CONGRESS OF THE UNITED STATES
HOUSE OF REPRESENTATIVES

Testimony before the
Committee on Science, Space, and Technology

Hearing “***Detecting and Quantifying Methane Emissions from the Oil and Gas Sector***”

June 8, 2022
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WRITTEN TESTIMONY

I. Introduction

Good morning, Chair Johnson, Ranking Member Lucas, and Members of the Committee. I am Riley Duren, Chief Executive Officer of Carbon Mapper, a non-profit organization with a mission to deliver actionable and transparent global methane and CO_2 emissions data at facility-scale to help inform and accelerate mitigation action.

The urgency of cutting methane emissions can't be overstated. Methane is a climate super-pollutant that packs a powerful punch – with nearly 90 times the heat-trapping power of CO_2 on a 20 year time horizon. Meanwhile, NOAA observations indicate growth rates in atmospheric methane concentrations over the past 2 years that are unprecedented since systematic measurements began in 1983 (Figure 1). But there are solutions at hand that can still reverse course and limit global warming to 1.5 degrees C. It starts with making invisible emissions from all sources visible—and thereby actionable. Tackling methane emissions in the oil and gas sector is cheaper than other sectors and can ultimately reduce costs for industry and consumers (UNEP, 2021; Octo *et al.,* 2021).

My comments are grounded in a methane research program I helped establish over a decade ago at NASA's Jet Propulsion Laboratory. This research continues today at Carbon Mapper and through my joint appointment at the University of Arizona and has benefited from sustained support from NASA with contributions from NIST and the California Air Resources Board. Over the years we have proved that—when armed with data and insights on methane point sources—people can take action to stop these emissions. It was these research findings and the support of philanthropic donors that motivated us to form a public-private partnership with JPL, Planet, the state of California, RMI, Arizona State University and the University of Arizona to launch a global constellation of satellites starting next year to find, measure, and communicate methane and CO_2 super-emitters.

The oil and gas industry has the tools and technology to cut methane emissions quickly and cheaply – if they know where to focus. The benefits of doing so extend far beyond climate. Given expanding demand for US natural gas exports, managing methane emissions from the oil and gas supply chain is also becoming increasingly critical for national security and global competitiveness. Additionally, because methane is an ozone precursor and is often co-emitted with other toxic compounds, improved methane monitoring and mitigation is important for local air-quality, health, and environmental justice for millions of Americans who live in close proximity to oil and gas infrastructure (Czolowski, *et al.,* 2017).

The US oil and gas sector is characterized by millions of active and inactive production sites, pipelines, compressor stations, processing plants and other infrastructure distributed over vast, often inaccessible, areas with significant variation in age, operational status, and productivity and management practices employed by operators. This enterprise is a complex and entangled web of different jurisdictions and regulations translating to significant variability by region, production segment, and equipment type in terms of monitoring requirements and enforcement responsibility. For example, there are nearly 10 federal and upwards of 100 state and local agencies with jurisdiction over sections of the US onshore and offshore natural gas supply chain with varying degrees of overlap.

Many operators and regulators in the US remain largely uninformed about actual methane leakage because current measurements are too sparse, infrequent and/or insensitive. And while some companies are undertaking prototyping programs, the resulting data is often proprietary or behind paywalls. **Bottom line: most US oil and gas infrastructure today is not sufficiently monitored for methane emissions.**

II. Summary of Research Findings

US onshore oil and gas emissions

Over the past several years, our research team and collaborating scientists at JPL, Arizona State University, the University of Utah, RMI and EDF have applied multi-scale methane observations from surface sensor networks, aircraft and satellites to assess methane emissions over multiple regions across the US, including multi-year studies in several cases. See Figure 2 for locations of related field studies and examples of methane emission sources. In 2016, the California Methane Survey began as a multi-year study using advanced NASA imaging spectrometers on aircraft to conduct the first comprehensive survey of high emission methane point sources[1] across the state. That initial survey in 2016 and 2017 covered 60% of methane emitting infrastructure in California including over 200,000 oil and gas wells and other production equipment and found that < 0.2% of equipment in the state manifested "super-emitter" point sources that were collectively responsible for 34-46% of the state's entire methane budget (Duren *et al.,* 2019). That study included multiple overflights to assess the degree of intermittency in emission sources and found that the median emitter was only active about 20% of the time. This highlights the need for frequent observations to properly account for intermittency and variability.

The California study was followed a similar large-scale survey of the Permian basin in fall 2019 (Cusworth *et al.,* 2021). That campaign located a total of 1,756 methane super-emitters in a 22,000-square-mile (57,000-square-kilometer) section of that immense oilfield. As the remote-sensing aircraft resurveyed the area over the course of a month, the team recorded emissions each time a plume was visible, whether once or a dozen times. This allowed us to calculate the degree of intermittency in emissions. The campaign also identified surprisingly large variations in the extent of emissions. In one part of the basin, emissions almost doubled over a five-day period and then dropped back almost to the original value over another 10 days. These large,

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[1] *We define 'point source' as a condensed surface feature or infrastructure component of less than 10 m in diameter that emits plumes of highly concentrated methane, typically with emission rates above 10 kg/hr. This contrasts with an 'area source', or the combined effect of many small emitters distributed over a large area (typically 1–100 km across) that releases methane in a more diffuse fashion.*

unpredictable variations prove that a single snapshot of methane emissions from any location is inadequate for decision-makers to monitor and regulate emission sources. By repeatedly measuring the size and persistence of emission sources, we estimated that repairing only the 123 sources that were leaking persistently would reduce methane emissions by 50 metric tons an hour. That's equivalent to 5.5% of the EPA's estimates of all methane emissions from oil and gas production in the entire United States.

In 2020 and 2021 we returned to the Permian basin to conduct follow-up overflights for the highest emitting areas as part of collaborations with RMI and Environmental Defense Fund. This provided an extended time-series over the basin that revealed that about 30 facilities—including pipelines, well pads, compressor stations and processing facilities—persistently emitted large volumes of methane over multiple years. We estimated that repairing those leaks could immediately eliminate 100,000 metric tons of methane per year. These 30 facilities make up less than .001% of the region's oil and gas infrastructure, and yet they produce the same near-term climate pollution as about half a million passenger vehicles. The mitigation of just these 30 long-lived super-emitters would prevent $26 million a year in wasted gas. ***The fact that these leaks continued for years without being detected, reported or repaired by operators is indicative of the gaps in current methane monitoring of oil and gas infrastructure.***

The high-resolution data from these airborne surveys also revealed important insights about the types of equipment releasing methane, to within a few meters of its location (Cusworth *et al.,* 2021). For example, by using high spatial resolution imaging and spectroscopy we were able to determine that about 12% of methane super-emitter activity in the Permian was due to incomplete and unlit flares (with roughly equal proportions). Gathering pipelines[2] also appear to be a significant source of leakage in the Permian, responsible for nearly 20% of the observed persistent super-emitters. But of the 435,000 miles of U.S. onshore gathering pipelines, only 11,569 miles (less than 3%) are currently subject to federal leak survey standards set by the Pipeline and Hazardous Materials Safety Administration (PHMSA). Again, this underscores the inadequacy of current monitoring.

More recently, in 2020 and 2021, we expanded the airborne surveys to characterize other important US oil and gas production areas including the Uinta, Denver-Julesburg and Marcellus basins; together with the Permian basin and California, these surveys covered an estimated 37% of North American onshore gas production in 2019. The combination of our overflight data, regional emission estimates derived from satellite observations, and previous field studies suggests that high emission methane sources (emissions rates higher than 10 kg/hr) likely account for 20 – 60% of net methane emissions from those regions(Cusworth *et al.,* 2022). The study was also able to constrain the relative contributions of high emission methane sources from other sectors in these domains including coal, waste and agriculture. In most cases, the oil and gas sector was responsible for the bulk of high emission methane activity in each region.

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[2] https://www.phmsa.dot.gov/faqs/gathering-pipelines-faqs

The potential for rapid, cost-effective mitigation of methane super-emitters from the oil and gas underscores the importance of continued screening for these sources.

We can use the large methane data set accumulated by the above studies to estimate the percentage of high emission methane sources that would be detectable with a given screening protocol as a function of detection limit, spatial coverage and sampling interval (measurement frequency). This concept is referred to as *observing system completeness* which in turn constrains the ultimate mitigation potential of abatement programs (Jacob *et al.,* 2022). By characterizing the persistence/intermittency (frequency of occurrence) of the super-emitters in our multiple basin study with repeated overflights we identified a bimodal pattern where 60% of the emissions come from intermittent sources (active < 50% of the time) and 40% of emissions come from more persistent sources (active at least 50% of the time). We find that sampling interval (measurement frequency) and spatial coverage have the greatest impact on observing system completeness for detection limits typical with existing aircraft remote-sensing technology, many of which have methane detection limits in the range of 1-50 kg/hr (Duren *et al.,* 2022). Based solely on sample frequency we assess that many intermittent sources – including a mix of expected process emissions and malfunctioning equipment - are unlikely to be detected with conventional sampling protocols in most jurisdictions where operators are only required to conduct screening with hand-held sensors for a small subset of infrastructure on a quarterly or annual basis. As a result, we and other groups have recommended that the EPA consider adopting a screening protocol that uses a “matrix approach” that would allow operators to trade higher frequency sampling and increased spatial coverage for higher detection limits (Duren *et al.,* 2022). This flexibility could reduce overall monitoring costs while increasing overall detection completeness for high emission sources.

Our team has also contributed to analyses of global oil and gas methane emissions using high frequency satellite observations. In one recent study, near-daily observations by the Sentinel-5 Precursor/TROPOMI satellite were analyzed to detect highly intermittent methane bursts across the global land surface – many of which were clustered in the US. While typically limited in duration to a few hours or days, these “ultra-emitters” tend to be extreme methane emission events – most exceeding 20,000 kg/hr – that were collectively equivalent to about 10% of global oil and gas methane emissions. Most of these intermittent ultra-emitters appear in thegeneral vicinity of oil and gas production or natural gas transmission infrastructure (Lauvaux *et al.,* 2022). We assessed that the likely cause for many of those ultra-emitters is planned maintenance events rather than malfunctions. The same study included an economic analysis that concluded that minimizing wasteful gas release to the atmosphere from such events could be done cost effectively (Lauvaux, *et al.,* 2022). This example is also important because highly intermittent ultra-emitters are not well represented in current greenhouse gas inventories and this is an area for improved attention by monitoring systems.

Methane emissions in the ocean environment

While existing oil and gas methane measurement programs are focused on onshore activities, it’s important to note that roughly 30% of global oil and gas comes from offshore production (IEA 2018, US EIA). Offshore platforms present unique logistical challenges for efficient methane measurements. Low-altitude airborne surveys using in-situ gas analyzers have provided some initial important indications that methane emission inventories for some categories for offshore production may under-estimate actual emissions (Gorchov Negron, 2020). Remote sensing offers a potential avenue to expand spatial coverage and achieve more frequent sampling however the ocean surface appears dark to passive remote-sensing sensors. To address this, we have experimented with new observing strategies to target sun-glint on the ocean surface with aircraft and satellites, similar to pointing a “flashlight” at areas of interest. These studies are also indicating that methane emissions from offshore oil and gas infrastructure is under-estimated in shallow waters in the Gulf of Mexico perhaps with even large discrepancies than reported between observed and predicted emissions from onshore production (Ayasse *et al.*, 2022).

Additionally, the growing demand for US liquefied natural gas (LNG) exports introduces another motivation for tracking methane emissions over water – in this case, cryogenic boil-off and engine exhaust slip from LNG tankers. To our knowledge there is very limited empirical data about the full methane footprint of the ocean segment for LNG and this suggests a focus on methane monitoring for this class of ocean-going vessels.

Methane monitoring for direct mitigation guidance

Historically, much of the focus of atmospheric methane measurements by the research community has been focused on independent verification of and contributing improvements to greenhouse gas inventories for key emission sectors at various levels of aggregation (e.g., basin, region, state, country). However, an equally important use-cases involves the use of atmospheric measurements with sufficient resolution, precision and timeliness to provide direction, actionable information to facility operators and regulators to guide mitigation efforts.

One important component of the aforementioned methane research program has been sustained and proactive data sharing with facility operators, regulators and other stakeholders. During the first round of methane overflights in California in 2017, as a pilot effort, our team began to notify selected operators when our remote-sensing aircraft detected a methane super-emitter at their facility. Since then, we have conducted multiple follow-up surveys and worked with our partners at CARB to expand this notification and data sharing program. While these pilot efforts are still limited by available funding to a few weeks of flights each year (and staffing) we have confirmed voluntary methane leak repairs at 44 facilities across California that translating to over 1.2 million metric tons of CO_2 equivalent emissions (using a 100-year global warming potential for methane of 25) that have been verified by follow-up observations. This includes a mix of oil and gas production facilities, natural gas transmission and distribution infrastructure, power plants, and landfills. CARB estimates this number could ultimately grow to 2.5 million tons CO_2 equivalent as additional follow-up flights confirm the impacted of mitigation action reported by operators. This experience and emerging examples in other states illustrates that timely and precise data can directly enable measurable emission reductions. See Figure 3 for a representative example.

The ultimate mitigation potential of advanced methane monitoring systems will be limited both by the previously described technical factors (e.g., observing system completeness, ability to detect methane over water, etc) but is also strongly dependent on the ability to transition monitoring systems from a research environment to an operational capability. The latter requires scale-up and continuity of methane observing systems and attention to building awareness and technical capacity by the agencies, companies, communities and other stakeholders that are the recipients and users of the data. Finally, it is important to note that the mitigation prototyping described here is focused on high emission point sources. It is equally important that monitoring programs also address a larger population of lower emission sources that could benefit from different observing strategies.

III. Recommended Research Priorities for Federal Science Agencies

Congress has an opportunity to lead the country—and the world—in marshalling US science agency contributions with the following recommendations.

I. NASA and NOAA could commission annual surveys using satellite and airborne observations to quantify regional net methane emissions from key US onshore and offshore production basins including attribution to sector, production segment and major equipment types. Results should be delivered to EPA and other cognizant agencies with 6 months of each survey to support the US national greenhouse gas inventory and evaluate efficacy of oil and gas methane regulations.
II. NIST could establish standards for methane emissions detection and quantification including independent evaluation of basin- and facility-level measurement techniques to validate their accuracy.
III. DOE and NASA could prioritize methane measurements in their technology development programs including improved sensitivity, spatial and temporal completeness, and solutions to variable illumination conditions and wind uncertainties.
IV. In meeting these priorities, federal science agencies could maximize the acquisition of data from non-federal sources including the private sector, academia and non-governmental organizations. By providing scientifically robust interpretation and transparent public dissemination of data, federal science agencies are uniquely suited to leverage the expanding global ecosystem of methane observing systems.

Additionally, federal science agencies should evaluate the potential benefits and costs of the following recommendations:

1. *USGS could establish a national database of associated gas composition including the relative fractions of methane and hazardous air pollutants for all US hydrocarbon reservoirs with oil and gas wells in close proximity to communities. The results could be published to support community toxic exposure assessments for high emission methane sources based on proximity to populations and the potential for co-emitted hazardous air pollutants (e.g., benzene, toluene, ethylbenzene and xylenes or "BTEX").*

2. *EPA (or other relevant federal agency) could establish a US Methane Data Analysis Center (or set of regional centers) and workflow for responding to reports by science agencies, communities, non-governmental organizations, and other third parties of potential larger emission events, defined as those with the potential for emission rates exceeding 100 kg/hr due to leaks, malfunctions or excessive venting.*

3. *Measurement strategies for large emission methane sources could be optimized for detection completeness, defined as the % of a population of emissions that can be detected by a monitoring system as a function of detection limit, spatial coverage and sample frequency.*

4. *Methane observations could cover all onshore production equipment including well sites, compressor stations, gathering pipelines, storage vessels, flares, and gas processing plants as well as natural gas high pressure transmission and storage infrastructure.*

5. *Operators could be incentivized to adopt the top-down quantification capabilities of remote sensing from satellites, aircraft and continuous sensor networks. Doing so would provide critical additional insight beyond conventional surveys with hand-held sensors which are typically limited to providing qualitative information about leak locations not emission rates. For example, such quantification could be pivotal in verifying progress against emission reduction targets for storage vessels, pneumatic devices, and flares.*

6. *US science agencies could embrace a system of systems (tiered observing system) approach that combines the attributes of airborne and satellite remote sensing for detection and quantification of large emission events along with surface sensor networks optimized for identifying lower emission activity across the O&G value chain.*

In closing, preventing leakage of the climate super pollutant, methane, can prevent runaway warming *now.* To do this, there is an urgent need for resources and help from US science agencies to strengthen methane accounting and mitigation efforts by federal, state, and local governments, companies, and broader civil society. These critical investments can improve US standing and technical contributions for international efforts to confront the climate crisis while supporting the air-quality and equity needs of local communities across America. Thank you for the opportunity to testify and I look forward to your questions.

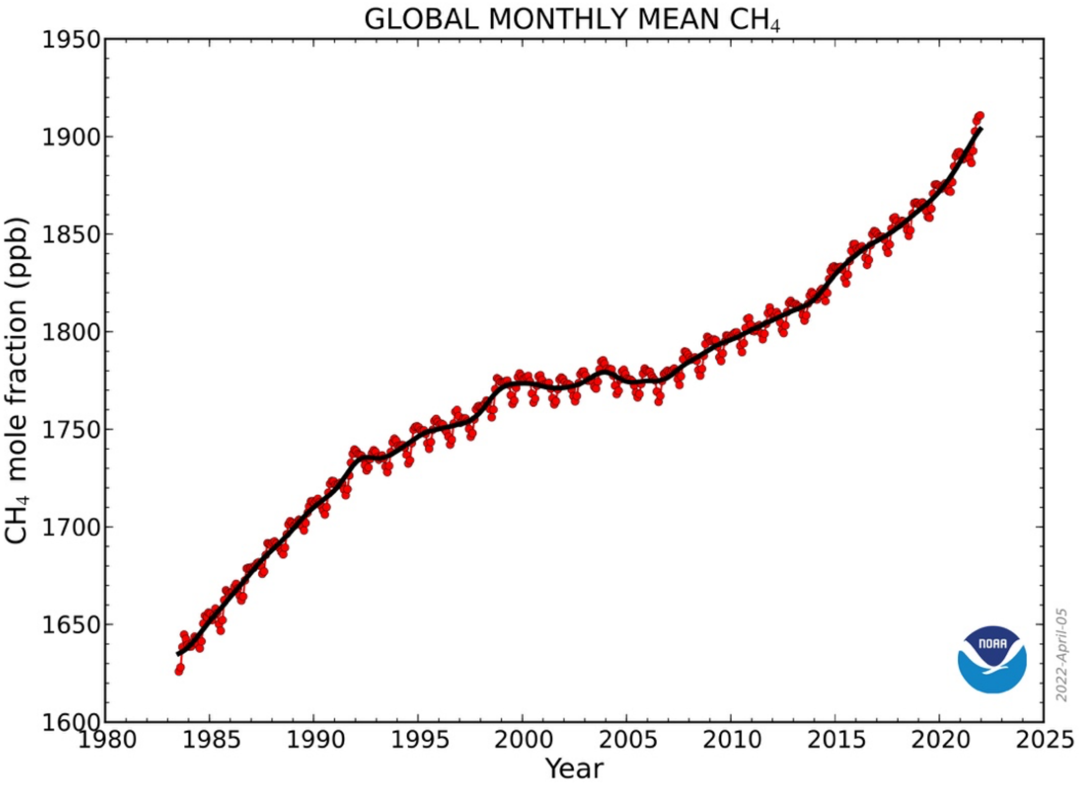


Figure 1: Sustained NOAA observations indicate annual growth rates in global average atmospheric methane concentrations that are unprecedented since systematic measurements began in 1983. (Source: NOAA Global Monitoring Laboratory)

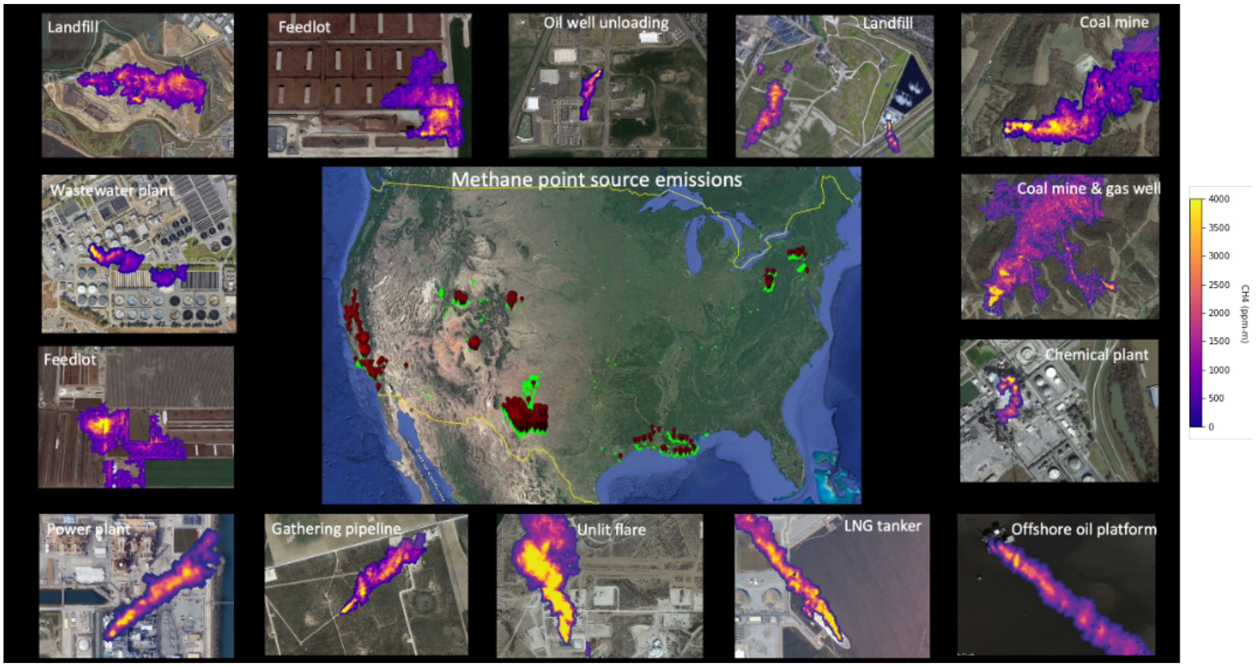
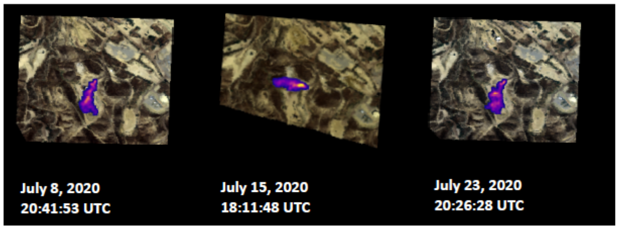


Figure 2: High emission methane point sources are frequently observed at oil and gas production sites and other sectors. The central map indicates the location of airborne remote-sensing overflights (green lines) that detected methane super-emitters (red pins). In this case, the ability of high spatial resolution imaging spectroscopy to pinpoint and quantify high emission point sources was critical for accurate quantification, sectoral attribution and in many cases, subsequent surface verification and leak repairs. (source: CarbonMapper.org)

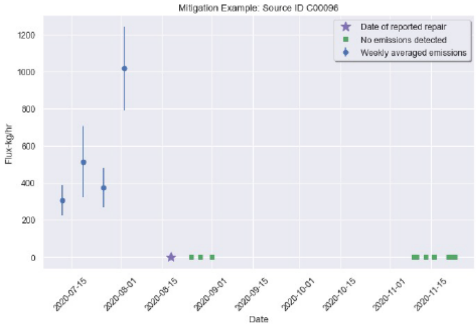
Imagery



Summary Table

Location	McKittrick oil field, Kern County, California
Latitude, Longitude	35.321497, -119.634728
Sector	Oil & Gas
Leak Type	Leaking flow line
Emissions Mitigated (kg CH4/hr)	500 kg CH4/hr

Time Series



Description

Overflights detected methane emissions from a leaking flow line in the McKittrick oil field, Kern County, California with multiple methane plume observations from July 8, 2020 through July 27, 2020.

Operator confirmed leak and reported repairs complete August 18, 2020.

Follow-up flights by Carbon Mapper in August 2020 and November 2020 detected no further methane emissions from the site.

Figure 3: Example of voluntary action by an oil and gas operator in California to repair a leak detected by remote-sensing overflights. (source: CarbonMapper.org)

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Biography

Riley Duren is Chief Executive Officer of the Carbon Mapper non-profit organization based in Pasadena, California and a Research Scientist at the University of Arizona in Tucson. He also maintains a part-time appointment as an Engineering Fellow at NASA's Jet Propulsion Laboratory, although that work is outside the scope of today's testimony. His career at NASA began with launching space shuttle science payloads from the Kennedy Space Center. He joined JPL in 1996 where he worked at the intersection of science and engineering to deliver earth observing systems and deep space telescopes including NASA's *Kepler* mission for which he served as Chief Engineer. From 2008-2019 he was the Chief Systems Engineer for JPL's Earth Science and Technology Directorate, with a broad portfolio of satellite and aircraft instruments and missions, research and analysis, applied science, and technology projects spanning NASA's earth science enterprise.

In 2008 he established a research program that extends the discipline of systems engineering to the challenge of climate change decision support. He has served as Principal Investigator for 10 research projects involving greenhouse gas observing systems and data analysis frameworks. His team combines atmospheric measurements from satellites, aircraft and surface-based observing systems, tracer transport modeling, machine learning, and big data methods to detect, quantify and attribute methane and carbon dioxide emissions. The team also applies considerable energy to engaging with and entraining end users of the data sets produced by these programs towards increasing the data's relevance, adoption and impact. His work has supported programs at NASA, the National Institute of Standards and Technology, the National Oceanographic and Atmospheric Administration, the California Air Resources Board, other state agencies, and multiple non-governmental organizations. In 2020, Mr. Duren co-founded Carbon Mapper, a new non-profit organization and public-private partnership involving leading philanthropists, the commercial satellite imaging company Planet, JPL, the State of California and two universities, with a public good mission to deploy a constellation of small satellites that will provide globally operational monitoring of methane and carbon dioxide point source emissions at facility scale to help accelerate climate mitigation action. The program also includes expanding airborne methane surveys of key regions to help prepare for and complement the satellites.

Mr. Duren's honors include two NASA Exceptional Achievement Medals, the agency's Systems Engineering Excellence Award, and seven Group Achievement awards. He has served on National Academy of Science and California Council of Science and Technology committees and was a contributing author to the Second State of the Carbon Cycle Report for the US Global Change Research Program. He received a BS degree in Electrical Engineering from Auburn University in 1991.

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