NATIONAL ACADEMIES Sciences Engineering Medicine

## 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.

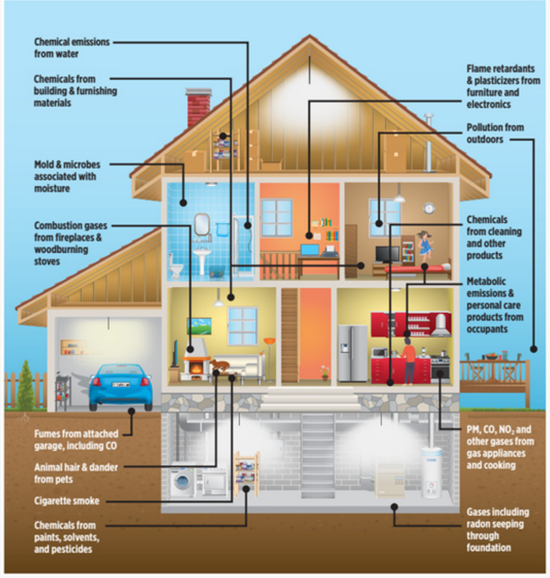



**Figure 1**
People are exposed to a wide variety of chemicals from diverse sources in their homes and other indoor environments. Impacts of exposure on human health can be highly variable and are influenced by factors such as human activities, building characteristics, and environmental conditions.

## Table 1

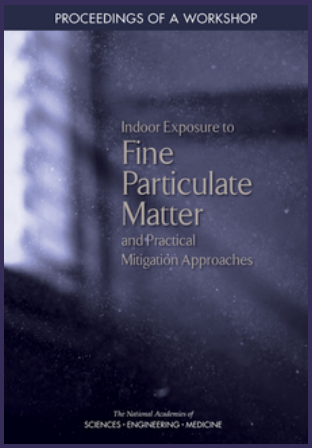
**Selected Indoor Chemicals of Indoor Origin and Health Impacts Associated with Exposure**

| **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<br>• 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<br>• 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<br>• Chronic exposure linked to cancers and damage to the liver, kidneys, and central nervous system |

*of outdoor origin

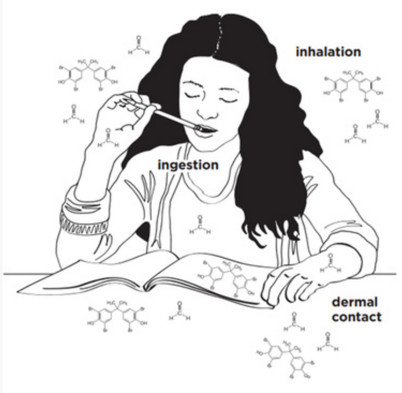
### Previous Studies on Indoor Chemistry and Impacts on Human Health

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.<br>• 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.<br>• Deferred maintenance and neglect of both residential and nonresidential buildings can lead to increases in indoor dampness and microbial contamination.<br>• Older and/or poorly maintained buildings have higher rates of outdoor chemicals and PM, higher levels of mold growth, and higher levels of dust.<br>• 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.<br>• Solid fuel burning for cooking or space heating leads to high concentrations of PM, carbon monoxide, and nitrogen oxide.<br>• 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.

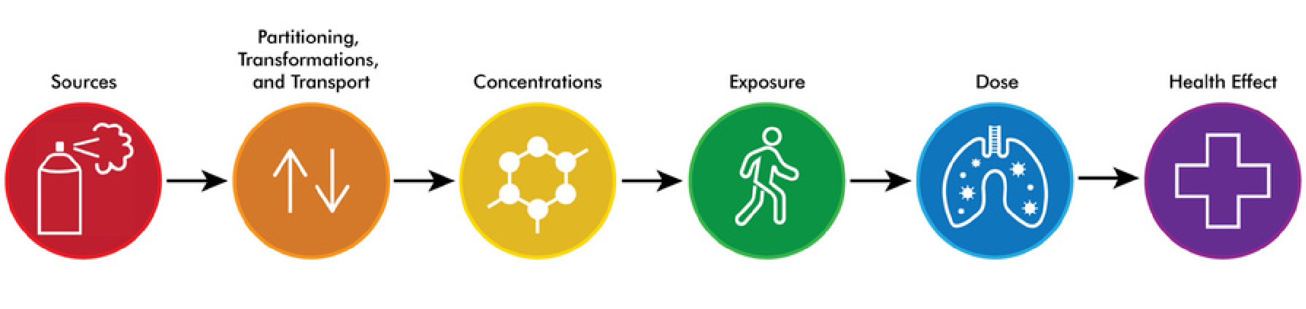



**Figure 2**
Source to health effect pathway schematic, as conceived within the environmental health paradigm, charting the emissions, fate, and transport of a chemical from source to human exposure, including dose and ultimate impact on health.

## 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<br>• Replacing one consumer product with a chemically safer alternative |
| Engineering controls | • Installing and ensuring the upkeep of mechanical ventilation and/or general exhaust systems<br>• Using local exhaust systems, such as stove range hoods<br>• Installation of fans or physical and chemical barriers |
| Administrative controls | • Implementing regulations, policies, and procedures to limit chemical exposure<br>• Including product safety labels<br>• 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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