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# Why Indoor Chemistry Matters Workshop 2: Prioritizing Indoor Chemistry Research

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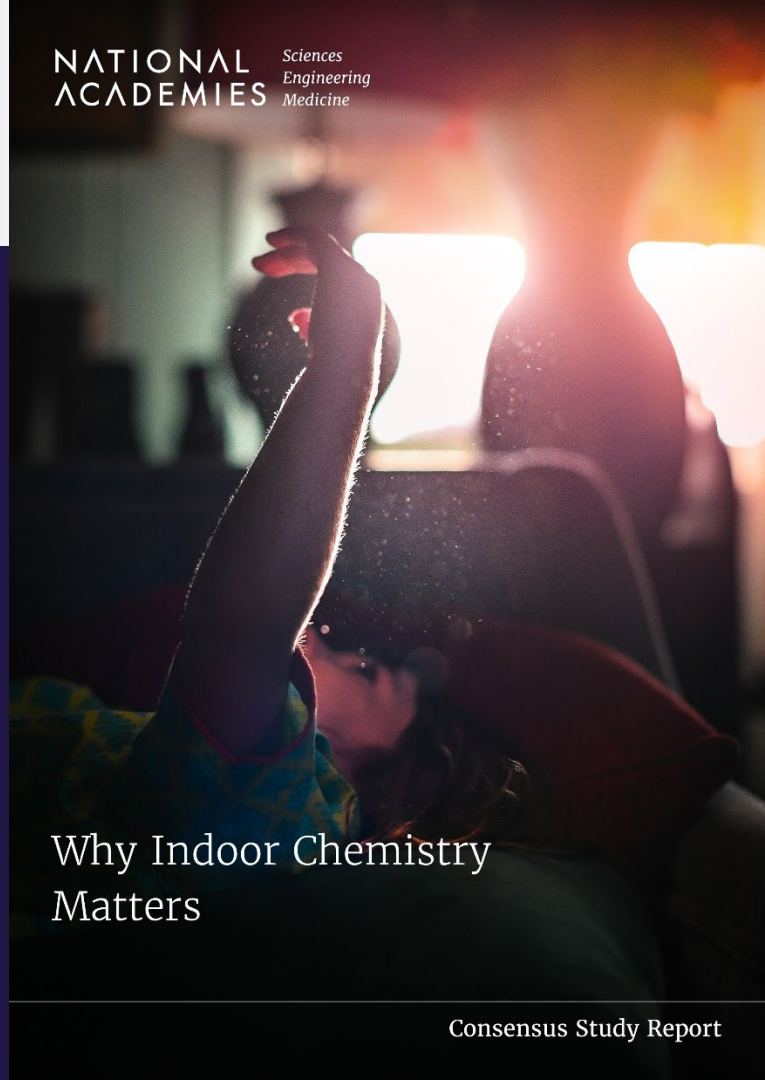
# Main Messages and Select Recommendations From Why Indoor Chemistry Matters: A National Academies Consensus Report



# Links to the report

https://nap.nationalacademies.org/catalog/26228/why-indoor-chemistry-matters

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# Report sponsors



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# Statement of Task (1/2)

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.**

# Statement of Task (2/2)

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.

# Committee roster and NASEM staff

- **David Dorman** (Chair)
  North Carolina State University
- **Jonathan Abbatt**
  University of Toronto
- **William Bahnfleth**
  Pennsylvania State University
- **Ellison Carter**
  Colorado State University
- **Delphine Farmer**
  Colorado State University
- **Allen Goldstein**
  University of California, Berkeley
- **Vicki Grassian**
  University of California, San Diego
- **Rima Habre**
  University of Southern California
- **Gillian Mittelstaedt**
  Partnership for Air Matters/Tribal Healthy Homes Network
- **Glenn Morrison**
  University of North Carolina
- **Jordan Peccia**
  Yale University
- **Dustin Poppendieck**
  National Institute of Standards and Technology
- **Kimberly Prather** (NAS/NAE)
  University of California, San Diego
- **Manabu Shiraiwa**
  University of California, Irvine
- **Heather Stapleton**
  Duke University
- **Meredith Williams**
  California Department of Toxic Substances and Control
- **Megan Harries**
  NASEM

# Why Does Indoor Chemistry Matter?

**Indoor Chemistry** matters because people spend the majority of their time at home or in other indoor locations

# Why Does Indoor Chemistry Matter?

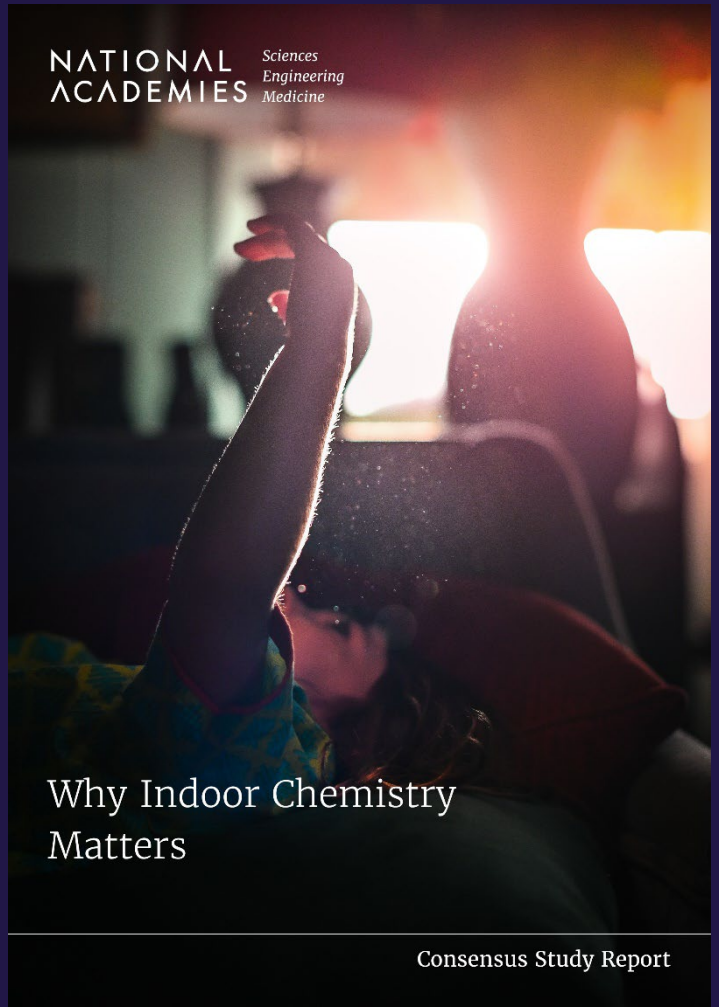
We have been well aware of indoor chemistry for some time

- Radon mitigation
- CO detectors

More recently

- $CO_2$ detectors
- Particle counters

# Report Structure, Main Messages and Select Recommendations



# Report structure

**Each chapter provides an overview of current state-of-the science and recommendations of research needs**

The main body of the report focuses on:

1. Introduction;
2. Primary sources and reservoirs of chemicals indoors;
3. Partitioning of chemicals in indoor environments;
4. Chemical transformations;
5. Management of chemicals in indoor environments;
6. Indoor chemistry and exposure;
7. A path forward for indoor chemistry.

# Sources to Health Effects – What We Need to Know

Charting the fate and transport of an agent from source to ultimate impacts on health.

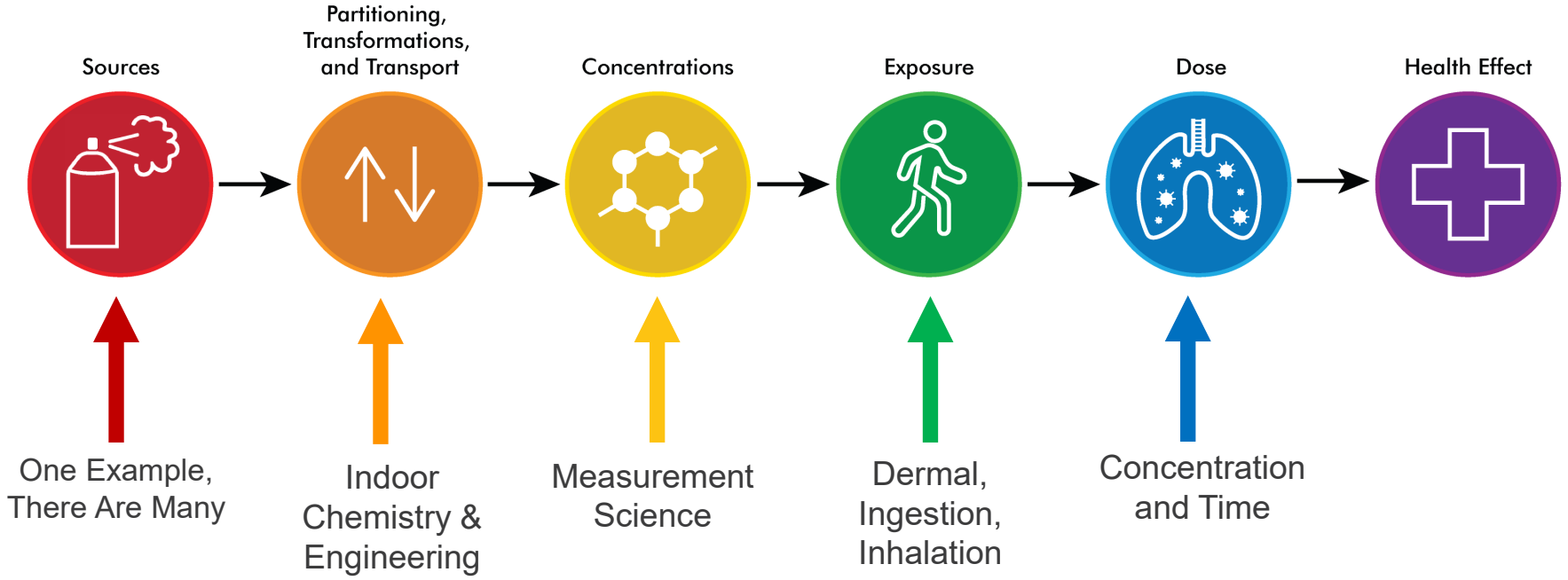



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Fig. 6.2

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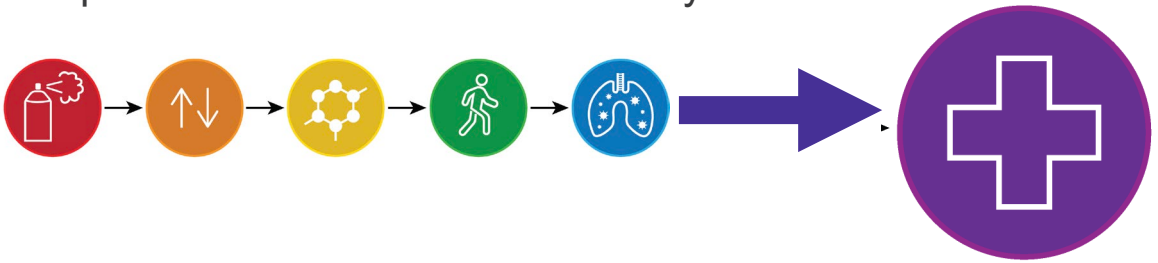

# Main messages

- Environmental conditions and indoor chemistry vary between buildings based on their purpose and use.
- Example of primary sources and reservoirs of chemicals indoors – single family home
  - Chemical emissions from water
  - Chemicals from building materials
  - Fumes from attached garage
  - Intrusion through the foundation
  - Particulate matter, CO, $NO_2$ from gas appliances and cooking, fireplaces and wood burning stoves
  - Personal care products
  - Metabolic emissions
  - Mold and microbes associated with water
  - Flame retardants and plasticizers from furniture and electronics
  - Cigarette smoke
  - etc

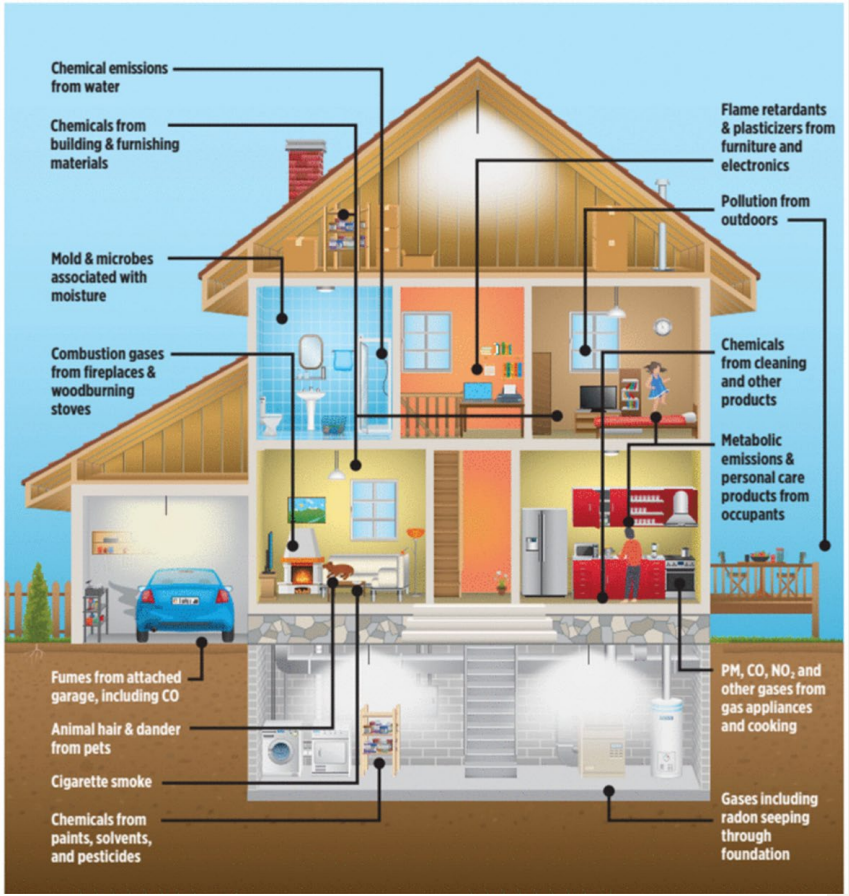


Fig. 2.1

# Main messages

- **Occupants and their activities** impact indoor chemistry.
  - Cooking
  - Cleaning
  - Primping and preening
  - Smoking (leading to second, and third hand smoke)
  - Etc.

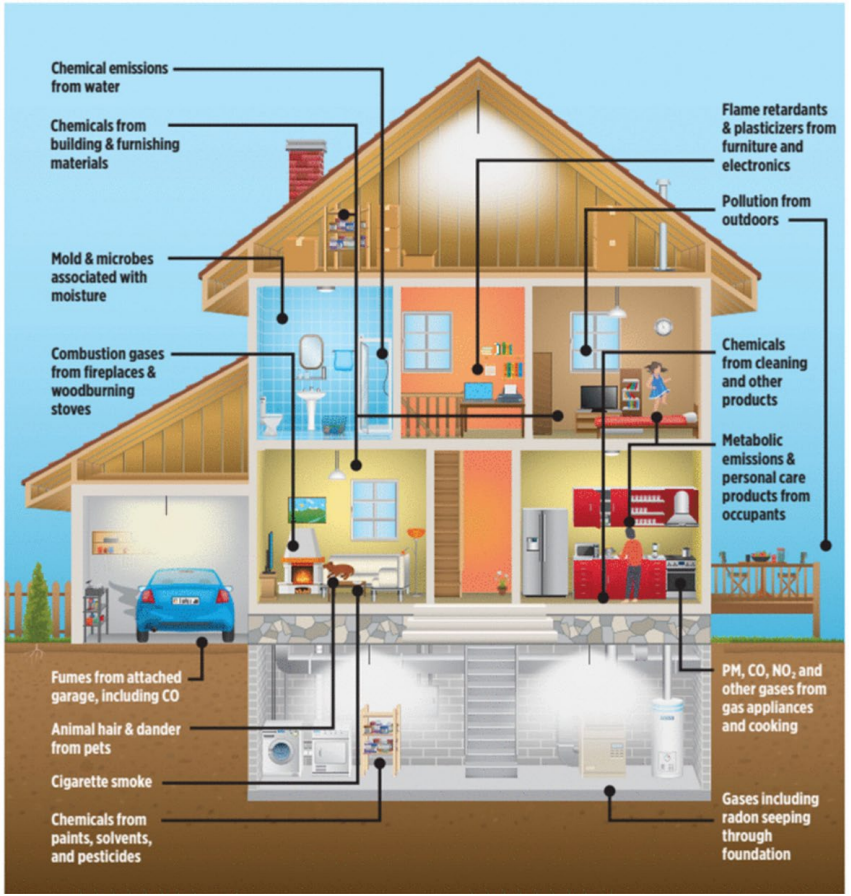


Fig. 2.1

# Main messages

- Researchers know very little about how humans are exposed to multiple indoor chemicals across phases and pathways, how these joint exposures interact across timescales, and the cumulative and long-term impacts of the indoor chemical environment on human health.

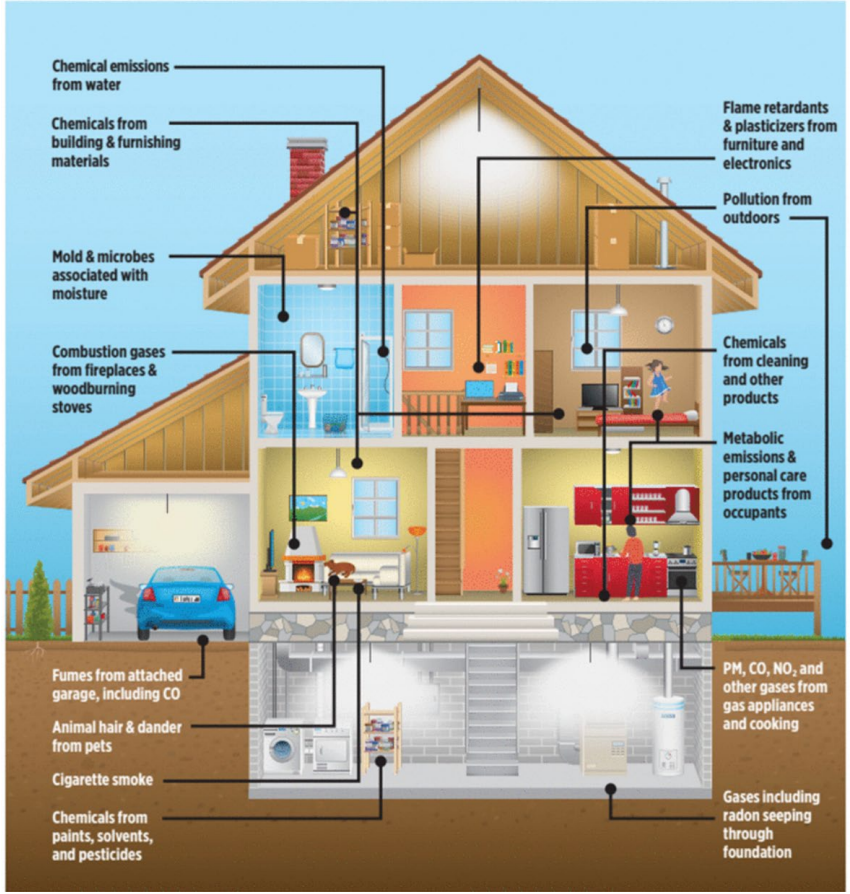


Fig. 2.1

# Main messages

- Indoor Surfaces Matter. Number of times mentioned in report:

  Chemical(s) – 1054
  Aerosols/Particles/PM – 672*
  **Surface(s) – 515**
  Gas(es) – 239

- Indoor environments have high surface-to-volume ratios thus surfaces play an important role in indoor chemistry and indoor air quality by acting as sinks and sources for different chemicals as well as can transform chemicals.

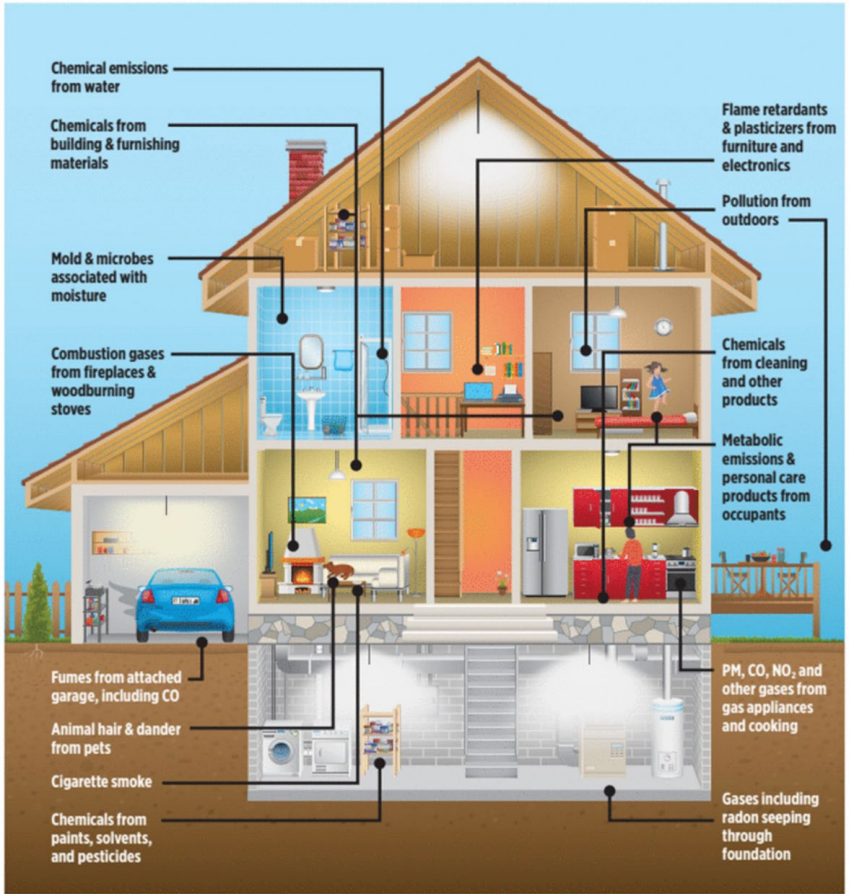


Fig. 2.1

*Indoor Exposure to Fine Particulate Matter and Practical Mitigation Approaches – NASEM Report

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# Main messages

- Changes in the **outdoor environment** owing to climate change, wildfires, and urbanization have significant impacts on **indoor environments**.

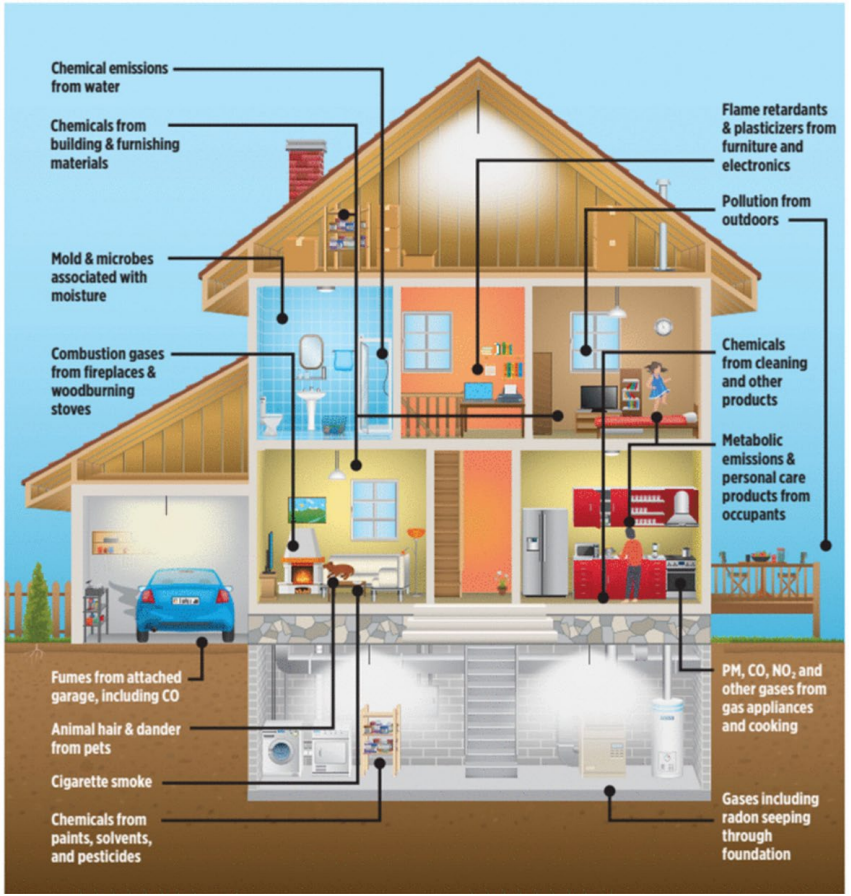



Fig. 2.1

# Main messages

- New analytical tools have been instrumental in improving understanding of indoor chemistry; however, key challenges remain that will require strategic investments.

  -Need robust measurements of air (gases and aerosols), surfaces, and dust.

# Main messages

- There is an ongoing need to effectively translate scientific knowledge about indoor chemistry into practice and policy.
- Many chemicals found indoors have little to no information regarding their toxicity, either as individual agents or in combination with other chemicals present in the environment.
- Mitigating chemical hazards will require efforts in: (1) changing building design and operation; (2) altering the use and contents of products and materials, and; (3) addressing the impact of human activity on indoor chemistry.

# Sources

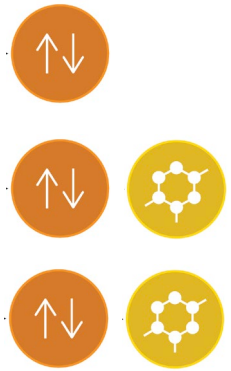
Recommendations center on:

- Understanding the **chemical composition of complex mixtures** in a wide range of residential and nonresidential settings
- Developing **novel methods and chemoinformatic resources** to identify/quantify wide classes of indoor chemicals, both primary emissions and secondary chemical reaction products
- Creating **emissions inventories specific to building types** and identifying indoor transformations that impact outdoor air quality

# Partitioning and Transformations

Recommendations center on:

- Understanding the **phase distribution of indoor chemicals between all indoor reservoirs** and incorporation of partitioning into exposure models
- 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
- Investigating the **impact of products and services on indoor chemistry**, especially under realistic conditions
- How standardized **consensus test methods** could enable potential certification programs for air-cleaning products and services



# Partitioning and Transformations

## How Emissions Evolve Over Time (Minutes, Hours, Years, Decades) and Spatial (Building, Room, Molecular) Scales

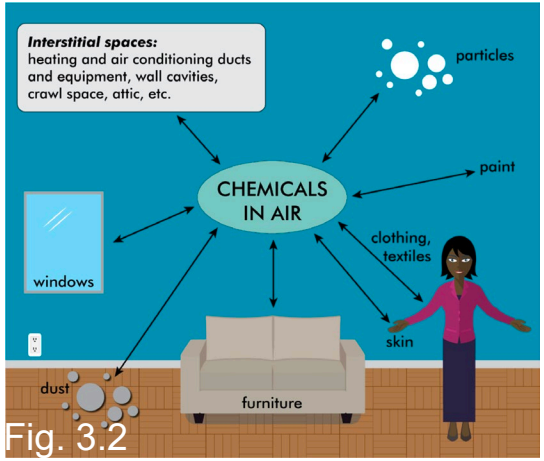
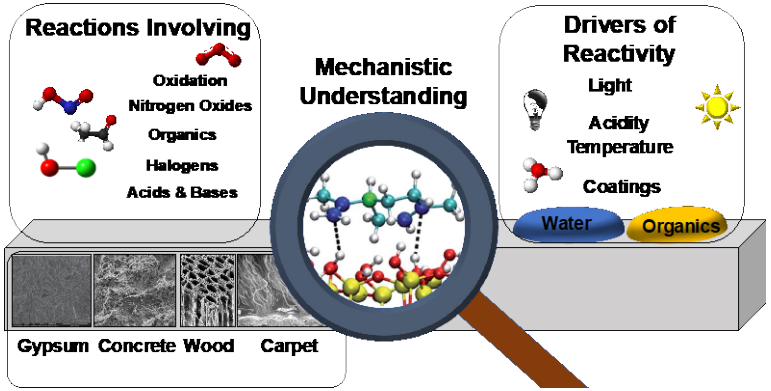



Fig. 3.2

Modified from Weschler and Nazaroff (2008)

To Understand This




Ault, A. P.; Grassian, V. H et al. Chem 2020, 6, 3203 –3219.

We Need Research Like This

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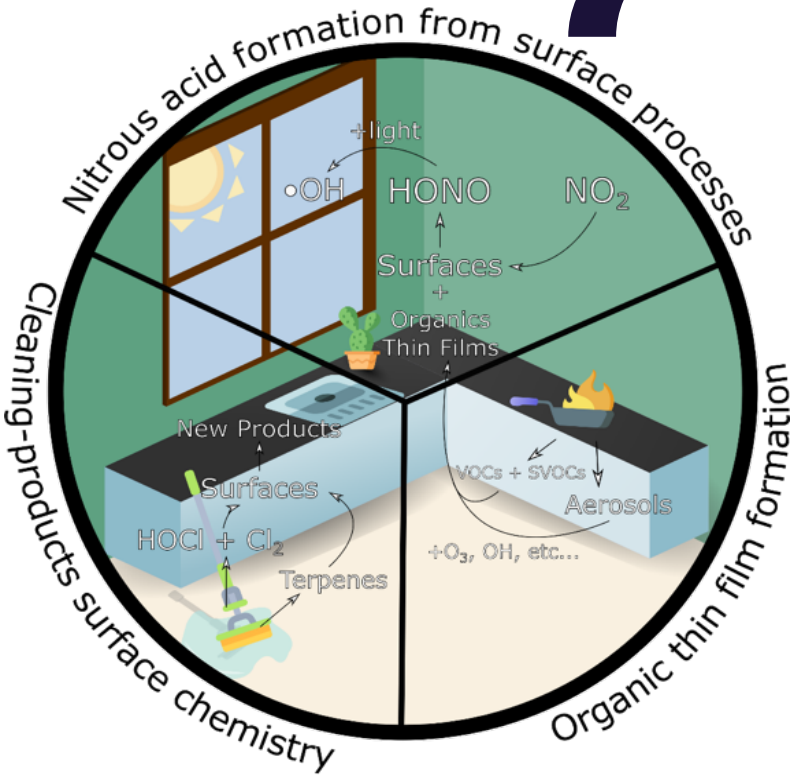
# Some Examples – HONO




**NOx Surface Chemistry To Produce Gas-Phase HONO**


Pandit, S.; Grassian, V. H. Environ. Sci. Technol. 2022, 56, 12045–12054.

**HONO Formation Is Controlled by Surface Interactions of Adsorbed Nitrite ($NO_2^-$) with Indoor Material Surfaces**

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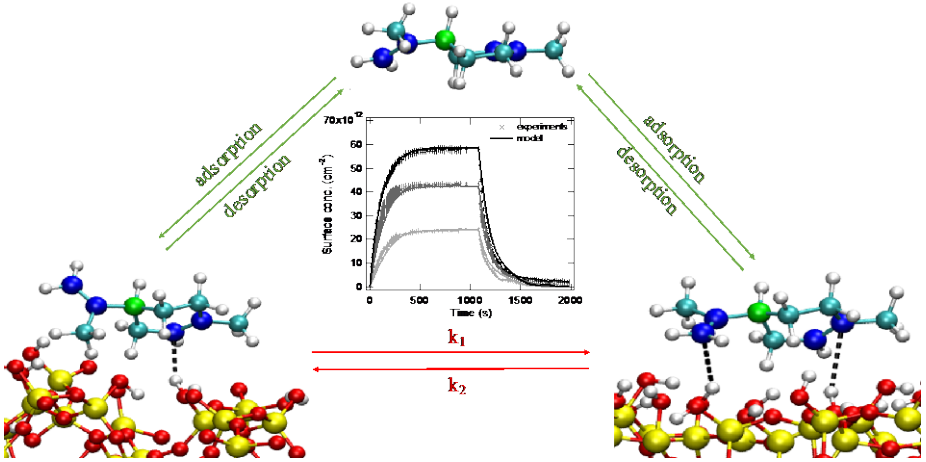
# Some Examples - Limonene

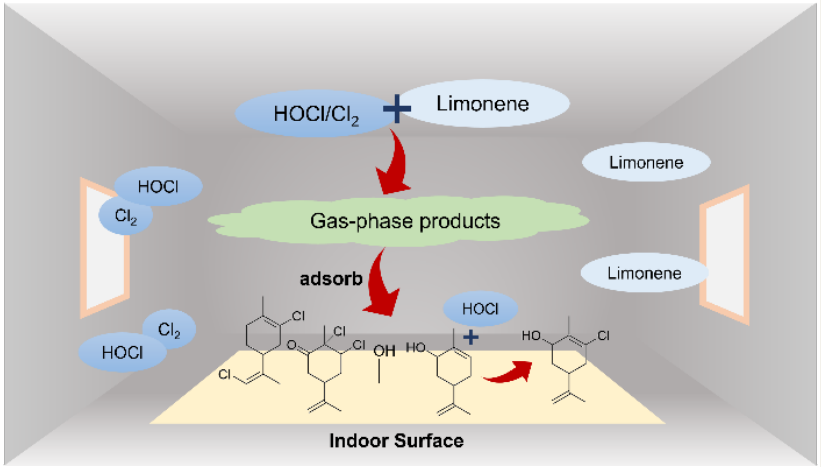
## Limonene Alone




Fang, Y. et al. ; Chemical Science 2019, 10, 2906 – 2914.

- Surface as a sink
- Surface as a source
- Some surfaces can transform limonene

## Limonene Plus Other Chemicals in Air




Deeleepojananan, C.; Grassian, V. H. Environ. Sci. Technol 2023, 57, 20699–20707,

- Surface interacts more strongly with these chlorination and oxidation products
- Surface as a source of these products
- Some surfaces can further transform products

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# Next Steps – Partitioning and Transformations: The Impact of Surfaces

1. Chemistry of Indoor Surfaces: Complexities and Challenges
2. Probing the Chemistry of Indoor Surfaces: New Approaches and New Reaction Mechanisms
3. Modeling the Chemistry of Indoor Surfaces
4. Connecting Surface Chemistry to Real-World Indoor Measurements

→ Need to put all of this in the context of charting the fate and transport of an agent from source to ultimate impacts on health.

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# Buildings and Measurement

Recommendations center on:

- **Integrating indoor chemistry considerations into building system design and mitigation approaches**; e.g., by engineers in consultation with indoor air scientists

- Applying and developing **new analytical tools** that can probe the chemical complexity of gases, aerosols, and surfaces

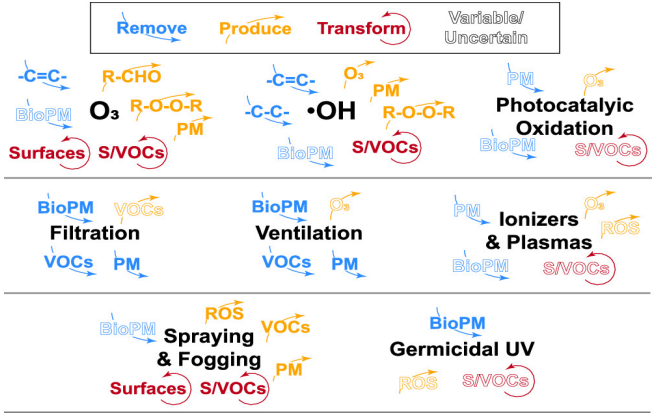
# Buildings and Measurements

## Lessons Learned During the COVID-19 Pandemic

– Importance of Ventilation and Filtration

– Cleaning Methods Can “Add” Chemicals Into the Air

**Testing Methods/Standards Are Needed for Commercial “Air Cleaners”, Both Products and Processes**




Colins, D.B. and Farmer, D. K. Environ. Sci. Technol. 2021, 55, 18, 12172-12179

# Buildings and Measurements

Lessons Learned During the COVID-19 Pandemic

– Cleaning Surfaces Not as Important as Cleaning Air (Ventilation and Filtration) for the Coronavirus

Lessons Learned During the CASA Experiment: Chemical Assessment of Surfaces and Air

– Cleaning Surfaces (Soapy Water Mopping and Wiping) Most Important in Cleaning Air of Persistent Volatile Organic Compounds (VOCs) from Wildfire Smoke In Indoor Air by Removing VOC Reservoirs

Li et al. “The Persistence of Smoke VOCs Indoors: Partitioning, Surface cleaning, and Air Cleaning in a Smoke-Contaminated House” Science Advances 2023, 9(41), DOI: 10.1126/SCIADV.ADH8263

**These Lessons Are Not Contradictory**

# Exposure and Health

## Exposure Pathways

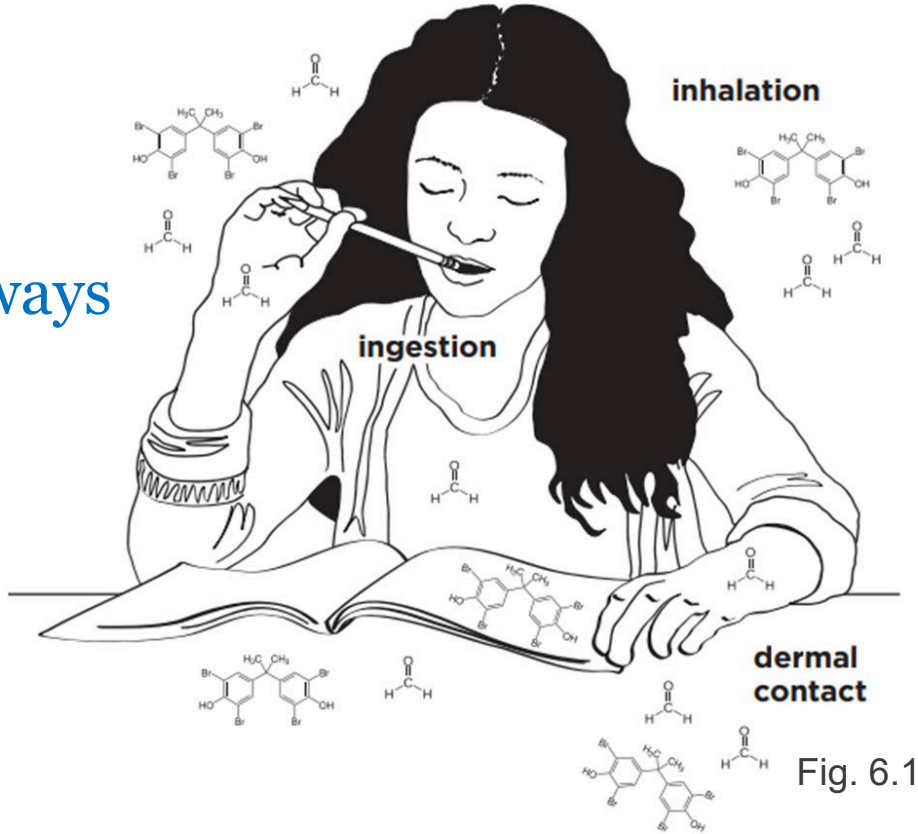


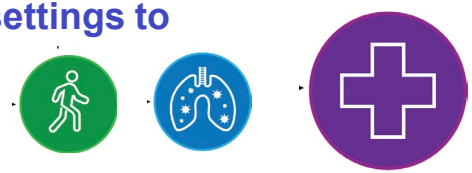

Fig. 6.1

# Exposure and Health

Recommendations center on:

- Updating the **National Human Activity Patterns Survey** to capture people's activities indoor environments
- Understanding indoor exposures to contaminants of **outdoor origin that undergo subsequent transformations indoors,** measurement science for exposure.
- Understanding exposure and health impacts in a **wide range of indoor settings to inform any future standards, guidelines, or regulatory efforts**
- **New approaches for measuring exposure in children**

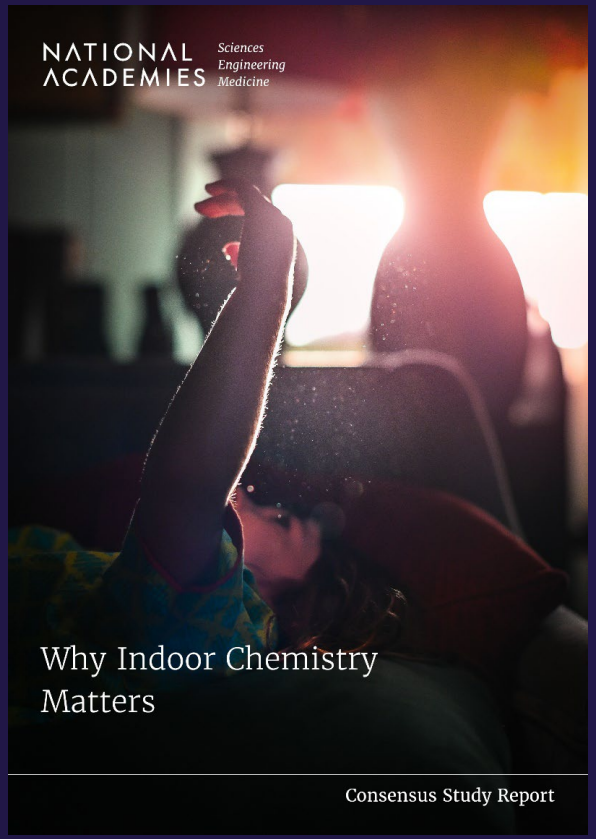




# Chapter 7: A Path Forward

Recommendations center on 4 cross-cutting topics

1. Chemical complexity in the indoor environment
2. Indoor chemistry in a changing world
3. Future investments in research
4. Communicating science and risks



# Accelerating the Field Forward

Recommendations center on:

- The need for federal agencies and others that fund research to make indoor chemistry and its impact on indoor air quality and public health **a national research priority**
- Proactively engaging in **collaborations and connections that promote research to application** throughout the indoor chemistry research paradigm
- The need for **engagement across disciplines** including fundamental indoor chemistry, indoor environmental quality, exposure assessment, and human health

# Collaboration and the Need to Engage Across Disciplines

## Indoor Chemistry Models + Exposure Models

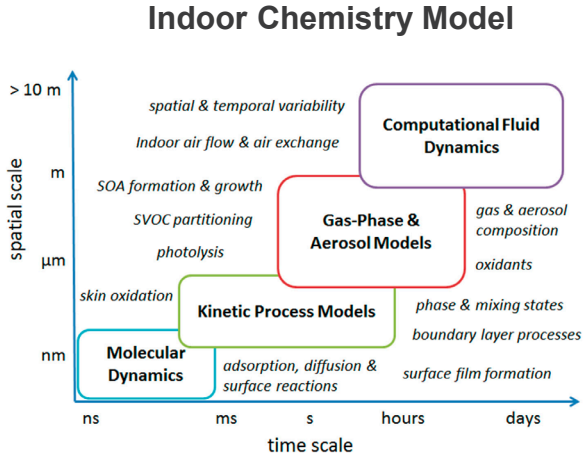



Fig. 4.1
Source – Modified from Shiraiwa et al. (2019)

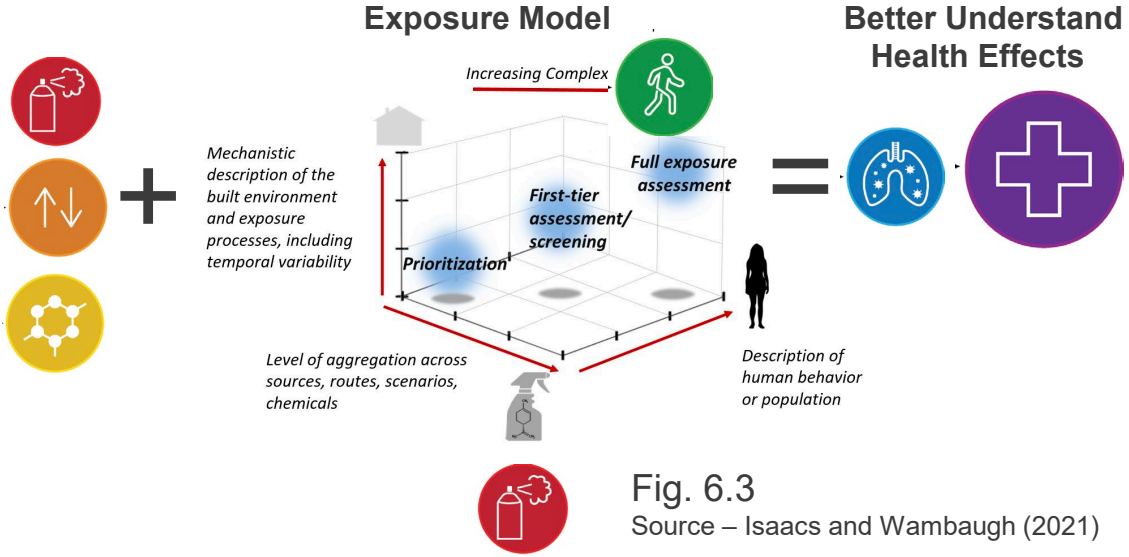



Fig. 6.3
Source – Isaacs and Wambaugh (2021)

## = New Paradigm for Understanding Health Effects.

# Recommendations for Accelerating the Field Forward

**1. Recognition of Indoor Chemistry as a National Research Priority**

**2. Collaboration and Engagement Across Disciplines**

**3. Invest in Coordinated, Interdisciplinary Research**

**4. Application of Knowledge**

**A Key Take Away From the Report:**

**Science and Technology Needed from the Fundamental to the Practical**

# Closing

This report provides a summary of the state-of-the science in indoor chemistry.

The research agenda presented in this report provides a roadmap that will advance the highly interdisciplinary, multisector field of indoor chemistry.