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Viewpoint

A Research Agenda for the Chemistry of Fires at the Wildland–Urban Interface: A National Academies Consensus Report

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Fires at the wildland–urban interface (WUI) are an increasingly common occurrence in the United States and internationally. The WUI is defined as "the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetation fuels".[1] WUI fires are increasing in number and severity due to climate change, the expansion of interface communities, and historical land management practices. The economic, environmental, and human health costs of WUI fires are substantial. Despite the increased impact of WUI fires, the current understanding of the unique chemistry of their emissions and subsequent impacts on health is very limited.

In September 2022, the National Academies of Sciences, Engineering, and Medicine released a consensus report authored by a committee of 12 subject matter experts that examines our current level of understanding of the chemistry of WUI fires and describes a multidisciplinary research agenda to advance that understanding in priority areas.[2] We, the study committee and staff, highlight some of our findings below and encourage the research community to explore the full report, which is freely available as a PDF from the National Academies Press website.

The combination of human-made materials and biomass that burns during a WUI fire generates a unique mixture of emissions. The increased presence of halogens, nitrogen, organic polymers, and other elements at the WUI, compared to wildlands, is expected to alter combustion chemistry and ultimately the composition of emitted species. WUI fire ventilation conditions (e.g., temperature and oxygen availability) also have impacts on the composition of emissions and are expected to be different from wildland or structural fires. Although we can extrapolate from the knowledge of wildland fires and structural fires to predict emissions-associated WUI fires, such inferences are not reliable. There is a need for direct investigation of WUI fire emissions using experimental and modeling approaches. Additionally, researchers need data on material loadings and compositions, structure density and arrangement in the WUI landscape, and combustion conditions in WUI fires. Experiments and mechanistic models are needed to probe the interactions between the chemistries in wildland fire plumes and urban (structural) fire plumes.

Downwind of a WUI fire, atmospheric chemistry and physical changes (such as dilution, partitioning, and deposition), which occur over minutes to days, lead to dramatic changes in the composition of the fire plume. The atmospheric chemistries driven by high concentrations of halogen radicals and other nitrogen- and halogen-containing molecular species are expected to lead to atmospheric transformations for WUI fire emissions that are distinctly different from transformations of emissions from wildland fires or structural fires. Because regional smoke exposure can impact a large number of people across hundreds of kilometers, it is important to identify the influences of WUI-specific emissions and key atmospheric oxidants on plume composition. Detailed study of these processes is needed. Models to forecast public health risks associated with toxicants found in WUI fire emissions are also needed.

In addition to atmospheric processes, pathways exist for the partitioning of emissions into nearby soil and water. Recent studies after WUI fires have found volatile organic compounds (VOCs) in source waters and water distribution systems and heavy metals in ash samples, but the mechanisms and impacts of such contamination warrant further investigation. Broadly speaking, we currently lack information about the concentrations of chemicals emitted from WUI fires in water runoff and soil.

Many of the chemicals that have been observed in the studies that are available on WUI fire emissions have the

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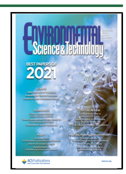

potential to cause acute, chronic, or delayed health effects through inhalation, dermal, or ingestion exposure. These toxicants include asphyxiant gases, acid gases, particulate matter (PM), VOCs, polycyclic aromatic hydrocarbons, polychlorinated compounds (such as dioxins and furans), flame retardants, heavy metals, and plasticizers; however, it is important to note that other primary and secondary species are likely unidentified. The vast majority of health studies to date focus on PM exposure as the primary metric. Some mitigation approaches are available, especially for inhalation exposure to PM; however, the effectiveness of these interventions is often poorly characterized. Further, the health consequences of particles depend on their chemical composition, so PM from WUI fires may have different health impacts than other sources of PM, including wildland fires. Vulnerable populations (due to life stage, race/ethnicity, socioeconomic position, or occupation) can experience disproportionate exposures, health effects, and lack of access to protective measures. Outdoor workers, including firefighters, constitute a high-exposure group because of their proximity to emissions and typical lack of respiratory protection. Future studies focused on these areas would address key information gaps.

Based on our analysis of the state of the science, our report recommends that researchers and funders of research implement a research agenda that integrates multiple disciplines. Measurements of WUI fires, their materials, emissions, chemical transformations and fate, exposures, and health impacts are historically available as isolated, ad hoc data sets, with each scientific discipline using its own methods. However, with enhanced coordination and communication across different areas of study, interdisciplinary research teams could combine these measurements to yield more information. For example, monitoring the same suite of chemicals across inventories of materials found in the WUI, field measurements of the WUI fire plume, and biomonitoring studies in multiple exposed subpopulations could lead to broader, more impactful conclusions. Coordinated research is essential to provide the information that decision makers need to guide environmental and public health policy (Figure 1).

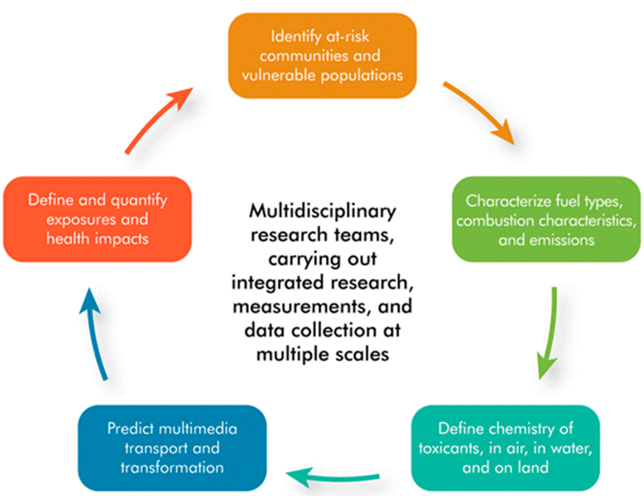

Figure 1. Interdependence of multidisciplinary research activities to characterize WUI fire emissions and their impacts. Credit: NASEM, 2022. Reproduced with permission from the National Academy of Sciences, courtesy of the National Academies Press, Washington, DC.

The committee used four primary factors to prioritize the report's research agenda: utility for decision makers, timeliness and cost-effectiveness, generalizability, and state of measurement capabilities. With these criteria in mind, the committee organized priority research needs into four overarching categories that span WUI materials and emissions, chemical transport and transformations, exposure and health, and measurement science. Table S-1 in the report's Summary details these research priorities.

In all of these categories, collecting WUI-specific data is paramount. One of the frequent challenges in conducting this study was the inability to attribute data specifically to WUI materials and emissions. Because WUI fires often start as wildland fires that spread to WUI communities, this is not easily untangled; however, in future studies, it will be important for research to include studies focused on the WUI.

Characterizing WUI fire chemistry and its effects on public health is a multidisciplinary goal. The committee represented a microcosm of the wide range of expertise that will be needed. The research agenda developed by the committee will require contributions from a wide range of disciplines, with effective exchange of information among diverse investigators. In addition to communicating across disciplines, it is crucial for policy-relevant research findings to reach decision makers who are charged with protecting public health. Commitment to advancing these priorities will benefit communities across the United States and beyond.

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Notes

The authors declare no competing financial interest.

Biographies

Dr. Megan E. Harries was the National Academies staff director of the Committee on the Chemistry of Urban Wildfires, which authored the report described in this Viewpoint. Trained as an analytical chemist, Dr. Harries received a BA from Fordham University and a PhD from the University of Colorado Boulder. Prior to joining the National Academies, she was the recipient of a National Research Council Research Associateship, which she spent at the National Institute of Standards and Technology developing methods for more sensitive and repeatable chemical characterization of trace forensic evidence.

Dr. David T. Allen is the Melvin H. Gertz Regents Professor of Chemical Engineering and the Director of the Center for Energy and Environmental Resources at the University of Texas at Austin. His research interests include urban air quality, the engineering of sustainable systems, and the development of materials for environmental and engineering education. Dr. Allen directs the Air Quality Research Program for the State of Texas, and he has been a lead investigator for multiple measurement studies that have had a substantial impact on the direction of air quality policies. Dr. Allen was elected to the National Academy of Engineering in 2017 and served as chair of the National Academies Committee on the Chemistry of Urban Wildfires.

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■ ABBREVIATIONS

PM, particulate matter; VOC, volatile organic compound; WUI, wildland-urban interface

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