generation capabilities that will replenish and augment these systems in the future.

Prior to becoming the DAAS, Dr. St. Germain served as the Director of the Office of Systems Architecture and Advanced Planning (OSAAP) where she led NOAA's enterprise-level architecture development to define NOAA future spaceborne capabilities. Dr. St. Germain is a leader in enterprise-level planning and multi-organizational programs of national significance. She is also an expert in major systems acquisition, with particular proficiency in transitioning new technology into operational systems. Prior work for NOAA included leading all aspects of system performance during the development of the Suomi-NPP system, from 2006 to 2011.

From 2011 to 2016, Dr. St. Germain served in the Space, Strategic and Intelligence Systems (SSI) Office, Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (OUSD AT&L). There, she led the DoD 2014 Strategic Portfolio Review for Space, a special assignment task for the Deputy Secretary of Defense to develop a strategy and implementation plan for adapting to evolving challenges in the space domain. Dr. St. Germain also led the Remote Sensing and Prompt Strike Division within SSI, where she was responsible for acquisition shaping and oversight of DoD strategic missile warning and space-based environmental monitoring portfolio.

Dr. St. Germain had a successful research career at the University of Massachusetts, the University of Nebraska, and the Naval Research Laboratory. She has performed research aboard ice-breakers in the Arctic and Antarctic, flown through hurricanes and tropical storms on NOAA's P-3 airplanes and measured glacial ice on a snowmobile traverse of the Greenland ice sheet. She also led the modeling and calibration of the WindSat Coriolis mission, the first space-borne radiometer to measure ocean surface wind direction.

Dr. St. Germain holds a Bachelor of Science degree in electrical engineering from Union College (1987) and a Doctor of Philosophy degree in Electrical Engineering from the University of Massachusetts (1993). She is also a Distinguished Graduate of the National War College, National Defense University where she earned a Master of Science degree in National Security Strategy in 2013.

Chairwoman STEVENS. Fabulous. And with that, we'll hear from Dr. Hubbell.

**TESTIMONY OF DR. BRYAN HUBBELL,
NATIONAL PROGRAM DIRECTOR
FOR AIR, CLIMATE, AND ENERGY,
OFFICE OF RESEARCH AND DEVELOPMENT,
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY**

Dr. HUBBELL. Good morning, Chairman—Chairwoman Stevens and Sherrill and Ranking Members Feenstra and Bice. My name is Dr. Bryan Hubbell. I'm the National Program Director for the Air, Climate, and Energy Research Program in U.S. EPA's Office of Research and Development, known as ORD. I have 24 years of experience at EPA applying, conducting, and leading research on the health and environmental effects of air pollution and climate change. A key element of the ACE program is development and application of methods for measuring air pollutants and greenhouse gases. I appreciate the opportunity to talk with you today about ORD's important work to advance greenhouse gas measurement.

Accurately quantifying greenhouse gas emissions is an important part of EPA's work. Greenhouse gas data are used in a variety of ways to inform decisions that help protect the health of our Nation. Accurate and comprehensive source-based greenhouse gas emissions data provide the foundation of EPA's emission reduction programs and allow EPA and others, including Congress, to evaluate the effectiveness of those programs. Emissions data are also used by States and communities to understand their emissions and develop mitigation strategies for their particular needs.

EPA's Office of Air and Radiation also uses source-based emission measurements and modeling for the U.S. greenhouse gas inventory. While ORD does not make policy decisions, we work hard to ensure that EPA program offices, other Federal agencies, States, tribes and communities have the highest possible data quality so they can make well-informed decisions with competence.

ORD's research is currently focused on source-based measurements of methane and other non-$CO_2$ gases. This work is critical to informing both national and international greenhouse gas inventories, and it supports regulatory and voluntary emissions reduction programs. It also contributes to EPA's broader efforts to close the gap between source-based, bottom-up inventories and top-down emission estimates. Our work in this area includes exploring ways to more accurately quantify methane emissions from oil and gas operations, improving mobile ground-based remote-sensing technologies to measure methane concentrations at facility fence lines, and evaluating methane emissions from municipal solid waste landfills.

In addition to this in-house research, ORD is also developing a request for applications through our Research Grant Program to study methane emissions from landfills. We're planning to award $1 million in research grants under this request, which we anticipate releasing by the end of the year.

While methane emissions from landfills and oil and gas facilities is a focus, our researchers are also looking at other greenhouse gas emission sources. For example, our research has significantly im-

proved the understanding of greenhouse gas emissions from freshwater reservoirs, lakes, rivers, and other water bodies, which can be sources of methane, $CO_2$, and nitrous oxide. Accurate measurements of these emissions are crucial to understanding the big picture of greenhouse gas emissions. New techniques developed by ORD researchers have already improved national and international greenhouse gas methodologies and inventories.

And finally, we plan to evaluate how aquatic systems such as watersheds and wetlands can remove and store $CO_2$ from the atmosphere. And we plan to research the role of blue carbon and how protecting coastal estuaries can benefit local communities, while also reducing atmospheric $CO_2$.

Monitoring and measuring all sources and sinks of greenhouse gases requires the combined expertise of multiple Federal agencies. EPA partners and coordinates with NOAA, NIST, NASA, DOE (Department of Energy), and USDA (United States Department of Agriculture) at multiple levels to ensure we're using the best available data and measurement technologies and practices. This includes engagement through the U.S. Global Change Research Program and the Greenhouse Gas Monitoring and Measurement Interagency Working Group, and also on other research efforts. For example, ORD is collaborating with NIST, NOAA, the California Air Resources Board, and others to combine airborne, satellite, and ground-based measurements for landfill greenhouse gas emissions assessments.

While EPA and other Federal agencies have made great strides in greenhouse gas measurement, there are gaps in knowledge that we are working to address. This work includes resolving uncertainties in various airborne and satellite systems, establishing approaches that capture information about source locations and operational status, and identifying locations and events that can account for disproportionate amounts of greenhouse gas emissions. Even though my office does not directly make decisions regarding greenhouse gases, I'm proud of the research we do that helps ensure that our EPA program partners, other Federal agencies, States, tribes, and communities have the data and information they need to make decisions to protect health and the environment. We look forward to continuing this research and to addressing key research needs the future.

Thank you again for the opportunity to appear before you today, and I'm happy to take any questions.

[The prepared statement of Dr. Hubbell follows:]

**Testimony of**
**Dr. Bryan Hubbell**
**National Program Director for Air, Climate, and Energy**
**Office of Research and Development**
**U.S. Environmental Protection Agency**

**Hearing on Greenhouse Gas Measurement Technology**
**Before the**
**Committee on Science, Space, and Technology**
**Subcommittee on Research and Technology and Subcommittee on Environment**
**U.S. House of Representatives**
**June 23, 2022**

Good morning, Chairwomen Stevens and Sherrill and Ranking members Feenstra and Bice. My name is Dr. Bryan Hubbell. I am the National Program Director for the Air, Climate, and Energy (ACE) Research Program in the U.S. Environmental Protection Agency's Office of Research and Development. I have 24 years of experience at EPA applying, conducting, and leading research on the health and environmental effects of air pollution and climate change. The ACE research program provides scientific and technical information critical to improve air quality, reduce the impacts of air pollutants and greenhouse gases on human health and ecosystems, reduce environmental and health inequities, and respond to impacts of climate change and transformations of the energy and transportation infrastructure. A key element of the ACE program is development and application of methods for measuring air pollutants and greenhouse gases. These include methods for measuring emissions from sources and concentrations of pollutants near sources and in ambient air.

I appreciate the opportunity to talk with you today about the important work EPA's Office of Research and Development is doing to advance greenhouse gas (GHG) measurement.

**Overview**

Accurately quantifying greenhouse gas emissions is an important part of EPA's work to address climate change and protect people's health. Over the past decades, EPA has developed a suite of tools for measuring, collecting, and estimating source-based GHG emissions that have been continually evaluated, improved, and refined. These tools and assets provide a solid scientific foundation to support ambitious climate change mitigation policies, even while we continue our work with our federal partners and external stakeholders on improving our GHG data.

Greenhouse gas data are used in a variety of ways to help inform decisions that help protect the health of our nation. Accurate and comprehensive, source-based greenhouse gas emissions data provide the foundation of EPA's emission reduction programs and allow EPA and others, including Congress, to evaluate the effectiveness of those programs. Source-based emissions data are used by states and localities to understand their emissions and develop mitigation strategies that are tailored to their particular needs. EPA's Office of Air and Radiation (OAR) uses a large number of source-based emissions measurements and modeling for the development and publication of the U.S. Greenhouse Gas Inventory (GHGI) of emissions by gas and sector, including data from the facility-level Greenhouse Gas Reporting Program. The GHG Inventory adheres to methodological standards agreed by the Intergovernmental Panel on Climate Change (IPCC) and is consistent with inventories submitted by other countries to the United Nations Framework Convention on Climate Change (UNFCCC).

EPA's Office of Research and Development (ORD) works closely with agency partners and others to design and conduct research to improve greenhouse gas measurement technology. While ORD does not make policy decisions, we work hard to ensure that EPA program offices, other federal agencies, states, tribes, and communities have the highest possible data quality so that they can make well-informed decisions with confidence.

**ORD Research on GHG Emissions Measurement**

ORD scientists continue to conduct research to improve measurement methods and data for greenhouse gas emissions from several sources and sinks. Our research is currently focused on ground-based measurements of methane and other non-CO2 gases. This work is critical to informing both national and international greenhouse gas inventories, and it supports regulatory and voluntary emissions reductions programs.

Our work in this area includes:

- Exploring ways to more accurately quantify methane emissions from oil and gas operations. This work uses optical gas imaging methods to identify sources combined with conventional sample collection to estimate emission quantities.
- Improving mobile, ground-based remote sensing technologies to measure methane concentrations at facility fencelines.
- Evaluating methane emissions from municipal solid waste landfills. This includes planned work to evaluate whether drone-based sensors can be used as an alternative to surface monitoring.

These efforts contribute to EPA's broader efforts to close the gap between source-based, bottom-up inventories and top-down emission estimates. These two approaches are complementary and have important roles to play in ensuring that the nation has the most accurate information

possible on GHG emissions. For instance, top-down measurements are indispensable as an independent check and can be used to estimate large anomalous methane leak events from individual facilities (e.g., well blow-outs). And bottom-up, source-specific data can support implementation of many emission mitigation actions. Properly combined, top-down and bottom-up approaches together can provide results which are superior to either approach alone.

In addition to this in-house research on methane emissions measurement, ORD is also developing a Request for Applications (RFA) through our Science to Achieve Results (STAR) program to study methane emissions from landfills. We are planning to award $1M in research grants under this RFA, which we anticipate releasing by the end of the year.

While methane emissions from landfills and oil and gas facilities is a focus, our researchers are also looking at other greenhouse gas emissions sources. For example, our research has significantly improved the understanding of greenhouse gas emissions from temperate freshwater reservoirs, particularly where human influences are causing increased emissions. Freshwater reservoirs, lakes, rivers, and other water bodies can be sources of methane, CO2, and nitrous oxide. Accurate measurements of these emissions are crucial to understanding how much we need to reduce emissions from man-made sources to achieve our national climate mitigation goals. This information can also be used to inform operation of managed aquatic systems, such as reservoirs, to meet multiple needs such as controlling water flows and reducing emissions. Prior measurement methods lacked adequate and representative data, but new techniques developed by ORD researchers have already improved national and international greenhouse gas methodologies and inventories.

And finally, we plan to evaluate how aquatic systems, such as watersheds and wetlands, can remove and store CO2 from the atmosphere. This will include developing a model to evaluate

seasonal and annual carbon sequestration by wetlands in soils and plant biomass and net CO2 and methane emissions in watersheds and wetlands. We also plan to research the role of "blue carbon," which is the carbon stored in coastal and marine ecosystems, and how protecting coastal estuaries can benefit local communities as well as reducing atmospheric CO2.

**Interagency Collaboration**

Monitoring and measuring all sources and sinks of GHGs requires the combined expertise of multiple federal agencies. EPA partners and coordinates with NOAA, NIST, NASA, DOE, and USDA at multiple levels to ensure we are using the best available data and measurement technologies and practices. This includes engagement through the U.S. Global Change Research Program, the White House Greenhouse Gas Monitoring & Measurement Interagency Working Group, and on other research efforts.

For example, ORD is working with NIST, NOAA, the California Air Resources Board, and other partners to combine airborne, satellite, and ground-based measurements for landfill GHG emissions assessment. This will include identifying high emitters and validating emerging satellite and airborne approaches for different landfill configurations and designs.

ORD is similarly engaging with NASA, NOAA, and DOE to investigate collaborative research approaches for oil and gas production. ORD researchers are also working with USGS on efforts to better characterize methane emissions from reservoirs and other freshwater bodies, leveraging USGS data on waterbody location and extent.

**Next Steps**

While EPA and other federal agencies have made great strides in greenhouse gas measurement, there are specific gaps in knowledge regarding some sources of non-CO2 emissions. ORD's research, in collaboration with federal partners, will help address these gaps

and to reduce uncertainties. This work includes resolving uncertainties in emission detection and quantification capabilities of various airborne and satellite systems now being used, and it also includes establishing refined measurement and monitoring approaches that capture information about source locations and operational status and activity, which is crucial to inform mitigation efforts and reduce emissions.

Another key research goal for ORD is to identify high emissions locations and events that can account for disproportionate amounts of greenhouse gas emissions. These efforts provide information beyond quantification of emissions to identify approaches to prevent or reduce those emissions. For example, results of one ORD study of methane emissions from oil and gas production pads showed that high emissions could be reduced by changes in operating or maintenance practices.

Additionally, as interest continues to grow in developing nature-based solutions to capturing and storing carbon, ORD will continue to coordinate with federal partners in studying how to measure the carbon stored by natural systems and the benefits they provide to their local communities. This work will include understanding variability in storage across different types of ecosystems, the stability of storage in a changing climate, and how to consistently evaluate greenhouse gas removal and storage.

**Conclusion**

Greenhouse gas measurement is clearly an active area of research at EPA and other federal agencies. I am proud of the work our researchers have made in improving measurement technology on the ground, in advancing remote sensing measurements, and in understanding how our natural environment can remove carbon from our atmosphere. Even though ORD does not directly make decisions regarding the mitigation of greenhouse gas, we are proud of our work to

help ensure that our EPA program partners, other federal agencies, states, tribes, and communities have the data and information they need to make decisions to protect health and the environment. We look forward to continuing this research and to addressing key research needs in the future.

Thank you again for the opportunity to appear before you today. I am happy to take any questions you may have.

Dr. Bryan Hubbell Bio:

Dr. Bryan Hubbell is the National Program Director for the Air, Climate and Energy Research Program in the US EPA Office of Research and Development, which provides information critical to improve air quality; reduce the impacts of air pollutants on to human health and ecosystems; reduce environmental and health inequities; and respond to impacts of climate change and transformations of the energy and transportation infrastructure. Dr. Hubbell has worked for the EPA for 24 years as an expert on the health and environmental impacts of air pollution. He led the EPA project team that developed the environmental Benefits Mapping and Analysis Program (BenMAP) which is used around the world to estimate the benefits of clean air. Bryan earned a Ph.D. in economics from NC State University. He is an author on over 50 peer-reviewed publications on a wide variety of topics and disciplines and has presented extensively in the U.S. and internationally on health and environmental impacts of air pollution and economic benefits and costs of air quality regulations.

Chairwoman STEVENS. Well, thank you so much.

And at this point, we're going to begin our first round of questions, and the Chair is going to recognize herself for 5 minutes.

So you all have spoken today about the fantastic work your agencies are doing and the interagency partnerships that are going to enable the success of much of the work at hand. Given all this collaboration, I wanted to dive a little deeper on the idea of integrated greenhouse gas observing system. So what is the ultimate vision of an integrated greenhouse gas observing system, and what do we need to do to achieve such a system? And anyone of you can start with that. Dr. St. Germain?

Dr. ST. GERMAIN. Certainly, thank you for the question. So—and I think that all of the members of the panel may have something to contribute to this one.

Chairwoman STEVENS. Yes.

Dr. ST. GERMAIN. I think it's really about doing the data assimilation. There are two elements, right, bringing together the data and the models that we that we have and the strengths of those from each of the agencies, but then also creating the interface that makes that easy to access, so, you know, unleashing the power of that science by making it easy to access and understand by users at all levels to inform the decisions they have before them.

Chairwoman STEVENS. Yes, Dr. Stein?

Dr. STEIN. An integrated system will require going from global measurements and models all the way to the local realm. I would envision the idea of using satellite, in situ, tower, airborne platforms, along with the integration of models together. We also need vertical profiles of the atmosphere in order to understand the three-dimensionality of that, and going again from the global to the local and also taking into account the sectors that we are going to study. Each sector is going to require a different solution. The stacks or industrial sectors do not have the same—do not—are not looking for the same solutions as the urban areas. The forest problem or the uptake from forests requires a different set of tools. So all of the—that integral way of responding to this problem is key for tackling it.

Chairwoman STEVENS. Yes. And, Dr. Lin, as we answer this question, just for the folks who are watching back at home, and given the division of NIST that you oversee, could you just give some examples of the units of measurement that we're talking about?

Dr. LIN. Well, probably the most important one is the concentration level. So of all the greenhouse gases, you need a concentration, so you need a composition measurement of the quantity of any gas within a given environment. That would be one. Another one would be basically all of the quantities that are used to connect to those concentration levels, so those would be like spectroscopic measurements where you need to know wavelengths and those types of units. But I'd say concentration is probably the most important.

Chairwoman STEVENS. And those are global measurements? It's a universal unit of measurement——

Dr. LIN. Yes, yes.

Chairwoman STEVENS [continuing]. Not subject to the pain of the imperial system——

Dr. LIN. No, it's part of the system, international system of measurements, the SI system. The relevant one here is really the mole and the gram, so it's a measure of quantities. And we say concentration is a quantity per unit volume, which is related to mass. So these are all very universal and tied to the SI system. And we work very closely with our partners to take these fundamentals of something as straightforward as concentration and mass and we have to connect it to concentration in the reference materials that are done in partnership with NOAA as the official reference materials, primary laboratory for the international system.

Chairwoman STEVENS. And so, Dr. Hubbell, how does this system of—enable us to meet the goal to reduce greenhouse gas emissions? This is the Integrated Greenhouse Gas Observing System.

Dr. HUBBELL. Right. So I just want to point out that in addition to these kind of global measurements, it's really also important to get very local to be able to inform mitigation. So the ground-based measurements that we typically are engaged with are looking at things like emission rates and looking at emissions coming from specific parts of the production process. So it's really important to—as we're thinking about global measurements of concentrations, to also remember that we need to get a good understanding of emissions from individual sources and parts of sources so that we can create mitigation strategies. That's a critical part as we're moving forward with thinking about these integrated systems.

Chairwoman STEVENS. Yes. Great. Well, I know Dr. St. Germain mentioned that in her testimony, and we're very proud in Michigan of our border relationship with Canada and the great work that we do, and this is another phenomenal example.

So I'm just slightly over time. I'm going to yield back. I'm going to recognize my hardworking colleague, Mr. Feenstra, for 5 minutes of questions. Thank you.

Mr. FEENSTRA. Well, thank you so much, Chairwoman. And I want to thank each of you for your testimony. It was very impressive and good information.

Dr. Lin, as you know very well, NIST's expertise lies in standards, and NIST has initiated the development of technical standards to help support accurate greenhouse gas emission measurements. Could you provide us with an update where NIST is in the process and how NIST is working with the industry to develop these standards?

Dr. LIN. Thank you very much for the question. So for us at NIST, as you know, we work in standards as a voluntary, consensus-based system, and so we really look for forums to where we can gather industry and other stakeholders in order to develop the standards that are needed. So NIST is currently very active in the international standards arena of really trying to provide technical expertise and focused on the technical standards that'll enable transparency and consistency across all the measurements that are needed to track emissions and sinks.

Currently, we are working in the technical groups and the International Organization of Standardization, ISO, and also within the American National Standards Institute, ANSI, and with a subcommittee that is focused on these greenhouse gases and related activities. It's very active, and a lot of progress is being made.

Mr. FEENSTRA. That's exciting to hear. Are you going to get consensus? I mean, this is a global thing. I mean, do you see some consensus happening in the next 2 years?

Dr. LIN. On the technical front I think we are making progress, and since it's a technical foundation and focus for the areas of work we're concentrating currently, then it's a yes, I believe that's certainly——

Mr. FEENSTRA. Well, that's great to hear.

Dr. Hubbell, a study conducted by Argonne National Laboratories revealed that the use of corn ethanol reduces greenhouse gases, very important to me. I am No. 1 in the country in ethanol production. From 2005 to 2019, corn ethanol production nearly quadrupled in the United States. During that same time, scientists found a 23 percent reduction in ethanol's greenhouse gas emission intensity. EPA's greenhouse gas reporting program collects greenhouse gas emission data from individual facilities and suppliers of certain fuels and gases.

So the question is this, it sort of begs the question, is corn ethanol one of those things that can help us and at what level of engagement can we see from this sector? I mean, is this something that we should promote and that's positive?

Dr. HUBBELL. So I can only really speak to the research that we're doing, which has been focused on the oil and gas industry and on landfills. I think that this question of emissions from ethanol is a very important one, and we have folks within our Office of Air and Radiation who can probably speak better to the question of how that feeds into greenhouse gas inventories and the role that they play. So if—I'm happy to take that back to our colleagues in the Office of Air and Radiation if you'd like.

Mr. FEENSTRA. Yes, to me, it's really interesting. And for me, it's about the regulatory environment with the EPA and when it comes to agriculture and ethanol and where that's going.

With that, I've got another question for Dr. Lin. You know, our farmers in Iowa, we can all say that carbon in the soil is a great thing because it because it can increase crop yields. That's a fact. And in fact, land absorbs approximately 26 percent of the total emissions humans put into the atmosphere each year, so this is really big. But when it comes to specifics, exactly where sinkholes are located, how they work, and how long they will continue to absorb carbon dioxide, there's a lot of uncertainty.

So my question is, how do we increase the knowledge related to greenhouse gas sinks and their single area of research and whether there's—you know, what type of data collection and modeling and verification can we do that can be beneficial? Again, I come from an agricultural State, and this is sort of a big deal.

Dr. LIN. Certainly, those are worthy of research, as we've heard from my colleagues, and we work in partnership for that. And basically in the scientific enterprise is really focusing attention and resources to do the best possible way to both understand and to quantify the effects that you named. So I think it really takes a whole system approach of many different types of measurements and modeling, especially modeling approaches to really get at the detailed answer that we need to be able to answer that question.

Mr. FEENSTRA. Yes. So my time is running out, but, Dr. Lin, would you agree that farming, agriculture promotes the reduction of carbon in the atmosphere?

Dr. LIN. That's not my area of expertise, but I would say that can be monitored and measured and quantified.

Mr. FEENSTRA. OK. Thank you. Thank you for that. And I yield back. Thank you very much.

Chairwoman STEVENS. Great. And with that, we're going to hear from Mr. Tonko for 5 minutes of questioning.

Mr. TONKO. Thank you, Madam Chair. And I thank you and Chair Sherrill and Ranking Members Feenstra and Bice for holding today's hearing and to the witnesses for being here today.

The concentration of greenhouse gases in our atmosphere due to human activities hits record levels every year. Without major cuts to emissions, the driving force of the climate crisis, humanity and our environment will continue to endure the consequences of an increasingly warming planet.

The work that all of you are doing at your respective agencies is indeed critical to ensuring that we have the scientific and technical data. These data are then utilized to improve our understanding of greenhouse gas emissions, their sources, and indeed their solutions. I believe our first priority in climate action is to mitigate our emissions in every possible way.

So, Dr. Hubbell, how does ORD's research on greenhouse gas emissions measurement support innovation?

Dr. HUBBELL. So we work very closely with industry partners, as well as with other agencies and with States to be able to identify the best new technologies that can help us to be able to characterize emissions, especially from leaks that are coming from oil and gas operations and in landfills. And we do this in a number of ways. We have cooperative research and development agreements that we enter into with industrial partners. We've worked with close to 20 industrial partners over the last number of years to be able to develop and test these technologies. And these cooperative research and development agreements allow us to more easily share data and expertise, including proprietary information, so that we can get the best technologies developed.

We also have our Small Business Innovation Research program that allows us to fund developers of innovative instruments to be able to address the emissions from these important sources. And we also have a prize challenge program that we work on with other agencies to encourage innovation by putting out a problem and then asking for creative solutions that we then are able to promote and support. So we have a number of different ways we work on innovation, but it's always in a partnership, and that's a really key part of the work we're doing on emissions measurement.

Mr. TONKO. Thank you. I appreciate that. And you stated in your testimony that you have helped improve greenhouse gas inventories. Can you share some examples, please?

Dr. HUBBELL. Sure. So one of the other areas that we work on in addition to landfills and oil and gas is we identified there was an opportunity to better characterize the emissions coming from reservoirs, as well as other freshwater bodies like lakes and rivers. And there was a recognition that these water bodies can be a sig-

nificant source of $CO_2$, methane, and nitrous oxide and that it'd be very valuable to be able to characterize these sources so that we got a better overall picture of the national greenhouse gas inventory.

So our scientists have worked with others in the Federal Government, including USGS (United States Geological Survey), to be able to characterize these emissions, especially for methane. That information has already been included in national and international greenhouse gas inventories. It's been recognized by the IPCC (Intergovernmental Panel on Climate Change) and as useful to other nations, as well as the United States. In addition, the work has got some very specific benefits to operators of these managed aquatic systems, as they're looking for ways to address multiple objectives like managing water flows, as well as trying to reduce emissions. So this has been very important research that we've conducted recently.

Mr. TONKO. Thank you. And would you cite additional opportunities within your agency for collaborations with the private sector, with research institutions, and other stakeholders to address both community-level and broader measurement concerns?

Dr. HUBBELL. Yes, we are always looking for opportunities for additional collaborations with industry partners. We do also have a Science to Achieve Results grant program that provides funding to academic institutions. And in fact, we are—as I mentioned in my testimony, we are issuing a request for applications this year, hopefully, to be able to address landfill emissions, and we hope to be able to fund about $1 million in grants to help address this important sector.

Mr. TONKO. Great. Are there any—are other members on the panel wishing to comment on that given set of opportunities that you see for your agency? Dr. Stein?

Dr. STEIN. In terms of interacting with the private sector?

Mr. TONKO. Private sector or institutions for research——

Dr. STEIN. Yes, in terms of the private sector, as I mentioned in my testimony, we are closely working with the airline industry to include measurements of greenhouse gases in their airplanes and basically to detect changes in the vertical, which is key to link the satellite images with concentrations so we can utilize that in a unified system that can provide information to the stakeholders.

Mr. TONKO. Thank you. Anyone?

Dr. ST. GERMAIN. And I'll just add that we are working with the private sector to transition our technologies, our observation technologies to them so that they can play a role and we can move on to the next, more difficult science questions, as well as interacting with industries like agriculture so that they can understand both how their crops are serving as sources and sinks of greenhouse gases, but also how their crops may be impacted by the climate change and how that may drive changes in how they interact in the carbon cycle.

Mr. TONKO. Wonderful. Thank you. Well, I've used up my time and more, and so I appreciate the patience of the Chair. And with that, Madam Chair, I yield back.

Chairwoman STEVENS. All good stuff. And if there are Members who wish to submit additional opening statements, your state-

ments will be added the record either at this point or from the time when we concluded opening statements.

I'd also right now like to recognize Dr. Baird for 5 minutes of questioning. Thank you.

Mr. BAIRD. Well, thank you, Ranking Member Stevens and—or Feenstra, and, Madam Chair Stevens, I appreciate you coordinating this Committee. And I always appreciate the witnesses sharing their expertise about these subject matters.

And so with that, Dr. Hubbell, I'm interested that—and from the fact that in my district, Purdue University has the Climate Change Research Center, which is focused on the interdisciplinary aspects of climate change. My question is, so how does each agency translate monitoring and the numbers to people on the ground? For example, agricultural communities seem particularly capable of immediate actions that slow climate change and enable them to benefit economically. So how is greenhouse gas data like that coming from NASA and NOAA satellites being translated to the actionable farming community and farming practices?

Dr. HUBBELL. So I'll certainly let my colleagues at NASA and NOAA speak to translate their satellite and other information. We do work to try to provide information in usable formats for different types of decisions, and one of the things that we've been working on in ORD is trying to, for example, develop more opportunities for community-engaged research where we work with the communities directly to understand measurements and be able to interpret them for supporting their decisions. And, you know, we are hoping that the work we're doing to reduce the cost and increase the ease of use of different measurement technologies will allow communities like the ones in your State to be able to better understand the measurements they're seeing and use that information to support their decisionmaking. So we are working to try to not just reduce the cost and improve the accuracy of measurement technologies, but also to make them easier to use and for us to make it easier to share information that's collected by those technologies.

Mr. BAIRD. You know, along in that same vein, it just occurred to me about, you know, we're collecting a lot of data on the farms with our machinery and our equipment. Is there—or do you have access to that kind of information or do you get feedback from the agricultural community and the monitoring that they do?

Dr. HUBBELL. So as I've mentioned, we're not doing any current research with the agricultural community looking at measurements with the ground-based measurements. Certainly, you know, EPA has worked with USDA and others to be able to think about ways we can address emissions from the agriculture sector, but for right now, we're not doing any current research in that area.

Mr. BAIRD. Thank you. Dr. Lin, do you have any additional concerns that you might share with us regarding this question?

Dr. LIN. I think that we have models of which we are testing with the Urban Dome testbed is an approach that is looking at how to integrate multiple sources of information into a whole so we can get holistically a lot more accurate picture of that. That idea certainly could be extended into rural areas and as a conceptual idea, and so I think any information certainly is useful to obtain.

Mr. TONKO [presiding]. And, Dr. St. Germain, I think that earlier they referenced NASA in regard to Dr. Baird's question, so perhaps you want to comment there?

Dr. ST. GERMAIN. Yes, absolutely. We have a lot of work going on with the agriculture sector in terms of exchange of information and understanding. And there are three, I'll say, principal mechanisms by which that happens. One is through other agencies like USDA or Department of Interior that—where we integrate our information into data products and tools that are already accessible to these communities so they don't have to learn another one.

In cases where we can make tools, information, insight available to them where such a tool doesn't exist through another agency, we do direct applications. We build applications, generally making them openly available, web-based, and that sort of thing.

And the third—and this is a recent thrust area is working directly with the agriculture sector. That is everything from the direct—the farmers themselves to agribusiness, to actually learn more about what data they have on the ground that may be useful to us to improve our models and capabilities, and likewise, how they need information delivered to them. And I just spent a week this summer or earlier this spring at the Commodity Classic meeting with the major commodities groups to really figure out how to tighten up that coupling. Thanks.

Mr. BAIRD. Great. We really appreciate you doing that. So, Dr. Stein, we only got about 30 seconds. Do you have any——

Dr. STEIN. Yes, I can give you a couple of examples of what NOAA is doing in terms of actionable data for agriculture. We run the National Integrated Drought Information System, and in climate.gov you can have that information readily available. And also we have our Geostationary Operational Environmental Satellite Series that are providing operational and long-term measurements of changes in land use that can be very useful for the agricultural sector.

Mr. BAIRD. Thank you very much, and I yield back.

Mr. TONKO. The gentleman yields back.

The Chair now recognizes the gentleman from Pennsylvania, Representative Conor Lamb. You're recognized for 5 minutes, please.

Mr. LAMB. Thank you, Mr. Chair. My first question is for Dr. Lin.

You know, Dr. Lin, in western Pennsylvania, there's a fair amount of natural gas drilling taking place and has been for a long time. And what you hear from some of these companies is that they are basically being rewarded by their own investors and stakeholders for continuing to try to reduce methane emissions below 1 percent if possible. And, you know, that is also their strongest argument for being a progressive alternative to coal in terms of, you know, our progress toward climate change. But both of those claims rest on accurate measurement of what their methane emissions actually are all throughout their system.

And so my question for you is about your level of confidence in what drilling operators are using to sense and detect and report their own methane emissions, as far as the reliability of the equipment, the accuracy, whether they're measuring everywhere that

they should be measured, whether the standards for this equipment are what they need to be, or, you know, sort of how far we have to go in terms of making sure that the measurement being used onsite from the wellhead all the way to the end user is as accurate as it should be.

Dr. LIN. Thank you very much for the question. Certainly, those are very important questions for the reasons that you stated and also for us as a measurement institute for the interest of making sure the data is consistent, transparent, and accurate. At this point, as I understand it is that the industry is using a range of technologies to do these measurements and reporting them, and new technologies are being developed every day. So, I think this is an area where a standard [inaudible] based on the best [inaudible] would be appropriate. I'm not exactly sure how that is related to this specific industry at this point but that is an area where I, where we could look into.

Mr. LAMB. It looks like the hearing room froze on us. I'm not sure what it looks like in there.

STAFF. Yes, it looks like it has. Mr. Lamb, I am checking with folks right now, and I'll check in the room as well.

Mr. LAMB. Oh, it looks like he's back if you could just unmute the hearing room. It looks like Dr. Lin is back. You're still muted, Dr. Lin, so just hold on a second.

STAFF. Yes, they probably don't hear. I'll let them know. It looks like we have audio back in the room. We're just waiting for the video to return.

STAFF. Hearing room audio test, test.

STAFF. We've got that coming through.

STAFF. Larry, I can hear you.

STAFF. Yes, and I can hear you.

STAFF. Testing 1, 2, 3 audio in the hearing room, test.

STAFF. Yes, I'm hearing. Can you hear me?

STAFF. I can hear you, Larry.

STAFF. OK, great. We've got audio. We just got to get the video back in the room. Thank you.

STAFF. OK.

Chairwoman STEVENS. Mr. LaTurner, can you hear us? OK. Can—well, what about Dr. Hubbell?

STAFF. Mr. LaTurner is not connected.

Chairwoman STEVENS. Oh, good, but Dr. Hubbell can hear us?

Dr. HUBBELL. Yes, I can hear you.

Chairwoman STEVENS. Oh, good. Well, so this—I mean——

STAFF. Yes, we've got——

Chairwoman STEVENS [continuing]. Well, we'll——

STAFF [continuing]. Audio back, ma'am. We're just waiting for the recording studio to return the video picture back, and then we can start back up.

Chairwoman STEVENS. OK, thanks. We're going to get the video started and we'll get started. Thanks.

STAFF. Yes, and there's the video, so we can start back up. We were still with Mr. Lamb.

Chairwoman STEVENS. Congressman Lamb, we're going to recognize you for another several minutes of questioning. Thank you.

Mr. LAMB. All right. Yes, we don't need too much more. I just—I'm going to restate it because we didn't get a whole lot of Dr. Lin's answer.

But my basic question is that it's increasingly important that drillers and natural gas distributors and everyone who's responsible for that whole kind of ecosystem are able to report accurate results as to their methane emissions. It's very important for their own investors. Obviously, it's important for any future scheme in which we are trying to either pay for or tax, you know, carbon emissions or savings.

So my question is really a technical one about your level of confidence in the quality of the sensors and equipment that they're using right now and whether new standards and rules are needed in order to make sure that what they're using actually provides us with accurate information.

Dr. LIN. So for our point of view at NIST as a measurement institute, the problem you described is a very real one. And we would go more toward the voluntary standards arena for where the stakeholders within the problem space you described could get together to to really tackle exactly what are the standards measurements for the technologies and how to report them. Since there's a range of technologies, each one has its strengths and weaknesses. I'm not really in a position to comment on any of those. Perhaps my colleagues who also have equities in this space could have more to add.

Mr. LAMB. Yes, I thought Dr. Hubbell potentially, I mean, I believe it's the EPA that has actually published some of the data showing the way that methane emissions are underreported and have been for some time. So I don't know if you had anything to add to that as far as just kind of weighing in on the quality of the equipment that we're talking about. You know, sometimes we talked about just are they monitoring it at all? Are they monitoring it in the right places? But even—I guess my question is even where they are monitoring methane emissions, are we using equipment and sensors to do so that are up to the proper standard?

Dr. HUBBELL. So just as Dr. Lin said, I think it depends on the technologies and there—and there's a wider range of those technologies that are used. You know, and again, we're focused right now on trying to improve the technologies for leak detection and repair so that we can quickly identify these sources of methane and stop them. So that's really our focus right now is on developing better ways to do that. And also, you know, it's not just the accuracy of the measurements, but it's also, you know, making them at a low enough cost that they can be used——

Mr. LAMB. Right.

Dr. HUBBELL [continuing]. And to trying to make them easier to use because some of these very accurate measurements are more costly and more difficult to operate, so it's really important to think about all those——

Mr. LAMB. Well, I guess what I'm getting at is I don't believe that we have any real requirements in place to sort of force operators to choose the highest quality equipment or whatever, the cutting edge of what you're discovering, right? I mean, to Dr. Lin's

point we're still in a very voluntary world when it comes to choosing, you know, the best the best equipment to use.

Dr. HUBBELL. Yes, and again, I think it's important to work with our industry partners to understand what the needs are in the particular industries in then different parts of the country as well.

Mr. LAMB. Great. Well, thank you very much for your participation and for all your hard work. And Madam Chair, I yield back.

Chairwoman STEVENS. Thank you. And now we're going to recognize the Congresswoman from North Carolina for 5 minutes of questioning, Ms. Ross.

Ms. ROSS. Thank you, Madam Chair. And thank you so much for your leadership on this important topic. And thanks to the Ranking Member and all of our witnesses for joining us.

Before being elected to Congress, I was a renewable energy lawyer in North Carolina and worked with companies there to mitigate and repurpose captured greenhouse gases, some of the first methane and also biogas projects I got to work on. And in my State of North Carolina, we're home to a unique kind of carbon sink ecosystem called pocosin, which is naturally occurring wetland. In fact, in the 1960's, North Carolina was home to over 2 million acres of pocosin ecosystems, nearly 75 percent of the country's total. And the measurement of carbon emissions of these ecosystems is vital to land management that keeps carbon locked in the soil rather than in the atmosphere.

My first question is for Dr. Lin. In your testimony, you discussed how vegetation and wetlands in cities complicates measurements of urban methane and carbon dioxide emissions that make it difficult to identify their sources. Can you talk about why the presence of vegetation and wetlands in cities complicate these measurements and what is needed to improve the accuracy and attribution of urban and regional methane and carbon dioxide emissions to specific sources?

Dr. LIN. Thank you very much for the question. It's certainly a complicated system to look at. Basically, vegetation and wetlands near cities complicates measurements because they are fluctuating, and they're fluctuating at levels that would impact the accuracy of the overall measurements of what the greenhouse gases emissions and sinks are. And so what we need is a much better idea, a study about the modeling about how vegetation and wetlands and their fluctuations have an impact on greenhouse gases. And we'd also need to advance ways which we have been doing of how to detect greenhouse gases that are coming from organic and vegetation sources as opposed to human and more urban sources. So there's a lot of work to do there. And certainly, we're doing that with our partners here across the government, which have very extensive efforts in attacking the details of how to understand that.

Ms. ROSS. And picking up on Congressman Lamb's last point, how can the private sector be involved and be helpful in these efforts, if at all?

Dr. LIN. Well, certainly the private sector is very much engaged for many of the drivers that have been shared earlier. So at NIST, our approach is to really build consensus and to convene parties to try to address them collectively. So our Urban Dome testbed program is an example where industry and multiple stakeholders

come together, share information, and contribute to the overall quality of the measurement of the overall system, in this case, an urban testbed.

Ms. ROSS. OK. Thank you. And then I wanted to take a little bit of a broader view because, as you've all indicated, we're not just measuring greenhouse gas emissions from the United States but from all over the world. And to anyone who wants to use this next minute and 30 seconds, why do we need global measurements of greenhouse gas emissions if the primary focus of Congress is on the United States? And I'll open it up to whoever is interested in answering.

Dr. ST. GERMAIN. Yes, Congressman Ross, thank you for the question. It's the Earth—as I mentioned earlier, the Earth operates as a system and so emissions in one location, of course, don't stay put. They mix in the atmosphere. They affect the entire carbon cycle. Likewise, regions around the world absorb carbon dioxide in different measures. And that's really where the power of merging surface-based observations with space-based observations can be most impactful. It's the satellite observations that can give us those insights in regions of the world where we don't have the surface-based observations because they, too, are impacting the global system.

Ms. ROSS. Does anyone have anything to add?

Dr. STEIN. Yes, in terms of the—we need a global view because everything, as Dr. St. Germain presented, it's intermingled. And we also not only want to detect changes in the United States, but we also want to detect changes in other countries and see if other countries are really—and holding them responsible for their commitments. So that is really an important thing.

And let me just give you an example. Going back to your question about wetlands, the work that we are doing at NOAA in terms of detecting changes in natural environments like in wetlands, we can use isotopes of carbon to distinguish between natural and anthropogenic sources there. And we—we're able to distinguish, for instance, that the latest increase in methane that we have observed—that we have been observing in the last 10 years globally is due to changes in biological activity.

Ms. ROSS. Thank you very much for your indulgence, Madam Chair, and I yield back.

Chairwoman STEVENS. Indulge away. With that, we're going to hear from Ms. Stansbury from the beautiful State of New Mexico for 5 minutes of questioning.

Ms. STANSBURY. Well, thank you, Madam Chairwoman, and also to the Ranking Member, and thank you to all of our esteemed panelists for being here today. You know, I know we've been talking a lot this morning about the science specifically and how we address the issues around monitoring, around standardization of how we measure greenhouse gases, and then what do we do with that information to help inform our climate action?

And I want to kind of direct the panel toward the policy side of the equation now and specifically science policy. You know, we all know we're at a global tipping point. We know that we have to take action as quickly as possible. And part of being able to take effective action on climate change requires that we know that the meth-

ods and the tactics that we're using to tackle emissions and sinks is actually effective and that we are making the investments that have the biggest bang for the buck.

And so I know we've already touched on some of this this morning, but I want to ask each of the panelists since you sit in different agencies and work on these with your other agency partners, are there specific policy actions that you feel Congress or the Federal Government as a whole could take that would help to standardize the way that we do measurement, the way that we deploy instrumentation across the United States on measuring carbon emissions and sinks as a sort of network of monitoring, and, as I said, standardizing the ways that we do it, and then how we deploy that information in terms of determining where to make investments as the Federal Government in both emissions reduction and in sinks? So if we could, why don't we go ahead and start with the panelist from NASA and go down the line.

Dr. ST. GERMAIN. Yes, so I think NASA's contribution in this space is really to provide the global, transparent, repeatable, open, trusted science on which policy decisions can be made. And that is reliant upon the sustained support and open process for calibrating our surface observations, and as well as our airborne and spaceborne. So I think the sustained focus on having that open—those open sources of data is really going to be foundational to informing the policy choices that Members of this Committee and others have before them and assessing the efficacy of those as we move along in time.

Ms. STANSBURY. Thank you. And let's go to Dr. Lin next. You know, are there things that we can do as a Federal Government, like I said, either as Congress or in the administrative branch that would help to standardize the way that we're doing emissions tracking and that would help to bring more coherence to all of the science that you all are talking about today?

Dr. LIN. I think the progress in the interagency working group has been really outstanding, and that is the forum in which these questions you're asking are being addressed. And so I think it's really as a continued, sustained—as my colleague stated, a sustained support of encouraging and facilitating that exercise. It's very difficult to pull all these multiple measurements and different points of view into a coherent whole that's precise, transparent, and we can have confidence in it. But a tremendous amount of progress has been made, and certainly there's more room to go.

Ms. STANSBURY. Thank you. And Dr. Stein?

Dr. STEIN. Yes, we're making—I'm part of the interagency working group, and we are making strides to tackle this problem from day one. And we see this as a big challenge in terms of harmonizing and sharing data sets. Also, the World Meteorological Organization is tackling this problem at this right moment. So you're asking the right question. And we are trying to provide an answer as soon as we can, so we're working on that.

Ms. STANSBURY. Thank you. And Dr. Hubbell?

Dr. HUBBELL. Yes, I just wanted to start by saying that, you know, the current inventory that we have is very high quality. And really what we're trying to do is being able to identify those few areas where there's an opportunity for improvements that can help

us inform mitigation actions, but what we have now is very high quality.

I think in terms of the interagency effort, I think, as the other panelists have said, the interagency working group has been really a great place to be able to work on these challenges. And one thing I did want to add to that is that it's important as we're getting new research and getting these systems linked to be thinking about having a steady flow of high quality data so that we can track trends and not just a snapshot in time, so being able to do this over time is really important.

Ms. STANSBURY. Thank you. And I know I'm out of time, Madam Chairwoman, but I just want to add that myself and other colleagues are very interested in looking at opportunities for Congress to partner with the Administration to help bring a policy framework to coherence and how we measure and deploy different climate strategies. Obviously, this is the most important and pressing question of the day is how do we meet our goal of reducing our carbon emissions by 2035, 2040 so that we don't cross this catastrophic tipping point? And so I look forward to working with all of you on that, as well as climate resilience and climate justice. And really thank all of you who are working in our Federal agencies for your service in this area. You are doing some of the most important work on the planet, and we thank you for your service.

Mr. TONKO [presiding]. The gentlewoman yields back.

The Chair now recognizes the gentleman from Illinois. Dr. Foster, you're recognized for 5 minutes, please.

Mr. FOSTER. Thank you, Mr. Chair. And I'd also like to thank Chairwoman Stevens, Ranking Member Feenstra, Chairwoman Sherrill, Ranking Member Bice, and our witnesses for joining us here today. Much of the testimony today has emphasized how this area of research is really reliant on a number of stakeholders, both throughout the Federal Government, as well in—as other sectors. Drs. Stein and Hubbell, in both of your testimonies you mentioned several partnerships that your departments are involved in. Could you expand on what partnerships your departments have with the Department of Energy and our national labs and the impact that these partnerships have on monitoring, measurement, and verification of sources and sinks of greenhouse gases?

Dr. STEIN. Thank you for the question. We have a long-term partnership with the Department of Energy, mostly working on modeling of climate variables. We also have worked with and continue working with the Department of Energy in terms of developing measurement techniques mostly for boundary layer, the lower part of the atmosphere, measurements, mostly in terms of meteorological variables. There is a very long-term relationship between the Department of Energy and NOAA in particular in that area.

Mr. FOSTER. Thank you.

Dr. HUBBELL. And I'll just add that, you know, our work right now on the oil and gas sector, we do have some collaborations and coordination going on with DOE, as well as with our other Federal partners, to be able to better understand how we can characterize emissions from this sector. And we've also worked with DOE and—we've also worked with DOE and other agencies in addressing the

overall inventory for almost 30 years. So it's been a long-term partnership, and it's something that we expect to continue going forward.

Mr. FOSTER. Thank you. And, Dr. Lin, your testimony highlights how NIST has initiated a documentary standards effort aimed at advancing the implementation of mature, measurements-based scientific tools and methods. This aims to lead the development of global standards as well. And so how does NIST incorporate the best practices of the research community into their standards development?

Dr. LIN. Thank you for the question. Our research and our attention to the research environment directly informs our work in the standards forums. So in these forums, those are voluntary consensus areas which are focused on the technical solutions and standardization, and we bring all the knowledge and the input from the research space that we know into that arena so that the best technical solutions can be determined.

Mr. FOSTER. OK. And could you speak a little bit about the importance of developing these global standards as we continue to understand the global impact of greenhouse gas?

Dr. LIN. Well, I think, as my colleagues have very well stated is that the global system is one as a whole. There's no boundaries for gases as they traverse the globe. And so as we are monitoring our own emissions and sinks, that we need to have a consistent way of how to know where the greenhouse gases and other things we're monitoring are, and to put it on the same baseline is a critical step in that.

Mr. FOSTER. And how important is the impact of the loss of contact with Russian scientists going to be in this field? And I know from my experience in physics that the Russians are some of the most brilliant and well-trained scientists on Earth. And they've also been very involved in things like understanding what Siberia is going to do to greenhouse gas emissions. And some—in light of the current situation in Ukraine, some Russian scientists are heroically standing up, others not so much, but we're going to lose contact with a lot of them. And how big a hit is that going to be in our ability to deal as a planet with greenhouse gases?

Dr. LIN. For our point of view—so I'm not sure—I don't know directly on this particular field of the impact of of what you noted. But in general, we've concentrated on multilateral fora which—it's a multilateral engagement and so it's not really dependent upon one country or another. And even in that environment in the technical arena where we work on, largely that is still in place because we're looking at technical solutions.

Mr. FOSTER. Yes. Anyone else want to comment on that?

Dr. ST. GERMAIN. Likewise, when our interactions with Russian scientists have generally been through multilateral fora, we haven't historically had access to Russian space-based data, so we aren't seeing a loss there. And we'll—we're continuing to use the data from U.S. systems, as well as other international partners to understand all regions of the globe, including the—Russia.

Mr. FOSTER. Yes. And I think, you know, Russia, as a country has not always been interested in having the numbers well known as they apply to Russia, but it's—you know, it's going to be—my

guess it's going to be very important because this is a whole-of-planet effort. Anyway, I am now out of time and yield back.

Mr. TONKO. The gentleman from Illinois yields back, and I believe that concludes the list of colleagues who choose to question our panelists.

Before, however, we bring the hearing to a close, I thank our witnesses for testifying before the Committee today, and I offer those thanks certainly on behalf of the the Chairs and Rankers who hosted this Committee hearing.

The record will remain open for 2 weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses. I ask, if you would, please, respond in a prompt fashion.

And with that, the witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 11:24 a.m., the Subcommittees were adjourned.]