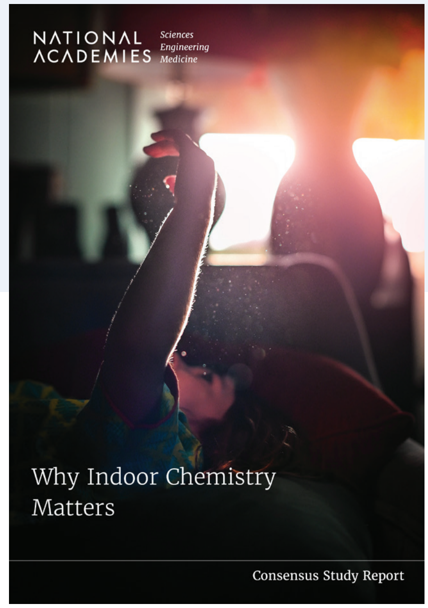
NATIONAL ACADEMIES Sciences Engineering Medicine

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.

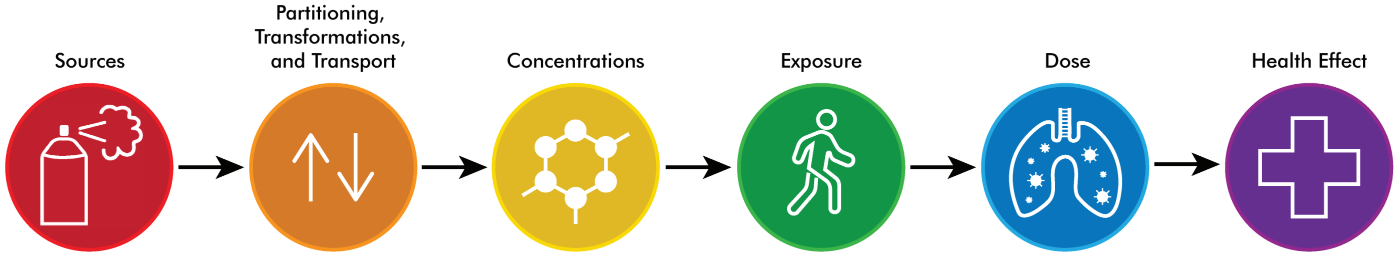


FIGURE 1 The report identifies research needs in charting the fate and transport of an indoor chemical agent from source to ultimate impacts on health.

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.

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