NATIONAL ACADEMIES *Sciences Engineering Medicine*

Atmospheric Methane Removal: Needs, Challenges, and Opportunities

Workshop

October 17-18, 2023

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NATIONAL ACADEMIES Sciences Engineering Medicine

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Atmospheric Methane Removal

Needs, Challenges, and Opportunities—A Workshop

OCTOBER 17-18, 2023

VIRTUAL | **KECK CENTER** (500 5th St. NW Washington DC, 20001)

Additional information available on the event page

This workshop will consider needs, challenges, and opportunities for emerging atmospheric methane removal approaches. The workshop will be an opportunity for the community to engage around questions of the need for atmospheric methane removal; the potential, risks, and co-benefits of viable technological options; and research gaps that could improve understanding. Information gathered during the workshop will be used to inform the current National Academies' consensus study, *Atmospheric Methane Removal: Development of a Research Agenda*.

TUESDAY, OCTOBER 17, 2023 | All times ET

9:30–9:45 **Welcome and Opening Remarks**

Gabrielle Dreyfus, Institute for Governance and Sustainable Development (IGSD), Committee Chair

9:45–10:30 **Session 1: Setting the Context: The Role of Methane in the Climate System and Methane Mitigation**

Moderators: Gabrielle Dreyfus, IGSD, & Rob Jackson, Stanford University, Committee Members

10 minute talks + 15 minutes Q&A

- **Euan Nisbet**, Royal Holloway, University of London
- **Claire Henly**, US Department of State
- **Kirsten Zickfeld**, Simon Fraser University

10:30–11:30 **Session 2: Potential Atmospheric Methane Removal Technologies and Applications**

Moderators: Chris Jones, Georgia Institute of Technology, & Lisa Stein, University of Alberta, Committee Members

5 minute lightning talks + 25 mins Q&A/discussion

- **Desirée Plata**, Massachusetts Institute of Technology
- **Matteo Cargnello**, Stanford University
- **Shu Hu**, Yale University
- **Matthew Johnson**, University of Copenhagen
- **Subir Roychoudhury**, Precision Combustion, Inc.
- **Mary Lidstrom**, University of Washington
- **Jessica Swanson**, University of Utah

11:30–11:45 **Break**

11:45–13:00 **Session 3: Costs and Key Leverage Points for Atmospheric Methane Removal Technologies**

Moderators: Tom McKone, UC Berkeley, & José Santiesteban, ExxonMobil (Retired), Committee Members

15 minute presentation on commissioned paper draft + 10 mins Q&A

- **Morgan Edwards**, University of Wisconsin-Madison
- **Kavita Surana,** Vienna University of Economics and Business

5 minute lightning talks + 30 mins Q&A/discussion with all speakers

- **Julie Zimmerman**, Yale University
- **Eric Masanet**, UC Santa Barbara
- **Sarah Baker**, Lawrence Livermore National Laboratory
- **Edan Prabhu**, Prabhu Energy

13:00–13:45 **Lunch**

13:45–14:55 **Session 4: Potential Intended and Unintended Consequences of Atmospheric Methane Removal Technologies**

Moderators: Hinsby Cadillo-Quiroz, Arizona State University, & Alex Turner, University of Washington, Committee Members

15 minute presentation on commissioned paper draft + 10 mins Q&A

- **Hannah Horowitz**, University of Illinois Urbana-Champaign

5 minute lightning talks + 25 mins Q&A/discussion with all speakers

- **Daphne Meidan**, Cornell University
- **Alex Archibald**, University of Cambridge
- **Sean Thomas**, University of Toronto
- **Vincent Gauci**, University of Birmingham

14:55–15:10 **Break**

15:10–16:20 **Session 5: Potential Social Impacts of Atmospheric Methane Removal Technologies**

Moderators: Ben Converse, University of Virginia, & Sikina Jinnah, UC Santa Cruz, Committee Members

15 minute presentation on commissioned paper draft + 10 mins Q&A

- **Emily Grubert**, University of Notre Dame

5 minute lightning talks + 25 mins Q&A/discussion with all speakers

- **Thomas Dietz**, Michigan State University

- **Simon Nicholson**, American University
- **Shuchi Talati**, Alliance for Just Deliberation on Solar Geoengineering
- **Mahmud Farooque**, Arizona State University

16:20–16:30 **Wrap Up and Plans for Day 2**

16:30 **END OF DAY 1**

WEDNESDAY, OCTOBER 18, 2023 | All times ET

10:00–10:15 **Welcome and Opening Remarks**

Gabrielle Dreyfus, IGSD, Committee Chair

10:15–11:25 **Session 6: Domestic and International Legal and Policy Landscape**

Moderators: Holly Buck, University at Buffalo, & Gabrielle Dreyfus, IGSD, Committee Members

15 minute presentation on commissioned paper draft + 10 mins Q&A

- **Romany Webb** and **Korey Silverman-Roati**, Columbia University

5 minute lightning talks + 30 mins Q&A/discussion with all speakers

- **Daniel Bodansky**, Arizona State University
- **Rory Jacobson**, US Department of Energy
- **Ilissa Ocko**, Environmental Defense Fund

11:25–11:40 **Break**

11:40–12:50 **Session 7: Potential Synergies and Co-benefits of Atmospheric Methane Removal Technologies**

Moderators: Jack Lewnard, Advanced Research Projects Agency–Energy, & Faruque Hassan, Texas A&M University, Committee Member

5 minute lightning talks + 30 minutes panel discussion

- **Jacek Koziel**, US Department of Agriculture
- **Zachary Smith**, Massachusetts Institute of Technology
- **Marc Dumont**, South Hampton University
- **Shaina Kelly**, Columbia University
- **Matteo Bertagni**, Princeton University
- **Thomas Graedel**, Yale University
- **Cooper Rinzler**, Breakthrough Energy

12:50–13:00 **Instructions for Breakout Discussions**

13:00–13:50 **Lunch**

13:50–14:35 **Session 8: Breakout Discussions**

Participants join assigned hybrid breakout rooms; 45 minutes structured discussion

14:35–14:50 **Break**

Transition back to plenary

14:50–15:20 **Report Back to Plenary**

Breakout moderators report back on key takeaways from their discussions

15:20–15:30 **Closing Remarks**

15:30 **ADJOURN WORKSHOP**

Speaker Bios

Alex Archibald is a Professor of Atmospheric Chemistry at the University of Cambridge, UK. He leads the Atmospheric Composition-Climate Modelling group and is the Science Director of the UK Chemistry and Aerosol model, widely used to simulate the interactions between atmospheric composition and climate change.

Sarah Baker leads the Materials for Energy and Climate group and is an Associate Program Leader for Carbon Dioxide Conversion at Lawrence Livermore National Laboratory. Sarah has a Ph.D. in Materials Chemistry from University of Wisconsin-Madison and a B.A. in Chemistry from Grinnell College. Her current portfolio includes carbon dioxide capture and conversion projects funded by the U.S. Department of Energy (DOE) and industrial partners and spans fundamental research to pilot scale demonstration. Sarah also leads the Biomass Carbon Removal and Storage analysis team for an upcoming DOE report, “Roads to Removal”, a comprehensive assessment of negative emissions opportunities in the US.

Matteo Bertagni is an environmental engineer, passionate about science, nature, and the great outdoors. He did his bachelor's at the University of Trieste (Italy) and master's and PhD at the Polytechnic of Torino (Italy), where he graduated with a thesis on environmental fluid dynamics. In 2020, he joined Princeton University as a postdoctoral researcher with Prof. A Porporato at the Carbon Mitigation Initiative. His research is at the interface between environmental fluid dynamics, ecohydrology, and biogeochemistry and currently focuses on the environmental impacts of hydrogen energy and the potential of enhanced weathering as a climate mitigation solution.

Daniel Bodansky is Regents’ Professor at the Sandra Day O’Connor College of Law, Arizona State University. He is the author of *The Art and Craft of International Environmental Law*, which received the 2011 Sprout Award from the International Studies Association as the best book that year on international environmental politics, and co-author of *International Climate Change* Law (with Lavanya Rajamani and Jutta Brunnee), which received the 2018 Certificate of Merit from the American Society of International Law as the best book that year in a specialized area of international law. Prior to joining the ASU faculty in 2010, he taught at the University of Washington Law School from 1989-1999, served as Climate Change Coordinator at the U.S. State Department from 1999-2001, and held the Woodruff Chair of International Law at the University of Georgia from 2002-2010. He is a member of the Council on Foreign Relations, served on the Board of Editors of the *American Journal of International Law* from 2001-2011, and is a graduate of Harvard (A.B.), Cambridge (M.Phil.) and Yale (J.D.).

Matteo Cargnello received his Ph.D. in Nanotechnology in 2012 at the University of Trieste, Italy, under the supervision of Prof. Paolo Fornasiero, and he was then a post-doctoral scholar in the Chemistry Department at the University of Pennsylvania with Prof. Christopher B. Murray before joining the Faculty at Stanford University in January 2015. He is currently Associate Professor of Chemical Engineering and, by courtesy, of Materials Science and Engineering and Vance D. and Arlene C. Coffman Faculty Scholar. Dr. Cargnello is the recipient of several awards including the Sloan Fellowship in 2018, the Mitsui Chemicals Catalysis Science Award for Creative Work in 2020, and the Early Career Award in Catalysis from the ACS Catalysis Division in 2022. The general goals of the research in the Cargnello group pertain to solving energy and environmental challenges. The group focuses on capture and conversion of carbon dioxide, emission control and reduction of methane and hydrocarbon emissions in the atmosphere, sustainable chemical practices through electro- and photocatalysis, sustainable production of hydrogen, and chemical recycling of plastics.

Thomas Dietz is Emerit University Distinguished Professor of Sociology, Environmental Science and Policy, and Animal Studies at Michigan State University and a Gund Fellow at the University of Vermont. He holds a B.G.S. from Kent State University and a Ph.D. in Ecology from the University of California, Davis. His

publications include 14 books, most recently *Decisions for Sustainability* (Cambridge University Press, 2023) and over 200 research papers and book chapters. He is a Fellow of the American Association for the Advancement of Science was awarded the Sustainability Science Award of the Ecological Society of America.

Marc Dumont is an environmental microbiologist and lecturer based at the University of Southampton, UK. The central theme of research in the Dumont lab is on the role of soil microbes in biogeochemical processes, in particular with an emphasis on microbes that produce or consume greenhouse gases. His research has primarily focused on the environmental distribution and activity of aerobic methanotrophs in various environments including wetlands, rice fields, lakes, forest soils among others. Currently he has projects on peatlands, chalk streams, and bacteria associated with plants.

Morgan Edwards is an Assistant Professor at the La Follette School of Public Affairs at the University of Wisconsin--Madison and affiliated faculty with the Nelson Institute Center for Sustainability and the Global Environment, Energy Analysis and Policy Program, Holtz Center for Science and Technology Studies, and Institute for Research on Poverty. Her research focuses on modeling the role of technology in addressing the threat of climate change and assessing policies to accelerate equitable energy transitions. Her current projects include modeling the role of climate-tech in meeting net zero targets, evaluating the equity impacts of building electrification policies, and assessing pathways to transition natural gas infrastructure. She holds a PhD in Data, Systems, and Society from the Massachusetts Institute of Technology (MIT), a SM in Technology and Policy from MIT, and a BS in Environmental Science and Economics from the University of North Carolina at Chapel Hill. Prior to coming to Madison, she was a President's Postdoctoral Fellow at the Center for Global Sustainability at the University of Maryland.

Mahmud Farooque is Clinical Professor and Associate Director for the Consortium for Science, Policy and Outcomes at Arizona State University. Mahmud's work focuses on linking science policy to better societal outcomes. He plays key roles in fostering communities of practice among innovative R&D program managers across various sectors, facilitating knowledge exchanges to address uncertainties, challenges, and opportunities. As the principal coordinator of the Expert and Citizen Assessment of Science and Technology (ECAST), Mahmud oversees a distributed network that engages communities, stakeholders and publics in science and technology policy decisions. He has led extensive public participation initiatives through projects encompassing Planetary Defense, Community Resilience, Climate Change, Autonomous Mobility, Solar Geoengineering, and Gene Editing. His current projects involve Nuclear Waste Storage and Carbon Dioxide Removal. Mahmud is a member of the National Academy Board on Environmental Studies and Toxicology and editorial board member of Journal for Technology Assessment in Theory and Practice.

Vincent Gauci is Professorial Fellow at the University of Birmingham, Institute of Forest Research (BIFoR) where he works to understand how carbon-rich ecosystems such as forests, wetlands and peatlands function and interact with the atmosphere. He has expertise in quantifying the exchange of methane and other greenhouse gases from these ecosystems and agroecosystems in response to global environmental change, with a recent focus on methane exchange in trees. He has worked in and led projects across the Andes, Amazon, Borneo and Sumatra as well as many other locations. Professor Gauci is the former director of the UK Methane Network and tweets under @methanenet and @gaucigauci. His web site is www.gauci.uk .
He maintains his visiting Chair in Global Change Ecology at the Open University.

Thomas Graedel joined Yale University in 1997 after 27 years at AT&T Bell Laboratories. He is currently an Emeritus Professor. One of the founders of the field of industrial ecology, he co-authored the first textbook in that specialty and has published extensively and lectured widely on industrial ecology's implementation and implications. His characterizations of the cycles of industrially-used metals have explored aspects of resource availability, potential environmental impacts, opportunities for recycling and reuse, materials criticality, and resources policy. He was the inaugural President of the International Society for Industrial Ecology from 2002-

2004 and winner of the ISIE Society Prize for excellence in industrial ecology research in 2007. He has served three terms on the United Nations International Resource Panel, and was elected to the U.S. National Academy of Engineering in 2002.

Emily Grubert is Associate Professor of Sustainable Energy Policy, and, concurrently, of Civil and Environmental Engineering and Earth Sciences at the University of Notre Dame. Her research focuses on justice-oriented deep decarbonization and decision support tools related to large infrastructure systems, with emphasis on evaluation of dynamic life cycle socioenvironmental impacts and the effects of different value systems on decision pathways. Grubert holds a Ph.D. in Environment and Resources from Stanford University, an M.S. in Environmental and Water Resources Engineering and an M.A. in Energy and Earth Resources from The University of Texas at Austin, and a B.S. in Mathematics and Atmosphere/Energy Engineering from Stanford. She completed postdoctoral work at the University of California, Berkeley and was previously Assistant Professor of Civil and Environmental Engineering and, by courtesy, of Public Policy at the Georgia Institute of Technology. She previously served as Deputy Assistant Secretary for Carbon Management (2021-2022) and Senior Advisor for Energy Asset Transformation (2022-2023) at the US Department of Energy. She is currently Editor-in-Chief of *Environmental Research: Energy*.

Claire Henly is Senior Advisor for the Special Presidential Envoy on Climate at the US Department of State. Claire is an energy technology and policy expert with a decade of experience advancing solutions to climate change. Claire recently served on the executive team of the Energy Web Foundation where she helped build a consortium of over 30 of the world's largest energy companies to accelerate renewable energy adoption with blockchain technology. Prior to that, Claire advised international governments on climate policy at the Rocky Mountain Institute. In this role, she led a project with Rwanda's Ministry of Infrastructure that identified over $30 million in utility savings while improving energy access and partnered with the China's Energy Research Institute on a multi-year carbon reduction study that informed the 13th Five Year Plan. In 2018, Claire provided expert testimony before the U.S. Senate Energy and Natural Resources Committee on blockchain in the energy sector. She has authored papers on subjects ranging from solar geoengineering to energy access in emerging economies and has spoken at over 20 climate-related forums worldwide. Claire recently graduated with a M.A. from Harvard's Kennedy School where she was awarded two prestigious environmental fellowships and co-led a successful effort to de-bias faculty hiring. Claire holds a B.S. in Environmental Engineering from Yale University.

Hannah M. Horowitz is an Assistant Professor in Civil and Environmental Engineering and an Affiliate Assistant Professor in Atmospheric Sciences at the University of Illinois Urbana-Champaign. Her research group predicts the future of pollution and climate by integrating the chemistry of the atmosphere into computer models of varying complexity. Currently, her group is investigating how Arctic Sea ice loss impacts sources of particles to the air that can then affect air pollution and climate, and the importance of marine aerosols to aerosol-cloud interactions over the Southeast Atlantic Ocean. Dr. Horowitz is also interested in predicting unintended consequences of climate intervention on air and environmental pollution, and the two-way interactions between air pollution and heat islands in urban environments. Dr. Horowitz is a member of the international GEOS-Chem Steering Committee, an Associate Editor for the journal "Earth's Future", and on the Early Career Board for ES&T Air.

Shu Hu is currently an Assistant professor of Chemical and Environmental Engineering at Yale University and is a faculty member of the Yale Energy Science Institute. The Hu group aims to address scale-up challenges of light-driven chemical production and materials synthesis. The research theme is to understand and control semiconductor-electrolyte interfaces across the molecular-to-macroscopic scales. He currently serves as the secretary of the New England Catalysis Society. His group's impact has been recognized through the U.S. Department of Energy Early Career Research Award, the Scialog Negative Emission Science Award, and he is a recent recipient of the Hydrogen Advanced Water Splitting Materials program under the DOE Hydrogen

Energy Earthshot Initiative, which seeks to reduce the cost of clean hydrogen by 80% to $1 per 1 kilogram in 1 decade.

Rory Jacobson is the Senior Advisor for Deployment at the Department of Energy and supports the Office of Fossil Energy and Carbon Management's programs for carbon capture, removal, and conversion. Prior to joining DOE, he was a Deputy Director of Policy at Carbon180, where he managed the federal policy portfolio for technological carbon removal pathways. Prior to his role as Deputy Director of Policy, Rory was a Science Advisor at Carbon Direct Inc., where he consulted for leading corporates working to develop customized decarbonization strategies for a variety of industries. Rory has both led and supported carbon removal and management research and analysist at NGOs including the Natural Resources Defense Council and the World Resources Institute. He received his master's in environmental management from the Yale School of Forestry, where he was a Kerry Fellow, and his B.A. and B.S. from the University of California, Berkeley.

Matthew Johnson is an American atmospheric chemistry scientist at Atmospheric Research Center at the University of Copenhagen. Johnson has made contributions to several areas of chemistry, including kinetics, spectroscopy, isotope effects and application of atmospheric chemistry knowledge to air pollution control systems. Johnson studied chemistry at S.A. Macalester College, Saint Paul, Minnesota. In 1995, he was promoted to the Spectroscopy of Reactive Molecules and Cluster Compounds at the California Institute of Technology, Caltech. After several stations in Minnesota and Caltech, he was a student of the Fulbright program at the MAX-Lab accelerator at the Swedish University of Lund, and in 1998 became an assistant professor in University of Copenhagen. In the field of kinetics, he coordinates the Nordic Network for Chemical Kinetics (NoNeCK), he has five filed patents and over 250 publications in internationally referenced scientific journals. In 2012, Johnson and Harnung published their book titled "Chemistry and the Environment". Two start-up company in air cleaning industries are established based on Johnson's scientific results.

Shaina Kelly and her research team investigate and optimize the interplay between transport phenomena and fluid-mineral interactions in geologic and engineered porous media for environmental and sustainable energy applications. Shaina joined the Department of Earth and Environmental Engineering at Columbia University as an assistant professor in July 2022. Prior to her appointment, Shaina's 6+ years of industry experience include roles as Senior Petrophysicist at ConocoPhillips Company and Senior Geoscience Engineer at AquaNRG Consulting Inc. working on related transport in porous media research topics. Shaina received her PhD in petroleum and geosystems engineering from The University of Texas at Austin in 2015, and her BSc in environmental engineering from the University of Florida in 2011.

Jacek Koziel serves as a Research Leader with the U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS) at the Conservation and Production Research Laboratory in Bushland, Texas. His current research focuses on improving the sustainability of beef and dairy production systems, a core mission of the Livestock Nutrient Management Research at ARS-Bushland. Koziel has over 30 years of experience in air quality, emissions measurement, and mitigation. Koziel is an Emeritus Professor at Iowa State University, where his research team explored photocatalysis and UV light for synergies and co-benefits of mitigating gaseous emissions of odorous volatile organic compounds, ammonia, greenhouse gases, and airborne pathogens. He was a visiting professor at the Animal Sciences Group, Wageningen University & Research, The Netherlands. Koziel is a two-time Fulbright alumnus. He serves as Editor of Emeritus of Biosystems Engineering. Koziel received M.S. in Mechanical Engineering from Warsaw University of Technology, M.S. in Environmental Quality Engineering from University of Alaska Anchorage, and Ph.D. in Civil Engineering from University of Texas at Austin.

Jack Lewnard is a Program Director in DOE's Advanced Research Program Agency- Energy (ARPA-E), which focuses on high-risk high-impact energy technologies. His programs include REMEDY (methane abatement), REPAIR (fix gas pipelines from the inside with high-strength coatings deposited by robots),

methane pyrolysis to make hydrogen and solid carbon, REUSE (convert unrecyclable plastics into fungible hydrocarbon liquids), and FLECCS II (load-following carbon capture systems for natural gas combined cycle power plants). Previously positions include VP Business Development at Chesapeake Utilities, CTO at the Gas Technology Institute, VP Process Development at Greenfuel Technologies (algae biofuel start-up), and 20 years prior experience in diverse engineering roles. He has a BS in Chemical Engineering from the University of Cincinnati and a PhD in Chemical Engineering from Berkeley.

Mary Lidstrom is Professor Emeritus of Chemical Engineering and Professor Emeritus of Microbiology, and from 1996-2022 held the Frank Jungers Chair of Engineering at the University of Washington, Seattle. She received her B.S. in Microbiology from Oregon State University. After receiving her M.S. and Ph.D. in Bacteriology from the University of Wisconsin, Dr. Lidstrom conducted work as a Leverhulme postdoctoral Fellow in Microbiology at the University of Sheffield. Dr. Lidstrom has previously held academic appointments in Microbiology at the University of Washington, in the Center for Great Lakes Studies in Milwaukee, Wisconsin, and in Environmental Engineering Science at the California Institute of Technology. She is a fellow of the American Academy of Microbiology, a fellow of the American Association for the Advancement of Science, and a member of the National Academy of Sciences. From 2005 until 2021, Dr. Lidstrom was the Vice Provost for Research and holds the title of Vice Provost Emeritus. Over the past 50 years, research in the Lidstrom Laboratory has addressed various aspects of bacteria that grow on one-carbon compounds, including those that grow on methane. Current work is focused on developing microbially-based technology for atmospheric removal of the potent greenhouse gas methane, to slow global warming by 2050.

Eric Masanet holds the Duncan and Suzanne Mellichamp Chair in Sustainability Science for Emerging Technologies at UCSB. His research develops energy and materials systems models to identify technology and policy pathways for decarbonizing industrial systems. From 2015-2017, he led the Energy Demand Technology Unit at the International Energy Agency in Paris, where he oversaw energy analyses of the global industrial, transport, and buildings sectors. He is currently a Lead Author of Chapter 5 (Demand) for Working Group III of the IPCC's Sixth Assessment Report and a member of the Research Advisory Board at the American Council for an Energy Efficient Economy (ACEEE). He is also the former Editor in Chief of Resources, Conservation, and Recycling, the leading peer-reviewed journal on sustainable resource systems. From 2012 -2019 he was an Associate Professor in the McCormick School of Engineering and Applied Science at Northwestern University. From 2004-2012 he was a Research/Staff Scientist and Deputy Head in International Energy Studies Group at Lawrence Berkeley National Laboratory. While at LBNL he held a joint research appointment in UC Berkeley's College of Engineering, where he also served as Program Manager for the Engineering and Business for Sustainability Certificate Program. He holds a PhD in mechanical engineering with an emphasis in sustainable manufacturing from UC Berkeley.

Daphne Meidan is a postdoctoral researcher at the Instituto de Química Física Blas Cabrera, CSIC (Spain). Previously, she was a postdoctoral associate in the Department of Earth and Atmospheric Sciences at Cornell University where her research included modeling atmospheric methane removal processes. Daphne is an atmospheric chemist with expertise in oxidative processes in the atmosphere. She received her Ph.D. in Chemistry (Earth and Planetary Science) from Weizmann Institute of Science (Israel), her M.S. in Environmental Engineering and B.S. in Material Engineering from Ben Gurion University of the Negev (Israel).

Simon Nicholson is Associate Professor of Global Environmental Politics in the School of International Service at American University. He also serves as the school's Acting Associate Dean for Research and co-directs American University's Institute for Carbon Removal Law and Policy. His research interests are broadly in the areas of global environmental governance and the governance of emerging technologies, with an interest most recently in the governance and social consideration of carbon removal and solar geoengineering responses to climate change.

Euan Nisbet is emeritus professor of Earth Sciences, at Royal Holloway, Univ. of London, and an Honorary Fellow of Darwin College, Cambridge, UK. He spent many field seasons mapping Archaean rocks in Zimbabwe (where he grew up), Canada and Australia, puzzling over volcanic rocks, as well as the record of early life and how it altered the planet. In the 1980s in Canada, he became increasingly concerned about atmospheric greenhouse gases, and especially using carbon isotopes to determine the sources of methane. He led the UK's 'MOYA' Global Methane consortium (2016-2022) and was long involved in leadership of European Union methane consortia. He serves on the scientific advisory panel for the United Nations International Methane Emissions Observatory, and was a co-author of the UN *Emissions Gap* report, prior to COP26.

Ilissa Ocko, Senior Climate Scientist II and Barbra Streisand Chair of Environmental Studies at Environmental Defense Fund, leads policy-relevant scientific research aimed at identifying and facilitating the most effective and pragmatic solutions to the current climate crisis. Her research explores how human-emitted climate pollutants and their mitigation impact climate change both during our lifetimes and for generations to come, with a focus on the role of short-lived climate pollutants. Dr. Ocko works closely with policy and business experts, economists, and lawyers to turn the best available science into action. Recent work includes peer-reviewed publications on the importance of fast action to reduce methane emissions and the climate implications of an emerging hydrogen economy. Dr. Ocko earned her Ph.D. in Atmospheric and Oceanic Sciences at Princeton University and holds a certificate in Science, Technology, and Environmental Policy from the Princeton School of Public and International Affairs.

Desirée Plata's research seeks to maximize technology's benefit to society while minimizing environmental impacts in industrially important practices through the use of geochemical tools and innovations. Plata earned her doctoral degree in Chemical Oceanography and Environmental Chemistry from the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution's Joint Program in Oceanography and her bachelor's degree in Chemistry from Union College in Schenectady, NY. Having previously served as Assistant Professor of Chemical and Environmental Engineering at Yale University and Associate Director for Research at the Center for Green Chemistry and Green Engineering at Yale, Plata is now Associate Professor of Civil and Environmental Engineering at MIT, co-director of the MIT Climate and Sustainability Consortium, and Faculty Lead of Belonging, Achievement, and Composition in the MIT School of Engineering. Plata directs MIT's Methane Network and serves on the Scientific Advisory Board of Spark Climate. Plata is co-founder of Nth Cycle and co-founder and President of Moxair Inc.

Edan Prabhu is the founder and CEO of Prabhu Energy Labs. A mechanical engineer and inventor, he has spent a lifetime on energy innovation. He has extensive experience with wind, solar, nuclear and fossil fuels, serving on the National Biomass Advisory Board after 20+ years at public utility Southern California Edison. Edan continues to champion sustainable energy, clean use of waste fuels and methane abatement. He was awarded 9 US patents on weak methane and other waste fuels.

Cooper Rinzler is an investor, technologist, and entrepreneur with a history of building and leading teams to develop and commercialize diverse climate technologies. He is a Partner at Breakthrough Energy Ventures, where he focuses on tackling the most recalcitrant challenges to avoiding a climate disaster. Cooper also continues to advise a diverse set of organizations defining new asset classes for investment in climate change mitigation and climate tech innovation. He serves as a Director of the Hertz Foundation and is a Founding Advisor and Director to Spark Climate Solutions. He has served as an advisor to the DOE's ARPA-E program, Cyclotron Road, and Prime Coalition in addition to several non-profits in the climate space. Cooper is a Hertz Fellow with a PhD in Materials Science and Engineering from MIT and a joint AB in Physics and Engineering Physics from Harvard University.

Subir Roychoudhury is the Vice President of Research & Engineering at Precision Combustion, a small

business developing clean power solutions. He has been with the company for 32 years and has an M.S. and a D.E. in Mechanical Engineering. He has developed and matured technologies ranging from air-cleaning in space stations to solid oxide fuel cell based electric propulsion systems and has 70 allowed patents.

Korey Silverman-Roati is a senior fellow in carbon management and negative emissions at the Sabin Center for Climate Change Law at Columbia University. He focuses his research on the legal framework for carbon dioxide removal, climate litigation, and other legal tools to fight climate change. While at the Sabin Center, Korey has written extensively on the international and U.S. legal framework applicable to ocean carbon dioxide removal, including co-editing the book *Ocean Carbon Dioxide Removal for Climate Mitigation: The Legal Framework*. Prior to the Sabin Center, Korey spent three years as a law fellow with the Institute for Governance and Sustainable Development (IGSD), where he focused on fast action climate strategies. Korey graduated from Harvard Law School in 2017.

Zachary P. Smith joined the Department of Chemical Engineering at Massachusetts Institute of Technology as an assistant professor in January, 2017. While at The University of Texas Austin, Smith developed structure/property relationships for gas diffusion and sorption in polymer membranes. His postdoctoral training with Jeffrey Long at the UC Berkeley examined the design of coordination solid (i.e. metal-organic frameworks) for selective adsorption based separations. His research focuses on the molecular-level design, synthesis, and characterization of polymers and inorganic materials for applications in membrane and adsorption-based separations. These efforts are promising for gas-phase separations critical to the energy industry and to the environment, such as the purification of olefins and the capture of CO2 from flue stacks at coal-fired power plants. Smith has co-authored over 20 peer-reviewed papers and been recognized with several awards, including the DoE Office of Science Graduate Fellowship. He was also selected as a U.S. delegate to the Lindau Nobel Laureate meeting on Chemistry in 2013. Smith earned his bachelor's degree in chemical engineering from Pennsylvania State's Schreyer Honors College, and completed his PhD in chemical engineering at the University of Texas at Austin, where he worked under the guidance of Benny Freeman and Don Paul.

Kavita Surana is a Professor of Data Ecosystems and Environmental Accountability at the Vienna University of Economics and Business (WU Vienna), Austria and a Senior Fellow at the Center for Global Sustainability, University of Maryland College Park, USA. Her research focuses on innovation in climate and energy technologies—from early-stage development to late-stage deployment. She is particularly interested in the interactions between public policy and decision-making in private industry and their economic and environmental impacts, locally and globally. Kavita was previously research associate and postdoctoral fellow in the Science, Technology, and Public Policy Program at the Belfer Center for Science and International Affairs at Harvard Kennedy School of Government, USA. Kavita has worked with the World Bank, ICF, and other private organizations, analyzing and advising on a range of issues related to innovation, energy policy, and energy investments. Most recently, she was an investment principal at xista science ventures, investing in technology-intensive climate-tech start-ups. Kavita worked at the French Alternative Energies and Atomic Energy Commission (CEA) during her Ph.D. in materials science and engineering from the University of Grenoble Alpes (Grenoble INP, France). She holds an M.Sc. in materials for energy storage and conversion from Paul Sabatier University, Toulouse (France) as part of a joint European Erasmus Mundus program, and a B.Sc. in physics from St. Stephen's College, Delhi University (India).

Jessica Swanson is an Assistant Professor of Chemistry at the University of Utah. Prior to that she was at the University of Chicago for 9 years where she researched biomolecular systems, particularly those involving charge transport, with multiscale modeling and simulations. She trained with Andy McCammon as a graduate student and Jack Simons as an NIH Ruth Kirstein Postdoctoral Fellow. Research in the Swanson Group bridges computational biophysics and theoretical chemistry with the development and application of multiscale simulation methods, particularly kinetic modeling, to probe medically and environmentally relevant biological

processes at the molecular level. Put simply, her group wants to understand *how and why* fascinating biological systems work the way they do. The group's most recent focus is on methanotrophic methane mitigation to address near-term warming.

Shuchi Talati is an emerging climate technology and governance expert and the founder of The Alliance for Just Deliberation on Solar Geoengineering (DSG), a global effort to elevate voices of climate vulnerable communities & nations in decision-making. She is also a co-chair of the Independent Advisory Committee to oversee SCoPEx, an effort to provide oversight for the potential outdoor solar geoengineering experiment proposed by Harvard University. She most recently served as a Presidential Appointee in the Biden-Harris Administration as Chief of Staff of the Office of Fossil Energy & Carbon Management at the U.S. Department of Energy where she was focused on creating just and sustainable frameworks for carbon dioxide removal. She was also previously the Deputy Director of Policy at Carbon180 and the Fellow on geoengineering research governance at the Union of Concerned Scientists. Dr. Talati was a AAAS/AIP Congressional Science Fellow in the U.S. Senate and served at the White House Office of Science and Technology Policy under President Obama. Dr. Talati earned a BS in environmental engineering from Northwestern University, an MA in climate and society from Columbia University, and PhD from Carnegie Mellon in engineering and public policy.

Sean Thomas has been preoccupied with the comparative biology of trees and forest responses to the intentional and accidental impacts of humans for some 25 years. He has been at the University of Toronto since 1999 and is currently appointed as an NSERC Industrial Research Chair in Biochar and Ecosystem Restoration. Dr. Thomas' research focuses on how trees and forests respond to human impacts — intentional impacts through forest management, and unintentional impacts via local, regional, and global changes in the environment. In this effort, he tries to link an understanding of functional ecology and ecophysiology of trees ("how trees work") to patterns of growth, mortality, recruitment, and reproduction at the population scale, to patterns of community composition, and to ecosystem processes, in particular carbon flux ("how forests work"). Sean Thomas' lab is currently involved in projects in temperate and boreal forests in Canada, and tropical forests at a variety of sites.

Romany Webb is Deputy Director of the Sabin Center for Climate Change Law, Research Scholar at Columbia Law School, and Adjunct Assistant Professor of Climate at Columbia Climate School. Romany's research focuses on two primary areas: (1) energy and (2) negative emissions technologies. Romany's energy-related research explores how legal and policy tools can be used to minimize the climate impacts of energy development as well the impacts of climate change on energy infrastructure. Romany also researches legal issues associated with the development and deployment of negative emissions technologies on land and in the ocean. From 2020 through 2022, she served on the National Academy of Sciences, Engineering, and Medicine Committee on Ocean Carbon Dioxide Removal and Sequestration. She now co-chairs the Climate Change, Sustainable Development, and Ecosystems Committee of the American Bar Association's Section of Environment, Energy, and Resources and serves on a number of other boards and advisory councils. Prior to joining the Sabin Center, Romany worked at the University of California Berkeley Energy and Climate Institute, researching executive authority to combat climate change. Romany also completed a fellowship with the Kay Bailey Hutchison Center for Energy, Law, and Business at the University of Texas at Austin, where she researched energy policy. The fellowship followed several years working in private practice in Sydney, Australia. Romany received an LL.M., with a certificate of specialization in environmental law, from the University of California, Berkeley in 2013. She also holds an LL.B., awarded with first class honors, from the University of New South Wales (Australia).

Kirsten Zickfeld is a Distinguished Professor of Climate Science at Simon Fraser University (SFU) in Vancouver, British Columbia. She holds a PhD in physics (2004) from the University of Potsdam in Germany. Dr. Zickfeld's research interests lie generally in the area of climate change science, with focus on the long-term effects of human activities on climate and interactions between the carbon and methane cycles and climate.

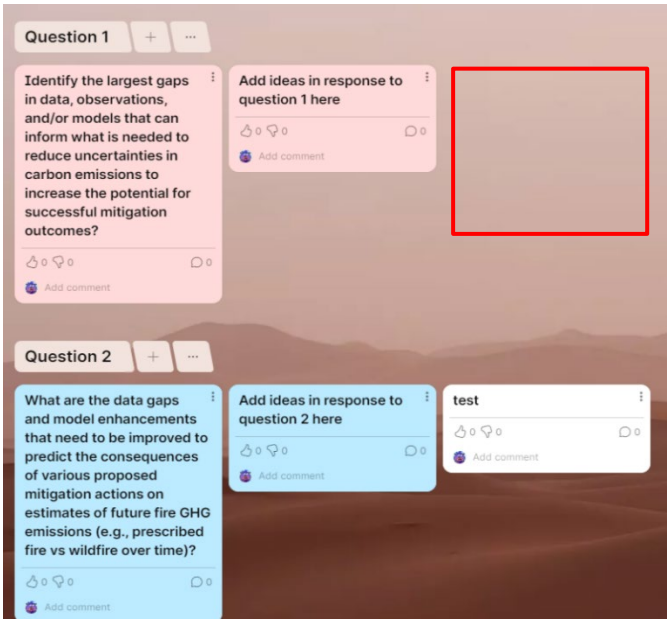
She is internationally recognized for her research on the reversibility of human-induced climate change, carbon budgets consistent with climate goals and the effects of carbon dioxide removal on the Earth system. Dr. Zickfeld served as Lead Author for the Working Group I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) as well as for the IPCC Special Report on the Global Warming of 1.5 degrees. She is a member of the Scientific Steering Committee of the Global Carbon Project.

Julie Beth Zimmerman serves as the inaugural Vice Provost for Planetary Solutions at Yale University. Julie holds joint appointments as a Professor in the Department of Chemical and Environmental Engineering, School of Engineering and Applied Sciences and the School of the Environment. Her research focuses on innovations in sustainable technologies and the policies necessary to advance them. She serves as the deputy director for the Center for Green Chemistry and Green Engineering at Yale and holds leadership positions in both national and international research consortia. In addition, Julie teaches in the Yale School of Management's Executive Education program on sustainability and leadership. Throughout her career, Julie has consulted for a wide range of organizations and institutions, including Fortune 500 companies and state and international organizations, providing guidance on sustainability, innovation, green chemistry, and green engineering. Beyond her roles at Yale, Julie is the editor-in-chief of Environmental Science & Technology, the most highly cited journal in the fields of environmental science and engineering. Prior to joining Yale, Dr. Zimmerman was an Engineer and program manager at the U.S. Environmental Protection Agency, Office of Research and Development. Dr. Zimmerman earned her B.S. from the University of Virginia and her Ph.D. from the University of Michigan jointly from the School of Engineering and Applied Sciences and the School of Environment and Sustainability.

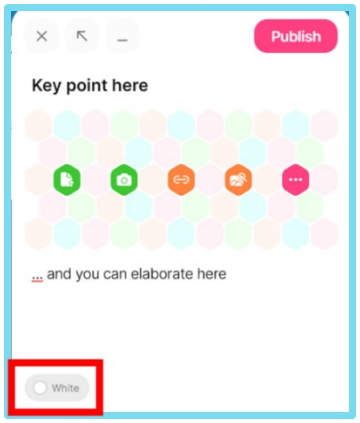
Padlet Instructions

1. Navigate to the appropriate Padlet: each breakout discussion will have its own Padlet page. The Padlet is pre-populated with 2 discussion questions and a section for key takeaways.

2. Use the “+” button beside the question or double-click anywhere in the open space to add your ideas.



3. Type your input. Padlet also allows you to add attachments (e.g., links, images, etc.). Click “Publish” to add your post.



4. You can “thumbs up” or add comments to posts from others.

Study Statement of Task

The National Academies will examine the need for atmospheric methane removal, assess the potential, risks, and co-benefits of viable technological options, and recommend research that could improve understanding. The following topics will be addressed:

- Why might atmospheric methane removal be needed? What specific situations/scenarios might call for deployment of methane removal?
- What are viable options for atmospheric methane removal? To the extent possible, assess the how much methane could be removed from the atmosphere for each option, as well as the cost of deployment, technological efficiency, scale potential, potential risks, and key uncertainties and challenges.
- What potential tradeoffs, co-benefits, and unintended consequences should be considered in developing atmospheric methane removal approaches? What are potential social barriers associated with atmospheric methane removal?
- What new research is needed to improve understanding of atmospheric methane removal?

Committee Bios

Gabrielle Dreyfus (*Chair*) is chief scientist at the Institute for Governance & Sustainable Development (IGSD) and an adjunct lecturer at Georgetown University. She has over a decade of experience working at the science and policy interface including through positions with the U.S. Department of Energy, National Oceanic and Atmospheric Administration, and U.S. Senate. In addition to dozens of scientific and technical publications, Dreyfus worked as the lead coordinating author on a synthesis report by the International Energy Agency and United Nations Environment Programme on the intersection of energy efficiency and the phasedown of fluorinated gases in the cooling sector. She is a member of the Climate and Clean Air Coalition's Scientific Advisory Panel and the Montreal Protocol's Technology and Economic Assessment Panel. She was a 2021 Honoree of Environment+Energy Leader 100. Dreyfus received a B.A. in Earth and planetary sciences from Harvard University, and an M.S. and Ph.D. in geosciences from Princeton University and Sorbonne Université. In 2022 she served on the National Academies of Sciences, Engineering, and Medicine's Committee on Development of a Framework for Evaluating Global Greenhouse Gas Emissions Information for Decision Making.

Dreyfus has provided uncompensated feedback to philanthropic organizations, including Spark Climate Solutions, that are engaged in activities related to methane removal research. IGSD has received funding from Spark Climate Solutions for research related to methane mitigation and the president of IGSD has made public statements related to curbing methane emissions. Dreyfus has co-authored several opinion pieces on reducing methane emissions.

Holly Buck is an Assistant Professor of Environment and Sustainability at the University at Buffalo. Previously, Buck was a NatureNet Science Fellow at UCLA's Institute of the Environment and Sustainability, and an Emmett Climate Engineering Fellow at the UCLA School of Law, with research focusing on the governance of climate engineering. She is an interdisciplinary social scientist who works across rural sociology, human geography, and science and technology studies to understand the social and environmental dimensions of emerging technologies. Her recent and current research involves understanding the social dimensions of technologies to remove carbon from the atmosphere. She is a contributing author to the Intergovernmental Panel on Climate Change's Sixth Assessment Report Working Group III chapter regarding carbon dioxide removal and cross-sectoral governance. Buck received a B.A. in English from University of Maryland Baltimore, M.Sc. in human ecology from Lund University, and a Ph.D. in development sociology from Cornell University with a focus on public engagement with emerging environmental technologies, with chapters on carbon removal and solar geoengineering. She previously served on the National Academies' Committee on a Research Strategy for Ocean Carbon Dioxide Removal and Sequestration.
Buck has made public statements about the need for responsible, publicly funded research into the risks and benefits of carbon removal and solar geoengineering as well as published advocating for the phaseout of fossil fuels.

Hinsby Cadillo-Quiroz is an Associate Professor at Arizona State University with a dual appointment in the School of Life Sciences and Biodesign Institute and leads the Ecology of Microorganisms and Ecosystems laboratory. His expertise spans the microbial physiology of methanogens and methanotrophs, ecosystem studies of methane emissions, as well as collaborations on landscape-level assessments of atmospheric methane. Cadillo-Quiroz's current research focuses on methane production, consumption, and possible management questions including microbial interaction tests with pure cultures, small to medium scale bioreactors, as well as environmental studies of landfills, northern forest, and tropical peatlands in the Amazon Basin. He has been recognized with a Fulbright Scholarship, a Presidential Scholarship at Cornell University, a National Science Foundation CAREER Award, and an Honorific Doctorate in Forestry by the National University of the Peruvian Amazon. Cadillo-Quiroz received a B.S. in biology and microbiology from

Universidad Nacional Mayor de San Marcos, Peru and a Ph.D. in microbiology with a minor in ecology from Cornell University.

Benjamin A. Converse is an Associate Professor of Public Policy and Psychology at the University of Virginia. He is a social psychologist with appointments in the Frank Batten School of Leadership and Public Policy and the Department of Psychology. As Director of the Social Behavior and Decisions Lab, Converse collaborates with graduate and undergraduate students, postdocs, and research associates at the University of Virginia and beyond to conduct behavioral science research in the lab and field. The team explores social, behavioral, and cognitive processes that contribute to human goal pursuit and decision making in a social and resource-constrained world. Converse received a B.A. in psychological and brain sciences from Dartmouth College and a Ph.D. in managerial and organizational behavior from the University of Chicago Booth School of Business.

Faruque Hasan is an Associate Professor and the Kim and Phillip McDivitt Faculty Fellow in the Artie McFerrin Department of Chemical Engineering at Texas A&M University. He also serves as an Assistant Director of Decarbonization at the Texas A&M Energy Institute. His research group develops multiscale methods, tools, and techniques for process systems engineering, design, analysis, and optimization with direct applications to decarbonization of the energy and industrial sectors. Specific technological interests include carbon capture, utilization and storage, methane separation, sustainable hydrogen economy, and resilient supply chains. Hasan is the recipient of a National Science Foundation CAREER award, American Chemical Society Petroleum Research Fund New Doctoral Investigator award, and Outstanding Young Researcher award from the Computing & Systems Technology Division of the American Institute of Chemical Engineers. Hasan received a Ph.D. in chemical engineering from National University of Singapore and completed his postdoctoral training at Princeton University.

Hasan is the scientific co-founder of CryoL, LLC, which focuses on technology for removal of carbon dioxide from industrial flue gas.

Robert Jackson is the Douglas Provostial Professor of Energy and Environment at Stanford University. He chairs the Global Carbon Project, which tracks emissions of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. His lab measures methane emissions from anthropogenic systems, including oil fields, city streets, and homes and buildings, and natural systems, recently establishing the new FLUXNET-CH4 database of nearly 100 methane flux towers globally and a new network of tropical wetland emissions. He is a member of the American Academy of Arts and Sciences, a Guggenheim Fellow, and a Fellow in the American Association for the Advancement of Science, American Geophysical Union, and the Ecological Society of America. Jackson received a B.S. in chemical engineering from Rice University and an M.S. in statistics and Ph.D. in ecology from Utah State University.

Jackson currently serves in an uncompensated advisory role for Spark Climate Solutions and previously received compensation for consulting services for Spark. Jackson serves on the board of Methane Action. He co-founded Torch, a methane mitigation startup in 2020, and the entity is no longer active. Jackson has made public statements in the media on methane emissions and methane removal.

Sikina Jinnah is a Professor of Environmental Studies and affiliated graduate faculty of Politics at the University of California, Santa Cruz. She edits the journal Environmental Politics and co-chairs Harvard University's Advisory Committee for the Stratospheric Controlled Perturbation Experiment (SCoPEx). Her research focuses on global environmental governance, in particular, the areas of climate change, climate engineering, and the nexus between international trade and environmental politics. Most recently she has been working to develop theoretically-derived recommendations for the governance of solar geoengineering technologies. She is the author or editor of 6 books, including "Post-treaty Politics" (MIT Press 2014), which received the 2016 Harold and Margaret Sprout Award for best book in international environmental affairs from

the International Studies Association and “Greening through Trade” (MIT Press 2020), which was a finalist for the 2021 Canadian Political Science Association Prize in International Relations. She is a 2017 Andrew Carnegie Fellow. Jinnah received a B.A. in environmental science from the University of California, Berkeley, an M.S. in environmental studies from the University of Montana, Missoula, and a Ph.D. in environmental science, policy, and management from the University of California, Berkeley.

Christopher W. Jones (NAE) is the John F. Brock III School Chair and Professor of Chemical and Biomolecular Engineering at the Georgia Institute of Technology. His research activities focus on catalysis and adsorptive gas separations and he has extensively studied the removal of carbon dioxide from the atmosphere. Jones is currently the Vice President of the North American Catalysis Society and the International Adsorption Society. He was the founding Editor-in-Chief (EIC) of the American Chemical Society (ACS) journal ACS Catalysis and is currently the EIC of the journal JACS Au. He is a Fellow of ACS, the American Association for the Advancement of Science, and was elected to the National Academy of Engineering in 2022. Jones received a B.S.E. in chemical engineering from the University of Michigan and an M.S. and Ph.D. in chemical engineering from the California Institute of Technology. He previously served on the National Academies of Sciences, Engineering, and Medicine’s Committee on Developing a Research Agenda for Carbon Dioxide Removal and Reliable Sequestration.
Jones has a financial interest in Global Thermostat, a technology start-up that seeks to remove carbon dioxide from the air.

April Leytem is a research scientist with the United States Department of Agriculture (USDA) – Agricultural Research Service at the Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho. Her research focuses on improving the sustainability of integrated cropping and livestock production systems. Leytem has over 17 years’ experience monitoring greenhouse gas emissions from livestock production and cropping systems. In addition, she works collaboratively to improve whole farm modelling efforts aimed at estimating the carbon footprint of dairy production as well as improving national inventories. She has participated as a contributing author to the IPCC 2019 refinement of “Chapter 10 - Emissions from Livestock and Manure Management” and is the lead author of the 2023 refinement of “Chapter 4 – Quantifying greenhouse gas sources and sinks in animal production systems” in the USDA “Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry.” Leytem received a B.A. in economics from Brandeis University and an M.A. in international development (natural resources) and Ph.D. in soil science with an organic chemistry minor from North Carolina State University. She previously served on the National Academies of Sciences, Engineering, and Medicine’s Committee on Anthropogenic Methane Emissions in the United States: Improving Measurement, Monitoring, Reporting, and Development of Inventories.

Thomas McKone is Professor Emeritus in the School of Public Health at the University of California, Berkeley and a Retired Affiliate at Lawrence Berkeley National Laboratory (LBNL). His research career focused on the development, use, and evaluation of models and data for environmental risk assessments and the health and environmental impacts of energy, industrial, and agricultural systems. He served on the U.S. Environmental Protection Agency Science Advisory Board, worked with several World Health Organization committees, and has been on consultant committees for the Organization for Economic Cooperation and Development, the World Health Organization, the International Atomic Energy Agency, and the Food and Agriculture Organization. McKone is a fellow of the Society for Risk Analysis, former president of the International Society of Exposure Science from which he received the Constance L. Mehlman Award and the Jerome J. Wesolowski award for outstanding contributions to exposure science, and was the 2019 Recipient of the LBNL Lifetime Achievement Award. McKone received a B.A. in chemistry from St. Thomas College and an M.S. and Ph.D. in engineering from the University of California, Los Angeles. He has been a member of more than a dozen committees of the National Academies of Sciences, Engineering, and Medicine and most recently served on its Board on Environmental Studies and Toxicology.

Simon Pang is an Associate Group Leader at Lawrence Livermore National Laboratory (LLNL) and leads the Direct Air Capture program within LLNL's Carbon Initiative. He is interested in development and implementation of materials and technologies for carbon dioxide removal, the interface between carbon capture and carbon conversion technologies to develop a circular carbon economy, and systems analysis for carbon removal and energy technologies. Pang's research spans topics from fundamental investigations of direct air capture materials degradation mechanisms to development of hybrid reactive capture processes that integrate carbon capture and conversion. He has participated as a contributing author to LLNL's report "Getting to Neutral," for which the team received a Department of Energy Secretary of Energy Achievement Award. Pang received a B.S. in chemical engineering from Cornell University and a Ph.D. in chemical engineering from the University of Colorado Boulder.

José G. Santiesteban (NAE) is retired from ExxonMobil, where he served for more than 30 years in a number of technical leadership and management roles, including, most recently, strategy manager for ExxonMobil Research and Engineering Company. In this role, he led a team that developed strategic technology direction, provided research guidance, and ensured the robustness of the research and development portfolio. His scientific and engineering expertise in heterogeneous catalysis includes design, synthesis, physical-chemical characterization of novel catalytic materials, and reaction mechanisms and kinetics. He has led and made significant technical contributions to the discovery, development, and commercialization of more than 20 novel catalyst technologies for the production of high-performing lubricants, clean fuels, and petrochemicals. Santiesteban is a member of The Academy of Medicine, Engineering, and Science of Texas, the National Academy of Engineering (NAE), and is a Council Member and on the Board of Trustees of NAE. He received the Society of Hispanic Professional Engineers 2018 Innovator Award and multiple technical and leadership awards within ExxonMobil Research and Engineering Company and Mobil Research and Development Company. Santiesteban received a B.S. in chemical engineering from Instituto Tecnológico de Chihuahua, México, an M.S. in chemical engineering from Instituto Tecnológico de Ciudad Madero, México, and a Ph.D. in physical chemistry from Lehigh University. He previously served as a member of the National Academies of Sciences, Engineering, and Medicine's Committee on Chemical Engineering: Challenges and Opportunities in the 21st Century and currently serves on the Board on Energy and Environmental Systems.

ExxonMobil Research and Engineering, where Santiesteban was the Strategy Manager from 2016-2021, has many activities related to the mitigation of methane emissions.

Lisa Stein is a Professor and the Associate Chair of Research in the Department of Biological Sciences at the University of Alberta where she leads the Climate Change Microbiology laboratory. She was a postdoctoral scholar at the California Institute of Technology and National Aeronautics and Space Administration Jet Propulsion Laboratory in the Astrobiology and Life Detection groups and was previously an Assistant Professor at the University of California, Riverside. Stein's expertise is on the ecophysiology and genomics of microorganisms that produce and consume methane and nitrous oxide. Projects include constructing genome-scale metabolic models for ammonia- and methane-oxidizing bacteria that can pinpoint global gene expression as their environment becomes conducive to greenhouse gas emissions, or they can predict how oxidation products of methane are gated into value-added products like bioplastics and biofuels for methane remediation. She received the Killam Award for Excellence in Mentoring in 2022 and the Great Supervisor Award in 2018. She was elected as a Fellow in the American Academy of Microbiology in 2023. Stein received a B.A. in molecular, cellular, and developmental biology from the University of Colorado Boulder and a Ph.D. in molecular and cellular biology from Oregon State University.

Stein previously served as an uncompensated advisor for Mango Materials, Inc. and currently serves as an uncompensated advisor to Cvictus, Inc. and Bioconversion Databank Foundation.

Alex Turner is an Assistant Professor at the University of Washington in the Department of Atmospheric Sciences and the Calvin Professor of Atmospheric Science. He is an atmospheric scientist whose research combines satellite remote sensing, numerical modeling, and Bayesian inference to study interactions between the carbon cycle and atmospheric chemistry. Much of Turner's work investigates the processes controlling the abundance and variations of greenhouse gases such as methane in the atmosphere. He is the recipient of the 2020 James R. Holton Junior Scientist Award from the American Geophysical Union. Turner received a B.S. in mechanical engineering from the University of Colorado Boulder, a Ph.D. in atmospheric chemistry from Harvard University, and was a Miller Postdoctoral Fellow at the University of California, Berkeley.
Turner is currently a compensated technical consultant on the use of satellite remote sensing for methane emission estimation for Geofinancial Analytics. Turner has previously provided expert commentary for news pieces on methane removal.

Katey Walter Anthony is an Aquatic Ecologist and Professor at the University of Alaska Fairbanks. Her research focuses on methane emissions from Arctic lakes, the degradation of permafrost, and its feedbacks to global climate processes through the carbon cycle. She has over 25 years' experience conducting field work in Alaska and Russia, is a science team member of the National Aeronautics and Space Administration Arctic-Boreal Vulnerability Experiment, and a member of the Permafrost Carbon Network. She received the National Wildlife Federation Award in 2009, National Geographic Society Early Explorer's Award in 2009, Mount Holyoke College Mary Lyon Award in 2010, WINGS WorldQuest Award in 2011, and the University of Alaska Usibelli Distinguished Research Award in 2019. Anthony received a B.A. in geology from Mount Holyoke College, an M.S. in restoration ecology from the University of California, Davis, and a Ph.D. in aquatic biology from the University of Alaska Fairbanks. She previously served on the National Academies of Sciences, Engineering, and Medicine's Polar Research Board.

Anthony has provided uncompensated advice to E44 Management Company Ltd about projects in the Arctic.

Margaret Wooldridge is the Walter J. Weber, Jr. Professor of Sustainable Energy, Environmental and Earth Systems Engineering, an Arthur F. Thurnau Professor in the Departments of Mechanical Engineering and Aerospace Engineering and the Director of the Institute for Energy Solutions at the University of Michigan. Wooldridge was on the faculty at Texas A&M University before joining the University of Michigan in 1998. Her research program spans diverse areas where high-temperature chemically reacting systems are critical, including power and propulsion systems, fuel chemistry, and synthesis methods for advanced nanostructured materials. Her research team has pioneered methods for characterizing fundamental fuel properties and performance in modern spark-ignition and gas turbine engines. She is a 2013 recipient of the Department of Energy Ernest Orlando Lawrence Award and a fellow of the Combustion Institute, American Society of Mechanical Engineers, Society of Automotive Engineers, and a Senior Fellow in the Michigan Society of Fellows. Wooldridge received a B.S. in mechanical engineering from the University of Illinois Urbana-Champaign and an M.S. and Ph.D. in mechanical engineering from Stanford University. She previously served as the Chair of the National Academies of Sciences, Engineering, and Medicine Committee on the Peer Review of Interim Report on Computational Fluid Dynamics Model for Predicting Wellhead Oil-Burning Efficiency at Bench and Intermediate Scales.

Background Materials on Methane Removal

SELECTED BACKGROUND READING ON METHANE REMOVAL

- Jackson, R.B., Solomon, E.I., Canadell, J.G. *et al.* Methane removal and atmospheric restoration. *Nat Sustain* **2**, 436–438 (2019). https://doi.org/10.1038/s41893-019-0299-x [Access article]

- Jackson, R. B., Abernethy, S., Canadell, J. G., Cargnello, M., Davis, S. J., Féron, S., ... & Zickfeld, K. (2021). Atmospheric methane removal: a research agenda. *Philosophical Transactions of the Royal Society A*, *379*(2210), 20200454. [Access article]

- Turner, J., Dreyfus, G., and Zaelke, D. (2022). Background Note: R&D Needed for Removing Methane from the Atmosphere. *Institute for Governance & Sustainable Development.* [Access note]

- Ming, T., Li, W., Yuan, Q., Davies, P., de Richter, R., Peng, C., Deng, Q., Yuan, Y., Caillol, S., & Zhou, N. (2022). Perspectives on removal of atmospheric methane. *Advances in Applied Energy*, 5, 100085. https://doi.org/10.1016/j.adapen.2022.100085 [Access article]

- Nisbet-Jones, P. B. R., Fernandez, J. M., Fisher, R. E., France, J. L., Lowry, D., Waltham, D. A., Woolley Maisch, C. A., & Nisbet, E. G. (2022). Is the destruction or removal of atmospheric methane a worthwhile option? *Philosophical Transactions*. Series A, Mathematical, Physical, and Engineering Sciences, 380(2215), 20210108. https://doi.org/10.1098/rsta.2021.0108 [Access article]

- Bond, C. Why capturing methane is so difficult. *E&E News.* January 17, 2023. [Access article]

PREVIOUS MEETINGS AND PRESENTATIONS TO THE COMMITTEE

The Committee held an open information gathering meeting on April 20, 2023. A full recording of the meeting can be accessed here: https://www.nationalacademies.org/event/04-20-2023/atmospheric-methane-removal-development-of-a-research-agenda-committee-meeting-1.

The following presentations to the committee can also be accessed online:

- Ben Poulter (NASA), *The Global Methane Budget: Emerging Climate Feedbacks* [Access presentation]

- Jack Lewnard (ARPA-E), *REMEDY – Reducing Emissions of Methane Every Day of the Year* [Access presentation]

- Volha Roshchanka and Jerome Blackman (US EPA), *EPA's Coalbed Methane Outreach Program (CMOP)* [Access presentation]

- Kris Johnson (Washington State University), *Agricultural emissions and possible intervention points* [Access presentation]

- Vanessa Suarez (Carbon180), *Equity, justice, and carbon dioxide removal (CDR)* [Access presentation]

- David Mann and Erika Reinhardt (Spark Climate Solutions), *Atmospheric Methane Removal Research* [Access presentation]

NATIONAL ACADEMIES *Sciences Engineering Medicine*

PREVENTING DISCRIMINATION, HARASSMENT, AND BULLYING:
POLICY FOR PARTICIPANTS IN NASEM ACTIVITIES

The National Academies of Sciences, Engineering, and Medicine (NASEM) are committed to the principles of diversity, inclusion, integrity, civility, and respect in all of our activities. We look to you to be a partner in this commitment by helping us to maintain a professional and cordial environment. **All forms of discrimination, harassment, and bullying are prohibited in any NASEM activity.** This policy applies to all participants in all settings and locations in which NASEM work and activities are conducted, including committee meetings, workshops, conferences, and other work and social functions where employees, volunteers, sponsors, vendors, or guests are present.

Discrimination is prejudicial treatment of individuals or groups of people based on their race, ethnicity, color, national origin, sex, sexual orientation, gender identity, age, religion, disability, veteran status, or any other characteristic protected by applicable laws.

Sexual harassment is unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature that creates an intimidating, hostile, or offensive environment.

Other types of harassment include any verbal or physical conduct directed at individuals or groups of people because of their race, ethnicity, color, national origin, sex, sexual orientation, gender identity, age, religion, disability, veteran status, or any other characteristic protected by applicable laws, that creates an intimidating, hostile, or offensive environment.

Bullying is unwelcome, aggressive behavior involving the use of influence, threat, intimidation, or coercion to dominate others in the professional environment.

REPORTING AND RESOLUTION

Any violation of this policy should be reported. If you experience or witness discrimination, harassment, or bullying, you are encouraged to make your unease or disapproval known to the individual at the time the incident occurs, if you are comfortable doing so. You are also urged to report any incident by:

- Filing a complaint with the Office of Human Resources at 202-334-3400 or hrservicecenter@nas.edu, or
- Reporting the incident to an employee involved in the activity in which the member or volunteer is participating, who will then file a complaint with the Office of Human Resources.

Complaints should be filed as soon as possible after an incident. To ensure the prompt and thorough investigation of the complaint, the complainant should provide as much information as is possible, such as names, dates, locations, and steps taken. The Office of Human Resources will investigate the alleged violation in consultation with the Office of the General Counsel.

If an investigation results in a finding that an individual has committed a violation, NASEM will take the actions necessary to protect those involved in its activities from any future discrimination, harassment, or bullying, including in appropriate circumstances **the removal of an individual from current NASEM activities and a ban on participation in future activities**.

CONFIDENTIALITY

Information contained in a complaint is kept confidential, and information is revealed only on a need-to-know basis. NASEM will not retaliate or tolerate retaliation against anyone who makes a good faith report of discrimination, harassment, or bullying.

Updated December 2, 2021

NATIONAL ACADEMIES Sciences Engineering Medicine

A GUIDE TO THE

Harassment Complaint Process for Participants

AT THE NATIONAL ACADEMIES

Review the Policy here.

Complaints regarding violations of the National Academies anti-harassment policies should be reported by:

- Filing a complaint with the Office of Human Resources at 202-334-3400 or hrservicecenter@nas.edu or
- Reporting the incident to an employee involved in the activity in which you are participating.

Complaints of harassment, discrimination, or bullying should be filed as soon as possible after an incident. The Office of Human Resources will investigate the alleged violation in consultation with the Office of the General Counsel.

When reporting an incident, please provide as much of the following information as is possible and applicable:

- Name and role of the person or persons allegedly causing the harassment;
- Description of the incident(s), including the dates, locations and the presence of any witnesses;
- Steps taken to try to stop the harassment; and
- Any other information that may be relevant.

If the National Academies determines that a participant in a National Academies activity has violated this policy, the National Academies will take action as it deems appropriate to address the situation and to prevent the participant from engaging in future discrimination, harassment, or bullying in National Academies activities, up to and including banning that individual from current or future participation in National Academies activities.

All inquiries, complaints, and investigations are confidential, and information is revealed only on a need-to-know basis. Information contained in a complaint is kept confidential. The National Academies will not retaliate or tolerate retaliation against anyone who makes a good faith report of discrimination, harassment, or bullying. or participates in a complaint investigation.

For more information, please watch the following videos from our Expert Volunteer Orientation:

- Making a Commitment to Diversity, Equity, and Inclusion
- Preventing Discrimination, Harassment, and Bullying