NATIONAL ACADEMIES Sciences Engineering Medicine

Why Indoor Chemistry Matters *Workshop 5*: Excessive Heat and the Indoor Environment

April 23, 2025 | 9:00am – 4:30pm ET | Hybrid Workshop

School of Health and Nursing Studies - University of Miami

NATIONAL ACADEMIES *Sciences Engineering Medicine*

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WORKSHOP OBJECTIVES

- Illuminate the experiences of workers exposed to heat and indoor chemicals.
- Explore the current landscape of interdisciplinary community-engaged research to address heat and indoor chemical pollution issues.
- Identify opportunities for future investments to build research capacity and a scientific evidence base to inform action.

PUBLIC AGENDA

09:00am – 09:20am **Welcome, Introductions, and Opening Remarks**

Charles Ferguson, The National Academies of Sciences, Engineering, and Medicine (NASEM)

Roxana Chicas, Emory University and National Academy of Medicine (NAM), American Academy of Nursing Fellow

Guillermo Prado, University of Miami

09:20am – 10:00am **Session 01: Keynotes**

Ellison Carter, Colorado State University
Breathing Room: Navigating Thermal and Chemical Risks Indoors

Jill Johnston, University of Southern California
It's Getting Hot in Here: Perceptions of Indoor Heat in Vulnerable Urban Communities

Moderator: Charles Ferguson

10:00am – 10:15am Break

10:15am – 11:45am **Session 02: Workers Exposed to Heat and Indoor Chemicals**

Natasha Solle, University of Miami
Heat Exposure in the Fire Service: The Impact of Occupational Heat Stress on Firefighter Health

Delphine Farmer, Colorado State University
How Heat and Chemistry Work Together to Enhance Indoor Air Pollution

Gerardo Reyes Chávez w/ Giselle Ramirez**, Coalition of Immokalee Workers (CIW)**
How Farmworkers Created the Fair Food Program and Built-in Protections from Heat and Other Hazards, Part 1

Moderator: Apurva Dave

11:45am – 12:45pm Lunch

12:45pm– 02:15pm **Session 03: Interdisciplinary, Community-Engaged Research**

Gillian Gawne-Mittelstaedt, Tribal Heathy Homes Network
Extreme Heat and Indoor Environments: Risk Factors within Tribal, Rural, Cold-Climate and Overburdened Communities

Robbie Parks, Columbia University
Heat Exposure and Temperature Equity (HEATE): Characterizing Indoor Heat Stress and Health Impacts in Housing in New York City

Gerardo Reyes Chávez w/ Giselle Ramirez**, Coalition of Immokalee Workers**
How Farmworkers Created the Fair Food Program and Built-in Protections from Heat and Other Hazards, Part 2

Moderator: Roxana Chicas

02:15pm – 02:30pm Break

02:30pm – 04:00pm **Session 04: Future Investments in Research**

Robin Dodson, Silent Spring Institute
Targeted Broad Thinking: Addressing Cumulative Exposures in Vulnerable Populations

Paula Olsiewski, Johns Hopkins University
Research to Policy to Practice - What's Needed?

Hudson Santos, University of Miami
Securing Funding for Climate/Environmental and Health Initiatives

Pratim Biswas, University of Miami
Indoor Air Quality: From Earth to Outer Space Abodes

Moderator: Apurva Dave

04:00pm – 04:30pm **Closing remarks & adjourn**

Biographies

Pratim Biswas, Dean of Engineering/U of Miami, Member NAE

Pratim Biswas I Dean, College of Engineering and Professor, Department of Chemical, Environmental and Materials Engineering, Joint Faculty: Atmospheric Sciences, University of Miami, USA. He received his PhD from the California Institute of Technology, MS from the University of California, Los Angeles, and his BTech from IIT Bombay. Prof Biswas is the Dean of the University of Miami College of Engineering. Prior to joining the University of Miami, he was the Lucy and Stanley Lopata Professor and Chair of the Department of Energy, Environmental and Chemical Engineering at Washington University in St. Louis. He also served as the Assistant Vice Chancellor for International Programs, and as the Director of the McDonnell Academy Global Energy and Environmental Partnership (MAGEEP). He is a pioneer in the application of aerosol science and engineering to multiple areas, such as energy and environmental nanotechnology, solar energy, air pollution control, and medicine. He has more than 470 refereed journal publications, with his 65 PhD graduates. He is a Fellow of several national and international organizations, including the American Association for the Advancement of Science (AAAS), International Aerosol Research Assembly (IARA) and American Association for Aerosol Research (AAAR). He has won several teaching and research awards, including the 2018 Fuchs Award, the premier international aerosol science award; the 2016 Harry White Award by the International Society for Electrostatic Precipitation; the 2015 Cecil Award by the American Institute of Chemical Engineers; the 2013 David Sinclair Award by the American Association for Aerosol Research; the Distinguished Faculty Award by Washington University in 2012; and the Distinguished Alumni Award by IIT Bombay in 2011. For his outstanding contributions in aerosol science and technology, he was elected to the US National Academy of Engineering in 2019.

Ellison Carter, Associate Professor, Civil and Environmental Engineering, Colorado State University

Ellison Carter is an Associate Professor of Civil and Environmental Engineering at Colorado State University, where her research integrates human-centered design and interdisciplinary approaches to address personal exposure risks associated with indoor air quality, worker health, and environmental hazards. Her scholarly contributions bridge engineering, public health, and environmental science, emphasizing innovative methods to assess and mitigate indoor air pollution. Dr. Carter has conducted extensive field studies employing novel sensor technologies to characterize indoor air pollutants, particularly in underserved and complex environments. She was a contributing author to the 2022 consensus study, Why Indoor Chemistry

Matters, published by the National Academies of Sciences, Engineering, and Medicine, which emphasized the influence of chemical processes on indoor environmental quality. As a JPB Environmental Health Fellow with the Harvard T.H. Chan School of Public Health, Dr. Carter focused on environmental exposures in indoor environments, pursuing pilot-scale research and professional development to address public health. Her work prioritizes interdisciplinary collaboration and innovative, user-centered approaches to improve environmental health through actionable policy and practical interventions.

Roxana Chicas, Assistant Professor, Emory University Nell Hodgson Woodruff School of Nursing

Roxana Chicas is currently an Assistant Professor, Tenure Track at Emory University Nell Hodgson School of Nursing. Her research focus is on occupational and environmental health disparities, investigating the physiological effects of heat exposures among farmworkers through community-engaged research, particularly their impact on kidney function. In collaboration with the Farmworker Association of Florida, she has led two intervention studies using real-time biomonitoring equipment among farm workers. Dr. Chicas' work is shaping the future of climate and occupational health science, two pressing fields of scientific inquiry. Her methodologies are unique and effective due to direct partnership with farmworker communities, who are now bearing the brunt of life-threatening and dehumanizing extreme heat health effects which more communities will face as climate change worsens. Dr. Chicas' research is creating solutions that are sustainable and grounded in the realities of labor. Her intervention studies are providing relief to workers, collecting critical health data, and informing prevention and intervention practices in the U.S. and globally. As a bilingual, bicultural nurse scientist, she is committed to conducting research that informs policy to advance environmental justice. Dr. Chicas earned her FAAN credential in 2023 when she was inducted into AAN and she is a member of the AAN Expert Panel on Environmental & Public Health.

Gerardo Reyes Chávez, Organizer/Farmworker, Coalition of Immokalee Workers (CIW)

Gerado Reyes Chávez is a key leader of the Coalition of Immokalee Workers (CIW), mobilizing communities across the world to advocate for the rights of exploited workers. Through CIW's Fair Food Program (FFP), Mr. Reyes Chávez has facilitated unique partnerships among farmers, farmworkers, and retail food companies to ensure humane wages and working conditions for the workers on participating farms. Mr. Reyes Chávez is a farmworker and has worked in the fields since age 11, first as a peasant farmer in Mexico and then in the fields of Florida picking oranges, tomatoes, blueberries, and watermelon. A CIW member since 1999, he has worked with consumer allies to organize national actions in the Campaign for Fair Food. As part of implementing the FFP, Mr. Reyes Chávez conducts workers' rights education with thousands of farmworkers on participating farms. Mr. Reyes Chávez has spoken extensively about the Fair Food Program at events such as Harvard Law School's Labor and Worklife Program Convening on Farm Labor Challenges, the Interfaith Council on Corporate Responsibility's Multi-stakeholder Roundtable on Ethical Recruitment, and TEDMED 2018's "How Farmworkers are Leading a 21st Century Human Rights Revolution." Mr. Reyes Chávez is a 2018 Aspen Institute Ricardo Salinas Scholar. The Aspen Institute's Economic Opportunities Program and Food & Society Program have invited him to present on panels, including "I Am Not a Tractor: A Book Talk and Discussion on Worker-Driven Social Responsibility" and "Job Quality in the Fields: Improving Farm Work in the US." Additionally, Mr. Reyes Chávez has been featured in numerous publications and documentaries, most recently in The Washington Post and Food Inc., 2.

Robin Dodson, Associate Director of Research Operations, Silent Spring Institute

Robin Dodson is an exposure scientist at Silent Spring Institute and an adjunct assistant professor at Boston University School of Public Health. Her research focuses on three main areas: development of novel exposure measurements for epidemiological and community-based studies, analysis of environmental exposure data with particular emphasis on semivolatile organic compounds (SVOCs), and interventions aimed at reducing chemical exposures. Dr. Dodson investigates environmental exposures of chemicals linked to a range of health outcomes, including asthma, altered neurological and reproductive development, and breast cancer. Her current research focuses on exposure to consumer product chemicals such as phthalates and flame retardant chemicals and has been used to identify exposure sources and implement effective exposure reduction strategies in homes. Dr. Dodson serves as the chair of the Massachusetts Toxics Use Reduction Institute's science advisory board. Dr. Dodson completed her doctorate in environmental health and masters in environmental science and risk management at Harvard T.H. Chan School of Public Health.

Delphine Farmer, Professor, Colorado State University

Delphine Farmer, PhD is a Professor in the Department of Chemistry at Colorado State University. Her research focuses on understanding the air we breathe both indoors and out, and how the chemistry of air impacts human health, ecosystems, and even climate. Her recent work has focused on wildfire smoke, starting with aircraft projects flying in large wildfire plumes, and more recently looking at how smoke interacts with building surfaces. Dr. Farmer grew up in Canada, and received her BSc in Chemistry from McGill University in Montreal. She earned her Master's in Environmental Science, Policy and Management and her PhD in Chemistry, both from the University of California at Berkeley before holding a NOAA Climate and Global Change Postdoctoral Fellowship at the University of Colorado Boulder. She is a recipient of the American Geophysical Union's Ascent Award and is the 2025 CSU College of Natural Sciences Professor Laureate.

Jill Johnston, Associate Professor, Wen School of Population and Public Health, University of California Irvine

Jill Johnston, PhD is an Associate Professor in Environmental and Occupational Health in the Wen School of Population and Public Health at University of California, Irvine. Dr. Johnston conducts community-driven epidemiology and exposure assessment to address multiple exposures to harmful contaminants that affect community health, including in Hispanic, Black and Asian Pacific Islander communities and among the working poor. She has two decades of experience inside and outside of academia in community organizing, popular education pedagogy, nurturing diverse partnership and translating environmental health research in community settings. Dr. Johnston leads multiple urban and rural studies in Southern California to examine environmental burdens and extreme heat in urban neighborhoods using quantitative and qualitative community-engaged methods. She directs the Community Engagement Core for the new CLIMA Center with a focus on how the most vulnerable communities of Southern California are being impacted by wildfire smoke and extreme heat. Dr. Johnston serves on multiple advisory boards, including for the South Coast Air Quality Management District (SCAQMD), LA Department of Public Health and CA Department of Toxic Substance Control. She served as Commissions for the Climate Emergency Mobilization Office for the City of Los Angeles. Dr. Johnston received her PhD in environmental sciences and engineering from the University of North Carolina at Chapel Hill, where she studied hazardous waste sites and industrial animal production.

Gillian Mittelstaedt, Director, Tribal Healthy Homes Network/Partnership for Air Matters

Gillian Mittelstaedt, DrPH, MPA, is an Indoor Air Quality and Public Health professional who leads the Tribal Healthy Homes Network, an EPA-funded program of the Tulalip Tribes that addresses indoor air hazards through Tribal training, research, and design of culturally tailored interventions. Dr. Mittelstaedt also directs the Partnership for Air Matters, providing low-cost indoor air toolkits to engage and empower environmental justice communities. Dr. Mittelstaedt recently co-chaired EPA's Clean Air Act 50th Anniversary Report and advised the White House on indoor air quality and infectious disease transmission. She co-chairs the National Safe and Healthy Housing Coalition and is past chair of the Washington Asthma Initiative and the Washington Leadership Council for the American Lung Association.

Paula J. Olsiewski, Contributing Scholar, Johns Hopkins Center for Health Security

Paula Olsiewski is a Contributing Scholar at the Johns Hopkins Center for Health Security. She is a pioneering leader in policy and scientific research programs in the microbiology and chemistry of indoor environments. Dr. Olsiewski leads the Center's work on indoor air quality policy to mitigate airborne disease and global catastrophic biological risks. During her 2 decades at the Alfred P. Sloan Foundation, she led innovative and multidisciplinary programs that inspired, accelerated, and produced lasting impact. Her expertise in partnering with academic, governmental, and for-profit stakeholders fostered innovation and built research capacity through the creation of diverse stakeholder networks. Her accomplishments include the creation and direction of the microbiology of the built environment, chemistry of indoor environments, and biosecurity programs. Dr. Olsiewski is recognized as a leading expert in biosecurity and is a member of the Council on Foreign Relations. She was Chair of the US EPA Homeland Security Research Subcommittee and was a member of the EPA Board of Scientific Counselors Executive Committee 2014-2022. She is a member of the Academy of Fellows of the International Society for Indoor Air Quality and Climate and Fellow of the AAAS in chemistry. Dr. Olsiewski received a PhD in biological chemistry at MIT and received a BS in chemistry, cum laude, from Yale University.

Robbie Parks, Assistant Professor, Columbia University

Robbie Parks is an environmental epidemiologist and physicist who has diverse experience in large-scale multi-disciplinary quantitative research focused on climate change, public health and equity. Robbie is a tenure-track Assistant Professor of Environmental Health Sciences at Columbia University's Mailman School of Public Health and an NIH NIEHS K99/R00 Fellow. He teaches the graduate course Atmospheric and Climate Science for Public Health at Columbia University. He is also the Lead Instructor of the Columbia University SHARP Course Bayesian Modeling for Environmental Health. Robbie supervises several post-doctoral fellows, PhD students, and Master's students. He was a Columbia University Earth Institute/Climate School Post-doctoral Fellow from 2019 to 2022 with Prof. Marianthi-Anna Kioumourtzoglou, completed my PhD at the School of Public Health at Imperial College London with Profs. Majid Ezzati and Ralf Toumi in 2019, and graduated with a BA/MA (Oxon) in Physics from Keble College, University of Oxford.

Guillermo (Willy) Prado, Interim Executive Vice President for Academic Affairs and Provost, University of Miami

Guillermo (Willy) Prado is the University of Miami's interim provost and executive vice president for academic affairs and professor of Nursing and Health Studies, Public Health Sciences, and Psychology at the University of Miami. He is a pioneer in the development and dissemination of behavioral interventions for the prevention of substance use and promotion of positive mental health in Hispanic families. Prado is a member of the National Academy of Medicine and is the recipient of numerous awards, including the Lifetime Achievement Award from the National Hispanic Science Network and the Community, Culture, and Prevention Science Award from the Society for Prevention Research. His research has been featured in multiple media outlets including the Miami Herald, NBC, Univision, and CNN en Español. He has also been invited to serve as a witness to the U.S. House Select Committee on Economic Disparities and Fairness in Growth to speak about prevention science.

Natasha Solle, University of Miami

Natasha Schaefer Solle is a Research Associate Professor in the Department of Medicine and Public Health Sciences at University of Miami Miller School of Medicine and Sylvester Comprehensive Cancer Center (SCCC). She serves as the co-Deputy Director of the Firefighter Cancer Initiative (FCI), a multi-faceted project funded by the state of Florida to study firefighters' exposure to carcinogens, examine their cancer risk, and develop methods of education about prevention and early detection, leading the firefighter cancer prevention, education and survivorship program. Schaefer Solle's research interests focus on occupational cancer risks and improving cancer screening in underserved communities. She has extensive experience in qualitative research methodology and community-based participatory research (CBPR). Most of her work has involved engaging minority populations in Florida to help circumvent barriers to care and increase cancer screening practices. The focus of her research is very well aligned with her leadership role at Sylvester Comprehensive Cancer Center as the Assistant Director of the Behavioral and Community-based Research Shared Resource (BCSR), where she is responsible for overseeing research services used to facilitate biobehavioral and population research, reflective of catchment area need for Cancer Center investigators.

Hudson Santos, Dean, University of Miami School of Nursing and Health Studies

Hudson P. Santos Jr., PhD, RN, FABMR, FAAN, is the dean of the University of Miami School of Nursing and Health Studies. He is also a tenured professor and the inaugural Dolores J. Chambreau, RN Endowed Chair in Nursing. As one of the three most NIH-funded nurse scientists in the United States, Dr. Santos has secured over $50 million in research funding. Among his current funded projects, he is the Principal Investigator for Miami cohort of the NIH Environmental Influences on Child Health Outcomes (ECHO) program. Dean Santos is the immediate past-president of the International Society of Nurses in Genetics (ISONG), chair-elect of the Council for the Advancement of Nursing Science National Advisory Council, a Fellow of the American Academy of Nursing, and Academy of Behavioral Medicine Research. He completed his postdoctoral fellowship at Duke University School of Nursing and was a visiting scholar at the University of British Columbia at Vancouver and UNC-CH. Santos holds a PhD in Nursing Science from the University of São Paulo and a Bachelor of Science in Nursing from the State University of Paraiba in his native Brazil.

Workshop Panel and Staff Roster

NASEM Workshop 5 Panel

Roxana Chicas
Assistant Professor, *Emory University*

Guillermo Prado
Interim Executive Vice President, *University of Miami*

Ellison Carter
Associate Professor, *Colorado State University*

Jill Johnston
Associate Professor, *University of Southern California*

Natasha Solle
Research Associate Professor, University of Miami

Delphine Farmer
Professor, *Colorado State University*

Gillian Gawne-Mittelstaedt
Director, *Tribal Heathy Homes Network*

Robbie Parks
Assistant Professor, *Columbia University*

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Coalition of Immokalee Workers

Robin Dodson
Associate Director of Research Operations, *Silent Spring Institute*

Paula Olsiewski
Contributing Scholar, *Johns Hopkins University*

Hudson Santos
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Pratim Biswas
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Kayanna Wymbs
Research Assistant, *The National Academies of Sciences, Engineering, and Medicine*

Acknowledgment for Report Sponsors and Workshop 5 Host

Sponsors of the Consensus Study Report

- Alfred P. Sloan Foundation*
- Centers for Disease Control and Prevention (CDC)
- Environmental Protection Agency
- National Institute of Environmental Health Sciences

** Provided Funding for report dissemination workshops*

Workshop 5 Host

About School of Nursing and Health Studies (SONHS) | University of Miami

Established in 1948 as South Florida's first collegiate nursing program, SONHS is a world-class, prestigiously accredited, research-driven school conferring undergraduate nursing, public health, and health science degrees, as well as advanced nursing degrees. The school's research infrastructure includes the Biobehavioral Research Laboratory, PAHO/WHO Collaborating Centre, Center for Latino Health Research Opportunities, NIH-supported Minority Health and Health Disparities Research Training Program, and 41,000-square-foot S.H.A.R.E. Simulation Hospital Advancing Research & Education®. To learn more, visit sonhs.miami.edu.

Reading Materials and Resources

Statement of Task and Report Committee Roster

The Committee on Emerging Science on Indoor Chemistry of the National Academies of Sciences, Engineering, and Medicine (2020 – 2022)

Statement of Task: The National Academies of Sciences, Engineering, and Medicine will convene an ad hoc committee of scientific experts and leaders to consider the state-of-the science regarding chemicals in indoor air.

Specifically, the committee will focus on:
• New findings about previously under-reported chemical species, chemical reactions, and sources of chemicals, as well as the distribution of chemicals; and
• How indoor chemistry findings fit into context of what is already known about the link between chemical exposure, air quality, and human health
The committee's consideration of this information will lead to a report with findings and recommendations regarding:
1) key implications of the scientific research, including potential near-term opportunities for incorporating what is known into practice; and
2) where additional chemistry research will be most critical for understanding the chemical composition of indoor air and adverse exposures. As appropriate, opportunities for advancing such research by addressing methodological or technological barriers or enhancing coordination or collaboration will be noted. The committee will also provide recommendations for communicating its findings to affected stakeholders. The indoor environments focused on in this study will be limited to non-industrial exposure within buildings.

Consensus Study Report: Why Indoor Chemistry Matters (2022)

COMMITTEE MEMBERS

DAVID C. DORMAN (Chair)
North Carolina State University

JONATHAN ABBATT
University of Toronto

WILLIAM P. BAHNFLETH
Pennsylvania State University

ELLISON CARTER
Colorado State University

DELPHINE FARMER
Colorado State University

GILLIAN GAWNE-MITTELSTAEDT
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RIMA HABRE
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GLENN MORRISON
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Yale University

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University of California, Irvine

HEATHER M. STAPLETON
Duke University

MEREDITH WILLIAMS
California Department of Toxic Substances Control

Report Recommendations and Conclusion

Recommendation 1: Researchers should further investigate the chemical composition of complex mixtures present indoors in a wide range of residential and nonresidential settings and how these mixtures impact chemical exposure and health.

Recommendation 2: Researchers should focus on understanding chemical transformations that occur indoors, using advanced analytical techniques to decipher the underlying fundamental reaction kinetics and mechanisms both in the laboratory and in indoor environments.

Recommendation 3: Researchers should prioritize understanding the phase distribution of indoor chemicals between all indoor reservoirs and incorporate these findings into exposure models.

Recommendation 4: All stakeholders should proactively engage across disciplines to further the development of knowledge on the fundamental aspects of complex indoor chemistry and its impact on indoor environmental quality, exposure assessment, and human health.

Recommendation 5: Researchers who study toxicology and epidemiology and their funders should prioritize resources toward understanding indoor exposures to contaminants, including those of outdoor origin that undergo subsequent transformations indoors.

Recommendation 6: Researchers and their funders should devote resources to creating emissions inventories specific to building types and to identifying indoor transformations that impact outdoor air quality.

Recommendation 7: Researchers and engineers should integrate indoor chemistry considerations into their building system design and mitigation approaches. This can be accomplished in different ways, including by consulting with indoor air scientists.

Recommendation 8: Given the challenges, complexity, knowledge gaps, and importance of indoor chemistry, federal agencies and others that fund research should make the study of indoor chemistry and its impact on indoor air quality and public health a national priority.

Recommendation 9: Researchers and their funders should invest in developing novel methods and chemoinformatic resources that increase our ability to identify and quantify the abundances of wide classes of indoor chemicals, both primary emissions and secondary chemical reaction products.

Recommendation 10: Researchers measuring indoor environments should apply and develop new analytical tools that can probe the chemical complexity of gases, aerosols, and surfaces.

Recommendation 11: Federal agencies should design and regularly implement an updated National Human Activity Pattern Survey. Federal and state agencies should add survey questions in existing surveys that capture people's activities in indoor environments as they relate to indoor chemistry and indoor chemical exposures.

Recommendation 12: Researchers should proactively engage in links that connect research to application throughout the indoor chemistry research process—for example, at the dissemination stage, by engaging with technical and standard-writing committees, presenting at conferences attended by practitioners, and disseminating the significance of research findings in social and mass media.

Recommendation 13: Researchers and practitioners should include environmental justice communities in the wide range of indoor environments they study and engage these communities in formulating research priorities and recommendations for future indoor air quality standards.

Recommendation 14: Funding agencies should support interdisciplinary research to investigate the impact of products and services on indoor chemistry, especially under realistic conditions. There is also a need to determine how occupant access to air quality data leads to behavior that influences indoor chemistry.

Recommendation 15: Researchers and their funders should prioritize understanding the health impacts from exposure to specific classes and mixtures of chemicals in a wide range of indoor settings. Such understanding is needed to inform any future standards, guidelines, or regulatory efforts.

Conclusion 1: Standardized consensus test methods could enable potential certification programs for air-cleaning products and services. Such test methods could help regulators determine whether action on these products and services is warranted.

Bolded recommendations represent workshop 5 discussion topics

Consensus Study Report Summary

Why Indoor Chemistry Matters

Impacts on Human Health

A report of the National Academies of Sciences, Engineering, and Medicine, *Why Indoor Chemistry Matters*, explores the sources and reservoirs of indoor chemicals and how they change in indoor environments. This summary document highlights the impacts of indoor chemistry on human health as presented in the report.

On average, people in the United States spend over 90 percent of their time indoors, with approximately 69 percent of that time spent in the home. In indoor environments, people are exposed to a wide range of chemicals that stem from a variety of sources and activities, including: building materials, furnishings, electronics, personal care products, cooking, cleaning, and the heating and cooling of homes (see Figure 1). The chemical composition of indoor environments is affected by the outdoor environment, as well as the microorganisms, plants, pets, and other biological sources that may be present. Indoor chemistry is further impacted by human factors, including the timing of when a building is occupied, occupant density, and occupant behaviors.

Exposure to indoor chemicals has been associated with several impacts on human health (see Table 1 for examples). The risk of an adverse health effect as the result from exposure to a chemical indoors is dependent on exposure duration, the inherent toxicity of the chemical (or mixture), its concentration, the route of exposure, and the susceptibility of the individual to health effects.

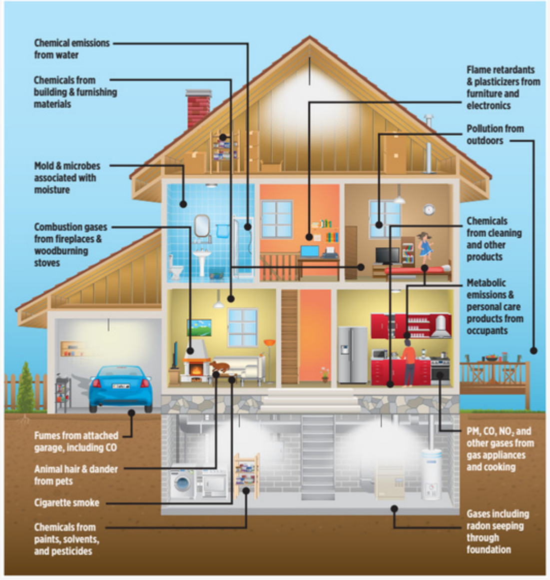


Figure 1
People are exposed to a wide variety of chemicals from diverse sources in their homes and other indoor environments. Impacts of exposure on human health can be highly variable and are influenced by factors such as human activities, building characteristics, and environmental conditions.

Table 1

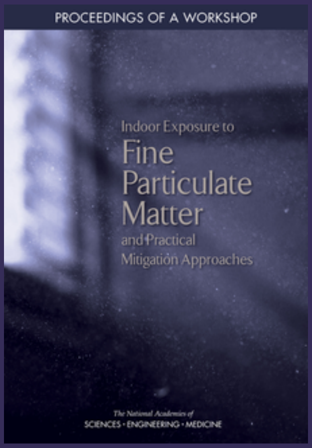
Selected Indoor Chemicals of Indoor Origin and Health Impacts Associated with Exposure

Chemical/Pollutant	**Example of Source(s)**	**Examples of Known Links to Health Impacts**
Radon	Soil gas*, building materials, water supply, natural gas	• Increased incidence of lung cancer
Flame retardants	Furniture, electronics, insulation	• Increased risk of neurodevelopmental deficits in children • Thyroid disease in adults
Particulate matter (PM)	Cooking, cleaning, tobacco smoke and other combustion sources, biological materials such as dust mites and dander, ozone chemistry, and outdoor air pollution*	• Increased risk of lung cancer, respiratory irritation, and asthma episodes
Carbon monoxide	Cooking, heating, and other incomplete combustion	• Low-level exposure linked to nausea and decreased concentration/focus • High-level exposures can be fatal
Volatile organic compounds (VOCs)	Paint, carpet, cookware, upholstery, cleaning products, personal care products, cooking, gas stoves, and wood-burning fireplaces	• Acute exposure linked to eye, nose, and throat irritation, headaches, nausea, and cardiovascular effects • Chronic exposure linked to cancers and damage to the liver, kidneys, and central nervous system

*of outdoor origin

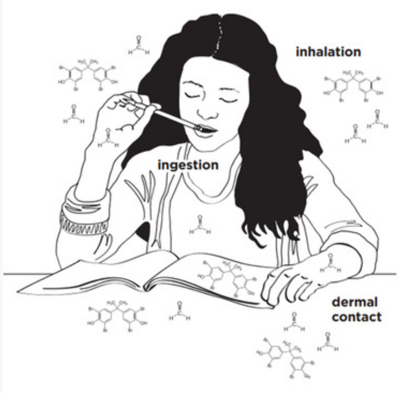
Previous Studies on Indoor Chemistry and Impacts on Human Health

For decades, much of the attention of the scientific and regulatory community has been focused on the chemistry of the outdoor environment. However, there are examples of influential studies focused on indoor chemistry. A 1981 National Academies' report examined the negative health effects of exposure to asbestos, radon, formaldehyde, tobacco smoke, combustion products, and microorganisms, and listed the symptoms of the "sick building syndrome" associated with the occupancy of certain buildings. A 2011 National Academies' report found that climate change may decrease the quality of indoor environments and that opportunities exist to mitigate or adapt to those alterations to improve human health. A 2016 National Academies' workshop focused on the growing evidence that human exposure to particulate matter is higher indoors than outdoors. Last, a follow-on workshop in 2021 focused on the state-of the-science on exposure to fine particulate matter indoors and practical mitigation solutions in residential settings.



Exposure and Susceptibility

People are exposed to chemicals indoors via three routes: inhalation, ingestion, and dermal uptake. Some indoor settings have the potential for more intense exposures; for instance, residences near major roadways or other outdoor point sources, or service-oriented work settings such as restaurants and nail salons. Homes where solid fuels are used for cooking and heating also pose significant risks to human health from the chemicals emitted during incomplete combustion. Table 2 lists some of the factors that can influence indoor emissions and chemical exposure.



Susceptibility factors come into play when thinking about exposure and health implications. Given similar levels of chemical exposure, different groups of people can be more susceptible to adverse health impacts. For example, children are more susceptible to negative health impacts from chemical exposure as they have less developed immune systems and receive higher doses of chemicals per body weight compared to adults. Individuals living in disadvantaged neighborhoods, historically marginalized populations, racial and ethnic minorities, communities of color, and low-income groups can also be more vulnerable to health implications, as they are often disproportionately exposed to multiple environmental contaminants. Further, climate change and extreme weather events contribute to disparities in indoor exposures among low-income households and communities of color compared to moderate- to high-income and white communities.

Table 2

Factors that Influence Indoor Chemistry and Exposure to Chemicals

Factor	Examples
Outdoor environment	• Housing near major roadways, oil and gas extraction sites, and other point sources create microenvironments with high concentrations of chemicals. • Wildfires can lead to elevated concentrations of PM in nearby buildings.
Building construction and upkeep	• Improper implementation of energy efficiency upgrades can result in over-tightening of the building envelope and inadequate air exchange rates. • Deferred maintenance and neglect of both residential and nonresidential buildings can lead to increases in indoor dampness and microbial contamination. • Older and/or poorly maintained buildings have higher rates of outdoor chemicals and PM, higher levels of mold growth, and higher levels of dust. • Design, installation, operation, and maintenance of air handling systems affects the chemical composition of indoor environments.
Occupant behavior	• Use of certain personal care products can emit VOCs or contain endocrine-disrupting chemicals. • Solid fuel burning for cooking or space heating leads to high concentrations of PM, carbon monoxide, and nitrogen oxide. • Client-oriented commercial settings present high exposure to chemicals, such as nail salons and dry-cleaning businesses.

Understanding Indoor Chemistry and Health Impacts

There is still much to learn about the impact of indoor chemistry exposure on human health. The flow chart shown in Figure 2 is a conceptual framework that highlights the steps that need to be examined to understand the causal relationship between sources and health effect. A complete evaluation of health effects related to indoor chemical exposure should consider all possible factors and processes. Such factors include source composition and emission rates, chemical changes, building factors (like air exchange rates), and human factors and behaviors.

An emerging theme in indoor chemistry research is the high degree of complexity that arises from chemical partitioning and chemical transformations. Chemical partitioning determines the concentration of chemicals in the air and on surfaces, while chemical transformations lead to the loss of certain substances and the generation of new substances. For example, cigarette smoke can partition to surfaces and leave residual nicotine, which over time can be chemically transformed to produce even more hazardous chemicals such as nitrosamines, which have been linked to cancers of the lung, pancreas, esophagus, and oral cavity.

Under different environmental conditions (e.g., temperature and relative humidity), the transformation and partitioning processes may be reversed, leading to a re-emission of chemicals into the gas phase. These complex processes make it difficult to truly understand the chemical composition of an indoor environment at any given time. A wide range of analytical techniques are currently being used to identify new chemicals that may be released into the indoor environment, but these approaches are costly and time-consuming. Major obstacles to completing chemical inventory and risk evaluation include a lack of transparency in chemical use in consumer products and a lack of information on the health effects of many of the chemicals found in the indoor environment. Recycling of older products can also reintroduce or extend the lifetime of banned chemicals into the indoor environment.

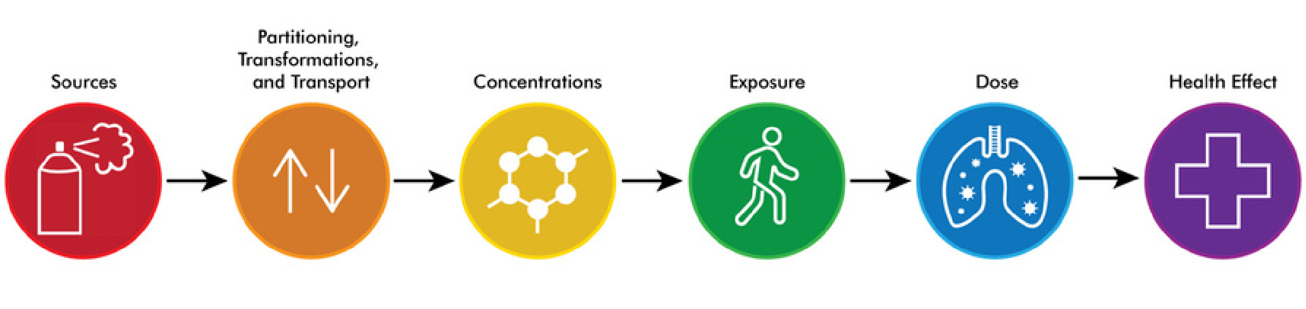


Figure 2
Source to health effect pathway schematic, as conceived within the environmental health paradigm, charting the emissions, fate, and transport of a chemical from source to human exposure, including dose and ultimate impact on health.

Managing Chemicals in Indoor Environments

Effective management of chemicals in the indoor environment is critical to human health. Methods to manage chemical contaminants in indoor environments include: elimination of the hazard, substitution of hazards, engineering controls, administrative controls, and personal protective equipment (see Table 3).No single management approach can remove all contaminants that are present indoors, therefore, hazard elimination is always the preferred method of control. However, combinations of management approaches can also be effective at reducing exposure, as can situation-specific choices.

Ultimately, proper management will require a better understanding of the sources, partitioning, and transformations of the chemicals found indoors. This level of holistic understanding can be accomplished through increased investments in multidisciplinary research. Additionally, refining the regulatory landscape would improve the management of chemicals in indoor environments. Examples may include regulating emission factors, reporting of chemical ingredients, and limiting specific chemicals from entering the market.

Table 3

Approaches to Manage Chemicals in Indoor Environments

Management Approach	Examples
Hazard elimination	• Removing emission sources, such as air fresheners or fragrances
Hazard substitution	• Reformulation of consumer products • Replacing one consumer product with a chemically safer alternative
Engineering controls	• Installing and ensuring the upkeep of mechanical ventilation and/or general exhaust systems • Using local exhaust systems, such as stove range hoods • Installation of fans or physical and chemical barriers
Administrative controls	• Implementing regulations, policies, and procedures to limit chemical exposure • Including product safety labels • Training end users on chemical misuse
Personal protective equipment	• Using specialized face masks and respirators

This document is based on the Consensus Study Report *Why Indoor Chemistry Matters* (2022). The study was sponsored by the National Institutes of Health, Department of Health and Human Services, Centers for Disease Control and Prevention, Environmental Protection Agency, and SLOAN. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project.

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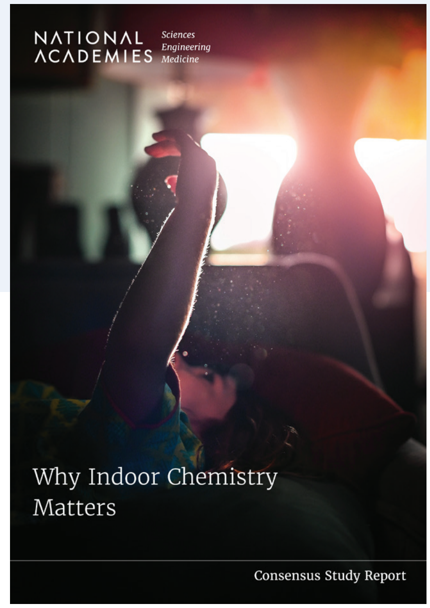
NATIONAL ACADEMIES Sciences Engineering Medicine

NATIONAL ACADEMIES *Sciences Engineering Medicine*

Consensus Study Report
Highlights



Why Indoor Chemistry Matters

Thousands of chemical compounds have been detected in indoor environments, including in air, particles, settled dust, or on surfaces. Chemicals that can include plasticizers, antioxidants, and flame retardants are emitted from a variety of sources in buildings—from construction materials to paints to furnishings and electronics, just to list a few. Human activities indoors, such as walking, cleaning, cooking, space-heating, and opening windows, all affect the mix and movement of indoor chemicals. Indoor chemistry can also be affected by microorganisms, plants, pets, and other biological sources.

Why does indoor chemistry matter? It matters because people spend most of their time at home or in other indoor locations. Complex mixtures of chemicals in indoor environments may adversely impact indoor air quality and human health. Whether exposures to indoor chemicals result in an adverse effect is dependent on exposure duration and additional factors, including the inherent toxicity of the chemical mixture, chemical concentrations in the environment, the route of exposure, and the susceptibility of the person.

This report explores indoor chemistry from different perspectives including sources and reservoirs of indoor chemicals and how they change in indoor environments. It presents new findings about previously under-reported chemical species, chemical reactions, and sources of chemicals, as well as the distribution of chemicals; and examines how indoor chemistry is linked with chemical exposure, air quality, and human health. The report identifies prioritity research that would help in charting the fate and transport of an indoor chemical from source to ultimate impacts on health. (see Figure 1).

CHALLENGES IN IDENTIFYING CHEMICAL SOURCES

A wide range of analytical techniques are currently being used to identify new chemicals that may be released into the indoor environment, but these approaches are costly and time-consuming. Major obstacles to completing chemical inventory and risk evaluation include a lack of transparency in chemical use in consumer products and a lack of information on the health effects or distribution of many of the chemicals found in the indoor environment. An emerging theme in indoor chemistry is the high degree of chemical complexity that arises from the chemical partitioning and chemical transformations.

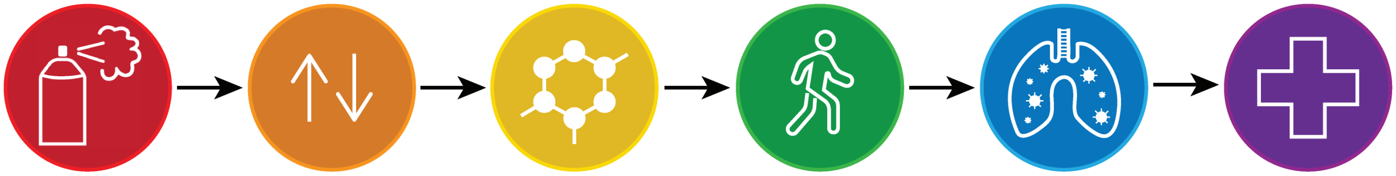


FIGURE 1 The report identifies research needs in charting the fate and transport of an indoor chemical agent from source to ultimate impacts on health.

Partitioning of Indoor Chemicals

Partitioning refers to both the thermodynamic state of chemicals distributed among phases in a system and the processes that transfer chemicals among phases. Partitioning determines the concentration of a chemical in air, on surfaces or elsewhere and distributes chemicals from their initial sources throughout indoor spaces, to air, building materials, furnishings, dust, and so forth. For example, phthalates emitted from plastics can partition to surfaces, porous materials, settled dust, and other compartments. These compartments buffer the air concentrations of chemicals, reducing the short-term effectiveness of controls by ventilation or filtration. Partitioning also influences occupant exposure to chemicals. For example, partitioning of indoor chemicals to aerosols increases inhalation exposure, while partitioning to dust and surfaces increases ingestion exposure, especially by toddlers.

Despite a rapidly growing base of knowledge about indoor partitioning, important data gaps remain. The materials that are present in buildings, or comprise buildings, are not physically or chemically well characterized. Partition coefficients have been measured for very few chemical contaminants and materials. Models to predict thermodynamic parameters exist, but their application to real indoor materials has not been widely demonstrated, nor have they been successfully applied to some chemical classes important in indoor environments, such as surfactants. The extent to which environmental and other building factors, occupant activities, and control systems influence partitioning and exposure remains to be explored.

Transformations of Indoor Chemicals

Chemical transformations are chemical processes that lead to the loss or removal of certain substances (e.g., reactants) and the generation or formation of new substances (e.g., products). The products that arise from these reactions frequently have very different properties from the reactants in terms of their partitioning, toxicity, and other properties. For example, chlorinated chemicals found in cleaning products can react with unsaturated organic compounds to produce higher molecular weight products that can contribute to film growth or secondary organic aerosol (SOA) formation.

Major findings from the past several years illustrate the complexity of chemical reactions that occur in indoor environments. That complexity currently precludes a quantitative understanding of these processes under actual indoor conditions, where factors such as relative humidity have been shown to affect the mechanisms and kinetics. Those data gaps can lead to incomplete toxicological and epidemiological evaluation of chemical dose and health outcomes and make it challenging to determine major exposure pathways for many indoor chemicals.

Important progress has been made in the past few years to develop models that integrate the growing knowledge of chemical transformations, partitioning between different indoor reservoirs, mass transfer, and indoor-outdoor air exchange. However, these models remain limited in their predictive capabilities due to uncertainties in the underlying fundamental chemistry, especially on surfaces. The role of occupants on indoor chemistry remains a research need. Addressing these data gaps may require the application of advanced instrumentation and analytical techniques to study chemistry taking place in buildings and surfaces.

MANAGEMENT OF CHEMICALS IN INDOOR ENVIRONMENTS

Effective management of chemicals in the indoor environment is critical to human health. The management of chemical contaminants in indoor environments includes removal (through ventilation, filtration, sorption, physical cleaning, and passive surface removal) and chemical transformations (including photolysis, ionizers, chemical additions, photocatalysis). No single management approach can remove all contaminants that are present indoors, therefore, source elimination is always the preferred method of control. However, combinations of management approaches can also be effective at reducing exposure, as can situation-specific choices, such as increasing ventilation to reduce airborne contaminant exposure.

Several knowledge gaps remain in the scientific community's understanding of underlying physical and chemical principles of air cleaning, including the fundamental chemistry of many air-cleaning technologies. Except for ventilation, particle filtration, and sorption, few air-cleaning approaches have been tested in real-world environments, which contain a far more complicated mixture of compounds than most laboratories.

Given the recent increased public interest in indoor air quality, driven in part by COVID-19, device manufacturers, researchers, and public health professionals need to communicate clearly to consumers about the efficacy and chemical consequences of different air cleaning approaches. The lack of testing and regulation has led to rampant, unsubstantiated claims about efficacy and health benefits of devices.

INDOOR CHEMISTRY AND EXPOSURE

To date, the foremost goal of exposure science has been to identify and characterize the inhalation, ingestion, and dermal uptake of harmful chemicals that can cause acute or chronic health effects. Exposure levels are influenced by factors such as the age of the building, human behaviors, environment and surroundings, and the agents to which people are exposed. Cost-effective policies and guidance need to take into account the diversity of indoor settings. For example, the location, build quality, and condition of housing have contributed to measurable environmental health disparities among vulnerable populations. Such environmental health disparities that are persistently observed in the United States and around the world too often remain understudied.

Researchers are working to understand exposure to chemical mixtures, complementing strategic priorities of federal agencies, like the National Institutes of Health. For example, the National Institute of Environmental Health Sciences has identified strengthening understanding of combined exposures as a strategic priority. Measurement science advances applied to indoor environments and personal sampling are helping to better understand discrepancies—for example, between personal exposures and stationary monitors or indoor and outdoor area concentrations. Yet inconsistency in chemical identifiers remains a challenge. Exposure data are not collected in a standardized manner and therefore not readily available to support modeling efforts.

A CALL FOR RESEARCH

Despite the importance of indoor exposure, researchers know very little about how humans are exposed to multiple indoor chemicals across phases and pathways, how these joint exposures interact across time scales, and the cumulative and long-term impacts of the indoor chemical environment on human health. Studies of exposure to mixtures in the indoor environment and their health effects are lacking, in part due to the complexity and dynamics of indoor chemistry. Investments in research that uses a holistic approach including chemistry, biology, and social contributions to health will pay dividends in the future.

Recommendation: Researchers should further investigate the chemical composition of complex mixtures present indoors in a wide range of residential and non-residential settings and how these mixtures impact chemical exposure and health.

Recommendation: All stakeholders should proactively engage across disciplines to further the development of knowledge on the fundamental aspects of complex indoor chemistry and its impact on indoor environmental quality, exposure assessment and human health.

Recommendation: Given the challenges, complexity, knowledge gaps and importance of indoor chemistry, federal agencies and others that fund research should make the study of indoor chemistry and its impact on indoor air quality and public health a national priority.

Recommendation: Federal agencies should design and regularly implement an updated National Human Activity Pattern Survey. Federal and state agencies should add survey questions in existing surveys that capture people's activities in indoor environments as they relate to indoor chemistry and indoor chemical exposures.

Indoor Chemistry in a Changing World

Unprecedented changes are occurring to the outdoor environment due to climate change, wildfires, and urbanization, standing in contrast to improvements derived from environmental regulations and advancements in technology. These changes have impacts on indoor environments, many of which have yet to be fully characterized. The report makes recommendations for ways in which researchers, engineers and funders should take those changes into account in understanding indoor exposure, creating emissions inventories, and in building design.

COMMUNICATING SCIENCE AND RISKS

It is critical to translate the emerging science on indoor chemistry into practice that benefits public health and the environment. In addition, standardized consensus test methods could enable future certification programs for air-cleaning products and services. Such test methods could help regulators determine whether action on these products and services is called for.

Recommendation: Researchers should proactively engage in links that connect research to application throughout the indoor chemistry research process; for example, at the dissemination stage, by engaging with technical and standard-writing committees, presenting at conferences attended by practitioners, and disseminating the significance of research findings in social and mass media.

Recommendation: Researchers and practitioners should include environmental justice communities in the wide range of indoor environments they study and engage these communities in formulating research priorities and recommendations for future indoor air quality standards.

Recommendation: Funding agencies should support interdisciplinary research to investigate the impact of products and services on indoor chemistry, especially under realistic conditions. There is also a need to determine how occupant access to air quality data leads to behavior that influences indoor chemistry.

Recommendation: Researchers and their funders should prioritize understanding the health impacts from exposure to specific classes and mixtures of chemicals in a wide range of indoor settings. Such understanding is needed to inform any future standards, guidelines, or regulatory efforts.

COMMITTEE ON EMERGING SCIENCE ON INDOOR CHEMISTRY **David C. Dorman** (*Chair*), North Carolina State University; **Jonathan Abbatt**, University Of Toronto; **William P. Bahnfleth**, Pennsylvania State University; **Ellison Carter**, Colorado State University; **Delphine Farmer**, Colorado State University; **Gillian Gawne-Mittelstaedt**, Partnership For Air Matters/Tribal Healthy Homes Network; **Allen H. Goldstein**, University Of California, Berkeley; **Vicki H. Grassian**, University Of California, San Diego; **Rima Habre**, University Of Southern California; **Glenn Morrison**, University Of North Carolina, Chapel Hill; **Jordan Peccia**, Yale University; **Dustin Poppendieck**, National Institute Of Standards And Technology; **Kimberly A. Prather** (NAS/NAE), University Of California, San Diego; Manabu Shiraiwa, University Of California, Irvine; **Heather M. Stapleton**, Duke University (since February 2021); **Meredith Williams**, California Department Of Toxic Substances Control

STUDY STAFF **Megan E. Harries**, Study Director; **Michelle Bailey**, Program Assistant (Until July 2021); **Kesiah Clement**, Research Associate (Until July 2021); **Meghan Harrison**, Senior Program Officer (Until July 2021); **Ellen K. Mantus**, Scholar (Until April 2021); **Emma Schulman**, Program Assistant (Until March 2022); **Marilee Shelton-Davenport**, Senior Program Officer (Until January 2021); **Abigail Ulman**, Research Assistant (Until November 2021); **Benjamin Ulrich**, Senior Program Assistant (Until August 2021)

This Consensus Study Report Highlights was prepared by the Board on Chemical Sciences and Technology based on the Consensus Study Report Why Indoor Chemistry Matters (2022).

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Division on Earth and Life Studies

NATIONAL ACADEMIES *Sciences Engineering Medicine*

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Why Indoor Chemistry Matters

Summary for Researchers and Research Funders

Although people spend most of their time in indoor locations, many challenges and data gaps remain in the understanding of indoor chemistry and its impact on the environment and human health. Challenges include identifying chemical sources, understanding the partitioning of chemicals and chemical transformations, and having limited information on the health effects or distribution of the chemicals found in the indoor environment.

A report from the National Academies of Sciences, Engineering, and Medicine explores these challenges and data gaps in indoor chemistry and identifies research priorities and recommendations to advance our understanding of this complex field. The report explores many aspects of indoor chemistry, including new findings related to underreported chemical species, chemical reactions, and sources of chemicals and their distribution in indoor spaces.

Complex mixtures of chemicals in indoor environments may adversely impact indoor air quality and human health. Indoor exposure profiles and human exposure to chemical mixtures must be understood to identify and characterize exposure impacts. Furthermore, effective management of chemicals in the indoor environment is critical to human health. Management of chemical contaminants includes removal and chemical transformations.

The report considers several **emerging themes** in indoor chemistry:

1. **Complex Chemical Mixtures and Processes**
    - There is a high degree of chemical complexity and many sources and processes that emit chemicals indoors. However, little is known about how humans get exposed to multiple chemicals across phases and pathways, how these joint exposures interact across timescales, and the cumulative and long-term impacts on human health.
2. **Chemical Reactivity**
    - Many indoor contaminants are chemically reactive via oxidative processes, photochemistry, hydrolysis, and other mechanisms. However, the dependence of multiphase reaction kinetics on oxidant concentrations, condensed-phase water abundance, light levels, and substrate chemical composition is poorly understood.
3. **Distribution of Indoor Chemicals**
    - Accurately describing the phase distribution of chemical contaminants remains a challenge. The integration of knowledge of partitioning processes, transformation chemistry, environmental conditions, human influences, and other parameters is essential to understand these complex processes and enable accurate chemical exposure and health risk assessments.

The report culminates with a vision for the future of indoor chemistry research. This vision relies on an increase in awareness within the scientific community of the challenges and opportunities for innovation in indoor chemistry research as well as the need to fund research in indoor chemistry.

Table 1

A PATH FORWARD FOR INDOOR CHEMISTRY

There is much left to learn and understand about indoor chemistry and the linkages between chemical exposure, air quality, and human health. The report identifies many ways that **researchers** and **research funders** can address critical needs to advance research, enhance coordination and collaboration, and overcome barriers for implementation of new research findings into practice in indoor environments. The consideration of these recommendations will be critical to translate the emerging science of indoor chemistry into a practice that benefits both public health and the environment.

RESEARCHERS SHOULD:

- Further investigate the chemical composition of complex mixtures present indoors;
- Focus on understanding chemical transformations that occur indoors;
- Prioritize understanding the phase distribution of indoor chemicals and incorporate these findings into exposure models;
- Apply and develop new analytical tools that can probe the chemical complexity of gases, aerosols, and surfaces;
- Proactively engage in links that connect research to application throughout the indoor chemistry research process;
- Include environmental justice communities in the wide range of indoor environments they study and engage these communities in formulating research priorities and recommendations for future indoor air quality standards.

RESEARCH FUNDERS SHOULD:

- Prioritize resources toward understanding indoor exposures to contaminants, including those of outdoor origin that undergo subsequent transformations indoors;
- Devote resources to creating emissions inventories specific to building types and to identifying indoor transformations that impact outdoor air quality;
- Make the study of indoor chemistry and its impact on indoor air quality and public health a national priority;
- Invest in developing novel methods and chemoinformatic resources that increase our ability to identify and quantify the abundances of wide classes of indoor chemicals;
- Design and regularly implement an updated National Human Activity Patterns Survey and add survey questions in existing surveys that capture people’s activities in indoor environments as they relate to indoor chemistry and indoor chemical exposures;
- Support interdisciplinary research to investigate the impact of products and services on indoor chemistry;
- Prioritize understanding the health impacts from exposure to specific classes and mixtures of chemicals in a wide range of indoor settings.

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Why Indoor Chemistry Matters

Summary for Building Professionals and Other Stakeholders

Chemicals found indoors can modify or degrade indoor environments. Indoor sources of chemicals include the materials used to construct buildings (e.g., wood, insulation, wall coverings, flooring, and wiring) and the products that are brought into those buildings. Chemicals from such sources create complex mixtures that may adversely impact indoor air quality and/or human health. A report from the National Academies of Sciences, Engineering, and Medicine explores the dynamic systems that connect humans, nonindustrial built environments, and indoor chemistry.

Building materials continuously emit chemicals into indoor environments and strongly influence the chemical composition of indoor air. Many commonly used building materials, including wood and wood composites, insulation, plastic piping, electrical cables and wiring, adhesives, paint, surface treatments and coatings, carpeting, and vinyl flooring, emit volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs), which are associated with human health impacts. Emission rates from these building material sources vary depending on such factors as material quality.

The types of materials used, and therefore the chemicals emitted into indoor environments, have changed over time. Recent material changes can be attributed to new or updated building codes and standards, the desire for improved performance, or the use of recycled building materials. Building material substitutions can have a variety of intended or unintended consequences.

Thousands of chemicals are present in indoor environments. Creating an inventory of these chemicals and their concentrations would allow researchers to better understand human exposure to chemicals indoors. Importantly, there is limited information on the detailed composition of building materials across the building stock. Additionally, the materials that are present in buildings or that comprise buildings are not physically or chemically well characterized. This report lays out research needs and recommendations to address these challenges.

A PATH FORWARD FOR INDOOR CHEMISTRY

The report identifies research needs and provides recommendations to improve the understanding of indoor chemistry, coordinate and collaborate across communities to enhance discovery, and implement new research into practice in indoor environments. The consideration and implementation of these research needs and recommendations by **building professionals** and **other stakeholders** will be critical to translate the emerging science of indoor chemistry into a practice that benefits indoor environments and human health.

RESEARCH NEEDS:

- Prioritize acquisition of actionable data and research to link chemical sources with exposures.
- Increase transparency in the use of building materials to minimize time and effort needed to establish evidence of exposure and health risks.
- Develop and maintain harmonized chemical information databases.
- Broaden our understanding of chemistry taking place on and within the complex surface materials and interfaces present within buildings.
- Conduct controlled field experiments to better understand the fundamental chemistry of emerging air-cleaning technologies, as well as mold and smoke remediation schemes.

RECOMMENDATIONS:

- Researchers and their funders should devote resources to creating emissions inventories specific to building types and to identifying indoor transformations that impact outdoor air quality.
- Researchers and engineers should integrate indoor chemistry considerations into their building system design and mitigation approaches. This can be accomplished in different ways, including by consulting with indoor air scientists.
- All stakeholders should proactively engage across disciplines to further the development of knowledge on the fundamental aspects of complex indoor chemistry and its impact on indoor environmental quality, exposure assessment, and human health.

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NATIONAL ACADEMIES Sciences Engineering Medicine

WHY DOES INDOOR CHEMISTRY MATTER?

People spend most of their time at home or in other indoor locations, and complex mixtures of chemicals in indoor environments may adversely impact indoor air quality and human health.

A consensus study report of the National Academies, *Why Indoor Chemistry Matters*, identifies gaps in current research and understanding of indoor chemistry and new approaches that can be applied to measure, manage, and limit chemical exposures.

MANAGING CHEMICALS IN INDOOR ENVIRONMENTS

Approaches to manage chemical contaminants in indoor environments include removal and chemical transformations.

Removal Approaches

- Filtration
- Physical cleaning
- Passive surface removal
- Sorption
- Ventilation

Chemical Transformations

- Photolysis
- Photocatalysis
- Chemical additions
- Ionizers

CHALLENGES IN IDENTIFYING CHEMICAL SOURCES

Techniques to identify new chemicals that may be released into the indoor environment are both costly and time-consuming. **Chemical partitioning** and **chemical transformations** present a high degree of complexity in the understanding of indoor chemistry.

Partitioning determines the concentration of a chemical in air, on surfaces or elsewhere and results in the distribution of chemicals from their initial sources throughout indoor spaces.

Chemical transformations lead to the loss or removal of certain substances and the generation or formation of new substances. The products that arise from these reactions frequently have different properties, including their partitioning behavior and toxicity.

EXPOSURE

Exposure routes include inhalation, ingestion, and dermal uptake. Exposures to indoor chemicals may result in adverse health effects. The likelihood of adverse health effects is influenced by variables such as:

- Exposure duration
- Inherent toxicity of the chemical mixture
- Chemical concentrations in the environment
- Route of exposure
- Susceptibility of the person

A PATH FORWARD

Further research is needed about the chemical transformations that can occur indoors, pathways and timing of indoor chemical exposure, and the cumulative and long-term impacts of exposure on human health.

To download the free report, visit nationalacademies.org/bcst

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Event Address and Map

Address

University of Miami

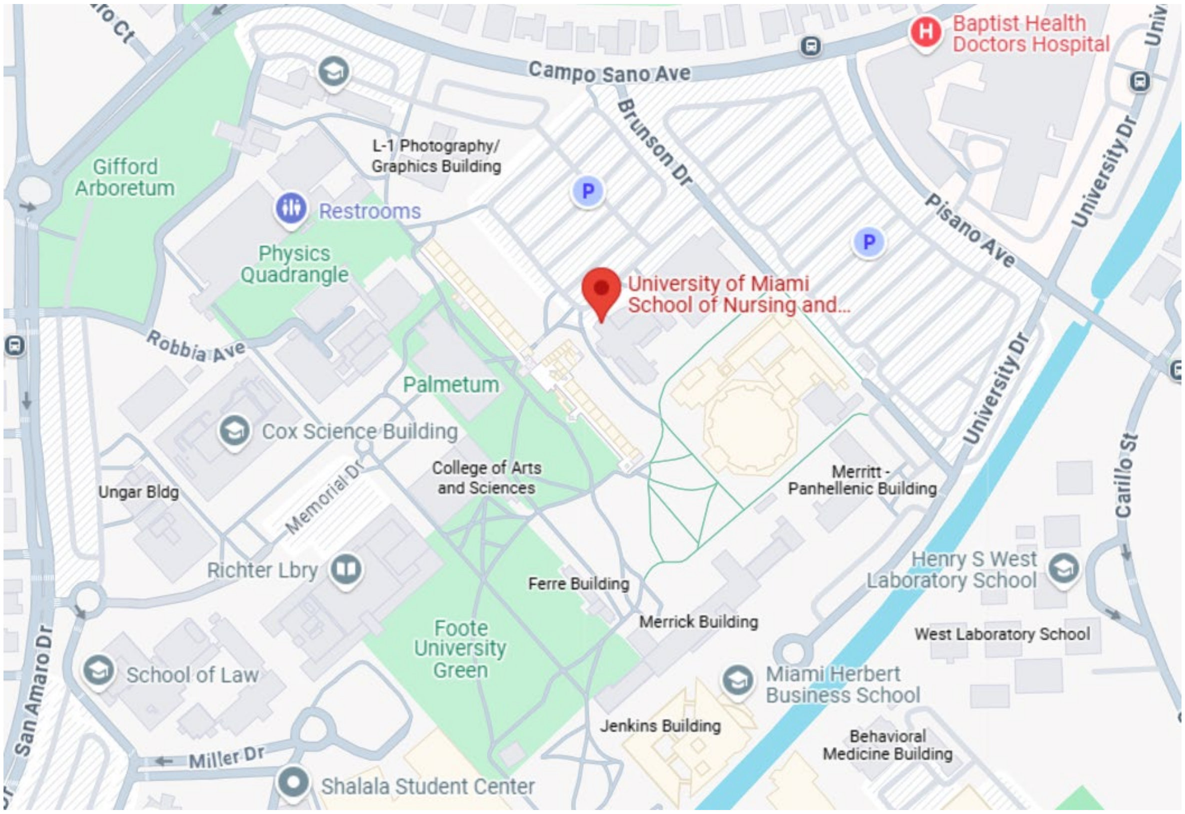
School of Nursing and Health Studies

S.H.A.R.E. Auditorium, 2nd Floor

5030 Brunson Drive

Coral Gables, FL 33146

Map



Preventing Discrimination, Harassment, and Bullying: Policy for Participants in National Academies Activities

PURPOSE

To prohibit discrimination, harassment, and bullying for all participants in National Academies activities.

APPLICABILITY

All participants in all settings and locations in which the National Academies work and activities are conducted.

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

The National Academies of Sciences, Engineering, and Medicine (National Academies) are committed to the principles of 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 National Academies activity.** This policy applies to all participants in all settings and locations in which National Academies' 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.

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- 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.

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