

Making Affordable Multifamily Housing More Energy Efficient

# A Guide to Healthier Upgrade Materials



## Project Team

Veena Singla, Cai Steger, and Eileen Quigley, Natural Resources Defense Council  
Rebecca Stamm, Jim Vallette, Melissa Coffin, Peter Sullivan, and Tom Lent, Healthy Building Network  
Elizabeth Chant, Stephanie Morse, and John Terborgh, Vermont Energy Investment Corporation  
Amanda Gramigna, Abigail Corso, Jessica Miller, and Angelina Benson-Glanz, Elevate Energy  
James Connelly and Andrea Cooper, International Living Future Institute  
Beth Hawkins, Bruce Tonn, and Erin Rose, Three3  
Alana D'Aleo, Consultant

## About Energy Efficiency for All

Energy Efficiency for All (EEFA) is dedicated to linking the energy and housing sectors in order to tap the benefits of energy efficiency for millions of low-income families. We work with electric and gas utilities and their regulators interested in innovative energy-efficiency program designs. We advise housing finance agencies on best practices in building owner engagement and finance products. We collaborate with owners, managers, businesses, and advocates to achieve energy savings in multifamily properties. EEFA is a partnership of the Energy Foundation, Elevate Energy, National Housing Trust, and Natural Resources Defense Council, made possible with funding from The JPB Foundation.

## Acknowledgements

This report was made possible through the generous support of The JPB Foundation. The authors gratefully acknowledge the external reviewers, internal reviewers, colleagues, partners, and sponsors who supported this study. Many thanks to Tanja Bos and Debby Warren for skilled help producing this guide. We would also like to thank the following individuals and organizations for supporting this research effort:

Lauren Asplen, BlueGreen Alliance  
Dana Bartolomei, National Housing Trust  
Lauren Baumann, New Ecology, Inc.  
Bill Beachy, Community Housing Partners Corporation  
KC Bleile, Viridiant  
Rob Brenner, CMC Energy Services  
Andrew Brooks, Association for Energy Affordability  
Sarah Burger, Green Coast Enterprises  
Scott Campbell, 3E Thermal  
Edward Connelly, New Ecology, Inc.  
Amy Dryden, Build It Green  
Scott E. Durrett, Michigan Energy Options  
Lara Ettenson, Natural Resources Defense Council  
Tammie Fallon, CommonBond Communities  
Karl Goetze, Efficiency Vermont  
Brian Just, Vermont Energy Investment Corporation  
Sunshine Mathon, Piedmont Housing Alliance  
Cara Mazurek, McCool Carlson Green

Stephanie Mezynski, Green Coast Enterprises  
Todd Nedwick, National Housing Trust  
Carl Nelson, Center for Energy and Environment  
Rebecca Olson, Neighborhood Energy Connection  
Ed Petersen, Hopeworks  
Sydney Roberts, Southface  
Lindsay Robbins, Natural Resources Defense Council  
Liz Robinson, Energy Coordinating Agency  
Matt Schwartz, California Housing Partnership Corporation  
Denise Stein, CMC Energy Services  
Chris Steinhoff, Elevate Energy  
Nehemiah Stone, Stone Energy Associates  
Bob Tinker, Michigan Energy Options  
Jane Willeboordse, New Ecology, Inc.  
Ashley Wisse, New Ecology, Inc.  
Nick Young, Association for Energy Affordability, Inc.



# Table of Contents

- Executive Summary** ..... 2
- Introduction** ..... 5
- Chapter 1: Challenges to Identifying and Adopting Healthier Upgrade Materials** ..... 9
- Chapter 2: Our Methodology** ..... 13
- Chapter 3: Insulation – Healthier Material Recommendations** ..... 18
- Chapter 4: Air Sealing – Healthier Material Recommendations** ..... 24
- Chapter 5: Engaging Multiple Stakeholders for Healthier Upgrades** ..... 29
- Chapter 6: Conclusion** ..... 34
- Materials Encyclopedia** ..... 36
  - Acronyms ..... 36
  - Glossary ..... 37
  - Insulation: Recommended and Other Materials, Cost, Performance, Installation,  
and Transparency Considerations ..... 42
  - Sealants: Recommended and Other Materials, Cost, Installation,  
and Transparency Considerations ..... 50
  - Further Resources ..... 55
  - Baseline Insulation and Air-Sealing Materials Used in EEFA States ..... 57
  - Materials Excluded From Recommendations ..... 59
  - Code Considerations ..... 60
- References** ..... 61

# Executive Summary



There is no question that investing in energy-efficiency upgrades has the potential to deliver substantial financial, environmental, and health benefits to building owners and residents. Robust evidence demonstrates that interventions such as weatherization and other energy-efficiency upgrades, particularly in poor quality housing, can significantly improve residents' health by reducing thermal stress, asthma symptoms, and energy costs.<sup>1</sup> What is far less understood and addressed, however, are the adverse health impacts produced by chemical emissions from some of the materials commonly used for these upgrades.<sup>a</sup> These materials often contain persistent, bioaccumulative, or toxic chemicals<sup>b</sup> and either show evidence or are suspected of being asthmagens, reproductive or developmental toxicants, endocrine disruptors, or carcinogens.<sup>c</sup> Not only are a building's residents endangered, but these chemicals of concern<sup>d</sup> can also pose threats over the materials' life cycles to the workers who manufacture, install, and dispose of these products, to the communities adjacent to these facilities, and to the broader environment. Many of these populations are some of our most vulnerable and have limited access to health care.

### Defining Our Audience

This guide is designed for those who decide what products to use in the energy-efficiency upgrade process — specifiers, contractors, building owners, developers, architects and engineers, program managers, and scientific advisors. Our focus is the affordable multifamily rental stock, a significant source of housing for low-income households that



can be substandard and poorly maintained, with relatively high utility bills and increased exposure to biological, chemical, and physical hazards. However, the research and recommendations presented in this guide will be useful to practitioners across the entire building industry.

### Defining the Health Issues

Because insulating and air sealing provide the most significant long-term savings from upgrade projects but can also introduce many chemicals of concern, this guide focuses on the materials used for these purposes — on their chemical composition and potential health impacts,<sup>e</sup> as well as on their general performance and relative cost. Some common types of chemicals found in insulation and air-sealing products that are of the greatest concern are halogenated flame retardants, formaldehyde-based binders, isocyanates, and phthalate plasticizers. The health effects of these chemicals include reproductive and developmental impacts, carcinogenicity, and the ability to cause or exacerbate asthma. Moreover, some of these chemicals persist and accumulate in the environment and in people and thus can have broad-reaching, long-term impacts.

### Ranking Healthier Materials

Through our research into the common content of insulation and air-sealing products, we have developed a ranking of materials from a health standpoint and provide practical recommendations for moving up the ladder of healthier materials. Recommendations are based on chemical hazard avoidance per the Hierarchy of Controls framework, used in occupational safety by organizations such as the National Institute for Occupational Safety and Health (NIOSH). Some of the best insulation materials from a health perspective are commonly used fiber glass and cellulose insulation and we recommend their use whenever possible. We also recommend avoiding foam insulation, particularly those products that are mixed and reacted on site, such as spray foam, because they contain several chemicals that are the most important to avoid.

---

**Some of the best insulation materials from a health perspective are commonly used fiber glass and cellulose insulation and we recommend their use whenever possible.**

---

For some air-sealing applications, prefoamed materials like foam sealant tapes offer a healthier option. Acrylic-based sealants with low volatile organic compound (VOC) content also rank well from a health perspective. We recommend avoiding, whenever possible, modified polymer and polyurethane sealants that commonly contain phthalates and other chemicals that raise the greatest concerns.

### Broadening Interventions for Healthier Materials

Looking at the broader practice and policy context, this guide makes the case for the following interventions:

- Improving the transparency of the chemical content of upgrade materials
- Investing in product innovation, demonstrations, and early adopters to mainstream and scale the use of healthier products
- Using state and local policy tools like the Low-Income Housing Tax Credit's allocation priorities to drive healthier upgrade materials usage
- Ensuring that the upgrade workforce is appropriately trained to use these healthier materials
- Engaging, above all, in wider and strategic industry dialogue to begin the complex process of forging consensus about the need to use healthier materials to achieve energy efficiency.

### Looking Forward

While there is reason for concern about some of the materials used to construct the buildings in which we live, work, and learn, there is also reason to be optimistic. Transparency about chemicals in building products is growing as chemical contents are disclosed through transparency platforms like the Health Product Declaration and Declare. Innovative new products and improved versions of well-known products are regularly coming on the market. These developments often improve performance or decrease cost and may also improve the health profile of the product. We still have a long way to go, however, toward mainstream adoption of healthier products.

The focus of this guide may introduce new ground for those energy-efficiency advocates, practitioners, and funders who have historically emphasized the energy performance and cost of upgrade materials, but not their health impacts. We envision a future when upgrades not only make buildings energy efficient, but also create environments that promote the health and well-being of their residents, installation workers, and the broader communities affected by materials' manufacture, production, and disposal.

---

**For some air-sealing applications, prefoamed materials like foam sealant tapes offer a healthier option. Acrylic-based sealants with low volatile organic compound (VOC) content also rank well from a health perspective.**

---

<sup>a</sup> Throughout this guide, we will use the term "upgrade" to refer to a holistic set of interventions to make a building more energy efficient.

<sup>b</sup> Commonly referred to as properties of concern, persistent chemicals do not break down readily in the environment; bioaccumulative chemicals build up in people and other animals and become more concentrated as they move up the food chain; and toxic chemicals are harmful to living organisms.

<sup>c</sup> This report focuses on a subset of toxicity endpoints, outlined in the methodology section.

<sup>d</sup> Chemicals of concern are those that may adversely affect human health. Different organizations may define different subsets of chemicals as chemicals of concern. For this report, health hazard information from the Pharos Chemical & Material Library was used to screen chemicals. Those rated as having high or very high hazard levels for the health endpoints shown in Table 1 of this report were considered to be chemicals of concern. In some cases in which research is still emerging, additional sources beyond the Pharos Library were consulted for associated health hazards, and in these cases, the additional sources are cited within the text.

<sup>e</sup> This analysis is based on health hazards to a person exposed to the contents of the insulation or air-sealing products, though this analysis does not assess the level of exposure to these chemicals. There is potential exposure to these substances throughout their life cycles. Manufacturing can expose workers and fenceline community residents; installation can expose workers and nearby occupants; occupancy can expose building occupants when chemicals migrate out of the products during use; and demolition and disposal can again expose workers and nearby occupants. Chemicals that persist in the environment can also travel long distances and have global impacts.

# Introduction





Making a residence, whether single or multifamily, more energy efficient clearly makes sense for the environment and for the pocketbooks of both owners and renters. Robust evidence also demonstrates that investing in energy improvements can improve the health of residents, particularly of those of lower socioeconomic status who are more likely to live in substandard housing and who are disproportionately burdened by disparities in health. Reducing the incidence of mold from water leaks, the infiltration of outdoor pollutants, dust, and pests, and the time that homes are kept at extreme temperatures are some of the most common and significant documented health benefits from energy-efficiency upgrades.<sup>2</sup>

What is far less understood and addressed, however, are the adverse health impacts of chemical emissions from some of the materials commonly used for these energy-efficiency upgrades.<sup>f</sup> Building materials matter to our health. They matter because Americans spend an average of 90 percent of their time indoors and because our indoor environmental quality is affected by the chemicals that are used to construct, rehab, and upgrade our buildings.<sup>3,4</sup> These materials often contain persistent, bioaccumulative, or toxic chemicals and either show evidence or are suspected of being asthmagens, reproductive or developmental toxicants, endocrine disruptors, or carcinogens.<sup>9</sup> Not only are a building's residents endangered, but these

chemicals of concern can also pose threats over the materials' life cycles to the workers who manufacture, install, and dispose of these products, to the communities adjacent to these facilities, and to the broader environment.

The following examples illustrate how chemicals of concern currently and historically found in insulation and air-sealing interventions — two of the most effective upgrade practices — can affect the health of building occupants, workers, adjacent communities, and others across the globe over a material's life cycle:

- Across the United States, homes with insulation containing formaldehyde, a known cancer-causing chemical and respiratory irritant, had significantly higher indoor levels of formaldehyde in the air that were associated with adverse health impacts for occupants.<sup>5</sup>
- In the State of Washington, a worker in his mid-30s developed occupational asthma from installing spray foam insulation in residential attics and was forced to leave his job, a not uncommon occurrence. Spray foam insulation contains isocyanates, chemicals that can cause asthma and are toxic to the respiratory system.<sup>6</sup> Isocyanates are a leading cause of occupational asthma, resulting in high economic costs to society. One study estimated that isocyanate-

induced asthma cost the United Kingdom about \$17 million over the lifetime of affected workers.<sup>7</sup> Though not all these cases and costs are due to spray foam, isocyanates in spray foam do contribute to this burden.

- Air-sealing materials can contain chemicals called orthophthalates (often shortened to phthalates, and pronounced *thal-ates*), many of which are known endocrine (hormone) disruptors. These interfere with the normal production or action of hormones in the body and have been found to damage reproductive systems and interfere with the normal development of a fetus. They have also been associated with asthma. A recent modeling exercise estimated that phthalate exposure cost the United States more than \$50 billion every year due to male infertility, endometriosis, and other diseases.<sup>8</sup> Although we don't know what portion of these costs are due to phthalates used in building materials, we do know that building materials contribute to people's phthalate exposure.<sup>9</sup>
- Fenceline communities adjoin hazardous sites and are usually comprised of low-income people, people of color, or both.<sup>10</sup> People in these communities can be affected by releases from the adjacent manufacturing and waste facilities. For example, factories manufacturing fiber glass insulation in the United States and Canada released nearly 600,000 pounds of formaldehyde into the air and nearby communities in 2005.<sup>11</sup> Market pressure for healthier alternatives has since driven residential fiber glass insulation manufacturers in the United States and Canada to phase out formaldehyde-based binders in favor of less hazardous alternatives, leading to a 90 percent drop in formaldehyde emissions from these facilities as of 2014.<sup>12</sup>
- The use of hazardous chemicals also reduces the recyclability of products at the end of their lives and adversely affects our moves toward a circular economy.<sup>13</sup> The Healthy Building Network estimates that between 30,000 and 60,000 metric tons of the persistent, bioaccumulative, and toxic flame retardant hexabromocyclododecane (HBCD) was consumed in the United States between 1988 and 2010, and most of this probably remains in polystyrene insulation in buildings. HBCD's use in polystyrene insulation continued into 2018.

The insulation is currently handled like regular construction debris, mostly going to landfills, where the U.S. Environmental Protection Agency (EPA) notes, HBCD will be released over time into the soil, water, and air.<sup>14</sup> If the insulation did not contain hazardous content, it would not only prevent these releases into the environment, but would also improve the recyclability of the material, keeping more of it out of landfills altogether.

- Chemicals that are persistent in the environment can travel long distances and accumulate in people and animals. When they are also toxic, these chemicals are of the greatest concern because they pose unmanageable global threats.<sup>15</sup> For example, HBCD was found in indoor dust samples, human tissue and blood, and in birds and animals in remote locations — including polar bears in the Arctic — clearly far from any foam-insulated buildings.<sup>16</sup>

These examples show how energy-efficiency materials containing toxic chemicals can adversely affect residents, workers, adjacent communities, and locales as far away as the Arctic. The example about fiber glass manufacturing also demonstrates a success, where customer demand for healthier products drove the market overall to phase out toxic content, positively affecting both building residents and fenceline communities. As this guide will demonstrate, insulating and air-sealing products are available that have less toxic profiles than some of the more toxic products commonly in use today. We want to move toward health for all, including especially vulnerable populations, and increasing our use of healthier upgrade materials is a critical step in this direction.



## About This Guide

This guide focuses on two upgrade techniques — insulating and air sealing — because they are commonly used to make a residence more energy efficient and because they can introduce many chemicals of concern into the indoor environment as well as into the broader community. Fortunately, there are healthier insulation and air-sealing materials now on the market than in the past and the newer materials are of comparable quality and in many cases, available at a reasonable cost.

We focus on the affordable multifamily rental segment of the housing sector because this guide is part of a broader national effort to make affordable multifamily rental housing more energy efficient. But we believe that the research presented and recommendations made will be useful to practitioners across the entire building industry.

The purpose of this guide is to provide research-based, detailed, and actionable information about healthier materials for those advisors, specifiers, and contractors who play key roles in determining what materials to use in the energy-upgrade process. For each of the most commonly used insulating and air-sealing products for upgrading affordable multifamily housing, we identify the chemical contents usually found in them and their associated hazards and hazard levels. We rank products based on their health profiles and provide recommendations on the best insulating and air-sealing products from a health perspective. We also provide information on performance and cost.

Chapter 1 discusses the challenges to the identification of and widespread usage of healthier materials in the multifamily upgrade process: a weak regulatory environment, public misconceptions about chemicals in building products and their impacts, and the lack of disclosure and transparency about the chemicals in products. In Chapter 2, we summarize the methodology underlying our research and recommendations, including our emphasis on

chemical hazard avoidance per the Hierarchy of Controls framework. Chapter 3 focuses on insulating materials commonly used in affordable multifamily upgrades, a ranking of different types of building and pipe insulations based on their health profiles, and summary recommendations for selecting insulation products with the least hazardous profiles to decrease impacts on residents, installers, and the broader community. This chapter also includes a discussion of important installation considerations that affect insulation performance and worker safety.

Chapter 4 provides analogous findings and recommendations for commonly used air-sealing materials. For those seeking more technical information underlying Chapters 2, 3, and 4, we encourage their review of the attached Materials Encyclopedia (discussed in more detail below). Chapter 5 presents a more comprehensive set of recommendations to ensure that the use of healthier materials in the upgrade process becomes standard practice. These recommendations address the need for greater product transparency from manufacturers, the importance of early adopters and demonstration projects, the need for wider industry dialogue and consensus building, the need for policies to promote and incentivize shifts in the demand for healthier products in the affordable multifamily upgrade sector, and the importance of training the installation workforce to effectively use healthier upgrade materials. We conclude by looking toward a future where energy upgrades not only improve building energy usage but also create physical environments that promote good health and well-being for all.

The Materials Encyclopedia provides more detailed information about the reviewed insulation and air-sealing materials (including specific factors to prefer or avoid in each product type); those products excluded from recommendations because of lack of disclosure or availability; and code considerations. The encyclopedia also provides more information on product guidance, chemical hazards, libraries of transparency documents, building program standards, cost effectiveness, and energy efficiency in the affordable multifamily housing sector.

<sup>f</sup> Throughout this guide, we will use the term “upgrade” to refer to a holistic set of interventions to make a building more energy efficient.

<sup>g</sup> This report focuses on a subset of toxicity endpoints, outlined in the methodology section.

CHAPTER 1:

# Challenges to Identifying and Adopting Healthier Upgrade Materials



Building materials matter to our health. So why do so many of the products commonly used to insulate and air seal our multifamily buildings contain chemicals that are hazardous? We believe that three primary factors are at work: a weak regulatory environment allowing the use of hazardous chemicals in products; misconceptions about chemicals in building products and their impacts; and the lack of disclosure and transparency about chemicals used in products. This guide has been developed to help directly or indirectly address these challenges.

## A Mostly Weak Regulatory Environment

*The limited applicability of the Toxic Substances Control Act.* Most people assume that the chemicals used in building products are tested and approved as safe for human health by the government, but this is not the case. The foundational U.S. law regulating toxic chemicals is the Toxic Substances Control Act of 1976 (TSCA).<sup>16</sup> This law, however, has extremely limited applicability. At the time of its creation, the use of about 62,000 chemicals was grandfathered in without any evaluation, and in the four decades since the law's enactment, the EPA has required human health impact testing for only about 200 of the original 62,000 chemicals. Less than a dozen of these chemicals or chemical groups have been regulated or banned under TSCA.<sup>17</sup> Chemicals are assumed safe unless proven otherwise. And even for restricted chemicals, the actual restrictions can be minimal. For example, in 1989 the EPA attempted to ban almost all asbestos uses, but in 1991 a federal appeals court struck down most of the EPA's rule.<sup>18</sup>

Intentional use of asbestos, a known cancer-causing material, in building products continued until very recently.<sup>19</sup> While 2016 updates to the TSCA improved some of EPA's ability to review and restrict dangerous chemicals, the pace of action will still be much too slow as the new law only requires the evaluation of 20 chemicals at any given time, with each evaluation taking up to three years.<sup>20</sup>

*Insufficient coverage of volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and other hazardous chemicals by current restrictions.* VOCs are chemicals that are released as gases into the air during the application and curing of paint, sealants, adhesives, or other wet-applied products. They can also be emitted slowly over time from solid products, such as insulation or carpets. Though there is growing recognition of VOCs as health hazards in building materials in regulations, standards, and certification programs, these restrictions are, for the most part, very limited. Also, volatile chemicals are exempt from VOC regulations if they do not contribute to smog formation (see example in sidebar). Other kinds of chemicals are not addressed at all.<sup>21</sup>

Current regulations and some certification programs largely ignore an entire universe of other potentially dangerous chemicals beyond VOCs that can be emitted by products. These other chemicals are semi- or nonvolatile and can also leach or migrate out of products, or become abraded into dust. Chemicals such as phthalates and many flame

### WHY VOC REGULATIONS MISS THE MARK

California has the strictest regulations in the nation for controlling VOCs in building products, restricting all smog-forming VOCs in architectural coatings and consumer products. It separately regulates emissions of a specific VOC, formaldehyde, from composite wood products.<sup>22</sup> Despite these regulations, formaldehyde levels exceeded guidelines for chronic and acute respiratory irritations and cancer risks in most California homes tested in a 2007-2008 study.<sup>23</sup> Why?

The VOC regulations focus on emissions from a single product, failing to account for the fact that homes contain many sources of VOCs (e.g., insulation, composite wood flooring, furniture, and adhesives). Further, because the regulations were designed only to reduce smog, they do not cover some VOCs that are toxic in *indoor* air. Various voluntary VOC emission certification programs target the health impact of VOCs in indoor air, but since these programs are not mandatory, they are unlikely to affect the market segment serving affordable housing. These voluntary programs only pertain to one source at a time, and do not address additive effects.



retardants are SVOCs that release more slowly over longer periods of time than VOCs and are usually not captured in VOC content or emission testing. SVOCs can migrate out of products into the air and deposit onto dust and surfaces.

---

**As an example, many studies have found the flame retardant HBCD, a known persistent, bioaccumulative, and toxic chemical, present in indoor dust. More than 90 percent of the HBCD produced is used in polystyrene insulation, suggesting that this is the most likely source of this toxic chemical within our buildings.<sup>24</sup>**

---

People can be exposed by inhaling contaminated air or dust, touching the contaminated dust or surface, or by ingesting the dust.<sup>25</sup> Some certification programs do include restrictions on the use of specific chemicals of concern of these types (volatile, semivolatile, and nonvolatile), using restricted

substances lists, such as the International Living Future Institute (ILFI) Red List.<sup>26</sup>

### **Misconceptions About Chemicals in Building Products and Their Impacts**

Even among those aware of the hazards of chemicals found in upgrade products, there is a common belief that because insulation is behind a wall, it poses less of a threat of exposure than other interior products. Building material scientists, however, rebut this contention. “Both air and moisture move through a building fabric, regardless of how tightly they are constructed,” noted a team of scientists looking at flame retardant chemicals in insulation. “Substances within building cavities have the potential to migrate out of those cavities via movement driven by air, liquid and/or water vapor that occurs due to temperature, air and vapor pressure differentials. Chemicals may be present in dust from abraded materials or could volatilize and then settle in indoor dust to which building residents could be exposed.”<sup>27</sup> A 2009 Healthy Building Network analysis of fiber glass insulation emissions studies revealed that formaldehyde from binders readily migrated through drywall and air barriers.<sup>28</sup>

This misconception contributes to a lack of public pressure, contractor awareness, and policymaker interest that hamper efforts to reduce the toxicity of energy-efficiency upgrade materials.

### Limited Transparency on Chemical Contents

In addition to there being a weak federal system for regulating chemicals used in our building products, it is difficult to obtain information from manufacturers about the chemical contents of their products. Unfortunately, standard product literature, like the Safety Data Sheets (SDSs) required by the federal Occupational Health and Safety Administration (OSHA), only provide a partial picture. Full disclosure is not required in these documents, and many manufacturers list only the minimum information about contents and associated health hazards required by law. Environmental Product Declarations, which are environmental impact disclosure documents, also do not require full content disclosure, and do not usually consider associated human health hazards.

To enable them to make healthier building product choices, designers and product specifiers are increasingly pushing for full content disclosure. Such disclosure allows for review of product content for associated health and environmental hazards

and empowers purchasers to choose products with the least impact. Two important transparency tools are: Health Product Declarations (HPDs),<sup>k</sup> which provide a standard format for disclosure of content and hazards; and Declare Labels, which also provide content disclosure, as well as hazard disclosure specific to the requirements of the Living Building Challenge.<sup>l</sup> While an increasing number of these documents are available, lack of transparency regarding chemical content still presents a major challenge in trying to select healthier products.

The first step toward addressing these barriers is to identify, through a scientifically rigorous process, the chemicals present in insulation and sealant materials and use that knowledge to develop a taxonomy of healthier materials that key audiences and decision makers can employ. Ideally, to comprehensively address potential health hazards, this taxonomy would be based on a complete accounting of substances present in specific insulation and air-sealant products. While the state of transparency in the industry is still limited, we have been able to derive sufficient information using available data and the research methods described in Chapter 2 to create health rankings for the product types used for insulation and air sealing.

h Other laws, such as the Clean Air Act and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), can lead to restrictions on chemicals that may be used in building products.

i Nine chemicals or chemical groups have been restricted under TSCA: asbestos, formaldehyde, lead, mercury, radon, polychlorinated biphenols (PCBs), dioxin, chlorofluorocarbons (CFCs), and some hexavalent chromium compounds. The CFC regulation was superseded by Clean Air Act bans and the dioxin regulation was superseded by a 1985 Resource Conservation and Recovery Act regulation. The remaining seven are currently subject to TSCA regulation.

j In 2011, an estimated 660 metric tons of asbestos was incorporated into new roofing products in the U.S. Since then, the intentional use of asbestos as a component of building products in the U.S. appears to have ceased. However, the chemical industry continues to import and consume thousands of tons of asbestos. The U.S. Geological Survey said in January 2017 that the chloralkali industry “likely accounted for 100% of asbestos consumption during 2016.”

k For more information on HPDs, see Parts II and V of the Materials Encyclopedia.

l For more information on Declare Labels, see Parts II and V of the Materials Encyclopedia.

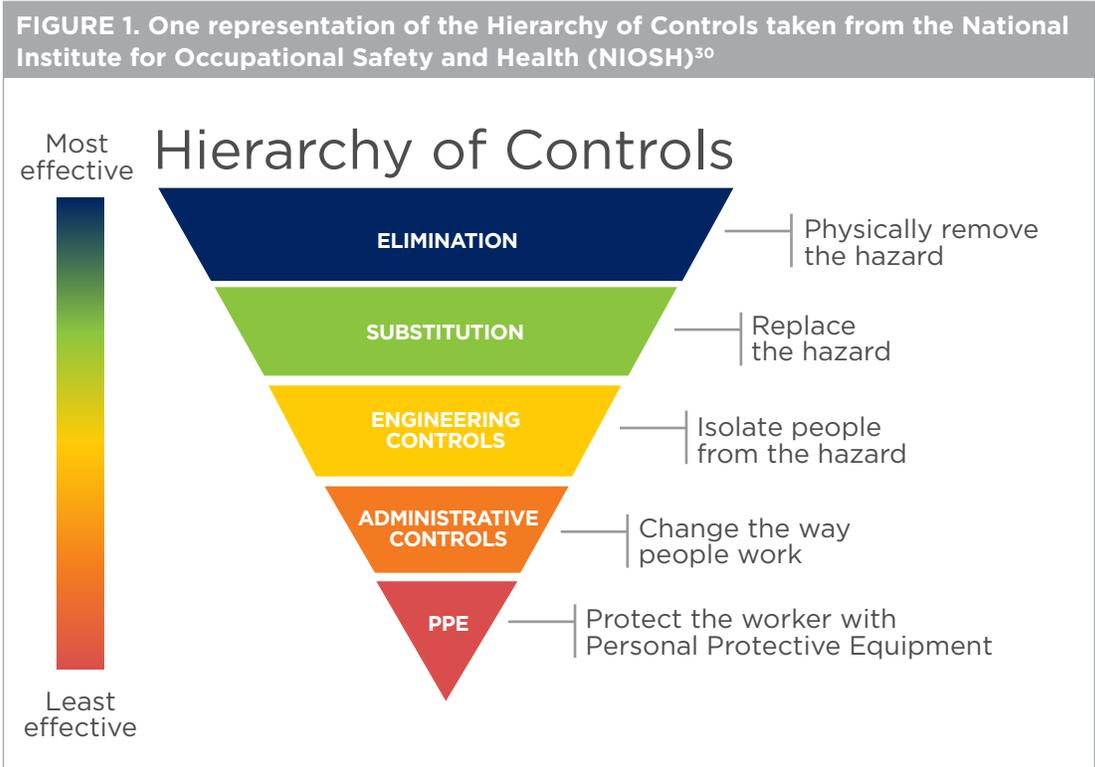
CHAPTER 2:  
**Our Methodology**



## The Hierarchy of Controls

The foundation of our recommendations for healthier upgrade materials is that avoiding toxic chemicals entirely is the best way to prevent negative health impacts. This can be done by either eliminating the need for hazardous chemicals (by using inherently safer technologies or determining when the functions provided by the hazardous chemicals are not needed) or by substituting less hazardous chemicals. These principles of elimination and substitution come from the fields of occupational safety and green chemistry and are well established as the most protective and effective approaches to reducing health impacts from toxic chemicals.<sup>29</sup> Figure 1 shows the hierarchy of controls used in occupational safety, with elimination and substitution situated above less effective approaches, such as trying to prevent people’s exposure to a toxic chemical (via engineering, administrative controls, or protective equipment).

Throughout this report, we use the terms “category” or “product category” to mean the general category for a product, such as building insulation or multipurpose sealant. We use the terms “product type” or “type of product” to refer to a subgroup within the category that is more general than a specific product. For example, a type of building insulation would be expanded cork board insulation and a type of multipurpose sealant would be an acrylic latex sealant. A specific product would be a specific brand of a product type.



## Our Four-Step Methodology

Project team members from Healthy Building Network (HBN) used the following four-step methodology to formulate evidence-based recommendations on insulation and sealant products with the least hazardous content.

### 1 PRODUCT TARGETING

We surveyed energy-upgrade program coordinators, partnering contractors, and specific project teams to determine which insulation and air-sealing products are baseline products, i.e., products usually used to upgrade affordable multifamily housing.<sup>m</sup> A total of 17 responses were received from 14 states and International Energy Conservation Code (IECC) climate regions 2-7, from very cold to hot and humid.<sup>n,31</sup> The survey requested information on the product types most commonly used for a set of insulation and air-sealing applications. The list of applications included in the survey was determined by this project team, based on our experience with energy-efficiency upgrades. A table with the applications considered, the baseline data by application, as well as other, less commonly reported materials, can be found in Part VI of the Materials Encyclopedia.

### 2 PRODUCT RESEARCH

We performed in-depth research on the baseline products identified through the surveys as well as on alternate products that could be used for the same applications. The purpose of the product research was to determine the common content in the baseline and alternative products. Transparency documents like HPDs and Declare Labels provide the most comprehensive information on chemical contents, but few product types have significant levels of disclosure. For all insulation and sealant product types, we supplemented with other sources, including safety and technical data sheets, patents, and other publicly available information. From this data, we created a Common Product profile using the methodology developed by Healthy Building Network for The Quartz Project. These profiles identify the chemical content found to be typical for each product type, describing the products as delivered to a job site. For more information on the Common Product methodology, see The Quartz Project website: <http://quartzproject.org/methodology>.

### 3 HAZARD SCREENING

The purpose of the screening was to compare the associated health hazards of the different product types reviewed and to rank the product types based on their health profiles. A variety of governmental bodies and nongovernmental organizations maintain lists of chemicals associated with health hazards, such as cancer. Healthy Building Network's Pharos Chemical & Material Library evaluates and cross-references the most important of these lists, creating one database that provides a summary of significant hazards and hazard levels (the potential of any one chemical to trigger a human health problem).<sup>o,32</sup>

Health hazard data from the above-mentioned Pharos Library were used to screen the chemicals commonly found in insulation and air-sealing products.<sup>p</sup> Chemicals found to have the health endpoints shown in Table 1 (below) and high, or very high, hazard levels were considered to be chemicals of concern in the analysis.<sup>q</sup> In some cases, where research is still emerging, additional sources beyond the Pharos Library were consulted for associated health hazards. In these cases, the additional sources are cited within the text.

### 4 PRODUCT COMPARISONS

The results of the hazard screens were then used to formulate recommendations of the best products from a health perspective. Products were compared within each category (insulation or air sealants) based on the quantity of chemicals of concern present for a given application of each Common Product (for the desired R-value and coverage area for insulation and the linear feet and bead size for sealants). These initial rankings were then adjusted on the following bases:

- Avoiding chemicals that are persistent, bioaccumulative toxicants (PBTs) and are particularly potent at low levels, or both, was given highest priority. The rankings of product types containing these chemicals were adjusted downward.
- Minor upward adjustments in the rankings were made where specific products better than the Common Product are available and where there is good product transparency within a product type. For example, modified polymer sealants would be ranked as dark

red based on the Common Product profile, but because there are a couple of specific products within this category that have fewer hazardous chemicals and have good transparency, the category is raised to the next higher color, medium red.

- Minor downward adjustments in the rankings were made for products containing chemicals with high global warming potential,<sup>r</sup> because of their overall environmental health impact.

See the product type descriptions in Parts III and IV of the Materials Encyclopedia for notes on where these adjustments were made. Comparisons are based on product composition during installation and use and do not take into account other chemicals used in production or those that may be formed as the result of end of life processing. In some cases, where problematic process chemicals or other life-cycle concerns were identified, they are noted in the product descriptions in Parts III and IV of the Materials Encyclopedia. Data sources

**TABLE 1. HEALTHY BUILDING NETWORK’S PHAROS LIBRARY HEALTH HAZARD ENDPOINTS, DESCRIPTIONS, AND CHEMICAL EXAMPLES**

<b>Toxicity/Health Hazard Endpoint</b>	<b>Description</b>	<b>Example of Hazardous Chemicals in Insulation and Sealants (function of chemical in parentheses)</b>
<b>PBT (Persistent Bioaccumulative Toxicant)</b>	Does not break down readily from natural processes, accumulates in organisms, increasing in concentration as it moves up the food chain, and is harmful in small quantities	Hexabromocyclododecane (HBCD) (flame retardant), Nonylphenol ethoxylate (surfactant)*
<b>Cancer</b>	Can cause or contribute to the development of cancer	Formaldehyde (binder component), Phthalate (plasticizer), <sup>^</sup> Stoddard solvent (solvent)
<b>Developmental</b>	Can cause harm to a fetus or developing organism, including birth defects, low birth weight, and biological or behavioral problems that appear during development	HBCD (flame retardant), Nonylphenol ethoxylate (surfactant)
<b>Reproductive</b>	Can disrupt the male or female reproductive systems, changing sexual development, behavior or functions, decreasing fertility, or resulting in loss of a fetus during pregnancy	Phthalate (plasticizer), Nonylphenol ethoxylate (surfactant)
<b>Endocrine</b>	Can interfere with hormone production or communication between cells that control metabolism, development, growth, reproduction, and behavior (the endocrine system). Linked to health effects such as obesity, diabetes, male and female reproductive disorders, and altered brain development, among others	Phthalate (plasticizer)
<b>Gene Mutation</b>	Can cause or increase the rate of mutations, which are changes in the genetic material in cells. This can result in cancer and birth defects.	Stoddard solvent (solvent)
<b>Respiratory/ Asthmagen</b>	Can result in lung irritation or sensitization such that small quantities of irritants trigger asthma, rhinitis, or other allergic reactions in the respiratory system. These compounds can exacerbate current asthma and some have been shown to cause the disease of asthma.	Formaldehyde (binder component), Isocyanates (reactive component), Phthalate (plasticizer)

\* Nonylphenol ethoxylates contain and break down into compounds called nonylphenols, which are persistent, bioaccumulative toxicants. The hazard associations given here are for nonylphenol ethoxylates and related substances.

<sup>^</sup> Different specific phthalates may have different associated hazards. Those listed here are specific to di(2-ethylhexyl)phthalate (DEHP).



for product content can be found in the Common Product profiles, which are cited in Parts III and IV of the Materials Encyclopedia as well.

Some product recommendations may not meet code requirements for all areas or building types. See Part VII of the Materials Encyclopedia for some code considerations, and check for specific code requirements in your area.

There are some limitations to the results presented in this guide, including:

- The product target list may not be complete since the survey was administered to only a limited number of parties.
- New health endpoints may be identified with new scientific evidence over time.

- We only have limited information about the composition of certain products, due to transparency limitations.
- New technologies and new products will emerge that were not part of this review.

Thus, the recommendations and product rankings in this guide are based on the best available information at the time the research was conducted. As new information becomes available, Healthy Building Network will update the product type rankings on our HomeFree site: <https://homefree.healthybuilding.net/>.

<sup>m</sup> In order to be considered baseline, a product type had to be used by at least 25% of the respondents for a particular application. If no product met this criteria, then the products with the most mentions greater than one were listed as the baseline.

<sup>n</sup> Information was received from the EEFA states of California, Illinois, Michigan, Minnesota, Rhode Island, Maryland, Louisiana, Virginia, Georgia, New York, and Pennsylvania and the non-EEFA states of Texas, Alaska, and Washington. These states cover IECC climate regions 2-7. No information was collected for the EEFA state of Missouri, but the other respondents cover the climate regions found in Missouri.

<sup>o</sup> HBN uses the framework of the GreenScreen For Safer Chemicals, which ranks chemicals both by reference to the certainty of the science and to the potency of the substance — the less required to affect human health, the more potent.

<sup>p</sup> Hazards noted in this report are based on the hazard lists in the Pharos Chemical & Material Library as of February 10, 2017, the Healthy Building Network high priority asthmagens list, and GreenScreen For Safer Chemicals full assessments.

<sup>q</sup> For more information, see the Chemical & Material Library Full System Description: [https://www.pharosproject.net/uploads/files/library/Pharos\\_CML\\_System\\_Description.pdf](https://www.pharosproject.net/uploads/files/library/Pharos_CML_System_Description.pdf).

<sup>r</sup> Global warming potential is a relative measure of how much heat a given greenhouse gas will absorb in a given time period. GWP numbers are relative to carbon dioxide, which has a GWP of 1. The larger the GWP number, the more a gas warms the earth.

CHAPTER 3:

# Insulation — Healthier Material Recommendations





### INSULATION – HEALTHIER MATERIAL RECOMMENDATIONS

- ✓ Expanded cork board is top ranked
- ✓ Prefer fiber glass and cellulose insulation
- ✓ Avoid products with formaldehyde-based binders
- ✓ If board insulation is required, prefer rigid mineral wool insulation
- ✓ Avoid foam insulation, whether board or spray-applied
- ✓ Use mechanical installation methods

### Product Rankings

Insulation is a very broad product category that employs a variety of material types, such as cellulose, glass and mineral fiber, plastic foam, and natural materials that are used in a range of forms — batt, blown, sprayed, and board. It is an important component of almost all new construction and many energy-efficiency improvements, and given the quantity of insulation used, it is easy to see how materials decisions can cumulatively affect the amount of toxic material brought into building spaces.

Our baseline data (see Part VI of the Materials Encyclopedia) revealed that a wide range of insulation products, some with high health rankings and some with low, are currently being used in multifamily energy-efficiency upgrades. Foam products like spray polyurethane foam (SPF), which contain many chemicals of concern, were found to be commonly used for certain applications. In each of these applications, however, alternative, less hazardous products (blown or batt fiber glass) were also used and were often equally common. Blown cellulose was also found to be a commonly used insulation product with relatively low health hazards associated with it.

Tables 2 and 3 provide a general ranking of different types of building and pipe insulations based on their health profiles, with green highlighting the best currently available product type and solid red the worst. The tables include the chemicals of highest concern within these products and the relative costs per R-value per square foot or linear-foot installed. For more complete information on other chemicals of concern in the products, the level of existing content transparency for each product type, and common performance information, including R-values, vapor permeability, and air-barrier characteristics, see the tables in Part III of the Materials Encyclopedia. Also check these detailed descriptions for information on best-in-class materials or for less common, undesirable characteristics to watch out for. These descriptions also provide the reasoning for the ranking of each product type.

Following the chart is a summary of our recommendations for selecting the least hazardous insulation products for residents, installers, and the broader community. Importantly, if a jump to the top-rated products is too difficult, incremental improvements from lower- to higher-ranked products can still significantly reduce potential exposures to chemicals of concern. Any step up the ladder of healthier materials can make a difference!

**TABLE 2. RANKING OF BUILDING INSULATION MATERIALS**

**Health-Based Ranking Information**

Rank (Green is best; red is worst)	Insulation Type	Common Chemical Content of Highest Concern and Associated Health Hazards*	Relative Installed Cost per R-value <sup>33</sup>
<b>RECOMMENDED MATERIALS</b>	Expanded Cork Board		\$\$\$\$
	Loose-Fill Fiber Glass		\$
	Dense-Pack Fiber Glass		\$-\$\$
	Spray-Applied Fiber Glass		\$-\$\$
	Fiber Glass Batts/Blankets (Kraft-Faced and Unfaced)		\$
	Fiber Glass Batts/Blankets (PSK-Faced (polypropylene-scrim-kraft) or FSK-Faced (foil-scrim-kraft), Basement Wall Insulation)		\$-\$\$
	Cellulose/Cotton Batts and Blankets (Unfaced)		\$\$-\$\$\$
	Loose-Fill Cellulose		\$
	Dense-Pack Cellulose		\$-\$\$
	Wet-Blown Cellulose		\$-\$\$
	Mineral Wool Batts	Formaldehyde-based binder (can release formaldehyde which has cancer and respiratory hazards)	\$
	Mineral Wool Boards	Formaldehyde-based binder (can release formaldehyde which has cancer and respiratory hazards)	\$\$-\$\$\$
	Polyisocyanurate (Polyiso)	Halogenated flame retardant (Tris(1-chloro-2-propyl) phosphate (TCPP)): developmental, reproductive, potential carcinogen**	\$\$-\$\$\$
	Expanded Polystyrene (EPS)	Halogenated flame retardant (HBCD): PBT, developmental	\$\$\$
	Extruded Polystyrene (XPS)	Halogenated flame retardant (HBCD): PBT, developmental	\$\$\$
	Spray Foam Insulation (SPF)	Organotin catalyst (Dibutyltin dilaurate): PBT, reproductive Halogenated flame retardant (TCPP): developmental, reproductive, potential carcinogen** Isocyanates (Methylene diphenyl diisocyanate (MDI), Polymeric MDI (PMDI)): respiratory	Closed cell: \$\$\$, Open cell: \$\$-\$\$\$

\* Chemicals of highest concern found to be common based on the Common Product research. These include persistent, bioaccumulative toxicants (PBTs), halogenated flame retardants, isocyanates, formaldehyde-based binders, and phthalates. Only chemicals of concern that are intentional content in the products are listed in this table. For more complete information on all chemicals of concern, see the individual product type information in Part III of the Materials Encyclopedia and the Common Product profiles in Pharos.

\*\* While there is currently limited data regarding the carcinogenicity of TCPP, chemicals of similar structure have been identified as carcinogens, suggesting a potential cancer concern for TCPP as well.<sup>34</sup>

^ Estimate of relative installed cost per square foot, per R-value. Based on information compiled from various sources. Scale of project, location, and other factors may affect relative costs. Relative costs are not comparable across the different tables in this report.

**TABLE 3. RANKING OF PIPE INSULATION MATERIALS**

Health-Based Ranking Information			
Rank (Green is best; red is worst)	Insulation Type	Common Chemical Content of Highest Concern and Associated Health Hazards*	Relative Installed Cost per R-value <sup>^35</sup>
<b>RECOMMENDED MATERIALS</b>	Fiber Glass Pipe Insulation  NOTE: ONLY FORMALDEHYDE-FREE IS RECOMMENDED	Formaldehyde-based binder (can release formaldehyde which has cancer and respiratory hazards) Nonylphenol ethoxylate (NPE): contains and breaks down into nonylphenols which have PBT, reproductive, and developmental hazards	\$
	Polyethylene Foam Pipe Insulation		\$
	Elastomeric Foam Pipe Insulation	Phthalate (Di(2-ethylhexyl) phthalate (DEHP)): cancer, reproductive, developmental, endocrine, respiratory	\$\$

\* Chemicals of highest concern found to be common based on the Common Product research. These include persistent, bioaccumulative toxicants (PBTs), halogenated flame retardants, isocyanates, formaldehyde-based binders, and phthalates. Only chemicals of concern that are intentional content in the products are listed in this table. For more complete information on all chemicals of concern, see the individual product type information in Part III of the Materials Encyclopedia and the Common Product profiles in Pharos.

<sup>^</sup> Estimate of relative installed cost per linear foot, per R-value. Based on information compiled from various sources. Scale of project, location, and other factors may affect relative costs. Relative costs are not comparable across the different tables in this report.

## Summary — Insulation Recommendations

Balancing all performance characteristics, including a material's health profile and effectiveness, is complex, but as the BlueGreen Alliance Foundation notes in its *Guide to Healthier Energy Efficient Housing Products*, “When considering the type of material to use, selecting healthy insulation products should be just as important — if not more important — than cost and comfort.”<sup>36</sup>

Following is a summary of our recommendations for selecting insulation products with the least hazardous profile to decrease impacts on residents, installers, and the broader community.

-  **Our top-ranked insulation is expanded cork board** because it is free of hazardous content, but it is expensive and may not be widely available, requiring advanced planning to allow for its use.
-  **Prefer fiber glass and cellulose insulation.** Not all products toward the top of the ranking are expensive or limited in availability. Commonly used fiber glass and cellulose insulations are some of the highest ranked from a health perspective, and have the lowest installed cost

for any given R-value. While the R-value per inch is higher for many foam products, the R-value per dollar is not. For applications with few space restrictions, the same insulative performance can be achieved with these healthier materials, and the cost savings per R-value on the insulation may allow for separate air-sealing measures, if needed.

-  **Avoid products with formaldehyde-based binders.** Formaldehyde is a carcinogen and respiratory hazard, even at low levels. If products that contain a formaldehyde-based binder must be used, make sure that they meet the California Department of Public Health (CDPH) Standard Method for the Testing and Evaluation of VOC Emissions (01350) for residential scenarios.
-  If board insulation is required, **prefer rigid mineral wool insulation** that meets the CDPH Standard Method for the Testing and Evaluation of VOC Emissions (01350) or consider upgrading to cork.
-  **Avoid foam insulation, whether board or spray-applied,** whenever possible. Foam insulations commonly contain highly toxic flame retardants,

and spray foam contains asthma-causing isocyanates. If foam insulation must be used, avoid products that are reacted on site, such as spray foam. Also, look for products that do not use halogenated flame retardants. In situations where both air-sealing and insulation properties are desired, consider using caulk or tape, or both, to seal gaps before installing insulation to achieve both these goals without using spray foam.



**Use mechanical installation methods, such as fasteners,** whenever possible to avoid unnecessary use of adhesives.

When our healthier material recommendations call for avoidance of specific chemicals or chemical groups or compliance with an emission specification or VOC content requirement, verify that the specific product you want to use meets these requirements.

- Specific chemicals can be avoided by checking product literature for statements such as “formaldehyde-free” or “phthalate-free.”
- For products that have transparency documents like HPDs and Declare Labels, check the disclosed content against the recommendations. Part II of the Materials Encyclopedia provides examples of some common chemicals of concern. Part V includes links to libraries of transparency documents.
- Test results for VOC content and emissions are often provided in product literature and can be checked against the healthier material recommendations.

When in doubt, ask the manufacturer to verify that the products meet these and other requirements of your project.

## Important Considerations: Installing Insulation

Proper installation techniques as well as protection during installation are key to achieving optimal product performance and to protecting both workers and residents during and after insulation is installed.

### PRODUCT PERFORMANCE

Because incorrect installation can lead to compromised performance for any type of insulation, it is critical to carefully follow installation protocols for any product. A few examples of important steps in the installation process, focused on fiber glass, cellulose, and spray foam insulation, are given below.

- To achieve the tested R-value, batt insulation must be carefully fitted so that it touches all sides of a cavity, leaves no gaps, and is not compressed.<sup>37</sup> While blown fiber glass or cellulose can make it easier to entirely fill cavities, settling may be an issue. In horizontal installation, loose cellulose settles a small amount over time, so the installed thickness must be adjusted to account for this. In dense-pack applications for fiber glass and cellulose, variations in installation techniques or installed density can lead to variations in R-value and airflow reduction, or to settling over time that can create gaps in the insulation.<sup>38</sup>
- Because spray foam insulation is manufactured on site as it is installed, several variables can affect performance, such as proper mix ratio, ambient temperature and humidity, substrate cleanliness, thickness of a single pass, and overall installed thickness. Problems such as cracks, blowholes in the foam, shrinkage away from the framing, or even scorching within the foam due to excessive heat given off by the chemical reaction have all been observed.<sup>39</sup> Cracks, holes, or gaps formed during installation may be difficult to detect and can compromise the R-value and air-sealing properties if they are not remedied.<sup>40</sup> There can also be significant nonuniformity in an application.<sup>41</sup> Improper installation can lead to gummy or brittle foam, as well as lingering odors, which are both performance and health concerns.<sup>42</sup>

## SAFETY

Proper installation is also key to protecting installer and resident safety. Most product literature suggests the use of certain personal protective equipment (PPE) when installing different insulation products, but the level of required PPE varies widely among different types of insulation, as noted below.

- For installation of fiber glass insulation, skin protection (long sleeves, long pants, and gloves), eye protection, and a dust respirator are recommended.<sup>43</sup> Similar recommendations are made for cellulose insulation.<sup>44</sup>
- In contrast, required PPE for spray foam installation usually includes full body protection in the form of disposable coveralls, chemical-resistant gloves and boots or booties, a hood, and eye and face protection as well as supplied air respirators.<sup>45</sup> Spray foam insulation reacts on site; hazardous chemicals are given off during this process. Respiratory impacts from isocyanate exposure can come not just from breathing in vapors, but also from skin contact with the chemicals.<sup>46</sup> Spills or leaks and cleaning processes present potential for additional exposure, as does the presence of unreacted isocyanates in dust created during trimming.<sup>47</sup> Excessive heat release can also lead to fires in extreme cases.<sup>48</sup>

Building residents and other workers should vacate a building during spray foam installation and until the foam has finished curing and the building has been ventilated and thoroughly cleaned. The EPA notes that, “It is not clear how much time is needed before it is safe for unprotected workers or building residents to re-enter”<sup>49</sup> and that, “Since re-entry time is dependent on product formulation and other factors that affect curing, more general research as well as product specific studies are needed to understand when it is safe for unprotected workers or building/home residents to re-enter.”<sup>50</sup>

While the industry has taken measures to provide educational materials and many installers most likely follow the prescribed guidelines, the fact remains that there are still cases where homeowners or installers become ill because of spray foam installation.<sup>51</sup> Problems noted in the last several years by the Occupational Health Clinical Centers in New York include: “possible improper application of the foam; inadequate respiratory protection and ventilation for workers; spray foaming when the building was occupied; re-occupying too soon (estimated at 23-72 hours but there is little evidence to support current recommendations); and lack of warning about the health hazards of spray foam insulation for the home owners and workers.”<sup>52</sup>

As noted in Chapter 2, the hierarchy of controls for workplace safety ranks elimination and substitution as the most effective hazard protection. The controls currently recommended by the SPF industry — personal protective equipment (PPE), administrative controls (such as policies and training), and engineering controls (like ventilation) — are less effective protection. There are a variety of reasons for this, including that PPE is not always used.<sup>53</sup> The California Department of Toxic Substances Control notes, “PPE and engineering controls are considered the lowest tiers in the Hierarchy of Controls against occupational exposure to hazards because any user-error or malfunction can result in exposure to the hazard...Because SPF applications produce measurable concentrations of airborne [isocyanates] in the breathing zone, any person involved in, or near, the application risks exposure to [isocyanates] even when protective measures are used.”<sup>54</sup>

CHAPTER 4:

# Air Sealing — Healthier Material Recommendations





### AIR SEALING — HEALTHIER MATERIAL RECOMMENDATIONS

- ✓ Prefer caulk-type sealants over spray foam sealants
- ✓ Prefer foam sealing products that are not reacted on site
- ✓ Avoid phthalate plasticizers
- ✓ Prefer acrylic-based sealants with very low levels of VOCs
- ✓ Prefer foil-backed butyl tape for HVAC sealing
- ✓ Avoid products that are marketed as being antimicrobial

Air sealing is at least as important as insulation in improving energy efficiency. Many air sealants are applied wet and emit chemicals of concern as they dry or cure. Consequently, solid forms of sealants are usually better options.

Our baseline data collection (Part VI of the Materials Encyclopedia) revealed that a wide range of air-sealing products are currently being used in multifamily energy-efficiency upgrades. For example, a variety of caulk-type sealants, including acrylic latex, polyurethane, and modified polymer, were all reported as being commonly used. SPF and 1-part spray foam were also found to be commonly used for some applications. Silicone sealants and foam gaskets were less frequently reported. The spray foam products and polyurethane sealants in particular contain many chemicals of concern.

Often, the South Coast Air Quality Management District (SCAQMD) Rule 1168 is referenced for limits on VOCs for wet-applied products. For architectural sealants, however, this limit is currently very permissive, allowing up to 250 grams per liter (g/L) VOCs. Products with significantly lower VOC content are available for air-sealing applications. A new version of SCAQMD Rule 1168 was released in 2017 and much more restrictive requirements ( $\leq 50$  g/L for most architectural sealants) go into effect in January 2019.<sup>55</sup>

### Ranking

Tables 4 and 5 provide a general ranking of different types of multipurpose and heating, ventilation, and air-conditioning (HVAC) sealants based on their health profiles, with green indicating the best currently available product type and solid red the worst. The tables include the chemicals of highest concern within these products and the relative material costs per linear foot. For more complete information on other chemicals of concern in the products, the level of content transparency available for each product type, and installation considerations, see the tables and descriptions in Part IV of the Materials Encyclopedia. Also check these detailed descriptions for information on best-in-class materials that have advantages over Common Products, or for less common, undesirable characteristics to watch out for. These descriptions also provide the reasoning for the ranking of each product type.

Again, if it's not possible to jump to the highest-ranked material, incremental improvements from lower- to higher-ranked materials can still have important impacts. A summary of our recommendations follows the tables below.

**TABLE 4. MULTIPURPOSE SEALANTS RANKING**

Health-Based Ranking Information			
Rank (Green is best; red is worst)	Sealant Type	Common Chemical Content of Highest Concern and Associated Health Hazards*	Relative Material Cost <sup>56</sup>
<b>RECOMMENDED MATERIALS</b>	Noncombustible Sodium Silicate Caulk		\$\$\$
	Expanding Polyurethane Foam Sealant Tape	Nonylphenol ethoxylate (NPE): contains and breaks down into nonylphenols which have PBT, reproductive, and developmental hazards	\$-\$\$\$^^
	Acrylic Latex Sealant		\$\$
	Siliconized Acrylic Sealant		\$\$
	Intumescent Acrylic Firestop Sealant		\$\$\$\$
	One-Component Silicone Sealant	Volatile methylated siloxane (Octamethylcyclotetrasiloxane (D4)): PBT 10,10'-Bis(phenoxyarsinyl)oxide: PBT, cancer	\$\$\$
	Modified Polymer Sealant (STPE Sealant)	Organotin catalyst (Di-n-butyltinbis (acetylacetonate)): PBT, developmental Phthalate (Diisodecyl phthalate (DIDP)): developmental	\$\$\$
	One-Part Polyurethane Spray Foam Sealant	Halogenated flame retardant (TCPP): developmental, reproductive, potential carcinogen** Halogenated flame retardant (Medium chain chlorinated paraffins – in Fireblock version): developmental Isocyanate (PMDI): respiratory	\$
	One-Component Polyurethane Sealant	Organotin catalyst (Dibutyltin dilaurate): PBT, developmental Phthalate (DIDP): developmental, respiratory Isocyanate (Toluene diisocyanate (TDI)): respiratory	\$\$\$

\*Chemicals of highest concern found to be commonly used based on the Common Product research. These include persistent, bioaccumulative toxicants (PBTs), halogenated flame retardants, isocyanates, formaldehyde-based binders, and phthalates. Only chemicals of concern that are intentional content in the products are listed in this table. For more complete information on all chemicals of concern, see the individual product type information in Part IV of the Materials Encyclopedia and the Common Product profiles in Pharos.

\*\* While there is currently limited data regarding the carcinogenicity of TCPP, chemicals of similar structure have been identified as carcinogens, suggesting a potential cancer concern for TCPP as well.<sup>57</sup>

^ Estimate of relative material cost per linear foot sealed at a set width and depth. Based on information compiled from various sources. Scale of project, location, and other factors may affect relative costs. Relative costs are not comparable across the different tables in this report.

^^ There can be a wide variation in cost for expanding polyurethane foam sealant tape. Interior-only sealant tapes are usually cheaper than dual-purpose interior and exterior tapes. The tape expands to fill the gap that is present, so for smaller gaps, the cost per volume filled will be greater than for larger gaps.

TABLE 5. HVAC SEALANTS RANKING

Health-Based Ranking Information			
Rank (Green is best; red is worst)	Sealant Type	Common Chemical Content of Highest Concern and Associated Health Hazards*	Relative Material Cost <sup>^58</sup>
<b>RECOMMENDED MATERIAL</b>	Foil-Backed Butyl Tape		\$\$
	Wet-Applied Mastic Sealant	Halogenated flame retardant (Medium chain chlorinated paraffins): developmental  Nonylphenol ethoxylate (NPE): contains and breaks down into nonylphenols which have PBT, reproductive, and developmental hazards	\$

\* Chemicals of highest concern found to be commonly used based on the Common Product research. These include persistent, bioaccumulative toxicants (PBTs), halogenated flame retardants, isocyanates, formaldehyde-based binders, and phthalates. Only chemicals of concern that are intentional content in the products are listed in this table. For more complete information on all chemicals of concern, see the individual product type information in Part IV of the Materials Encyclopedia and the Common Product profiles in Pharos.

<sup>^</sup> Estimate of relative material cost per linear foot sealed at a set width. Based on information compiled from various sources. Scale of project, location, and other factors may affect relative costs. Relative costs are not comparable across the different tables in this report.

## Summary — Air-Sealing Recommendations

-  **Prefer caulk-type sealants to spray foam sealants.** Spray foam sealants have the lowest relative cost to seal a given space because of their low density, but they contain many chemicals of high concern. Some nonisocyanate (nonpolyurethane) spray foam sealants are becoming available, but because there is little or no disclosure on their contents available to the public, we do not yet know whether they are less toxic than polyurethane spray foam sealants.<sup>59</sup>
-  **Prefer foam sealing products that are not reacted on site,** like a foam sealant tape or backer rod, for sealing larger gaps for which caulk sealants are not recommended. For even larger gaps, a piece of drywall can be used to cover the gap with the edges sealed with a caulk-type sealant.
-  **Avoid phthalate plasticizers.** In some categories of sealants, phthalate plasticizers are still used. Make sure the sealants you use are free of these hazardous chemicals.
-  **Prefer acrylic-based sealants with very low levels of VOCs** in the absence of product disclosure. Options with  $\leq 25$  g/L are available for many applications.
-  **Prefer foil-backed butyl tape for HVAC sealing.** If you must use mastic, ask manufacturers for content information to avoid halogenated flame retardants, and prefer no-VOC products.
-  **Avoid products that are marketed as being antimicrobial** or claim to kill germs on surfaces because they have not been shown to have a health benefit, and can have negative impacts on human health and the environment.<sup>60</sup>



Like for our summary insulation recommendations, where our healthier material recommendations call for avoidance of particular chemicals or chemical groups, or compliance with an emission specification or VOC content requirement, verify that specific products meet these requirements.

- For specific chemical avoidance, for example, check product literature for statements such as “formaldehyde-free” or “phthalate-free.”
- For products that have transparency documents like HPDs and Declare Labels, check the disclosed content against the recommendations. Part II of the Materials Encyclopedia provides examples of some common chemicals of concern. Part V includes links to libraries of transparency documents.
- Test results for VOC content and emissions are often provided in product literature and can be checked against the healthier material recommendations.

When in doubt, ask the manufacturer to verify that products meet these and the other requirements of your project.

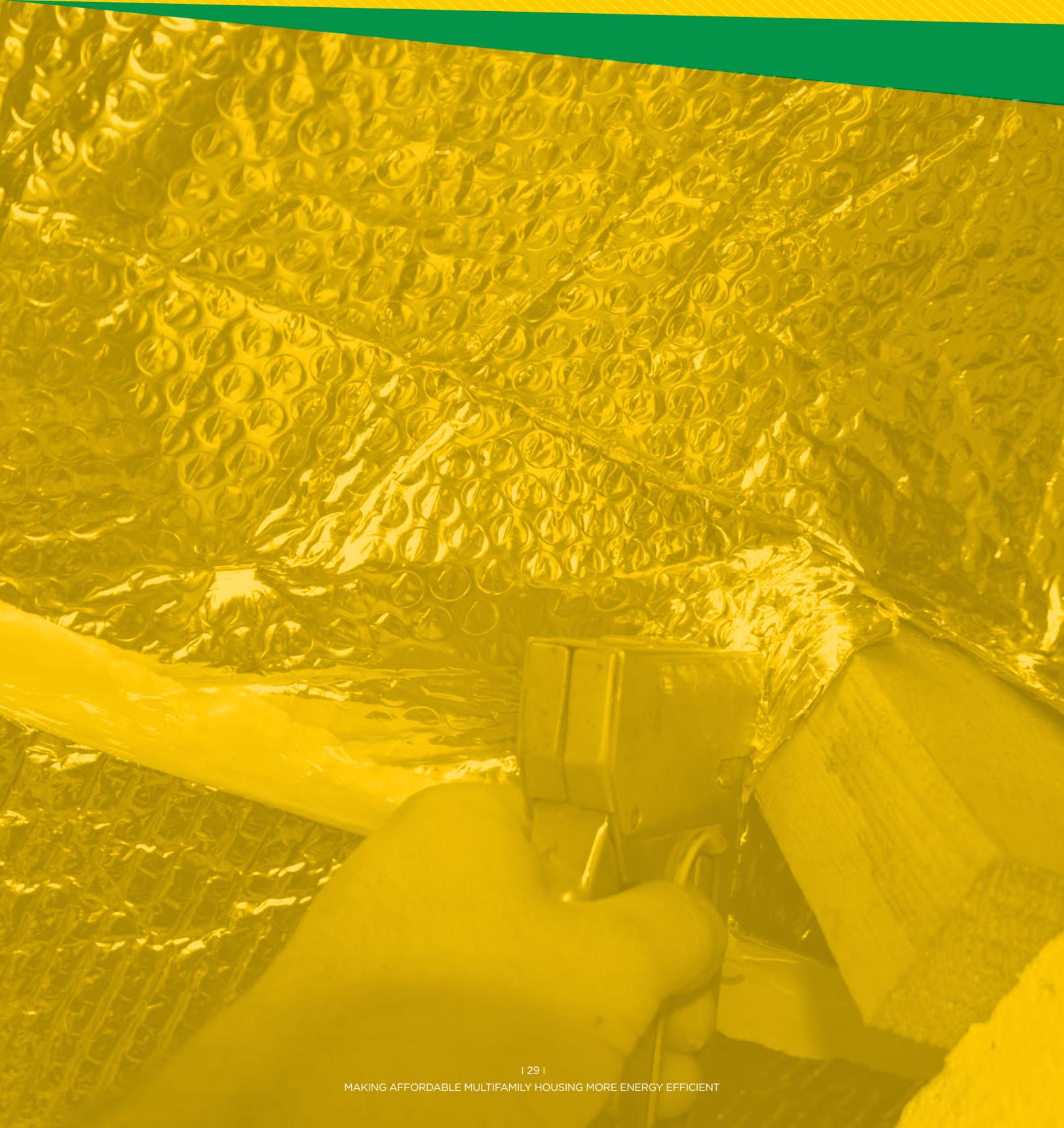
#### **A NOTE ON WEATHERSTRIPPING**

Several survey respondents noted that they used weatherstripping or foam gaskets for sealing window and door gaps. There are a wide variety of weatherstripping materials available, with minimal information on the content of these various products. Here are our general recommendations:

- Prefer metal weatherstripping when possible. (V-strip or spring metal strip are options.)
- Avoid products made with polyvinyl chloride (PVC, vinyl) because of concerns about toxic chemicals in the supply chain.
- Push for full content transparency. This can be done by asking manufacturers to provide an HPD or Declare Label and preferring products that have this documentation.

CHAPTER 5:

# Engaging Multiple Stakeholders for Healthier Upgrades



In this guide, we have so far focused on one specific point in the affordable multifamily rental housing market upgrade process — the practice of selecting materials for a specific project. The first few chapters focus on selecting the best products from those currently available. But there are important actions that also can be taken with other stakeholders in the building products ecosystem that can improve the range of healthy products available and the transparency needed to find them. In this chapter, we touch briefly on five strategies that emerged during our research as critical to moving the market to healthier products:

- Engage manufacturers to provide greater transparency.
- Support product development to bring healthier products to market with the intent of quickly achieving scale.
- Invest in wider building industry dialogue and consensus building.
- Influence state and local policy in the affordable multifamily development sector.
- Ensure appropriate workforce development.

### Engage Manufacturers to Provide Greater Transparency

Even as we seek safer alternatives to harmful chemicals in building products, we at the same time need content transparency so that we can know what chemicals comprise a given product. Unfortunately, chemical transparency has been difficult to secure. Manufacturers often cite proprietary concerns, face complex supply chains, or simply fail to recognize the need to disclose detailed material information. This is particularly unfortunate for air sealing for which there is a critical need for healthier products that can seal large gaps at a lower cost than current alternatives. A lack of transparency here means that it is nearly impossible to make specific product choices based on products' health profiles.

While our Common Product analysis allows for general recommendations of product types, it does not work for undisclosed, one-off type products. The Common Product analysis relies on there being multiple products and multiple sources of information to determine the common content. Product types for which there is only a single product and the content is not fully disclosed cannot

be analyzed using this method. So, this guide could not recommend some promising products because of the lack of information on chemical content (see Part VII of the Materials Encyclopedia). For example, because of the lack of content disclosure for nonisocyanate 1-part spray foams, we were unable to develop health profiles for these products. Manufacturers of these and other products should disclose product content using a program like Health Product Declaration or Declare so these products can be vetted as potentially healthier alternatives to existing options.

### Support Product Development to Bring Healthier Products to Market with the Intent of Quickly Achieving Scale

Several products in the research and testing phase, such as mushroom-based (mycelium) insulation and nonisocyanate spray foam insulation, could be excellent options once they are available at scale (see Part VII of the Materials Encyclopedia). We have seen that when manufacturers see a market demand, they innovate and create new products that can meet both health and energy performance criteria. There must be further investment in their efforts in order for these new products to be adopted quickly and widely enough to gain efficiencies of scale.

Our research shows that it is imperative to invest in early adopters and demonstration projects. Case study projects that incorporate healthier building materials are crucial to drive broader engagement and policy change on healthier materials. Such case studies may be successful in that they showcase a new product, or they may reveal that a product is not suitable for a particular application, or that it is prohibitively expensive. Case studies that define the downside of new products are as necessary as those that show the benefits. These demonstrations can show the real-world implications of and answer questions about the additional costs and benefits of changing standards to require healthier building materials. The demonstrations usually engage a range of early adopters along the value chain — from building design through product supply to installation. And they provide early data on what costs and impediments must be overcome to create wider industry changes — including those not yet envisioned. Finally, whether new products conform to code requirements should be a part of case studies. A new product may create a need for changes to code if it is better but does not comply with current code requirements, or if its performance is so much better that it should become the new code baseline.



Change in the building industry tends to be slow and cautious. The history of energy efficiency in buildings, now extending over 40 years, shows this. There are a variety of reasons for this slow pace, including complex supply chains, long development cycles, and an apprenticeship model of education in the building trades. Demonstration projects are helpful, and necessary for creating policy change. The dissemination of information about successful demonstration projects is critically important, and industry events, where peers can hear from each other, can be important drivers of incremental change that lead to wider policy change and ultimately industry transformation.

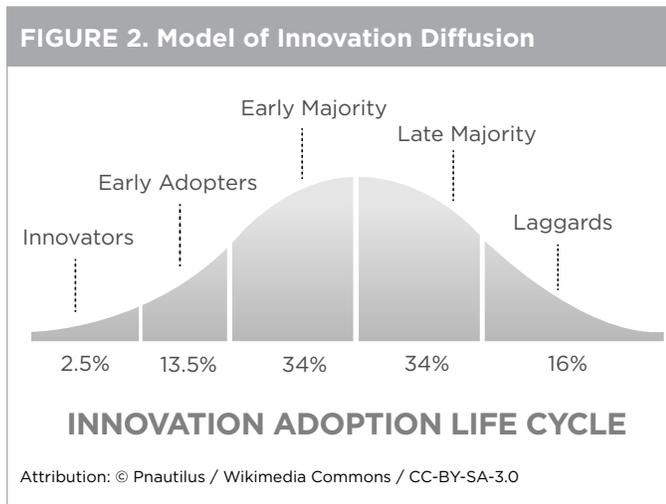
### **Invest in Wider Building Industry Dialogue and Consensus Building**

The building industry overall, and affordable housing providers in particular, need to be engaged around the issue of hazardous chemicals in building materials. Industry education starts with building a dialogue among leaders in the industry about the need for change. There needs to be broad agreement about both the problem and the solution. That consensus only comes after wide industry engagement.

The list of needed industry participants is long, and shows the complexity of the affordable

housing world. It includes product manufacturers, distributors, housing developers, general contractors, construction trades, architects, engineers, and housing financiers. Each of these participants has its own industry-specific events that bring leaders together, can provide forums for discussing the problem and the solutions, and can create the forces needed for initial and then wider-scale industry change.

It is important to note that the dialogue needs to be tailored for different stages of the cycle of product change. The useful model of innovation diffusion developed by E.M. Rogers (see Figure 2) breaks the potential purchasing population into five groups: innovators, early adopters, early majority, late majority, and laggards.<sup>61</sup> For the development of healthier upgrade materials in affordable housing, we are at the innovation stage, seeking to replace old ways of doing things with new products. We need to identify the innovators and appeal to their wishes to innovate, be at the leading edge, and do the right thing. As we move along the adoption curve, the messaging should change to match the motivations and drivers of each pertinent group. While the innovators are the ones who are ideal subjects for early case study work, the early adopters are the ones who can be motivated to



act by those first successes. While an innovator or early adopter may be primed to review and act on new information (e.g., content disclosure) alone, it may take programmatic and financial incentives to encourage the purchase of healthier materials by the early majority. Strengthened financial incentives, regulatory requirements, and other policies may be needed to drive late majority and laggards to the appropriate product choices. We outline this sequence in the next section.

### Influence State and Local Policy in the Affordable Multifamily Development Sector

Public policy, particularly at the state and local levels, also drives upgrade decisions for the affordable multifamily rental sector. The state-specific funding criteria that govern the allocation of the Low-Income Housing Tax Credit (LIHTC) are particularly important since LIHTCs are the most common financing source for building, renovating, and upgrading this part of the housing stock. Because independent subcontractors tasked with doing specific pieces of an upgrade make purchasing decisions, any effort to influence material selection for an entire project (rather than just individual elements) must be undertaken early in the workflow process by a well-informed team. And although many states incorporate green standards in their LIHTC funding criteria, those green standards are often incorporated as optional, rather than required. Again, a broad industry discussion is needed to build consensus around how to promote the use of healthier upgrade materials. Finally, any approach to strengthening

materials standards should focus on those product categories with the highest usage, that produce the most dangerous hazard exposure, and for which alternatives are readily available.

In addition to the LIHTC, there are many avenues for using policy or regulation to promote healthier upgrade materials, depending on the specific state context. These avenues include the following:

- ✔ Utility commission proceedings focused on requirements for building materials and cost-effectiveness testing
- ✔ Legislative committees with oversight over public health, housing and community development, and energy policy
- ✔ State building and energy codes, whether newly introduced or poised for improvement and revision
- ✔ Professional certifications awarded at the state level that focus on the building industry
- ✔ State-owned or managed buildings and requirements to meet green certifications
- ✔ Funding and financing allocation processes that could involve healthier materials specifications

Finally, local governments can be early adopters of policy change, particularly if there are new initiatives related to energy, climate, or public health; a demand for certifications, such as the Living Building Challenge, that directly address material health issues; or local building or energy codes that are scheduled for adoption or revision.

For more information on using state and local policy to incentivize the move toward healthier upgrade materials for the affordable multifamily housing sector, see our accompanying policy briefing document, available at [www.energyefficiencyforall.org](http://www.energyefficiencyforall.org).

**Building codes don't usually require the use of specific building materials. Rather, they mandate that certain performance requirements (like fire testing standards) be met. These requirements might result in the addition of toxic chemicals like halogenated flame retardants in order for some products (like plastic foam insulation) to pass muster. Because building codes don't require the use of certain types of materials, promotion of healthier materials can be accomplished through updates to performance requirements or through product innovation instead. See Part VIII of the Materials Encyclopedia for more information.**



### Ensure Appropriate Workforce Development

Installers, project managers, design professionals, and other decision makers need the appropriate education and training to increase the selection and use of healthier materials while continuing to secure the desired performance of an installation. Without education and training opportunities for the various types of workers involved in upgrades, it is less likely that healthier material use will increase, particularly in such a way as to meet the performance requirements of installations. For example, the party that makes the materials decision needs to look at cost per R-value, rather than just R-value. Workers who might have previously relied on spray foam applications to provide both air-sealing and insulation properties may need to be trained to use healthier products, such as caulk and fiber glass, to achieve the same performance standard.

In developing this training focus and content, it will be important to draw on the experience of pilot projects to identify the largest knowledge gaps among current workers by region and the training content that would be the most relevant. Utility and public benefit programs can be important partners in this training. Other successful models for workforce education include manufacturer training programs and professional certification programs like the Building Performance Institute's Healthy Home Evaluator.<sup>62</sup>

<sup>62</sup> See Part VII of the Materials Encyclopedia for products we considered but were unable to include in our evaluation because of disclosure or availability issues. These include some exciting new products that are not yet commercially available.

# CHAPTER 6: **Conclusion**



**We know that energy-efficiency interventions have significant benefits for building residents and society at large; as energy-efficiency investments proliferate, we should ask how we can ensure that these benefits are equally available for the low-income populations served by affordable housing. Healthy materials can benefit these populations in many ways — by creating better indoor environmental quality for residents, safer jobs for upgrade and construction workers, and healthier communities with reduced pollution from toxic chemicals released when materials are manufactured, processed, and disposed of.**

## HERE IS OUR CALL TO ACTION:

**Get Engaged, Builders.** It is time for a discussion about the connections between people’s health and buildings. While the impacts of housing quality on health are well known to public health professionals, this understanding has only recently gotten traction in the energy-efficiency and building performance industry. As the sector begins to examine how buildings improve or degrade the health of their residents and explores health funding sources to upgrade buildings in general, this is an opportune time to refine this discussion to include healthier building materials for the residents and neighbors of affordable multifamily housing.

**Catalyze Product Innovation.** While there is reason for concern about some materials in the buildings where we live and work, there is also reason to be optimistic. Innovative new products and improved versions of well-known products are regularly coming on the market.<sup>5</sup> Product developments often improve performance or decrease cost and can also improve health profiles. We need to continue to encourage product innovation to ensure a future where commonly used upgrade materials are all free of chemicals of concern.

**Expand Disclosure.** Chemical content disclosure for building products is growing as more and more product contents are revealed through programs like the Health Product Declaration and Declare, but lack of transparency can still present a major challenge for those trying to select healthier products.

Clearly, we need to continue to advocate for more transparency and disclosure for more products.

**Leverage Policy Incentives to Create Change.** The Low-Income Housing Tax Credit system presents both challenges and opportunities to use policy to create demand for healthy materials. As an industry, we must better define what a healthy material is, and then work to include requirements for healthy materials in the Qualified Allocation Plans (QAPs) for the LIHTC in a state-by-state campaign. Further, since QAPs regularly reference specific green building standards, we should support specifically those programs that better address material health, such as the Living Building Challenge and LEED V4. We should advocate for the inclusion of standards that comprehensively address material toxicity in the commonly cited Enterprise Green Communities standard. Accomplishing this would immediately influence a number of state policies across the United States and create demand for healthier materials.

**We envision a future when upgrades make buildings energy efficient, create environments that promote health, and contribute to the well-being of communities living in affordable housing. Please join us in making this future our future.**

# Materials Encyclopedia

## I. List of Acronyms

D4	Octamethylcyclotetrasiloxane
DEHP	Di(2-ethylhexyl) phthalate
DIDP	Diisodecyl phthalate
EEFA	Energy Efficiency For All
EPDs	Environmental Product Declarations
FSK	Foil-scrim-kraft
HBCD	Hexabromocyclododecane
HBN	Healthy Building Network
HPDs	Health Product Declarations
HVAC	Heating, Ventilation, and Air Conditioning
IECC	International Energy Conservation Code
LEED	U.S. Green Building Council's Leadership in Energy and Environmental Design
LIHTC	Low-Income Housing Tax Credit
MDI	Methylene diphenyl diisocyanate
NPE	Nonylphenol ethoxylate
PBTs	Persistent, Bioaccumulative Toxicants
PMDI	Polymeric methylene diphenyl diisocyanate
PSK	Polypropylene-scrim-kraft
PVC	Polyvinyl chloride
QAP	Qualified Allocation Plan
SDS	Safety Data Sheet
SPF	Spray Polyurethane Foam
SVOCs	Semivolatile Organic Compounds
TCPP	Tris(1-chloro-2-propyl) phosphate
TDI	Toluene diisocyanate
TSCA	Toxic Substances Control Act of 1976
VOCs	Volatile Organic Compounds

## II. Glossary

This appendix provides definitions for some terms and types of chemicals referenced in the report. Some specific chemicals that have been found in insulation and air-sealing products are listed. This is not a comprehensive list but is meant to provide representative examples.

**Alkylphenol ethoxylates** — Alkylphenol ethoxylates, including nonylphenol ethoxylates (NPEs) and octylphenol ethoxylates (OPEs), are chemicals of concern commonly used as surfactants. NPEs contain and break down into nonylphenols, which are persistent in the environment, bioaccumulate in the food chain, and are toxic. OPEs contain and break down into octylphenols. Both octylphenols and nonylphenols have been shown to have endocrine-disrupting properties.<sup>63</sup>

*Examples of alkylphenol ethoxylates include:*

*Nonylphenol polyethylene glycol ether (CAS 27177-08-8)*

*Nonylphenol, branched, ethoxylated (CAS 68412-54-4)*

*Octylphenoxy polyethoxyethanol (CAS 9036-19-5)*

For a more complete and up-to-date list of alkylphenol ethoxylates, see the Chemical Hazard Data Commons for nonylphenol ethoxylates: <https://commons.healthymaterials.net/chemicals/2072220> and for octylphenol ethoxylates: <https://commons.healthymaterials.net/chemicals/2072201>.

**Antimicrobial, Biocides** — Biocides are usually necessary in water-based, wet-applied products to protect them from spoilage prior to installation or compromised performance once installed. These preservatives, however, are considered to be pesticides and therefore carry health and environmental hazards. Some preservatives have higher associated hazards than others. Lower hazard preservatives should be substituted when possible.

Manufacturers market some products as “antimicrobial,” or claim that the products kill microbes on surfaces. These claims implying a health benefit can be misleading. Such products may contain biocides that are not necessary for product preservation or performance, have not been shown to have a health benefit, and can in fact have many negative impacts on human health and the environment. It is not common for insulation products to be marketed as “antimicrobial,” but some sealants may be marketed in this manner and should be avoided.

**Blowing agents** — Blowing agents are used to generate foam in materials such as insulation. Many blowing agents have high global warming potential (GWP). Production of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) has mostly stopped since the 2000s, but hydrofluorocarbons (HFCs) are still prevalent. Foam insulation manufacturers are poised to shift from HFC blowing agents to low global warming potential hydrofluoroolefins (HFOs), but there are concerns about the ozone-depleting feedstock (carbon tetrachloride) used to produce these HFO blowing agents. With increased production and use of carbon tetrachloride for this application, increased emissions of the ozone-depleting substance are expected. Other, less impactful blowing agents, including hydrocarbons and water, are also used in some insulation products.

**CASRN** — A Chemical Abstract Services Registry Number is assigned by the Chemical Abstract Service of the American Chemical Society to uniquely identify chemical elements, compounds, and other materials and mixtures. Frequently used in Safety Data Sheets (SDSs), such an identifier is also known as a “CAS number.”

**Catalyst** — A substance that increases the rate of a reaction without being consumed. It is usually used in small amounts relative to the reactants.

**Chemical Hazard Data Commons** — The Chemical Hazard Data Commons is a collaborative tool to help identify substances that are hazardous to human and environmental health and find safer alternatives. The Data Commons provides open access to chemical hazard information compiled from human and environmental hazard lists published by governmental and professional scientific bodies and includes GreenScreen Benchmark and List Translator scores. Collaborative tools include a library of scientific chemical hazard and exposure literature and open forum discussions about critical hazard assessment issues. The Data Commons is developed and managed by the Healthy Building Network. For more information, see: <https://commons.healthymaterials.net>.

**Common Product** — A profile of a generic, nonmanufacturer-specific product type. The profile includes a brief description of the product type, the common composition (chemicals and their associated weight percentages and functions) based on publicly available sources, and corresponding health hazards associated with this composition. For links to the Common Product profiles referenced in this guide, see the references for each product type in the Materials Encyclopedia, sections III and IV. For more details on how Common Product profiles are developed, see: <http://www.quartzproject.org/methodology>.

**Declare Label** — Declare is a transparency platform and product database including information about where a product comes from, what it is made of, and where it goes at the end of life. The Declare Label is presented in a nutrition label format, includes a list of contents as well as VOC information, and indicates whether the product complies with the Living Building Challenge Red List. The Red List is comprised of worst-in-class chemicals that the International Living Future Institute considers the most important to avoid. For more information, see: <https://living-future.org/declare/declare-about/>.

**Dedusting oil** — A dedusting oil is usually added to fiber glass batts or blankets, loose-fill fiber glass, and cellulose insulations in order to keep dust down during manufacturing and installation. Some dedusting oils used in fiber glass and cellulose insulation are carcinogens. These are usually variations of petroleum distillates and are often called mineral oil. For some types of insulation, products are available with alternative dedusting oils, like vegetable oil.

*Examples of hazardous dedusting oils include:*

*Hydrotreated heavy paraffinic petroleum distillates (CAS 64742-54-7)*

*Distillates (petroleum), hydrotreated light paraffinic (CAS 64742-55-8)*

*Distillates (petroleum), solvent-dewaxed light paraffinic distillate (CAS 64742-56-9)*

*Solvent-dewaxed heavy paraffinic petroleum distillates (CAS 64742-65-0)*

*Distillates (petroleum), hydrotreated light naphthenic (CAS 64742-53-6)*

*Residual oils, petroleum, solvent-refined (CAS 64742-01-4)*

**Global Warming Potential (GWP)** — Certain gasses, commonly referred to as “greenhouse gasses,” have the ability to warm the earth by absorbing heat from the sun and trapping it in the atmosphere. Global warming potential is a relative measure of how much heat a given greenhouse gas will absorb in a given time period. GWP numbers are relative to carbon dioxide, which has a GWP of 1. The larger the GWP number, the more a gas warms the earth. To learn more about interpreting GWP numbers, see: [www.epa.gov/ghgemissions/understanding-global-warming-potentials](http://www.epa.gov/ghgemissions/understanding-global-warming-potentials).

**Halogenated flame retardants** — Flame retardants are chemicals added to products to reduce their flammability. Halogenated flame retardants contain chlorine or bromine bonded to carbon (chlorinated or brominated flame retardants). Chemicals in this group are considered very important to avoid because of their toxicity and ability to migrate from products. Many within this class are also persistent in the environment, bioaccumulate in the food chain, or both.

*Examples of halogenated flame retardants include:*

*HBCD (CAS 3194-55-6, 25637-99-4)*

*TCPP (CAS 13674-84-5)*

*Chlorinated paraffins (CAS 85535-85-9)*

*DecaBDE (CAS 1163-19-5)*

For a more complete and up-to-date list of halogenated flame retardants, see the Chemical Hazard Data Commons: <https://commons.healthymaterials.net/chemicals/2072163>.

**Health Product Declaration (HPD)** — The HPD provides a framework for manufacturers to inventory and disclose the contents of their products and any associated human and environmental hazards. Through the standardized HPD form, manufacturers provide information on both intentional content and impurities within their products. The framework is maintained and updated by the Health Product Declaration Collaborative. For more information, see: <http://www.hpd-collaborative.org/>.

**Health hazard/toxicity endpoint** — Disease symptom or related marker of a health impact on a human or other being, e.g., cancer or reproductive toxicity.

**Impurity (residual or contaminant)** — An unintended constituent present in a material or mixture as manufactured. It may originate from the starting materials or be the result of secondary or incomplete reactions during the manufacturing process. While it is present in the final material or mixture, it was not intentionally added.

**Isocyanates** — Isocyanates are used in the creation of polyurethanes. They are potent asthmagens; research suggests that exposure to very small quantities through inhalation or dermal contact can cause the onset of asthma disease. This is a particular concern for polyurethane products that are reacted on site.

*Examples of isocyanates include:*

*MDI (CAS 101-68-8)*

*PMDI (CAS 9016-87-9)*

*TDI (CAS 91-08-7, 584-84-9)*

For a more complete and up-to-date list of isocyanates, see the Chemical Hazard Data Commons: <https://commons.healthymaterials.net/chemicals/2072237>.

**Living Building Challenge** — The Living Building Challenge is a rigorous building standard, requiring that buildings not only minimize resource use but also are regenerative in form and function. Certification is organized into seven so-called “petals,” one of which is focused on materials. The materials petal includes a requirement that the content of all materials used in a building be disclosed, a level of transparency that can help clarify the healthy and unhealthy materials that comprise buildings.

**Low-Income Housing Tax Credit (LIHTC)** — Created by the Tax Reform Act of 1986, the LIHTC program gives state and local LIHTC-allocating agencies a dollar-for-dollar tax credit for the acquisition, rehabilitation, or new construction of affordable housing aimed at low-income Americans.

**Organotin compounds** — Organotin compounds are often used as catalysts in on-site cured polyurethane products and may also be used in factory-cured polyurethane foams. This group of chemicals is persistent in the environment, bioaccumulates in the food chain, and is toxic. Federal lawmakers have also designated tin, a component of organotin compounds, as a conflict mineral because it often is mined in conflict areas of the eastern Congo.

*Examples of organotin compounds include:*

*Dibutyltin dilaurate (CAS 77-58-7)*

*Di-n-butyltin bis(acetylacetonate) (CAS 22673-19-4)*

*Dioctyl tin oxide (CAS 870-08-6)*

For a more complete and up-to-date list of organotin compounds, see the Chemical Hazard Data Commons: <https://commons.healthymaterials.net/chemicals/2072028>.

**Phthalates** — Commonly referred to as phthalates, orthophthalates are plasticizers that have historically been added to products like sealants and foam insulation to make them more flexible. These chemicals of concern are structurally and toxicologically different from terephthalates. Many orthophthalates are known endocrine (hormone) disruptors and have been found to damage reproductive systems and interfere with normal development of a fetus. They have also been associated with asthma. Alternative plasticizers without these associated health hazards are available, and many manufacturers have made the switch.

*Examples of phthalates include:*

*DIDP (CAS 26761-40-0, 68515-49-1)*

*DEHP (CAS 117-81-7)*

*DINP (CAS 28553-12-0, 68515-48-0)*

*DNOP (CAS 117-84-0)*

For a more complete and up-to-date list of orthophthalates, see the Chemical Hazard Data Commons: <https://commons.healthymaterials.net/chemicals/2072101>.

**Plasticizer** — A plasticizer is a substance, commonly added to some plastics and sealants, that increases flexibility and decreases brittleness. Plasticizers can migrate out of products over time and some, such as phthalates, are hazardous.

**Post-consumer recycled content** — This form of recycled content refers to waste material coming out of households or institutions that is reused rather than sent to landfills. These materials are of varying quality. Contaminants can be incorporated during their service life and from cross-contamination from other materials. These contaminants may negatively affect the health of recycling workers, surrounding communities, and the global environment. For example, cathode ray tubes from old televisions can contaminate recycled container glass with lead if the two materials are commingled. If this glass is recycled into fiber glass, lead is emitted during processing. The highest lead-emitting fiber glass manufacturing facilities do not meet the post-consumer recycled content requirements set in this document.

**Qualified Allocation Plan (QAP)** — A document required by the LIHTC and published by each state (usually a state's housing financing agency) that outlines specific criteria and eligibility requirements for awarding federal tax credits to housing properties.

**Red List** — A list of chemicals that have been designated as harmful to living creatures, including humans, or the environment. Several organizations have developed their own red lists or banned lists of chemicals. The International Living Future Institute (ILFI) developed its own red list for the built environment from a human and ecological health standpoint. The chemicals on the ILFI Red List may not be included in products used in construction that seeks to meet the criteria of the Living Building Challenge, unless an exception is allowed.

**Surfactant** — A surfactant is a compound that lowers surface tension to allow for dispersion or suspension of a solid or immiscible liquid in another liquid. Alkylphenol ethoxylates are examples of hazardous surfactants that may be used in building products.

**Upgrade** — The term “upgrade” is used in this guide to refer to a holistic set of interventions to make a building more energy efficient.

**Volatile methylated siloxanes** — Volatile methylated siloxanes are used as precursors to silicone polymers and are commonly found in reactive silicone sealants. Residual quantities may also be found in pre-reacted silicone polymers used as additives in other products. These chemicals are persistent in the environment, bioaccumulate in the food chain, and toxic.

*Examples of volatile methylated siloxanes include:*

*D4 or Octamethylcyclotetrasiloxane (CAS 556-67-2)*

*D5 or Decamethylcyclopentasiloxane (CAS 541-02-6)*

For a more complete and up-to-date list of volatile methylated siloxanes, see the Chemical Hazard Data Commons: <https://commons.healthymaterials.net/chemicals/2072411>.

**Volatile organic compounds (VOCs)** — VOCs are commonly defined as chemicals that are released as gases into the air during the application and curing of a product. Some VOCs may be released quickly during installation; others can be emitted slowly over time from solid products. Some volatile compounds are exempt from regulatory reporting on product labels and specifications as part of the VOC content if they do not contribute to smog formation. These exempted VOCs may, however, still be hazardous to workers and residents who breathe them in during or after installation.



### III. Insulation — Recommended and Other Materials, Cost, Performance, Transparency, and Installation Considerations

These tables reflect our best understanding of typical performance properties for each product type, but there will be variations in specific product performance. Some products may not meet code requirements for all applications for all jurisdictions or building types. Check that any specific products used meet the requirements of your project.

**TABLE 6. BUILDING INSULATION<sup>64</sup>**

Health-Based Ranking  (Green is best; red is worst)	Insulation Type	R-Value per Inch*	Relative Installed Cost per R-Value**	Special Installation Equipment Required	Vapor Retarder <sup>^</sup>	Air Barrier Material <sup>^^</sup>	Level of Transparency on Chemical Content <sup>^^^</sup>
							(Less shading indicates more transparency within a product type)
	Expanded Cork Board	3.6-4.2	\$\$\$\$	no	Class III	Information not available	
<b>Blown-In Fiber Glass</b>							
	Loose-Fill Fiber Glass	2.2-3.1	\$	yes	Vapor permeable	Not an air barrier	
	Dense-Pack Fiber Glass	3.7-4.6	\$-\$\$	yes	Vapor permeable	Not an air barrier but does reduce airflow	
	Spray-Applied Fiber Glass	4.0-4.3	\$-\$\$	yes	Vapor permeable	Not an air barrier but does reduce airflow	
	Fiber Glass Batts/Blankets (Kraft-Faced and Unfaced)	2.9-4.3	\$	no	Kraft-faced: Class II; Unfaced: Vapor permeable	Not an air barrier	
	Fiber Glass Batts/Blankets (PSK or FSK-Faced, Basement Wall Insulation)	Duct wrap: 2.7-3.2# Basement wall insulation: 3.0-3.5	\$-\$\$	no	Class I (except basement wall insulation where facing is perforated to allow for moisture transfer)	Facing may be an air barrier material	
	Cellulose/Cotton Batts and Blankets (Unfaced)	3.5-4.0	\$\$-\$\$\$	no	Vapor permeable	Not an air barrier	
<b>Blown-In Cellulose</b>							
	Loose-Fill Cellulose	2.7-3.4	\$	yes	Vapor permeable	Not an air barrier	
	Dense-Pack Cellulose	3.5-3.8	\$-\$\$	yes	Vapor permeable	Not an air barrier but does reduce airflow	
	Wet-Blown Cellulose	3.6-3.8	\$-\$\$	yes	Vapor permeable	Not an air barrier but does reduce airflow	

**TABLE 6. BUILDING INSULATION<sup>64</sup>**

<b>Health-Based Ranking</b>  (Green is best; red is worst)	<b>Insulation Type</b>	<b>R-Value per Inch*</b>	<b>Relative Installed Cost per R-Value**</b>	<b>Special Installation Equipment Required</b>	<b>Vapor Retarder<sup>^</sup></b>	<b>Air Barrier Material<sup>^^</sup></b>	<b>Level of Transparency on Chemical Content<sup>^^^</sup></b>  (Less shading indicates more transparency within a product type)
	Mineral Wool Batts	4.0-4.3	\$	no	Vapor permeable	Not an air barrier	
	Mineral Wool Boards	3.4-4.2	\$\$-\$\$\$	no	Vapor permeable	Not an air barrier	
	Polyisocyanurate (Polyiso)	5.4-6.9	\$\$-\$\$\$	no	Foil-faced: Class I; Fiber-faced: Class II or Class III	Air barrier material	
	Expanded Polystyrene (EPS)	3.1-4.5	\$\$\$	no	Class II or Class III, depending on type and thickness	Not an air barrier	
	Extruded Polystyrene (XPS)	3.9-5.0 <sup>##</sup>	\$\$\$	no	Class II or Class III, depending on type and thickness	Air barrier material	
	Spray Foam Insulation (SPF)	Closed cell: 5.8-6.9 Open cell: 3.5-4.5	Closed cell: \$\$\$ Open cell: \$\$-\$\$\$	yes	Closed cell: Class II or Class III; Open cell: Class III or vapor permeable, depending on type and thickness	Closed Cell: Air barrier material (at ≥ approx. 1.5" thick); Open Cell: Air barrier material (at ≥ approx. 3.5-5.5" thick)	

\* R-values can vary with temperature and are reported here for a standard 75-degree Fahrenheit mean temperature. R-values are as measured under laboratory conditions, and actual performance in a building can often depend on the quality of installation. The range was based on reported R-values per inch or by dividing R-value by thickness for the range of products available. R-value per inch can vary with overall product thickness and density as well as between products. Consult product literature for actual R-values for a given product and thickness.

\*\* Estimate of relative installed cost per square foot per R-value is based on information compiled from various sources. Scale of project, location, and other factors may affect relative costs. Relative costs are not comparable across the different tables in this report.

<sup>^</sup> The insulation thickness and facing material may affect the permeability rating. Check specific product literature for details. Permeability levels for different classes of vapor retarders as tested per ASTM E96 (Method A) — Class I: ≤ 0.1 perm (vapor barrier), Class II: > 0.1 to ≤ 1.0 perm (vapor semi-impermeable), Class III: > 1 perm to ≤ 10.0 perm (vapor semipermeable), Vapor permeable > 10.0 perms. Note: The Cellulose Insulation Manufacturers Association (CIMA) does not recommend the use of a vapor barrier with cellulose insulation except for in extremely cold climates and facilities with very high interior moisture levels, like indoor pools. The U.S. Department of Energy notes that, "some building codes don't recognize sprayed foam insulation as a vapor barrier, so installation might require an additional vapor retarder."

<sup>^^</sup> An air barrier material must have an air permeance of less than 0.02 L/s/m<sup>2</sup> at 75 Pa (0.004 cfm/ft<sup>2</sup> at 1.57 psf) per ASTM E2178. Air barrier materials are used as part of an air barrier assembly. Joints must be taped or otherwise sealed to achieve an air barrier. Changes in the dimensions of foam because of temperature changes can compromise the overall seal against vapor, air, and water.

<sup>^^^</sup> Level of transparency is based on the percentage of products within a product type that have HPDs or Declare Labels and the level of transparency within those documents. At the time of our analysis, none of the product types had full transparency. For product types with full transparency, the symbol would be completely unshaded.

<sup>#</sup> Values are for installed R-value per advertised thickness; out of bag R-value per inch is higher because insulation is intentionally compressed on installation.

<sup>##</sup> Most XPS has an R-value per inch of about 5.0, but ASTM C578 allows for Type XIII XPS with an R-value per inch of 3.9.

## RECOMMENDED INSULATION MATERIALS

### Expanded Cork Board Insulation<sup>65</sup>

#### *Common content and associated hazards:*

Cork insulation boards are made by exposing cork granules to superheated steam in a block-shaped press mold. The cork expands and is forced together under pressure. Suberin, a waxy resin naturally present in cork, is activated by the steam and pressure and acts as a binder between the granules. The insulation is composed entirely of natural cork and has no known hazards. Because there are only a few manufacturers and limited distributors in the United States, there may be no or limited local supply. Advanced planning is most likely required to acquire expanded cork board insulation. Because of its lack of hazardous chemicals, expanded cork board insulation has a green (best) ranking.

### Fiber Glass Insulation: Blown-In, Unfaced, and Kraft-Faced<sup>66</sup>

#### *Common content and associated hazards:*

Fiber glass insulation is available in many forms. It can be found as blown-in, batts, or blankets, and unfaced or faced with a variety of materials. These products all contain glass fibers that are produced from a combination of virgin and recycled materials, such as sand and recycled glass. It is important to note that while some specialty glass fibers are carcinogens, the glass fibers used in fiber glass insulation are not because they are biosoluble (readily dissolved and cleared from the lungs).<sup>t,67</sup> Glass fibers from insulation can cause temporary eye, skin, and lung irritation. (See the Important Considerations: Installing Insulation section in Chapter 3 for more information on personal protective equipment.)<sup>68</sup> Fiber glass insulation products do usually contain about 0.5-1.5 percent of a carcinogenic dedusting oil, used to keep dust levels down during manufacture and installation.

Blown-in fiber glass insulation may be installed as loose-fill (usually used in attic applications where space is not limited), dense-pack (more densely packed for wall cavities to prevent settling), and spray-applied (usually with a small quantity of adhesive to adhere the insulation to the cavity). Dense-pack fiber glass has the advantage that it can be used to upgrade the insulation of enclosed wall cavities.

Batts and blankets (and bonded blown-in insulation) also contain a binder to hold the fibers together. This binder was historically formaldehyde-based, but residential and commercial batt manufactured in the United States and Canada is now formaldehyde-free; the formaldehyde binders are replaced, in some cases, with biobased materials.<sup>69</sup> Faced products contain some additional chemicals of concern. Kraft-faced batts usually use an asphalt-based binder that contains polycyclic aromatic hydrocarbon impurities. These impurities are PBTs and carcinogens.

Because of the small amounts of hazardous substances in the dedusting oils and in the kraft facing, these products receive a paler green rating than cork. Using safer dedusting oil and avoiding those trace hazards could put these products in the dark green ranking.

#### *Preferred product:*

Currently, one company offers a fiber glass batt that does not use a carcinogenic dedusting oil, but instead uses a vegetable oil.<sup>70</sup>

#### *Watch out for:*

Depending on the source of cullet (recycled glass) used to produce fiber glass insulation, lead emissions during production may be a concern. Some cullet comes from lead-containing cathode ray tubes (CRTs) from old TV sets, rather than from windows and bottles. These tubes contain a lot of lead, which is released when the tubes are processed into fiber glass. Two plants accounted for nearly 75 percent of lead releases from fiber glass manufacturing in the United States and Canada between 2011 and 2015.<sup>u</sup> Look for fiber glass insulation products containing high percentages of post-consumer recycled content ( $\geq 60$  percent for batts and  $\geq 50$  percent for blown) as these products come from facilities that do not process CRTs.

### **Fiber Glass Insulation: PSK- or FSK-Faced<sup>71</sup>**

Fiber glass insulation with a PSK or FSK facing raises additional concerns beyond standard fiber glass insulation and so is given a lower ranking of yellow. These facings can be found on fiber glass batts, fiber glass basement wall insulation, and HVAC duct wrap. The flame retardant facings usually contain a small amount of antimony trioxide, which poses cancer, developmental, and reproductive hazards.

#### *Watch out for:*

A halogenated flame retardant may be in some flame retardant facings or the adhesives used to attach them to the batt. These chemicals are persistent and bioaccumulative toxicants. In addition, some fiber glass duct wrap insulations may still use formaldehyde-based binders. Formaldehyde, which is emitted from these products over their lifetime, is a carcinogen and asthmagen. Avoid both chemicals of concern when using products in this category.

### **Cellulose Insulation<sup>72</sup>**

#### *Common content and associated hazards:*

Cellulose-based insulation products can use a variety of cellulose fibers. The most common cellulose insulation is blown-in insulation that is made up of almost 85 percent recycled newspaper fibers, about 15 percent a boric acid flame retardant and pesticide, and a small quantity of a mineral oil to reduce the amount of dust generated. Blown-in cellulose insulation may be installed as loose-fill (usually used in attic applications where space is not limited), dense-pack (more densely packed for wall cavities to prevent settling), or wet-blown (with a small quantity of water or adhesive to adhere the insulation to the cavity). Dense-pack cellulose has the advantage that it can be used to upgrade the insulation of enclosed wall cavities.

Cellulose insulation can also be found in batt or blanket form, made either from newspaper or cotton (often denim) fibers. The flame retardant is usually a combination of boric acid and ammonium sulfate. The fibers consist of primarily recycled cellulose, with some polymer fibers to bind everything into a batt shape. Cellulose batts and blankets are usually unfaced.

Government agencies have raised fewer human health concerns about the boric acid flame retardant in cellulose insulation than about halogenated flame retardants, but boric acid is still a potential concern because of its associated developmental and reproductive hazards and the large quantity used in insulation. This keeps cellulose from getting a green rating. Exposure to boric acid is of particular concern during installation and if dust enters a living space. More research is needed on the potential migration of boron-based flame retardants.

#### *Preferred product:*

There is currently one batt product that is free of boric acid and instead uses an ammonium phosphate salt.<sup>73</sup> This replacement does not appear to be a chemical of concern but its contents should be fully disclosed for verification.

#### *Watch out for:*

While not common, some of the dedusting oils used in blown-in cellulose may be carcinogens.

## OTHER INSULATION MATERIALS

### Mineral Wool Insulation<sup>74</sup>

#### *Common content and associated hazards:*

Mineral wool fibers are made from a molten mixture of rock and blast furnace slag from the steel industry. Heavy metals, such as lead, may be present in small quantities from the blast furnace slag. Mineral wool batt and board insulations still usually rely on formaldehyde-based binders to hold the fibers together. These products can release formaldehyde, which is a carcinogen and asthmagen, into living spaces over time. Because of the formaldehyde, the potential presence of heavy metals in the finished products, and the confidence in the health hazards from both, these products are rated orange.

#### *Preferred product:*

In 2017, two manufacturers released the first formaldehyde-free mineral wool batt insulation.<sup>75</sup> Prefer these products when possible. If you must use products that contain a formaldehyde-based binder, make sure that they meet the California Specification 01350 on emissions for residential scenarios.

### Polyisocyanurate Insulation<sup>76</sup>

#### *Common content and associated hazards:*

Polyisocyanurate (polyiso) foam insulation is a closed-cell, rigid insulation board. These products consist of a foam core between two facers. The facer materials vary with the manufacturer and the application. Polyiso for roof applications is usually faced with a glass-reinforced fiber material whereas boards for wall applications usually have an aluminum foil-laminated kraft facer. The foam itself comes from the reaction of isocyanates with polyols. Isocyanates are substances of concern, with respiratory hazards, and residual, unreacted isocyanates may be present in foam board. Catalysts, surfactants, and blowing agents are also used, but are not usually chemicals of concern. A chlorinated flame retardant, Tris(1-chloro-2-propyl) phosphate (TCPP), is included as well. Chlorinated flame retardants as a class are considered of very high concern and to be avoided because of their toxicity and ability to migrate from products. TCPP has been widely found in indoor dust.<sup>77</sup> The EPA has identified TCPP as a reproductive and developmental hazard as well as highly persistent in the environment.<sup>78</sup> While there is currently limited data regarding the carcinogenicity of TCPP, chemicals of similar structure have been identified as carcinogens, suggesting a potential cancer concern for TCPP as well.<sup>79</sup> Because of the large quantity of chlorinated flame retardant it contains — around 6 percent of the product by weight — polyiso insulation has a dark orange rating.

#### *Preferred product:*

Some polyiso board insulation without halogenated flame retardants is becoming available.<sup>80</sup> These products are better options from a health standpoint than other foam plastic insulation.

### Expanded Polystyrene Insulation and Extruded Polystyrene Insulation<sup>81</sup>

#### *Common content and associated hazards:*

Rigid polystyrene board insulation comes in two main types, expanded polystyrene (EPS) and extruded polystyrene (XPS). The underlying chemistry of the two is similar: both are produced using polystyrene, a blowing agent to create the foam structure, and a flame retardant. The halogenated flame retardant used, HBCD, is a PBT.<sup>82</sup> Residual styrene, which is a carcinogen and asthmagen, may also be present in small quantities. EPS commonly contains imidacloprid, an insecticide, which does not have any high human health hazards, but is toxic to honeybees.<sup>83</sup> In addition, XPS uses a high global warming potential blowing agent, a hydrofluorocarbon (HFC). The most commonly used is 1,1,1,2-tetrafluoroethane (HFC-134a), which is 1,430 times more potent than carbon dioxide.<sup>84</sup> Because of its use of the halogenated flame retardant, polystyrene has a dark orange rating. And, because of the additional concern of a potent global warming agent, XPS is rated lower than EPS.

In the coming years, XPS manufacturers are poised to shift from HFC blowing agents to reduce the product's global warming potential HFOs (hydrofluoroolefins).<sup>85</sup> There are, however, serious questions about the impact of these new HFOs because they use a potent ozone-depleting substance, carbon tetrachloride, as a feedstock. With increased production and use of carbon tetrachloride for this application, increased emissions of the ozone-depleting substance are expected.<sup>86</sup>

*Preferred product:*

XPS produced with a flame retardant that the EPA has assessed to be less hazardous than HBCD is beginning to come on the market in the United States.<sup>87</sup> At least one EPS product is currently available in the United States with this alternative flame retardant.<sup>88</sup> This alternative is still halogenated and there are gaps in the available hazard data so it does still present some concerns.

## **Spray Foam Insulation<sup>89</sup>**

*Common content and associated hazards:*

Spray Polyurethane Foam (SPF) insulation is a two-part product that is combined and reacted on site. Part A is a mixture of isocyanates that have respiratory hazards, even in very low quantities. According to the National Institute for Occupational Safety and Health (NIOSH), isocyanates are a leading cause of work-related asthma. Anyone installing reactive products based on isocyanate chemistry may become exposed by touch or breathing.<sup>90</sup> Part B contains polyols (intermediate polymers), a combination of amine catalysts (which may also contribute to respiratory health effects),<sup>91</sup> organotin catalysts (PBTs), chlorinated flame retardants (which are considered of very high concern and to be avoided because of their toxicity and ability to migrate from products), and blowing agents. (For more information on chlorinated flame retardants, see the Polyisocyanurate section.) Closed-cell SPF uses a blowing agent that is a major contributor to global warming. The most common blowing agent, HFC-245fa (1,1,1,3,3-pentafluoropropane), is 1,030 times more potent than carbon dioxide.<sup>92</sup>

A few manufacturers offer closed-cell foam with an HFO blowing agent instead of HFCs, and the remainder of the spray foam industry will be moving away from HFCs in the coming years.<sup>93</sup> See the notes in the Extruded Polystyrene section above for concerns about the HFO alternative. A closed-cell foam that uses water as the blowing agent is available, and some products are marketed as “bio-based” because they use some bio-based content, mainly replacing petrochemical polyols with soy-based polyols.<sup>94</sup> But these formulations are only marginal improvements. The bio-based content is generally a small percentage of the product (always less than 25 percent and often less than 10 percent).<sup>95</sup> Most of the product is still made up of the primary chemicals of concern.

Exposure to chemicals of concern in SPF can occur during application and immediately following, as well as over longer periods of time. (See the section Important Considerations: Installing Insulation in Chapter 3 for more information on personal protective equipment.) The EPA cautions that, “The potential for off-gassing of volatile chemicals from spray polyurethane foam is not fully understood and is an area where more research is needed.”<sup>96</sup> A microchamber emission study recently published by the National Institute of Standards and Technology (NIST) concluded that, “emissions from SPF can be highly variable.” TCPP, the common chlorinated flame retardant used, was detected in emissions from all four samples tested, including one that was tested 18 months after application. Other chemicals were found to be emitted as well. One sample, taken from a residential application of closed-cell SPF (applied during the summer of 2015 and tested March 2016), emitted more than 80 different chemicals. As the study's authors note, these chemicals may not all have negative health impacts, but some most likely do, including the carcinogens 1,4-dioxane and 1,2-dichloropropane.<sup>97</sup>

Because of its PBT catalyst and large quantity of chlorinated flame retardants combined with its significant potential for exposure to asthmagenic isocyanates, SPF receives the lowest health ranking.

**TABLE 7. RECOMMENDED PIPE INSULATION**

Health-Based Ranking	Insulation Type	Thermal Conductivity, BTU-in/(hr-sq ft-F)*	Relative Installed Cost per R-Value <sup>98</sup>	Level of Transparency on Chemical Content <sup>^</sup>
(Green is best; red is worst)	Fiber Glass Pipe Insulation  NOTE: ONLY FORMALDEHYDE-FREE IS RECOMMENDED	0.23	\$	
	Polyethylene Foam Pipe Insulation	0.23 - 0.26	\$	
	Elastomeric Foam Pipe Insulation	0.25 - 0.27	\$\$	

\* Typical R-values are not applicable for cylindrical systems such as pipe insulation. R-values for pipe insulation vary with both insulation diameter and wall thickness. Thermal conductivity values given here are for a mean temperature of 75 degrees Fahrenheit.

<sup>^</sup> Level of transparency is based on the percentage of products within a product type that have HPDs or Declare Labels and the level of transparency within those documents. At the time of our analysis, none of the product types had full transparency. For product types with full transparency, the symbol would be completely unshaded.

**RECOMMENDED PIPE INSULATION**

**Fiber Glass Pipe Insulation<sup>99</sup>**

Fiber glass pipe insulation is like the other types of fiber glass insulation except that most manufacturers still use formaldehyde-based binders. Formaldehyde, which is emitted from these products over their lifetimes, is a carcinogen and asthmagen. The jacketing used with fiber glass pipe insulation may take different forms but is often like the FSK facing used for duct wrap. This facing commonly contains small quantities of antimony trioxide, which has cancer, reproductive, and developmental hazards.

*Preferred product:*

One fiber glass pipe insulation manufacturer offers a formaldehyde-free option.<sup>100</sup> Because of the common presence of formaldehyde in this product, it warrants an orange rating, but because of the wide availability of the formaldehyde-free pipe insulation, the category ranking is slightly higher than it would be otherwise. If a product that contains a formaldehyde-based binder must be used, make sure that it meets the California Specification 01350 for emissions for residential scenarios.

*Watch out for:*

Halogenated flame retardants may be present in some jacketing. Avoid products with this hazardous content or use insulation without a jacket when possible. See the note above on lead emissions from fiber glass manufacturing facilities that use recycled content containing CRTs. Look for fiber glass insulation products containing high percentages of post-consumer recycled content (≥ 30 percent for pipe insulation), as these products come from facilities that do not process CRTs.

**Polyethylene Foam Pipe Insulation<sup>101</sup>**

*Common content and associated hazards:*

Polyethylene foam pipe insulation is made of about 85 percent polyethylene resin and about 5 percent each of isobutane blowing agent and antimony trioxide flame retardant. Isobutane has cancer and gene mutation hazards and antimony trioxide has cancer, reproductive, and developmental hazards. Other additives are present in smaller quantities and are not chemicals of concern. Foam pipe insulation also usually contains carbon black pigment, which has small quantities of polycyclic aromatic hydrocarbon (PAH) contaminants,

which are PBTs and carcinogens. Because of its relatively large quantity of antimony trioxide and hazardous blowing agent, this insulation receives an orange rating.

## OTHER PIPE INSULATION

### Elastomeric Foam Pipe Insulation<sup>102</sup>

#### *Common content and associated hazards:*

Elastomeric foam pipe insulation is usually made from a blend of nitrile butadiene rubber (NBR) and polyvinyl chloride (PVC). While PVC has no direct hazards during use, there are significant concerns about hazards throughout its life cycle. These include the use of asbestos or mercury to produce one of raw materials, chlorine, and the formation of persistent, bioaccumulative toxicants (dioxins) when PVC burns.<sup>103</sup> Several additives are also included in elastomeric foam pipe insulation. Those of high concern are the foaming agent azodicarbonamide, which is an endocrine disruptor and respiratory hazard, and a phthalate plasticizer, which can have cancer, reproductive, developmental, endocrine, and respiratory hazards, depending on the exact component. Foam pipe insulation usually contains carbon black pigment, which has small quantities of PAH contaminants, which are PBTs and carcinogens. Because of its relatively large quantity of chemicals of concern — approximately 20 percent of the product — elastomeric foam pipe insulation has a red rating. Because there are no intentionally added PBTs in the product, it is not ranked a darker red color.

#### *Preferred product:*

Some specialty PVC-free elastomeric foam pipe insulation is available and may be identified as “halogen-free.”<sup>104</sup> If elastomeric foam pipe insulation must be used, ask manufacturers if they have a phthalate-free version and about the blowing agents they use.

---

t In 1988, the International Agency for Research on Cancer (IARC) released a monograph on man-made mineral fibers. This study concluded that mineral wool fibers (including glass and rock or slag wool) were “possibly carcinogenic to humans.” In 2002, new data from additional studies were reviewed and incorporated into a new monograph that concluded that the type of mineral wool fibers used in insulation are, “not classifiable as to their carcinogenicity to humans.” In 2011, both the National Toxicology Program (NTP) and the California Office of Environmental Health Hazard Assessment (OEHHA) made a distinction in their listings between biosoluble glass fibers, which are cleared from the body, and certain other glass fibers that are inhalable and persist in the body (are biopersistent). This change meant that the cancer hazard association and a cancer warning, which was previously required on packaging, were no longer warranted for products using biosoluble fibers. The prior labeling of fiber glass insulation products with cancer warnings has led to some confusion in the industry, but the scientific consensus is that the biosoluble glass fibers that are used in insulation are not carcinogens.

u Fiber glass insulation factories in Newark, Ohio and Waxahachie, Texas released 27 tons of lead from 2011 to 2015; all other fiber glass insulation plants released about 3 tons combined over that same period. Based on data synthesized from the U.S. EPA Toxics Release Inventory and the Canadian National Pollutant Release Inventory, 2011-2015.

v The U.S. Department of Agriculture (USDA) only requires 7% of the content of spray foam insulation to be bio-based for the product to be considered “bio-based.” One product certified to have 24% bio-based content is listed in the USDA’s BioPreferred® list. Most products on the list only claim to meet the minimum requirement for bio-based content.

## IV. Sealants — Recommended and Other Materials, Cost, Installation, and Transparency Considerations

Note on installation considerations: All types of sealants require surfaces to be clean before application.

**TABLE 8. MULTIPURPOSE SEALANTS**

Health-Based Ranking  (Green is best; red is worst)	Sealant Type	Relative Material Cost*	Installation Considerations <sup>105</sup>	Level of Transparency on Chemical Content <sup>^^</sup>  (Less shading indicates more transparency within a product type)
	Noncombustible Sodium Silicate Caulk	\$\$\$	Noncombustible backing material needed for large, deep openings; not recommended where there is continuous vibration or in areas expected to come into contact with water	
	Expanding Polyurethane Foam Sealant Tape	-\$\$\$\$^	Usually expands to fill 1 to 1 1/2"	
	Acrylic Latex Sealant	\$\$	Backing material needed for gaps deeper than about 1/2"; not for gaps wider than about 1/2"	
	Siliconized Acrylic Sealant	\$\$	Backing material needed for gaps deeper than about 1/2"; some products can be used for gaps up to 1"	
	Intumescent Acrylic Firestop Sealant	\$\$\$\$	Noncombustible backing material needed for large or deep openings	
	One-Component Silicone Sealant	\$\$\$	Backing material needed for gaps deeper than about 1/2"; not for gaps wider than 1"	
	Modified Polymer Sealant (STPE Sealant)	\$\$\$	Backing material needed for gaps deeper than about 1/2"; not for gaps wider than 1"	
	One-Part Polyurethane Spray Foam Sealant	\$	For gaps up to about 1 1/2"; variations available for gaps of up to about 3"	
	One-Component Polyurethane Sealant	\$\$\$	Backing material needed for gaps deeper than about 1/2"; not for gaps wider than about 1 1/2"	

\* Estimate of relative material cost per linear foot sealed at a set width and depth. Based on information compiled from various sources. Scale of project, location, and other factors may affect relative costs. Relative costs are not comparable across the different tables in this report.

^ There can be a wide variation in cost for expanding polyurethane foam sealant tape. Interior-only sealant tapes are usually cheaper than dual-purpose, interior and exterior tapes. The tape expands to fill the gap that is present, so for smaller gaps, the cost per volume filled will be greater than for larger gaps.

^^ Level of transparency is based on the percentage of products within a product type that have HPDs or Declare Labels and the level of transparency within those documents. At the time of our analysis, none of the product types had full transparency. For product types with full transparency, the symbol would be completely unshaded.

### RECOMMENDED MULTIPURPOSE SEALANTS

#### Noncombustible Sodium Silicate Caulk<sup>106</sup>

*Common content and associated hazards:*

Noncombustible sodium silicate caulks are single component, nonintumescent, mortar-type caulks. They can be used as a draft, smoke, and fireblocking sealant for penetrations around ducting and electrical and plumbing equipment. Specifications requiring noncombustible sealants are common for one- and two-family construction and nonrated assemblies in multifamily construction. This type of sealant is not recommended where there is continuous vibration or in areas expected to come into contact with water. The primary components are sodium silicate, kaolin clay, and water. There are no known chemicals of concern common in sodium silicate caulk, so this sealant has a green rating.

## Expanding Polyurethane Foam Sealant Tape<sup>107</sup>

### *Common content and associated hazards:*

Expanding polyurethane foam sealant tape is a compressed tape of polyurethane foam, impregnated with an acrylic, fire-retardant resin. The tape is usually coated on one side with a pressure sensitive adhesive. Once installed, the tape slowly returns to its original, uncompressed state, thereby forming a tight seal. Since the foam is factory formed, it does not react on site. The flame retardants, commonly ammonium polyphosphate, appear to be low hazard, and water is the common blowing agent.

There can be a wide variation in cost for expanding polyurethane foam sealant tape. Interior-only sealant tapes are usually cheaper than dual-purpose interior and exterior tapes. The tape expands to fill the gap that is present, so for smaller gaps, the cost per volume filled will be greater than for larger gaps.

Small quantities of PBT chemicals may be present in the finished product, including a nonylphenol ethoxylate (NPE) surfactant in the adhesive as well as impurities from carbon black and a siloxane polymer. Monomer residuals (including isocyanates, which are respiratory hazards) are also possible. While this product is not as highly rated as the sodium silicate caulk, the low density of this product and the fact that it does not react or dry on site keeps the quantity of hazardous chemicals in this product low and it has a yellow rating.

### *Watch out for:*

Some products may contain a chlorinated paraffin flame retardant or an organotin catalyst, both of which are PBT chemicals. HFCs, which have high global warming potential, can be used as supplemental blowing agents. Avoid these chemicals when using this type of product.

## Acrylic Latex Sealants, Siliconized Acrylic Sealants, and Intumescent Acrylic Firestop Sealants<sup>108</sup>

### *Common content and associated hazards:*

Acrylic latex sealants are water based and nonreactive when installed. The primary components are an acrylic polymer, filler, and water. Other additives are plasticizers, an antifreeze agent, solvent, surfactant, and biocide. Some of these common additives are chemicals of concern. Ethylene glycol is a common antifreeze agent and is a reproductive and developmental toxicant. Stoddard solvent or other organic solvents are commonly used at about 1.5 percent by weight to slow skinning of the sealant and can have many high hazard components. Formaldehyde may also be present as an impurity.

Siliconized acrylic sealants are a variation of standard acrylic latex sealants. In these formulations, manufacturers add small proportions of silicone fluid or silanes to enhance adhesion under wet conditions. Like standard acrylic latex, and unlike silicone sealants that are chemically cured, siliconized acrylic sealants cure from evaporation of water. There is minimal disclosure of the preservatives or surfactants used; a hazardous biocide and a hazardous surfactant, an octylphenol ethoxylate, may be common.

Intumescent acrylic firestop sealants are similar to other acrylic sealants, but contain filler materials that react and expand when exposed to very high temperatures. These specialty products are used to seal joints and fill voids around penetrations in fire-rated assemblies to prevent the spread of smoke and fire. There is minimal disclosure of the preservatives or surfactants used; a hazardous biocide and a hazardous surfactant, an octylphenol ethoxylate, may be common. Zinc borate is also a common flame retardant included in these sealants. Although borate-based flame retardants are less of a concern than halogenated flame retardants, they are still chemicals of concern because of the associated developmental and reproductive hazards. More research is needed on potential migration of borate-based flame retardants.

While the different types of acrylic sealants do contain chemicals of concern, they do not generally contain PBTs or phthalate plasticizers, and there are options with very low VOC content, so the category has a light orange rating.

*Preferred product:*

Some acrylic sealants may be available without the hazardous antifreeze agent, and many sealants in this category are available with low VOC content, several with  $\leq 25$  g/L.<sup>109</sup> There are some acrylic firestop sealants available with low-hazard alumina trihydrate instead of zinc borate flame retardants.<sup>110</sup>

*Watch out for:*

While many acrylic latex sealants have transitioned to dibenzoate plasticizers, some may still contain hazardous phthalates. Make sure products are free of phthalates. Since these sealants are water based, biocides are included as preservatives to protect the product from spoilage before installation and its performance being compromised once installed. These biocides are not often disclosed and some may have high hazards.

## OTHER MULTIPURPOSE SEALANTS

### One-Component Silicone Sealant<sup>111</sup>

*Common content and associated hazards:*

One-component silicone sealants are comprised of polymers, silicone oils, filler, biocides, and silanes, and they cure upon application in the presence of moisture. Volatile methylated siloxanes, like octamethylcyclotetrasiloxane (D4), are the key components of silicone chemistry. D4 and an arsenic-based biocide, as PBTs, are both chemicals of high concern. In addition, the most common type of systems are “neutral cure,” and a carcinogen, methyl ethyl ketoxime, is released in the reaction that occurs when they are installed. Because PBT volatile methylated siloxanes are key to the chemistry of silicone sealants and are usually present at about 1 percent in the product, these sealants are ranked lower than acrylics.

*Watch out for:*

Organotin catalysts may be used as well and are PBTs. High hazard solvents may also be present in some products. Both should be avoided if silicone sealants are used.

### Modified Polymer Sealant (STPE Sealant)<sup>112</sup>

*Common content and associated hazards:*

Silyl-terminated polyether sealants are single-component, moisture-cured sealants. They usually contain the base polymer, filler, plasticizer, catalyst, and various other additives. These sealants can be referred to as hybrid or modified polymer sealants. They are often touted as environmentally friendly, being free of solvents and isocyanates. However, hazardous phthalate plasticizers and tin catalysts are still commonly used in them. Methanol, a developmental and reproductive toxicant, is emitted as these products cure. Because of their PBT organotin catalysts and phthalate content of about 15 percent, these sealants warrant a dark red rating, but since there are better options within this category with good transparency, the rating is bumped up slightly.

*Preferred product:*

There are at least two STPE sealants available with alternative plasticizers, like polypropylene glycol, which are low hazard.<sup>113</sup>

### One-Part Polyurethane Spray Foam Sealant<sup>114</sup>

*Common content and associated hazards:*

One-part polyurethane spray foam comes in many varieties for specific applications, but the different varieties are fairly similar to each other chemically. These products are reacted on site and may release significant quantities of hazardous volatile chemicals, such as isocyanates and isobutane blowing agents. Isocyanates are a leading cause of work-related asthma, and anyone installing reactive sealants based on isocyanate chemistry

may become exposed by touch or breathing. The chlorinated flame retardant, TCPP, is also a common component and is considered of very high concern and to be avoided because of its persistence, toxicity, and ability to migrate from products.

Fireblock one-part spray foam also contains chlorinated paraffins, which are developmental hazards. Carbon tetrachloride is sometimes used in the manufacture of chlorinated paraffins and may be present as a residual.<sup>115</sup> Carbon tetrachloride is an ozone depleter and global warming agent as well as a carcinogen.

Because of the large percentage of chlorinated compounds in this product — about 11-20 percent — and the potential for harm from reactive isocyanates on site, one-part polyurethane foam sealants warrant a low ranking. The low density of these products (less chemicals used for a given area sealed) moves them up slightly from dark red.

*Watch out for:*

One-part firestop versions also contain HFC-134a, a potent global warming agent. These firestop versions do not appear to be common, but are available.<sup>116</sup>

**One-Component Polyurethane Sealant<sup>117</sup>**

*Common content and associated hazards:*

One-component polyurethane sealants cure with moisture in the air when applied. They are primarily made of a polyurethane prepolymer, filler, plasticizer, and solvent. Additional additives, including moisture scavengers, catalysts, and adhesion promoters, are commonly included in these formulations. The isocyanates toluene diisocyanate (TDI) and methylene diphenyl diisocyanate (MDI) can both be included as reactants for this type of chemistry. Isocyanates are a leading cause of work-related asthma. Hazardous solvents are also common in these sealants. There is limited disclosure on the plasticizers and catalysts used, but hazardous phthalates and PBT organotin catalysts are believed to be commonly used. Because of the large quantity of chemicals of concern in these sealants, they have the lowest rating.

*Preferred product:*

If a polyurethane sealant must be used, use the one, confirmed to be available, without a phthalate plasticizer.<sup>118</sup>

*Watch out for:*

Some polyurethane sealants may contain PVC (polyvinyl chloride) as a flexibility additive. While PVC presents no direct hazards, there are significant concerns about hazards throughout its life cycle.

**DUCT SEALANTS RANKING**

**TABLE 9. HVAC SEALANTS**

Health-Based Ranking  (Green is best; red is worst)	Sealant Type	Relative Material Cost*	Installation Considerations <sup>119</sup>	Level of Transparency on Chemical Content^  (Less shading indicates more transparency within a product type)
Green	Foil-Backed Butyl Tape	\$\$		
Red	Wet-Applied Mastic Sealant	\$	Fiber glass mesh tape needed for gaps larger than about 1/8"	

\* Estimate of relative material cost per linear foot sealed at a set width. Based on information compiled from various sources. Scale of project, location, and other factors may affect relative costs. Relative costs are not comparable across the different tables in this report.

^ Level of transparency is based on the percentage of products within a product type that have HPDs or Declare Labels and the level of transparency within those documents. At the time of our analysis, none of the product types had full transparency. For product types with full transparency, the symbol would be completely unshaded.

## RECOMMENDED DUCT SEALANTS

### Foil-Backed Butyl Tape<sup>120</sup>

*Common content and associated hazards:*

Several types of tape are available for sealing heating, ventilation, and air conditioning (HVAC) ducts. Unlike cloth duct tapes, butyl tape has been shown to have good longevity for duct sealing.<sup>121</sup> Foil-backed butyl tape has an aluminum foil backing and a thick, tacky adhesive so it can stick to irregular surfaces. The adhesive is made primarily of butyl rubber, polybutene plasticizer, and fillers. There do not appear to be intentionally added chemicals of concern in these tapes, but residual isoprene monomer, which presents a cancer hazard, and PAHs (PBTs) from the carbon black may be present. Because of the limited disclosure in product literature and potential residual hazard, this product is ranked light green instead of dark green.

*Watch out for:*

Talc may be used as a filler in some products. When it is, asbestos may be a concern since some talc mines have asbestos fibers interwoven with the talc that can contaminate the filler.<sup>122</sup>

## OTHER DUCT SEALANTS

### Wet-Applied Mastic Sealant<sup>123</sup>

*Common content and associated hazards:*

Wet-applied HVAC duct sealant (also called mastic) used for residential applications is usually water based. The highest percentage components besides water are an acrylic or vinyl acetate polymer binder and a filler. Chlorinated paraffins are also commonly included in these formulations and can act as both plasticizer and flame retardant. The chlorinated paraffins themselves are hazardous and may also contain residual carbon tetrachloride, which is an ozone depleter and global warming agent as well as a carcinogen. There is limited disclosure on the surfactants used, but NPEs, which are PBTs, appear to be commonly used.

*Preferred product:*

Several products classified as “zero VOC” are available.<sup>124</sup> Because of this, wet-applied mastic sealants are ranked slightly higher than they would otherwise be. Because of limited disclosure, it is not clear whether there are halogen-free or NPE-free options in this category, but if there were, these products would be ranked higher still.

*Watch out for:*

One product listed DecaBDE (decabromodiphenyl ether), a PBT halogenated flame retardant, as a component. The hazardous antifreeze agent ethylene glycol is also present in some products.

## V. Further Resources

### Product Guidance

**HomeFree, <https://homefree.healthybuilding.net/>.**

HomeFree is a program created by the Healthy Building Network for affordable housing practitioners wanting to learn about and use healthier materials. HomeFree will share the data on successfully identified and installed healthier materials to help affordable housing providers keep pace with changes, make informed decisions, and work with manufacturers to make high performing, healthier products available at prices that work for their industry.

**Building Clean, <http://www.buildingclean.org/harmful-chemicals-building-products>.**

Building Clean can help determine if products used in residential housing — whether for energy-efficiency or other purposes — pose toxic threats to residents or installers.

### Chemical Hazards

**Chemical Hazard Data Commons, <https://commons.healthymaterials.net/home>.**

The Chemical Hazard Data Commons is a collaborative site to help identify substances that are hazardous to human and environmental health and find safer alternatives. The Data Commons provides open access to chemical hazard information compiled from human and environmental hazard lists published by governmental and professional scientific bodies. It also includes GreenScreen Benchmark and List Translator scores. Collaborative tools include a library of scientific chemical hazard and exposure literature and open forum discussions about critical hazard assessment issues. The Data Commons is developed and managed by the Healthy Building Network.

### Libraries of Transparency Documents

**Declare Product Database, <https://access.living-future.org/declare-products>.**

Declare, the ingredients label for building products, is a transparency document created in support of the Living Building Challenge Materials Petal requirements.

**HPD Public Repository, <http://www.hpd-collaborative.org/hpd-public-repository/>.**

The HPD Public Repository is the authoritative source for published HPDs.

**HPD Library, <http://hpd.smithgroupjjr.org/Pages/default.aspx>.**

The HPD Library, developed by SmithGroupJJR, is a searchable database that contains hundreds of HPDs, which owners and designers can get access to, free of charge, to assist in their LEED documenting process.

### Building Program Standards

**Enterprise Green Communities (EGC) Criteria, <http://www.enterprisecommunity.org/solutions-and-innovation/green-communities/criteria>.**

**LEED Credit Library, <http://www.usgbc.org/credits>.**

Standards, such as Multifamily Midrise and Building product disclosure and optimization, may be searched.

**EarthCraft Resources, <http://www.earthcraft.org/builders/resources/>.**

EarthCraft Resources is a compendium of resources, such as a Multifamily Renovation Worksheet, for energy, water, and resource-efficient buildings in the Southeast.

### **Cost-Effectiveness Resources**

**National Efficiency Screening Project, <https://nationalefficiencyscreening.org/wp-content/uploads/2017/03/The-Resource-Value-Framework-Reforming-EE-Cost-Effectiveness-14-027.pdf>.**

This document provides an overview of NESP's recommendations for using the Resource Value Framework to improve cost-effectiveness testing for energy efficiency.

**Synapse Energy Economics, [http://www.synapse-energy.com/sites/default/files/SynapseReport.2012-11.RAP\\_EE-Cost-Effectiveness-Screening.12-014.pdf](http://www.synapse-energy.com/sites/default/files/SynapseReport.2012-11.RAP_EE-Cost-Effectiveness-Screening.12-014.pdf).**

This report addresses two elements of energy-efficiency screening: program impacts and the cost of complying with environmental regulations.

### **QAPs**

**Novogradac & Company's Affordable Housing Resource Center, <https://www.novoco.com/resource-centers/affordable-housing-tax-credits>.**

The firm works in the affordable housing, community development, and renewable energy fields, providing tax, accounting, audit, and valuation services to affordable housing developments.

### **Additional Housing Resources**

**Relay Network, [www.relaynetwork.org](http://www.relaynetwork.org).**

Relay Network is a network of mission-oriented organizations that aims to help multifamily building owners with high quality and cost-effective efficiency improvements using the one-stop-shop model.

**PrezCat, [www.prezcat.org](http://www.prezcat.org).**

PrezCat is an online, searchable catalog of state and local affordable housing preservation policies.

## VI. Baseline Insulation and Air-Sealing Materials Used in Upgrades in EEFA States

The table below outlines the types of products currently used for affordable multifamily upgrades. Its contents are based on our survey of upgrade program coordinators, partnering contractors, and specific project teams. Baseline types are those that were most commonly reported to be used. In order to be considered baseline, a product type had to be used by at least 25% of the respondents for a particular application. If no product met this criteria, then the products with the most mentions greater than one were listed as the baseline. The table also includes less common types of materials that were reported as currently being used. See the Methodology section of this report for more details on the survey.

**TABLE 10. BASELINE INSULATION PRODUCTS BY APPLICATION**

Application	Baseline Type(s)	Other Types Listed in Survey
<b>Attic ceiling</b>	Blown-in fiber glass, SPF, fiber glass batt and roll	Blown-in cellulose, wet-applied cellulose
<b>Attic floors (open cavity)</b>	Blown-in cellulose, blown-in fiber glass	SPF, fiber glass batts, wet-applied cellulose
<b>Attic floors (enclosed cavity)</b>	Blown-in and dense-pack cellulose, blown-in and dense-pack fiber glass	
<b>Attic hatch</b>	XPS	Cellulose batt
<b>Cathedral ceiling</b>	Blown-in and dense-pack fiber glass, SPF	Blown-in and dense-pack cellulose
<b>Enclosed walls</b>	Blown-in and dense-pack fiber glass, blown-in and dense-pack cellulose	
<b>Open wall cavities</b>	Fiber glass batt	Dense-pack cellulose, wet-applied cellulose, SPF
<b>Interior basement wall</b>	<i>no baseline identified</i>	Fiber glass batt, cellulose batt, polyisocyanurate
<b>Exterior basement wall</b>	XPS, fiber glass batt and blanket	Polyisocyanurate
<b>Basement ceiling</b>	Fiber glass batt	SPF, wet-applied cellulose
<b>Crawl space</b>	Fiber glass batt, SPF	
<b>HVAC ducts</b>	Fiber glass duct wrap	
<b>Water pipe insulation</b>	Foam pipe insulation, fiber glass pipe insulation	

**TABLE 11. BASELINE SEALANT PRODUCTS BY APPLICATION**

<b>Application</b>	<b>Baseline Type(s)</b>	<b>Other Types Listed in Survey</b>
<b>Air ducts</b>	Wet-applied mastic sealant	Aeroseal, foil-backed acrylic tape
<b>Door gaps (exterior)</b>	Modified polymer sealant, weatherstripping, latex sealant	Silicone sealant, polyurethane sealant, 1-part spray foam, caulk
<b>Window gaps (exterior)</b>	Modified polymer sealant, latex sealant	Silicone sealant, polyurethane sealant, 1-part spray foam, caulk
<b>Door gaps (interior)</b>	1-part spray foam, latex sealant	Silicone sealant, modified polymer sealant, foam gasket, 2-part SPF, caulk
<b>Window gaps (interior)</b>	1-part spray foam	Latex sealant, silicone sealant, modified polymer sealant, foam gasket, 2-part SPF, caulk
<b>Foundation air sealing</b>	Caulk, polyurethane sealant, SPF	Modified polymer sealant, HDPE sheet membrane, PSK vapor barrier
<b>HVAC penetrations</b>	Fire-rated caulk, fire-rated spray foam	Latex sealant, high temperature and fire barrier silicone sealant, latex nonintumescent firestop, caulk
<b>Plumbing and electrical penetrations</b>	Fire-rated caulk, spray foam	High temperature and fire barrier silicone sealant, fire barrier sodium silicate sealant, caulk, intumescent acrylic latex firestop sealant
<b>Roof cavity</b>	<i>no baseline identified</i>	Fire-rated spray foam, XPS, polyisocyanurate board, plywood, gypsum board, caulk
<b>Top and bottom of wall plates</b>	Spray foam, caulk	Fire-rated caulk, fire-rated spray foam, foam gasket, latex nonintumescent firestop spray, intumescent acrylic latex firestop sealant
<b>Trim (exterior)</b>	Latex sealant	Modified polymer sealant, caulk
<b>Trim (interior)</b>	Latex sealant	Silicone sealant, caulk

## VII. Insulation and Air-Sealing Products Excluded From Recommendations

We were unable to evaluate all products currently available, and some exciting new products are not yet commercially available. The table below gives examples of products we considered, but were unable to include in our evaluation and the reasons for their exclusion.

**TABLE 12. PRODUCTS EXCLUDED FROM CONSIDERATION**

Product Type	Reason(s) for Exclusion
Mycelium insulation (Mushroom insulation)	Appears to be a good option from a health perspective. Currently available in limited quantities for select projects.
Cellular glass board insulation (Foamglas)	Appears to be a good option from a health perspective. Seems to be limited distribution, and no longer marketed for general insulation purposes.
Sheep's Wool insulation	Appears to have somewhat limited availability and high cost. Similar levels of boric acid as in cellulose insulation, so does not seem to be a better option than cellulose from a health perspective and costs are significantly higher.
Wood foam board	Currently in research phase, could potentially be a good option once developed. More specific information on content and process would be needed.
Blown rock and slag wool	Unable to locate actual products available as blown rock and/or slag wool. If available, the health profiles would be like that of loose-fill fiber glass, with the additional potential for some heavy metal emissions in production and residuals in the products because of the incorporation of slag.
Polyester fiber	This product doesn't seem to be available. Some products have been discontinued. May still be produced in Australia and New Zealand.
Foamed concrete (Cementitious foam, Airkrete)	Foamed concrete is most likely a preferable alternative to spray foam but disclosure is limited. This product does not use blowing agents with high global warming potential or halogenated flame retardants, which are common in SPF. But, because of the lack of disclosure, the product cannot be fully checked for hazardous content. Based on the most recent patent literature, about 11% of the product is a proprietary expanding agent that we could not further identify. Because of the unknown content, HBN does not recommend foamed concrete.
Elastomeric spray sealant (Knauf Ecosseal, Owens Corning EnergyComplete)	There is currently little disclosure on the contents of these products. Lacking transparency, we do not feel comfortable recommending them. Communication with the manufacturers indicates that both products are free of content on the ILFI Red List. With further content disclosure, these products could prove to be good air-sealing alternatives.
Nonisocyanate spray foam (Hybridsil, Green Polyurethane)	A couple of variations of nonisocyanate spray foam insulation are reported to be under development, but none are currently available.
Nonisocyanate one-part spray foam (can type)	As with the elastomeric spray sealant, there is limited disclosure on the content of these products. The chemistry appears to vary between acrylic, latex, and silyl-modified polymer. Based on a patent review, there is the possibility that phthalate plasticizers, flame retardants, and blowing agents with high global warming potential are included. More product disclosure is needed before this type of product can be recommended.
Foam gaskets (for sealing top and bottom of wall plates)	This type of product was mentioned in only one survey and it does not appear that it would be common in an upgrade application, so it was not further investigated.

## VIII. Code Considerations

Specific building code requirements can vary for different jurisdictions, but most state and local building codes are based on those developed by the International Code Council.<sup>125</sup> Affordable multifamily housing buildings fall either under the International Residential Code (for one- and two-family dwellings, not more than three stories above grade) or the International Building Code.<sup>126</sup> Some of the recommended products may not meet code requirements for all applications, jurisdictions, or building types. Check that any products that are used meet the code requirements of a project.

Building codes do not have requirements that specify the use of certain chemicals. Codes do require that products meet performance criteria for certain applications, and chemicals might be added to products to ensure they meet these requirements. For example, flame retardant chemicals are usually added to plastic foam insulation to meet flammability standards.<sup>127</sup>

Codes require, with certain exceptions and modifications, that insulation products have a flame spread rating of no more than 25 and a smoke developed index of no more than 450 (as measured by the ASTM E84 or UL 723 standard test methods).<sup>128</sup> This is sometimes referred to as a Class A or Class I rating. The recommended insulation materials meet this requirement without additional treatment, except for expanded cork insulation that is Class B rated and kraft-faced insulation, for which the facing is flammable and therefore should not be left exposed.<sup>129</sup> Foam insulation products often need to be covered by a thermal barrier (like 1/2-inch drywall) or ignition barrier (like 1/4-inch plywood) to meet code requirements.<sup>130</sup>

For some applications, sealants may need to have certain flammability or fire-resistance ratings, including Class A, fireblock (ASTM E136), or firestop (ASTM E814). Within the recommended products, there are options for fireblock sealants (noncombustible sodium silicate) and firestop sealants (acrylic firestop), and some acrylic latex sealants are Class A rated.<sup>131</sup> Check with specific product manufacturers for information on flammability ratings of their products and other product performance questions.

## References

- 1 Bruce Tonn et al., *Health and Household-Related Benefits Attributable to the Weatherization Assistance Program* (Oak Ridge National Laboratory, 2014), [weatherization.ornl.gov/Retrospectivepdfs/ORNL\\_TM-2014\\_345.pdf](http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2014_345.pdf); Scott Pigg et al., *Weatherization and Indoor Air Quality: Measured Impacts in Single-Family Homes Under the Weatherization Assistance Program* (Oak Ridge National Laboratory, 2014), [weatherization.ornl.gov/Retrospectivepdfs/ORNL\\_TM-2014\\_170.pdf](http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2014_170.pdf); Philippa Howden-Chapman et al., *Effect of insulating existing houses on health inequality: cluster randomised study in the community* (BMJ Publishing Group Ltd: 2007), doi.org/10.1136/bmj.39070.573032.80.
- 2 BlueGreen Alliance Foundation, *Guide to Healthier Energy Efficient Housing Products: Focus on Insulation* (2016), [www.bgafoundation.org/wp-content/uploads/2016/08/BGAF-Guide-to-Insulation\\_2016.pdf](http://www.bgafoundation.org/wp-content/uploads/2016/08/BGAF-Guide-to-Insulation_2016.pdf); Bruce Tonn, et al., *Health and Household-Related Benefits Attributable to the Weatherization Assistance Program* (Oak Ridge National Laboratory, 2014), [weatherization.ornl.gov/Retrospectivepdfs/ORNL\\_TM-2014\\_345.pdf](http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2014_345.pdf); Scott Pigg et al., *Weatherization and Indoor Air Quality: Measured Impacts in Single-Family Homes Under the Weatherization Assistance Program* (Oak Ridge National Laboratory, 2014), [weatherization.ornl.gov/Retrospectivepdfs/ORNL\\_TM-2014\\_170.pdf](http://weatherization.ornl.gov/Retrospectivepdfs/ORNL_TM-2014_170.pdf); Philippa Howden-Chapman et al., *Effect of insulating existing houses on health inequality: cluster randomised study in the community* (BMJ Publishing Group Ltd: 2007), doi.org/10.1136/bmj.39070.573032.80.
- 3 EPA's Report on the Environment: Indoor Air Quality (U.S. EPA, Office of Research and Development), (n.d.), [cfpub.epa.gov/roe/chapter/air/indoorair.cfm](http://cfpub.epa.gov/roe/chapter/air/indoorair.cfm).
- 4 Charles J. Weschler, "Changes in indoor pollutants since the 1950s," *Atmospheric Environment*, 43, no. 1 (2009), pp. 153–69, doi.org/10.1016/j.atmosenv.2008.09.044.
- 5 I. Broder, et al., "Comparison of health of occupants and characteristics of houses among control homes and homes insulated with urea formaldehyde foam. II. Initial health and house variables and exposure-response relationships," *Environmental Research*, 45, no. 2 (1988), pp. 156-178.
- 6 Washington State Department of Labor & Industries, *Isocyanate-based foam and Work-Related Asthma*, 2017, [www.ini.wa.gov/safety/research/files/42\\_03\\_2017\\_isocyanate\\_foam.pdf](http://www.ini.wa.gov/safety/research/files/42_03_2017_isocyanate_foam.pdf).
- 7 D. Lefkowitz et al., "Isocyanates and work-related asthma: Findings from California, Massachusetts, Michigan and New Jersey, 1993-2008," *American Journal of Industrial Medicine*, 58, no. 11 (2015), pp. 1138-1149; JG Ayres et al., "Costs of occupational asthma in the UK," *Thorax*, 66, no. 2, (2011), pp. 128 - 133.
- 8 Teresa M. Attina et al., "Exposure to endocrine-disrupting chemicals in the USA: a population-based disease burden and cost analysis," *The Lancet Diabetes & Endocrinology*, 4, no. 12 (2016), pp. 996-1003, doi.org/10.1016/S2213-8587(16)30275-3.
- 9 Carl-Gustaf Bornehag et al., "Phthalates in Indoor Dust and Their Association with Building Characteristics," *Environmental Health Perspectives*, 113, no. 10 (2005), pp. 1399-1404.
- 10 Benjamin Chavis, *Toxic Wastes and Race In The United States: A National Report on the Racial and Socio-Economic Characteristics of Communities with Hazardous Waste Sites* (Commission for Racial Justice, United Church of Christ, 1987), <https://www.nrc.gov/docs/ML1310/ML13109A339.pdf>.
- 11 Jim Vallette, "Residential Fiber Glass Insulation Transformed: Formaldehyde is No More," Healthy Building Network, 30 October 2015, <https://healthybuilding.net/news/2015/10/30/residential-fiberglass-insulation-transformed-formaldehyde-is-no-more>.
- 12 Ibid.
- 13 Alice Bernard and Vito Buonsante, *Keeping It Clean: How to Protect the Circular Economy from Hazardous Substances* (Brussels: European Environmental Bureau, 2017), [eeb.org/publications/83/waste-and-recycling/1651/keeping-it-clean-how-to-protect-the-circular-economy-from-hazardous-substances.pdf](http://eeb.org/publications/83/waste-and-recycling/1651/keeping-it-clean-how-to-protect-the-circular-economy-from-hazardous-substances.pdf).
- 14 Safer Chemicals, Healthy Families; Environmental Health Strategy Center; and Healthy Building Network; *Comments to the U.S. Environmental Protection Agency (EPA) on the Scope of Its Risk Evaluation for the TSCA Work Plan Chemicals: CYCLIC ALIPHATIC BROMIDE CLUSTER or HEXABROMOCYCLODODECANE (HBCD) CAS Reg. Nos. 25637-99-4, 3194-55-6, 3194-57-8* (2017), [healthybuilding.net/uploads/files/saferchemicals-hbcd.pdf](http://healthybuilding.net/uploads/files/saferchemicals-hbcd.pdf).
- 15 Tracey Easthope and Laurie Valeriano, *Background Paper for Reform No. 2 of the Louisville Charter for Safer Chemicals* (The Louisville Charter, 2005), [smartpolicyreform.org/assets/media/documents/CharterBkgrdPaper2.pdf](http://smartpolicyreform.org/assets/media/documents/CharterBkgrdPaper2.pdf).
- 16 U.S. EPA, *Flame Retardant Alternatives for Hexabromocyclododecane (HBCD)* (2014), [www2.epa.gov/sites/production/files/2014-06/documents/hbcd\\_report.pdf](http://www2.epa.gov/sites/production/files/2014-06/documents/hbcd_report.pdf).
- 17 Charles W. Schmidt, "TSCA 2.0: A New Era in Chemical Risk Management," *Environmental Health Perspectives*, 124, no. 10 (2016), [ehp.niehs.nih.gov/124-A182/](http://ehp.niehs.nih.gov/124-A182/); U.S. Government Accountability Office, *Chemical Regulation: Options Exist to Improve EPA's Ability to Assess Health Risks and Manage Its Chemical Review Program* (2005), [www.gao.gov/assets/250/246667.pdf](http://www.gao.gov/assets/250/246667.pdf); Testimony of James Jones, Assistant Administrator, Office of Chemical Safety and Pollution Prevention, U.S. Environmental Protection Agency, Before the Committee on Energy and Commerce Committee, Environment and the Economy Subcommittee, United States Congress, 14 April 2015, [www.epa.gov/sites/production/files/2015-08/documents/epa\\_test.tscas\\_4.14.15.pdf](http://www.epa.gov/sites/production/files/2015-08/documents/epa_test.tscas_4.14.15.pdf); U.S. EPA, *Toxic Substances Control Act (TSCA) and Federal Facilities*, 2017, [www.epa.gov/enforcement/toxic-substances-control-act-tscas-and-federal-facilities](http://www.epa.gov/enforcement/toxic-substances-control-act-tscas-and-federal-facilities).

- 18 Warren E. Leary, "Appeals Court Strikes Down Major Parts of Federal Asbestos Ban," *New York Times*, 22 October 1991, [www.nytimes.com/1991/10/22/us/appeals-court-strikes-down-major-parts-of-federal-asbestos-ban.html](http://www.nytimes.com/1991/10/22/us/appeals-court-strikes-down-major-parts-of-federal-asbestos-ban.html).
- 19 Environmental Protection Agency (EPA) on the Scope of Its Risk Evaluation for the TSCA Work Plan Chemical: ASBESTOS CAS Reg. No. 1332-21-4, 15 March 2017, [healthybuilding.net/uploads/files/saferchemicals-asbestos.pdf](http://healthybuilding.net/uploads/files/saferchemicals-asbestos.pdf).
- 20 U.S. EPA, *EPA Names First Chemicals for Review Under New TSCA Legislation*, 2016, [https://19january2017snapshot.epa.gov/newsreleases/epa-names-first-chemicals-review-under-new-tsca-legislation\\_.html](https://19january2017snapshot.epa.gov/newsreleases/epa-names-first-chemicals-review-under-new-tsca-legislation_.html).
- 21 California Air Resources Board, *Reactivity Program*, 2016, [www.arb.ca.gov/research/reactivity/reactivity.htm](http://www.arb.ca.gov/research/reactivity/reactivity.htm).
- 22 California Air Resources Board, *Architectural Coatings Program-VOC Limits*, 2015, [www.arb.ca.gov/coatings/arch/VOCLimits.htm](http://www.arb.ca.gov/coatings/arch/VOCLimits.htm); California Air Resources Board, *Current Regulations: Consumer Products Regulations*, 2015, [www.arb.ca.gov/consprod/regs/regs.htm](http://www.arb.ca.gov/consprod/regs/regs.htm); California Air Resources Board, *Composite Wood Products Airborne Toxic Control Measure*, 2018, [www.arb.ca.gov/toxics/compwood/compwood.htm](http://www.arb.ca.gov/toxics/compwood/compwood.htm).
- 23 Francis J. Offermann, *Ventilation and Indoor Air Quality in New Homes* (California Energy Commission, 2009), [www.arb.ca.gov/research/apr/past/04-310.pdf](http://www.arb.ca.gov/research/apr/past/04-310.pdf).
- 24 United Nations Environment Programme, *Hexabromocyclododecane Risk Management Evaluation: Report of the Persistent Organic Pollutants Review Committee on the work of its seventh meeting* (2011), [echa.europa.eu/documents/10162/18074545/a4a\\_comment\\_551\\_1\\_attachment\\_en.pdf](http://echa.europa.eu/documents/10162/18074545/a4a_comment_551_1_attachment_en.pdf).
- 25 Charles J. Weschler and William W. Nazaroff, "Semivolatile organic compounds in indoor environments," *Atmospheric Environment*, 42, no. 40 (2008), pp. 9018–40, [doi.org/10.1016/j.atmosenv.2008.09.052](https://doi.org/10.1016/j.atmosenv.2008.09.052).
- 26 International Living Future Institute, *The Red List*, [living-future.org/declare/declare-about/red-list/](http://living-future.org/declare/declare-about/red-list/) (December 19, 2017).
- 27 Vytenis Babrauskas et al., "Flame retardants in building insulation: a case for re-evaluating building codes," *Building Research & Information*, 40, no. 6 (2012), pp. 738–55, [dx.doi.org/10.1080/09613218.2012.744533](https://doi.org/10.1080/09613218.2012.744533).
- 28 Tom Lent, *Formaldehyde emissions from fiber glass insulation with phenol formaldehyde binder* (Healthy Building Network, 2009), [healthybuilding.net/uploads/files/formaldehyde-emissions-from-fiber-glass-insulation-with-phenol-formaldehyde-binder.pdf](http://healthybuilding.net/uploads/files/formaldehyde-emissions-from-fiber-glass-insulation-with-phenol-formaldehyde-binder.pdf).
- 29 Centers for Disease Control and Prevention, *Hierarchy of Controls*, 2016, [www.cdc.gov/niosh/topics/hierarchy/](http://www.cdc.gov/niosh/topics/hierarchy/); Paul Anastas and John Warner, *Green Chemistry: Theory and Practice* (New York: Oxford University Press, 1998).
- 30 Centers for Disease Control and Prevention, *Hierarchy of Controls*, 2016, [www.cdc.gov/niosh/topics/hierarchy/](http://www.cdc.gov/niosh/topics/hierarchy/).
- 31 U.S. Department of Energy, *Building Science-Based Climate Maps*, 2013, [energy.gov/sites/prod/files/2014/01/f6/4\\_3a\\_ba\\_innov\\_buildingscienceclimatemaps\\_011713.pdf](http://energy.gov/sites/prod/files/2014/01/f6/4_3a_ba_innov_buildingscienceclimatemaps_011713.pdf).
- 32 The Pharos Project of the Healthy Building Network, *Chemical & Material Library: Full System Description*, 2017, [www.pharosproject.net/uploads/files/library/Pharos\\_CML\\_System\\_Description.pdf](http://pharosproject.net/uploads/files/library/Pharos_CML_System_Description.pdf).
- 33 Gordian RS Means, *Building Construction Cost Data*, <https://www.rsmeans.com/>; BuildingGreen, *The BuildingGreen Guide to Insulation* (2012); Leroy Anthony, "Insulating With Damp-Spray Cellulose," *Green Building Blogs*, 26 March 2015, [www.greenbuildingadvisor.com/articles/dept/green-building-blog/insulating-damp-spray-cellulose](http://www.greenbuildingadvisor.com/articles/dept/green-building-blog/insulating-damp-spray-cellulose); Zero By Degrees, *What Does Insulation Cost?*, 2016, [www.insulation-guide.com/insulation-cost.html](http://www.insulation-guide.com/insulation-cost.html); The Municipal Art Society of New York, *Greening NYC's Historic Buildings: Green Rowhouse Manual* (2012), [www.nyc.gov/html/lpc/downloads/pdf/pubs/Manual%20-%20Greening%20Rowhouses%20-%202012.pdf](http://www.nyc.gov/html/lpc/downloads/pdf/pubs/Manual%20-%20Greening%20Rowhouses%20-%202012.pdf); U.S. Department of Energy, *Guide to Home Insulation*, 2010, [energy.gov/sites/prod/files/guide\\_to\\_home\\_insulation.pdf](http://energy.gov/sites/prod/files/guide_to_home_insulation.pdf); Insulation Materials, *Insulation Materials*, [www.insulationmaterials.com/](http://www.insulationmaterials.com/); Personal Communication with Small Planet Supply; Jelinek Cork Group, "Semi Rigid Insulation Cork | Expanded Cork Board for Insulation," [www.corkstore.com/Products/Cork-Sheet-insulation](http://www.corkstore.com/Products/Cork-Sheet-insulation).
- 34 U.S. EPA, *TSCA Work Plan Chemical Problem Formulation and Initial Assessment: Chlorinated Phosphate Ester Cluster Flame Retardants* (2015), [www.epa.gov/sites/production/files/2015-09/documents/cpe\\_fr\\_cluster\\_problem\\_formulation.pdf](http://www.epa.gov/sites/production/files/2015-09/documents/cpe_fr_cluster_problem_formulation.pdf); European Commission Scientific Committee on Health and Environmental Risks, *Opinion on tris(2-Chloroethyl)phosphate (TCEP) in Toys* (2012), [ec.europa.eu/health/sites/health/files/scientific\\_committees/environmental\\_risks/docs/scher\\_o\\_158.pdf](http://ec.europa.eu/health/sites/health/files/scientific_committees/environmental_risks/docs/scher_o_158.pdf).
- 35 Gordian RS Means, *Building Construction Cost Data*, <https://www.rsmeans.com/>; Bud Fraser et al., *Mechanical Insulation Guide and Specifications for British Columbia* draft (2012), [mispec.org/wp-content/uploads/2013/03/Mechanical-Insulation-Guide-for-BC-Aug-7-2012.pdf](http://mispec.org/wp-content/uploads/2013/03/Mechanical-Insulation-Guide-for-BC-Aug-7-2012.pdf); The Home Depot, [www.homedepot.com/](http://www.homedepot.com/).
- 36 Blue Green Alliance Foundation, *Guide to Healthier Energy Efficient Housing Products: Focus on Insulation* (2016), [www.bgafoundation.org/wp-content/uploads/2016/08/BGAF-Guide-to-Insulation\\_2016.pdf](http://www.bgafoundation.org/wp-content/uploads/2016/08/BGAF-Guide-to-Insulation_2016.pdf).
- 37 Shawna Henderson, "The Consequences of Improperly Installed Batt Insulation," *SBC Magazine*, 6 March 2017, [www.sbcmag.info/news/2017/mar/consequences-improperly-installed-batt-insulation](http://www.sbcmag.info/news/2017/mar/consequences-improperly-installed-batt-insulation); Insulation Institute, *Home Insulation: Achieving Grade 1 Installation*, [insulationinstitute.org/im-a-building-or-facility-professional/residential/installation-guidance-2/grade-1-installation/](http://insulationinstitute.org/im-a-building-or-facility-professional/residential/installation-guidance-2/grade-1-installation/).

- 38 The Cellulose Insulation Manufacturers Association, *Standard practice for installing cellulose building insulation* (Dayton, Ohio), [www.cellulose.org/userdocs/CIMA-TechnicalBulletin02.pdf](http://www.cellulose.org/userdocs/CIMA-TechnicalBulletin02.pdf); Cellulose Insulation Manufacturers Association, *Settling The Myth About Cellulose Insulation Settling*, 2016, [cellulose.org/GreenestInsulation/2016/02/19/settling-the-myth-about-cellulose-insulation-settling/](http://cellulose.org/GreenestInsulation/2016/02/19/settling-the-myth-about-cellulose-insulation-settling/); C.J. Schumacher, M.J. Fox, and J. Lstiburek, *Airflow Resistance of Loose-Fill Mineral Fiber Insulations in Retrofit Applications* (U.S. Department of Energy, 2015), [www.nrel.gov/docs/fy15osti/63081.pdf](http://www.nrel.gov/docs/fy15osti/63081.pdf).
- 39 Mason Knowles, "Troubleshooting Spray-Foam Insulation," *The Journal of Light Construction* (2010), [www.jlconline.com/how-to/insulation/troubleshooting-spray-foam-insulation\\_o](http://www.jlconline.com/how-to/insulation/troubleshooting-spray-foam-insulation_o).
- 40 475 High Performance Building Supply, *Foam Fails Reason #5: Excessive Shrinkage*, 2014, [foursevenfive.com/foam-fails-reason-5-excessive-shrinkage/](http://foursevenfive.com/foam-fails-reason-5-excessive-shrinkage/); Jamie Kaye, "GUEST POST: Spray Foam, Infrared Cameras, & the New Big Holes," *The Energy Vanguard*, 21 March 2012, [www.energyvanguard.com/blog/52381/GUEST-POST-Spray-Foam-Infrared-Cameras-the-New-Big-Holes](http://www.energyvanguard.com/blog/52381/GUEST-POST-Spray-Foam-Infrared-Cameras-the-New-Big-Holes).
- 41 Dustin G. Poppendieck et al., *Lessons Learned from Spray Polyurethane Foam Emission Testing using Micro-chambers* (American Chemistry Council, 2016), [ws680.nist.gov/publication/get\\_pdf.cfm?pub\\_id=921259](http://ws680.nist.gov/publication/get_pdf.cfm?pub_id=921259).
- 42 Mason Knowles, "Troubleshooting Spray-Foam Insulation," *The Journal of Light Construction* (2010), [www.jlconline.com/how-to/insulation/troubleshooting-spray-foam-insulation\\_o](http://www.jlconline.com/how-to/insulation/troubleshooting-spray-foam-insulation_o); Melanie B. Biggs, *Status Report: Staff Review of Five Amine Catalysts in Spray Polyurethane Foam*, (United States Consumer Product Safety Commission, 2012), [www.cpsc.gov/PageFiles/129845/amine.pdf](http://www.cpsc.gov/PageFiles/129845/amine.pdf).
- 43 CertainTeed Insulation, *Technical Bulletin #78: Recommended Fiber Glass Installation Guidelines*, 2007, [www.certainteed.com/resources/TB\\_\\_78\\_-\\_Recommended\\_Fiber\\_Glass\\_Installation\\_Guidelines.pdf](http://www.certainteed.com/resources/TB__78_-_Recommended_Fiber_Glass_Installation_Guidelines.pdf); North American Insulation Manufacturers Association, *Working Smart with Fiber Glass, Rock Wool and Slag Wool Products: Recommended Work Practices for the Installation of Synthetic Vitreous Fibers (SVF)*, 2003, [insulationinstitute.org/wp-content/uploads/2016/02/N027.pdf](http://insulationinstitute.org/wp-content/uploads/2016/02/N027.pdf).
- 44 Robert McCleery et al., *NIOSH Exposure Assessment of Cellulose Insulation Applicators* (National Institute for Occupational Safety and Health, 2001), [www.cdc.gov/niosh/hhe/reports/pdfs/2000-0332-2827.pdf](http://www.cdc.gov/niosh/hhe/reports/pdfs/2000-0332-2827.pdf); GreenFiber, *Cellulose Insulation, Loose Fill Borate Formula (Safety Data Sheet)*, 2015, <https://www.buildsite.com/pdf/greenfiber/GreenFiber-All-Borate-Loose-Fill-Insulation-SDS-974270.pdf>.
- 45 U.S. EPA, *Spray Polyurethane Foam Product Types*, [www.epa.gov/saferchoice/spray-polyurethane-foam-product-types](http://www.epa.gov/saferchoice/spray-polyurethane-foam-product-types); OSHA, *Health and Safety Practices for SPF Applications*, [www.osha.gov/dte/grant\\_materials/fy10/sh-21003-10/manual.pdf](http://www.osha.gov/dte/grant_materials/fy10/sh-21003-10/manual.pdf).
- 46 U.S. EPA, *Health Concerns about Spray Polyurethane Foam*, [www.epa.gov/saferchoice/health-concerns-about-spray-polyurethane-foam](http://www.epa.gov/saferchoice/health-concerns-about-spray-polyurethane-foam); Dennis Fengmao Guo et al., *Summary of Technical Information and Scientific Conclusions for Designating Spray Polyurethane Foam Systems with Unreacted Methylene Diphenyl Diisocyanates as a Priority Product* (California Environmental Protection Agency, 2017), [www.dtsc.ca.gov/SCP/upload/SPF-Systems-Summary-of-Technical-Information.pdf](http://www.dtsc.ca.gov/SCP/upload/SPF-Systems-Summary-of-Technical-Information.pdf).
- 47 Dennis Fengmao Guo et al., *Summary of Technical Information and Scientific Conclusions for Designating Spray Polyurethane Foam Systems with Unreacted Methylene Diphenyl Diisocyanates as a Priority Product*; U.S. EPA, *Potential Chemical Exposures From Spray Polyurethane Foam*, [www.epa.gov/saferchoice/potential-chemical-exposures-spray-polyurethane-foam](http://www.epa.gov/saferchoice/potential-chemical-exposures-spray-polyurethane-foam).
- 48 Aaron Gouveia, "'Green' insulation suspected as cause of fatal fire," *Cape Cod Times*, 20 May 2008, [web.archive.org/web/20130131034138/http://www.capecodonline.com:80/apps/pbcs.dll/article?AID=/20080520/NEWS/805200318/-1/rss01](http://web.archive.org/web/20130131034138/http://www.capecodonline.com:80/apps/pbcs.dll/article?AID=/20080520/NEWS/805200318/-1/rss01); Martin Holladay, "Three Massachusetts Home Fires Linked to Spray-Foam Installation," *Green Building News*, 16 August 2011, [www.greenbuildingadvisor.com/blogs/dept/green-building-news/three-massachusetts-home-fires-linked-spray-foam-installation](http://www.greenbuildingadvisor.com/blogs/dept/green-building-news/three-massachusetts-home-fires-linked-spray-foam-installation); "Spontaneous combustion of insulation blamed in Stella's fire," *CBC News*, 8 October 2015, [www.cbc.ca/news/canada/manitoba/spontaneous-combustion-of-insulation-blamed-in-stella-s-fire-1.3263923](http://www.cbc.ca/news/canada/manitoba/spontaneous-combustion-of-insulation-blamed-in-stella-s-fire-1.3263923); Debra Bogstie, "Homeowner Moves On After Devastating Middlebury Fire," *NBC Connecticut*, 14 July 2014, [www.nbcconnecticut.com/news/local/Homeowner-Moves-On-After-Devastating-Fire-267070781.html](http://www.nbcconnecticut.com/news/local/Homeowner-Moves-On-After-Devastating-Fire-267070781.html).
- 49 California's Worker Occupational Safety and Health Training and Education Program, *SPF Insulation is Energy-Efficient, but is it Safe for Workers?*, 2013, [www.dir.ca.gov/chswc/WOSHTEP/Publications/Spray\\_Polyurethane.pdf](http://www.dir.ca.gov/chswc/WOSHTEP/Publications/Spray_Polyurethane.pdf); U.S. EPA, *Vacate and Safe Re-Entry Time for Spray Polyurethane Foam Application*, [www.epa.gov/saferchoice/vacate-and-safe-re-entry-time-spray-polyurethane-foam-application](http://www.epa.gov/saferchoice/vacate-and-safe-re-entry-time-spray-polyurethane-foam-application).
- 50 U.S. EPA, *Quick Safety Tips for Spray Polyurethane Foam Users*, [www.epa.gov/saferchoice/quick-safety-tips-spray-polyurethane-foam-users](http://www.epa.gov/saferchoice/quick-safety-tips-spray-polyurethane-foam-users).
- 51 Dennis Fengmao Guo et al., *Summary of Technical Information and Scientific Conclusions for Designating Spray Polyurethane Foam Systems with Unreacted Methylene Diphenyl Diisocyanates as a Priority Product*.
- 52 Michael Lax et al., *Comments on Green Seal GS-54 Proposed Standard* (Occupational Health Clinical Centers, 2016).
- 53 Centers for Disease Control and Prevention, *Hierarchy of Controls*, 2016, [www.cdc.gov/niosh/topics/hierarchy/](http://www.cdc.gov/niosh/topics/hierarchy/); Dennis Fengmao Guo et al., *Summary of Technical Information and Scientific Conclusions for Designating Spray Polyurethane Foam Systems with Unreacted Methylene Diphenyl Diisocyanates as a Priority Product*.
- 54 Dennis Fengmao Guo et al., *Summary of Technical Information and Scientific Conclusions for Designating Spray Polyurethane Foam Systems with Unreacted Methylene Diphenyl Diisocyanates as a Priority Product*.

- 55 *South Coast Air Quality Management District Rule 1168. Adhesive and Sealant Applications*, 2017, [www.aqmd.gov/docs/default-source/rule-book/reg-xi/rule-1168.pdf](http://www.aqmd.gov/docs/default-source/rule-book/reg-xi/rule-1168.pdf).
- 56 The Home Depot, [www.homedepot.com/](http://www.homedepot.com/) (November 2016); Gordian RS Means, *Building Construction Cost Data*, <https://www.rsmeans.com/> (January 2017); Lowe's, [www.lowes.com/](http://www.lowes.com/) (November 2016); Grainger, [www.grainger.com/](http://www.grainger.com/) (December 2016); Roof Things, [www.roofthings.com](http://www.roofthings.com) (January 2017).
- 57 U.S. EPA, *TSCA Work Plan Chemical Problem Formulation and Initial Assessment: Chlorinated Phosphate Ester Cluster Flame Retardants* (2015); European Commission Scientific Committee on Health and Environmental Risks, *Opinion on tris(2-Chloroethyl) phosphate (TCEP) in Toys* (2012).
- 58 Grainger, [www.grainger.com/](http://www.grainger.com/) (December 2016); Amazon, [www.amazon.com/](http://www.amazon.com/) (December 2016); Conservation Mart, [www.conservationsmart.com/](http://www.conservationsmart.com/) (November 2016).
- 59 Dap Products, *Touch N' Foam Multi-Purpose Foam Sealant*, <https://web.archive.org/web/20170427101050/www.touch-n-foam.com/easy-fill.html>; Soudal N.V., *SoudaFoam SMX*, [www.soudal.com/soudalweb/productDetail.aspx?p=410&ID=1984](http://www.soudal.com/soudalweb/productDetail.aspx?p=410&ID=1984) (March 24, 2017); DAP, *DAPtex Plus Multi-Purpose Foam Sealant*, [www.dap.com/dap-products-ph/daptex-plus-multi-purpose-foam-sealant/](http://www.dap.com/dap-products-ph/daptex-plus-multi-purpose-foam-sealant/) (March 24, 2017).
- 60 Bill Walsh, "Perkins + Will Adds Antimicrobial Products to Precautionary List," *Healthy Building News*, 1 March 2017, [healthybuilding.net/news/2017/03/01/perkins-will-adds-antimicrobial-products-to-precautionary-list](http://healthybuilding.net/news/2017/03/01/perkins-will-adds-antimicrobial-products-to-precautionary-list).
- 61 Everett M. Rogers, *Diffusion of Innovations*, Fifth Edition (New York: Free Press, 2003).
- 62 Building Performance Institute Inc., *Healthy Home Evaluator*, [www.bpi.org/certified-professionals/healthy-home-evaluator](http://www.bpi.org/certified-professionals/healthy-home-evaluator).
- 63 Eva C. Bonfeld-Jørgensen et al. "Endocrine-Disrupting Potential of Bisphenol A, Bisphenol A Dimethacrylate, 4-n-Nonylphenol, and 4-n-Octylphenol in Vitro: New Data and a Brief Review," *Environmental Health Perspectives*, 115, suppl. 1 (2007), pp. 69-76, doi.org/10.1289/ehp.9368.
- 64 Common Product sources in the Pharos Building Product Library were consulted for the properties in this table. Additional sources include:

**R-value:** CertainTeed, *Basement Wall Blanket Insulation (Specification Sheet)*, 2016, [certainteed.com/resources/30-45-052.pdf](http://certainteed.com/resources/30-45-052.pdf); Knauf Insulation, *Basement Wall Insulation with Ecos Technology (Data Sheet)*, 2016, [www.knaufinsulation.us/sites/us.knaufinsulation.com/files/BI-BWI-DS-new.pdf](http://www.knaufinsulation.us/sites/us.knaufinsulation.com/files/BI-BWI-DS-new.pdf); **Cost:** Gordian RS Means, *Building Construction Cost Data* (January 2017); BuildingGreen, *Insulation: The BuildingGreen Guide to Insulation Products and Practices* (2012); Leroy Anthony, "Insulating With Damp-Spray Cellulose," *Green Building Blogs*, 26 March 2015; Zero By Degrees, *What Does Insulation Cost?*, [www.insulation-guide.com/insulation-cost.html](http://www.insulation-guide.com/insulation-cost.html) (February 3, 2017); The Municipal Art Society of New York, *Greening NYC's Historic Buildings: Green Rowhouse Manual* (2012); U.S. Department of Energy, *Guide to Home Insulation*, 2010, [energy.gov/sites/prod/files/guide\\_to\\_home\\_insulation.pdf](http://energy.gov/sites/prod/files/guide_to_home_insulation.pdf); *Insulation Materials*, [www.insulationmaterials.com/](http://www.insulationmaterials.com/) (February 3, 2017); Personal Communication with Small Planet Supply; Jelinek Cork Group, *Semi Rigid Insulation Cork | Expanded Cork Board for Insulation*, [www.corkstore.com/Products/Cork-Sheet-insulation](http://www.corkstore.com/Products/Cork-Sheet-insulation) (February 3, 2017); Mason Knowles, "Troubleshooting Spray-Foam Insulation," *The Journal of Light Construction* (2010); U.S. Department of Energy, *Types of Insulation*, [energy.gov/energysaver/types-insulation](http://energy.gov/energysaver/types-insulation) (May 16, 2017); **Vapor retarder:** U.S. Department of Energy, *Building America Top Innovations Hall of Fame Profile: Vapor Retarder Classification*, 2013, [energy.gov/sites/prod/files/2014/01/f6/4\\_3b\\_ba\\_innov\\_vaporretarderclassification\\_011713.pdf](http://energy.gov/sites/prod/files/2014/01/f6/4_3b_ba_innov_vaporretarderclassification_011713.pdf); BuildingGreen, *Insulation: The BuildingGreen Guide to Insulation Products and Practices* (2012); U.S. Department of Energy, *Vapor Barriers or Vapor Diffusion Retarders*, n.d., [energy.gov/energysaver/vapor-barriers-or-vapor-diffusion-retarders](http://energy.gov/energysaver/vapor-barriers-or-vapor-diffusion-retarders); Mason Knowles, "Troubleshooting Spray-Foam Insulation," *The Journal of Light Construction* (2010); Cellulose Insulation Manufacturers Association, *Cellulose Insulation Manages Moisture Without Air/Vapor Barriers*, n.d., [www.cellulose.org/BuildersContractors/AirVaporBarriers.php](http://www.cellulose.org/BuildersContractors/AirVaporBarriers.php); Joseph Lstiburek, "Understanding Vapor Barriers," *Building Science Digest*, 24 April 2011, [buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers](http://buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers); Peter Baker, *GM-0702: Guide to Insulating Sheathing* (Building Science Corporation, 2007), [buildingscience.com/documents/guides-and-manuals/gm-guide-insulating-sheathing/view](http://buildingscience.com/documents/guides-and-manuals/gm-guide-insulating-sheathing/view); National Association of Home Builders, *Floors above Crawl Spaces: Reducing the Risk of Moisture Accumulation within Wood Floor Assemblies*, 2014, [www.homeinnovation.com/-/media/Files/Reports/TechNotes-Floors-above-Crawl-Spaces-June-2014.pdf](http://www.homeinnovation.com/-/media/Files/Reports/TechNotes-Floors-above-Crawl-Spaces-June-2014.pdf); Joseph Lstiburek, *Insulations, Sheathings and Vapor Retarders* (Building Science Corporation, 2004), [buildingscience.com/documents/reports/rr-0412-insulations-sheathings-and-vapor-retarders/view](http://buildingscience.com/documents/reports/rr-0412-insulations-sheathings-and-vapor-retarders/view); Martin Holladay, "All About Vapor Diffusion," 12 June 2015, <http://www.greenbuildingadvisor.com/blogs/dept/musings?page=15>; Building Science Corporation, *Info-500: Building Materials Property Table*, 2015, [buildingscience.com/documents/information-sheets/building-materials-property-table](http://buildingscience.com/documents/information-sheets/building-materials-property-table); **Air barrier:** Wagdy Anis, *Air Barrier Systems in Buildings* (Whole Building Design Guide, 2016), [www.wbdg.org/resources/air-barrier-systems-buildings](http://www.wbdg.org/resources/air-barrier-systems-buildings); S. Roberts and R. Stephenson, *Measure Guideline: Wall Air Sealing and Insulation Methods in Existing Homes; An Overview of Opportunity and Process* (U.S. Department of Energy, 2012), [https://www1.eere.energy.gov/buildings/publications/pdfs/building\\_america/measure\\_guide\\_wall\\_airsealing.pdf](https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_wall_airsealing.pdf); BuildingGreen, *Insulation: The BuildingGreen Guide to Insulation Products and Practices* (2012); DuPont, *Weather Barriers Are a Must with Exterior Foam Sheathing*, 2011, <https://web.archive.org/web/20170307042008/http://www.dupont.com/content/dam/assets/products-and-services/construction-materials/assets/Architectural%20Binder/Weather%20Barriers%20A%20Must%20with%20Exterior%20Foam%20Sheathing%20K25107.pdf>; Linda Brock, *Designing the Exterior Wall: An Architectural Guide to the Vertical Envelope* (John Wiley & Sons, 2005); Spray Polyurethane

- Foam Alliance, *Spray Foam - Frequently Asked Questions*, [www.sprayfoam.org/technical/faqs](http://www.sprayfoam.org/technical/faqs) (April 4, 2017); R. Aldrich, P. Mantha, and S. Puttagunta, *Measure Guideline: Basement Insulation Basics* (U.S. Department of Energy, 2012), [www1.eere.energy.gov/buildings/publications/pdfs/building\\_america/measure\\_guide\\_basement\\_insul.pdf](http://www1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_basement_insul.pdf).
- 65 Pharos Project, Healthy Building Network, *Common Product: Expanded Cork Board Insulation*, [pharosproject.net/material/show/2085578](http://pharosproject.net/material/show/2085578) (February 1, 2017).
- 66 Pharos Project, Healthy Building Network, *Common Product: Unbonded Blow-in Fiber Glass Insulation*, [pharosproject.net/material/show/2086034](http://pharosproject.net/material/show/2086034) (February 1, 2017); Pharos Project, Healthy Building Network, *Common Product: Spray-applied Fiber Glass Insulation*, [pharosproject.net/material/show/2086293](http://pharosproject.net/material/show/2086293) (February 14, 2017); Pharos Project, Healthy Building Network, *Common Product: Unfaced Fiber Glass Batt Insulation*, [pharosproject.net/material/show/2080060](http://pharosproject.net/material/show/2080060) (February 1, 2017); Pharos Project, Healthy Building Network, *Common Product: Kraft-faced Fiber Glass Batt Insulation*, [pharosproject.net/material/show/2085494](http://pharosproject.net/material/show/2085494) (February 1, 2017).
- 67 World Health Organization: International Agency for Research on Cancer, *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Volume 81, Man-Made Vitreous Fibres* (Lyon, France: 2002), [monographs.iarc.fr/ENG/Monographs/vol81/mono81.pdf](http://monographs.iarc.fr/ENG/Monographs/vol81/mono81.pdf); World Health Organization: International Agency for Research on Cancer, *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Volume 43, Man-made Mineral Fibres and Radon*, (Lyon, France: 1988), [monographs.iarc.fr/ENG/Monographs/vol43/mono43.pdf](http://monographs.iarc.fr/ENG/Monographs/vol43/mono43.pdf); California Environmental Protection Agency, *Modification of the Listing of Glasswool Fibers (Airborne Particles of Respirable Size) to Glass Wool Fibers (Inhalable and Biopersistent)*, 2011, [oehha.ca.gov/proposition-65/crnrf/modification-listing-glasswool-fibers-airborne-particles-respirable-size-glass](http://oehha.ca.gov/proposition-65/crnrf/modification-listing-glasswool-fibers-airborne-particles-respirable-size-glass); National Institute of Environmental Health Sciences, *New Substances added to HHS Report on Carcinogens*, 2011, [web.archive.org/web/20110817141807/http://www.niehs.nih.gov:80/news/releases/2011/roc/](http://web.archive.org/web/20110817141807/http://www.niehs.nih.gov:80/news/releases/2011/roc/).
- 68 Agency for Toxic Substances & Disease Registry, *ToxFAQs™ for Synthetic Vitreous Fibers*, [www.atsdr.cdc.gov/toxfaqs/tf.asp?id=907&tid=185](http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=907&tid=185) (June 14, 2017).
- 69 Healthy Building Network, *New Research Shows Formaldehyde No Longer Used in Residential Fiber Glass Insulation*, 2015, [www.pharosproject.net/blog/show/206/bluegreen-statement-on-formaldehyde-in-insulation](http://www.pharosproject.net/blog/show/206/bluegreen-statement-on-formaldehyde-in-insulation).
- 70 International Living Future Institute, *Unfaced EcoTouch® Insulation*, [access.living-future.org/unfaced-ecotouch%C2%AE-insulation-0](http://access.living-future.org/unfaced-ecotouch%C2%AE-insulation-0) (February 9, 2017).
- 71 Pharos Project, Healthy Building Network, *Common Product: FSK-faced Fiber Glass Duct Wrap*, [pharosproject.net/material/show/2086301](http://pharosproject.net/material/show/2086301) (March 1, 2017); CertainTeed, *Residential Building Insulation - Sustainable Insulation Safety Data Sheet*, 2016, [www.certainteed.com/resources/30-45-002.pdf](http://www.certainteed.com/resources/30-45-002.pdf); CertainTeed, *Basement Wall Blanket Insulation Specification Sheet*, 2016, [www.certainteed.com/resources/30-45-052.pdf](http://www.certainteed.com/resources/30-45-052.pdf); Knauf Insulation, *Basement Wall Insulation with Ecosse Technology Data Sheet*, 2016, [www.knaufinsulation.us/sites/us.knaufinsulation.com/files/BI-BWI-DS-new.pdf](http://www.knaufinsulation.us/sites/us.knaufinsulation.com/files/BI-BWI-DS-new.pdf).
- 72 Pharos Project, Healthy Building Network, *Common Product: Blown-in Cellulose Insulation*, [pharosproject.net/material/show/2085584](http://pharosproject.net/material/show/2085584) (February 1, 2017); Pharos Project, Healthy Building Network, *Common Product: Unfaced Cellulose/Cotton Batt Insulation*, [pharosproject.net/material/show/2086071](http://pharosproject.net/material/show/2086071) (February 1, 2017); Pharos Project, Healthy Building Network, *Common Product: Wet-Blown Cellulose Insulation*, [pharosproject.net/material/show/2085582](http://pharosproject.net/material/show/2085582) (February 1, 2017).
- 73 Applegate Insulation Systems, *Applegate Cotton Armor™ Thermal & Acoustical Insulation Products Safety Data Sheet*, 2015, [fabricmate.com/wp-content/uploads/2016/09/SDS-Cotton-Armor.pdf](http://fabricmate.com/wp-content/uploads/2016/09/SDS-Cotton-Armor.pdf).
- 74 Pharos Project, Healthy Building Network, *Common Product: Mineral Fiber Batt Insulation* [pharosproject.net/material/show/2085502](http://pharosproject.net/material/show/2085502) (February 1, 2017); Pharos Project, Healthy Building Network, *Common Product: Mineral Wool Board Insulation*, [pharosproject.net/material/show/2086296](http://pharosproject.net/material/show/2086296) (February 14, 2017).
- 75 Owens Corning, *Formaldehyde-Free Thermafiber® Mineral Wool Insulation*, [www.owenscorning.com/formaldehyde-free](http://www.owenscorning.com/formaldehyde-free) (May 3, 2017); Rockwool, *ROXUL AFB evo™ Technical Data Sheet*, 2017, [static.rockwool.com/globalassets/rockwool-na/downloads/technical-data-sheets/residential/afb-evo.pdf](http://static.rockwool.com/globalassets/rockwool-na/downloads/technical-data-sheets/residential/afb-evo.pdf).
- 76 Pharos Project, Healthy Building Network, *Common Product: Polyisocyanurate Wall Insulation Board*, [pharosproject.net/material/show/2085579](http://pharosproject.net/material/show/2085579) (February 1, 2017).
- 77 Susanna D. Mitro et al., "Consumer Product Chemicals in Indoor Dust: A Quantitative Meta-analysis of U.S. Studies," *Environmental Science & Technology*, 50, no. 19 (2016), pp. 10661-72, doi.org/10.1021/acs.est.6b02023.
- 78 U.S. EPA, *Flame Retardants Used in Flexible Polyurethane Foam: An Alternatives Assessment Update* (2015), [www.epa.gov/sites/production/files/2015-08/documents/ffr\\_final.pdf](http://www.epa.gov/sites/production/files/2015-08/documents/ffr_final.pdf); U.S. EPA, *TSCA Work Plan Chemical Problem Formulation and Initial Assessment: Chlorinated Phosphate Ester Cluster Flame Retardants* (2015), [www.epa.gov/sites/production/files/2015-09/documents/cpe\\_fr\\_cluster\\_problem\\_formulation.pdf](http://www.epa.gov/sites/production/files/2015-09/documents/cpe_fr_cluster_problem_formulation.pdf).
- 79 U.S. EPA, *TSCA Work Plan Chemical Problem Formulation and Initial Assessment: Chlorinated Phosphate Ester Cluster Flame Retardants* (2015); European Commission Scientific Committee on Health and Environmental Risks, *Opinion on tris(2-Chloroethyl) phosphate (TCEP) in Toys* (2012).

- 80 Johns Manville, *JM Polyiso Insulation ENRGY 3.E (Health Product Declaration)*, 2015, [www.jm.com/content/dam/jm/global/en/commercial-roofing/Resources/E3.E%20HPD%20August%202015.pdf](http://www.jm.com/content/dam/jm/global/en/commercial-roofing/Resources/E3.E%20HPD%20August%202015.pdf); International Living Future Institute, *EnergyGuard™ NH Polyiso*, <https://access.living-future.org/energyguard%E2%84%A2-nh-polyiso> (February 9, 2017).
- 81 Pharos Project, Healthy Building Network, *Common Product: EPS Insulation (Expanded Polystyrene)*, [pharosproject.net/material/show/2079007](http://pharosproject.net/material/show/2079007) (February 1, 2017); Pharos Project, Healthy Building Network, *Common Product: XPS Insulation (Extruded Polystyrene)*, [pharosproject.net/material/show/2078867](http://pharosproject.net/material/show/2078867) (February 1, 2017).
- 82 The Stockholm Convention, *All POPs Listed in the Stockholm Convention*, [chm.pops.int/TheConvention/ThePOPs/ListingofPOPs/tabid/2509/Default.aspx](http://chm.pops.int/TheConvention/ThePOPs/ListingofPOPs/tabid/2509/Default.aspx) (May 16, 2017).
- 83 Pharos Project, Healthy Building Network, *Common decking and insulation pesticide is a honeybee-killer*, 2016, [www.pharosproject.net/blog/show/209/honeybee-killer-products](http://www.pharosproject.net/blog/show/209/honeybee-killer-products).
- 84 Intergovernmental Panel on Climate Change, *IPCC Fourth Assessment Report: Climate Change 2007: 2.10.2 Direct Global Warming Potentials*, [www.ipcc.ch/publications\\_and\\_data/ar4/wg1/en/ch2s2-10-2.html](http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html) (February 1, 2017).
- 85 U.S. EPA, *Substitutes in Polystyrene: Extruded Boardstock and Billet*, [www.epa.gov/snap/substitutes-polystyrene-extruded-boardstock-and-billet](http://www.epa.gov/snap/substitutes-polystyrene-extruded-boardstock-and-billet).
- 86 Safer Chemicals, Healthy Families; Environmental Health Strategy Center; and Healthy Building Network, *Comments to the U.S. Environmental Protection Agency (EPA) on the Scope of Its Risk Evaluation for the TSCA Work Plan Chemical: CARBON TETRACHLORIDE (CTC) CAS Reg. No. 56-23-5*, 2017, [healthybuilding.net/uploads/files/saferchemicals-carbon-tetrachloride.pdf](http://healthybuilding.net/uploads/files/saferchemicals-carbon-tetrachloride.pdf).
- 87 Pharos Project, Healthy Building Network, *HBCD-free Styrofoam™ Insulation Coming to USA*, 2016, [www.pharosproject.net/blog/show/224/hbcd-free-at-last](http://www.pharosproject.net/blog/show/224/hbcd-free-at-last).
- 88 BASF SE, *BASF is first in China to adopt safer flame retardant for EPS insulation product*, [www.basf.com/hk/en/company/news-and-media/news-releases/cn/2016/01/EPS.html](http://www.basf.com/hk/en/company/news-and-media/news-releases/cn/2016/01/EPS.html) (March 1, 2017).
- 89 Pharos Project, Healthy Building Network, *Common Product: Spray Foam Insulation*, [pharosproject.net/material/show/2079008](http://pharosproject.net/material/show/2079008) (February 1, 2017).
- 90 U.S. EPA, *Health Concerns about Spray Polyurethane Foam*, [www.epa.gov/saferchoice/health-concerns-about-spray-polyurethane-foam](http://www.epa.gov/saferchoice/health-concerns-about-spray-polyurethane-foam) (February 6, 2017).
- 91 Melanie B. Biggs, *Staff Review of Five Amine Catalysts in Spray Polyurethane Foam* (United States Consumer Product Safety Commission, 2012), [www.cpsc.gov/PageFiles/129845/amine.pdf](http://www.cpsc.gov/PageFiles/129845/amine.pdf).
- 92 Intergovernmental Panel on Climate Change, *IPCC Fourth Assessment Report: Climate Change 2007: 2.10.2 Direct Global Warming Potentials*.
- 93 Scott Gibson, "Next Generation Spray Foams Trickle into the Market," *Green Building News*, 9 February 2017, [www.greenbuildingadvisor.com/blogs/dept/green-building-news/next-generation-spray-foams-trickle-market](http://www.greenbuildingadvisor.com/blogs/dept/green-building-news/next-generation-spray-foams-trickle-market); U.S. EPA, *Substitutes in Rigid Polyurethane: Spray*, [www.epa.gov/snap/substitutes-rigid-polyurethane-spray](http://www.epa.gov/snap/substitutes-rigid-polyurethane-spray) (April 3, 2017).
- 94 Icynene, *Icynene ProSeal Eco - the world's first 100% water blown closed-cell spray foam*, 2013, [www.icynene.com/en-us/blog/icynene-proseal-eco-worlds-first-100-water-blown-closed-cell-spray-foam#](http://www.icynene.com/en-us/blog/icynene-proseal-eco-worlds-first-100-water-blown-closed-cell-spray-foam#).
- 95 U.S. Department of Agriculture, *BioPreferred Catalog: Minor Construction - Insulation - Plastic Foams*, [www.biopreferred.gov/BioPreferred/faces/catalog/Catalog.xhtml](http://www.biopreferred.gov/BioPreferred/faces/catalog/Catalog.xhtml); USDA, *BioPreferred: Product Categories*, [www.biopreferred.gov/BioPreferred/faces/pages/ProductCategories.xhtml](http://www.biopreferred.gov/BioPreferred/faces/pages/ProductCategories.xhtml) (April 12, 2017).
- 96 U.S. EPA, *Potential Chemical Exposures From Spray Polyurethane Foam*, [www.epa.gov/saferchoice/potential-chemical-exposures-spray-polyurethane-foam](http://www.epa.gov/saferchoice/potential-chemical-exposures-spray-polyurethane-foam) (March 30, 2017).
- 97 Dustin G. Poppendieck et al., *Lessons Learned from Spray Polyurethane Foam Emission Testing using Micro-chambers*.
- 98 Gordian RS Means, *Building Construction Cost Data* (January, 2017); Bud Fraser et al., *Mechanical Insulation Guide and Specifications for British Columbia* draft; The Home Depot, [www.homedepot.com/](http://www.homedepot.com/) (January 2017).
- 99 Pharos Project, Healthy Building Network, *Common Product: Fiber Glass Pipe Insulation*, [pharosproject.net/material/show/2086247](http://pharosproject.net/material/show/2086247) (February 1, 2017).
- 100 International Living Future Institute, *Redi Klad® Pipe Insulation*, [access.living-future.org/redi-klad%C2%AE-pipe-insulation](http://access.living-future.org/redi-klad%C2%AE-pipe-insulation) (February 9, 2017).
- 101 Pharos Project, Healthy Building Network, *Common Product: Polyethylene Pipe Insulation*, [pharosproject.net/material/show/2079060](http://pharosproject.net/material/show/2079060) (February 1, 2017).
- 102 Pharos Project, Healthy Building Network, *Common Product: Closed Cell Elastomeric Foam Pipe Insulation*, [pharosproject.net/material/show/2086035](http://pharosproject.net/material/show/2086035) (February 1, 2017).
- 103 Bill Walsh, "PVC's Asbestos & Mercury Problems," *Healthy Building News*, 3 October 2016, [healthybuilding.net/news/2016/10/03/](http://healthybuilding.net/news/2016/10/03/)

- pvcs-asbestos-mercury-problems; Melissa Coffin, "Perkins + Will, HBN, Unravel the Myth of 'Clean Vinyl,'" *Healthy Building News*, 18 November 2015, [www.healthybuilding.net/news/2015/11/18/perkins-will-hbn-unravel-the-myth-of-clean-vinyl](http://www.healthybuilding.net/news/2015/11/18/perkins-will-hbn-unravel-the-myth-of-clean-vinyl).
- 104 Armacell, *NH Amraflex Non-halogen Insulation in Tubes, Sheets and Rolls*, [www.armacell.us/products/nharmaflex/](http://www.armacell.us/products/nharmaflex/) (February 9, 2017); General Insulation Company, *K-Flex Non Halogen Tubing*, [www.generalinsulation.com/products/marine/marine-insulation/kflex-non-halogen-tubing/](http://www.generalinsulation.com/products/marine/marine-insulation/kflex-non-halogen-tubing/) (February 9, 2017).
- 105 Common Product sources in the Pharos Building Product Library were consulted for the installation considerations in this table.
- 106 Pharos Project, Healthy Building Network, *Common Product: Non-Combustible Sodium Silicate Caulk*, [pharosproject.net/material/show/2086267](http://pharosproject.net/material/show/2086267) (February 13, 2017).
- 107 Pharos Project, Healthy Building Network, *Common Product: Flame Retardant Polyurethane Foam Window/Door Seal*, [pharosproject.net/material/show/2078859](http://pharosproject.net/material/show/2078859) (February 1, 2017).
- 108 Pharos Project, Healthy Building Network, *Common Product: Acrylic Latex Sealant*, [pharosproject.net/material/show/2086268](http://pharosproject.net/material/show/2086268) (February 13, 2017); Pharos Project, Healthy Building Network, *Common Product: Siliconized Latex Sealant*, [pharosproject.net/material/show/2086269](http://pharosproject.net/material/show/2086269) (February 13, 2017); Pharos Project, Healthy Building Network, *Common Product: Intumescent Firestop Sealant*, [pharosproject.net/material/show/2085504](http://pharosproject.net/material/show/2085504) (February 1, 2017).
- 109 Soudal Accumetric, *Boss 826 Acoustical Acrylic Sound Sealant (Safety Data Sheet)*, 2015, [www.accumetricinc.com/uplimg/boss/MSDS/BOSS%20826%20\(11-10-15\).pdf](http://www.accumetricinc.com/uplimg/boss/MSDS/BOSS%20826%20(11-10-15).pdf); Red Devil, *Red Devil, Lifetime® Ultra Sealant - White & Colors (Safety Data Sheet)*, 2013, [www.reddevil.com/sku-docs/sds-0770.pdf](http://www.reddevil.com/sku-docs/sds-0770.pdf); Tremco, *Tremflex 834 White (Safety Data Sheet)*, 2015, [www.tremcosealants.com/application/drywall-\(gypsum\)metal-stud-partition.aspx](http://www.tremcosealants.com/application/drywall-(gypsum)metal-stud-partition.aspx); McCormick Paints, *Flexseal™ 250 Painter's Acrylic Latex Caulk (Product Data Sheet)*, [www.mccormickpaints.com/wp-content/uploads/2014/11/5200606-FLEXSEAL250-W-TDS.pdf](http://www.mccormickpaints.com/wp-content/uploads/2014/11/5200606-FLEXSEAL250-W-TDS.pdf); Specified Technologies, Inc., *SpecSeal® Series SSS Intumescent Sealant (Health Product Declaration)*, 2015, [hpdrepository.hpd-collaborative.org/repository/HPDs/3864-20151202143055.pdf](http://hpdrepository.hpd-collaborative.org/repository/HPDs/3864-20151202143055.pdf); DAP Products, *Blockade Fire-Rated Intumescent Acrylic Latex Sealant (Safety Data Sheet)*, 2015, [www.dap.com/media/33592/00077365004english.pdf](http://www.dap.com/media/33592/00077365004english.pdf); EverKem Diversified Products, *Firestop-814+ (Material Safety Data Sheet)*, 2014, [www.everkemproducts.com/wp-content/uploads/2014/03/Firestop-814+-MSDS.pdf](http://www.everkemproducts.com/wp-content/uploads/2014/03/Firestop-814+-MSDS.pdf); Hilti, Inc., *FS-ONE Max Hilti Firestop Filler Mastic CFS-FIL (Material Safety Data Sheet)*, 2015, [www.us.hilti.com/medias/sys\\_master/documents/he2/9143657234462/Material\\_Safety\\_Data\\_Sheet\\_MSDS\\_for\\_FS-ONE\\_MAX\\_Intumescent\\_Firestop\\_Sealant\\_Documentation\\_ASSET\\_DOC\\_LOC\\_4085785.pdf](http://www.us.hilti.com/medias/sys_master/documents/he2/9143657234462/Material_Safety_Data_Sheet_MSDS_for_FS-ONE_MAX_Intumescent_Firestop_Sealant_Documentation_ASSET_DOC_LOC_4085785.pdf).
- 110 Specified Technologies, Inc., *SpecSeal® Series SSS Intumescent Sealant (Health Product Declaration)*, 2015, [hpdrepository.hpd-collaborative.org/repository/HPDs/3864-20151202143055.pdf](http://hpdrepository.hpd-collaborative.org/repository/HPDs/3864-20151202143055.pdf); Specified Technologies, Inc., *SpecSeal® LCI Sealant (Safety Data Sheet)*, 2017, [files.systems.stfirestop.com/5.%20Safety%20Data%20Sheet/1.%20English/SDS\\_LCI%20Intumescent%20Sealant.pdf](http://files.systems.stfirestop.com/5.%20Safety%20Data%20Sheet/1.%20English/SDS_LCI%20Intumescent%20Sealant.pdf).
- 111 Pharos Project, Healthy Building Network, *Common Product: One-Component Silicone Sealant*, [pharosproject.net/material/show/2086291](http://pharosproject.net/material/show/2086291) (February 13, 2017).
- 112 Pharos Project, Healthy Building Network, *Common Product: Silyl-terminated Polyether Sealant*, [pharosproject.net/material/show/2086299](http://pharosproject.net/material/show/2086299) (February 16, 2017).
- 113 Henry Company, *HE925W - BES Sealant - White (Health Product Declaration)*, 2014, [us.henry.com/fileadmin/pdf/literature/hpd/HE925W%20-%20BES%20SEALANT%20WHITE.pdf](http://us.henry.com/fileadmin/pdf/literature/hpd/HE925W%20-%20BES%20SEALANT%20WHITE.pdf); International Living Future Institute, *R-GUARD AirDam*, [access.living-future.org/r-guard-airdam](http://access.living-future.org/r-guard-airdam) (February 9, 2017).
- 114 Pharos Project, Healthy Building Network, *Common Product: Single Component Spray Polyurethane Foam*, [pharosproject.net/material/show/2086088](http://pharosproject.net/material/show/2086088) (February 1, 2017); Pharos Project, Healthy Building Network, *Common Product: Fireblock Single Component Spray Polyurethane Foam*, [pharosproject.net/material/show/2086089](http://pharosproject.net/material/show/2086089) (February 1, 2017).
- 115 Chlorinated Paraffins Industry Association, *Chlorinated Paraffins: A Status Report*, [www.regnet.com/cpia/status\\_report.html](http://www.regnet.com/cpia/status_report.html) (February 2, 2017).
- 116 Soudal Accumetric, *Boss 813 "The First" Expanding Firestop Foam (Safety Data Sheet)*, 2015, [https://web.archive.org/web/20161020170052/http://www.accumetricinc.com:80/uplimg/boss/MSDS/BOSS%20813%20\(12-18-15\).pdf](https://web.archive.org/web/20161020170052/http://www.accumetricinc.com:80/uplimg/boss/MSDS/BOSS%20813%20(12-18-15).pdf); Abesco Fire LLC, *Abesco FP200 FR Foam (Safety Data Sheet)*, 2015, [www.fp200abesco.com/downloads/FP200\\_FR\\_Expanding\\_Foam\(MSDS006\).pdf](http://www.fp200abesco.com/downloads/FP200_FR_Expanding_Foam(MSDS006).pdf).
- 117 Pharos Project, Healthy Building Network, *Common Product: Single Component Polyurethane Sealant*, [pharosproject.net/material/show/2086292](http://pharosproject.net/material/show/2086292) (February 13, 2017).
- 118 Tremco U.S. Sealants, *Dymonic White (Safety Data Sheet)*, 2015, [www.tremcosealants.com/fileshare/msds/955806\\_323\\_U.pdf](http://www.tremcosealants.com/fileshare/msds/955806_323_U.pdf).
- 119 Common Product sources in the Pharos Building Product Library were consulted for the installation considerations in this table. Additional sources include: RCD Corporation, *How to Seal Duct Leaks*, [www.rcdmastics.com/duct-sealing/how-to-seal-air-duct-leaks.html](http://www.rcdmastics.com/duct-sealing/how-to-seal-air-duct-leaks.html) (February 3, 2017); Martin Holladay, "Sealing Ducts: What's Better, Tape or Mastic?" *GreenBuilding Advisor*, 6 August 2010, [www.greenbuildingadvisor.com/blogs/dept/musings/sealing-ducts-what-s-better-tape-or-mastic](http://www.greenbuildingadvisor.com/blogs/dept/musings/sealing-ducts-what-s-better-tape-or-mastic) (February 3, 2017).
- 120 Pharos Project, Healthy Building Network, *Common Product: Foil-backed Butyl Tape*, [pharosproject.net/material/show/2086297](http://pharosproject.net/material/show/2086297) (February 14, 2017).

- 121 Iain S. Walker and Max H. Sherman, *Assessing the Longevity of Residential Duct Sealants in Durability of Building and Construction Sealants* (Berkeley, Calif.: Lawrence Berkeley National Laboratory, 2000), [http://eta-publications.lbl.gov/sites/default/files/assessing\\_the\\_longevity\\_of\\_residential\\_duct\\_sealants\\_2000\\_lbnl-43381.pdf](http://eta-publications.lbl.gov/sites/default/files/assessing_the_longevity_of_residential_duct_sealants_2000_lbnl-43381.pdf).
- 122 U.S. EPA, *Health Assessment Document for Talc*, 1992, [nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=3000105C.TXT](http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=3000105C.TXT).
- 123 Pharos Project, Healthy Building Network, *Common Product: Fiber-reinforced Wet-applied HVAC Duct Sealant*, [pharosproject.net/material/show/2085583](http://pharosproject.net/material/show/2085583) (February 1, 2017).
- 124 Elgen Manufacturing Company, *Elgen Duct Sealer (Safety Data Sheet)*, 2016, [www.elgenmfg.com/uploaded/files/msds/sds\\_elgen\\_seal\\_it.pdf?direct=1](http://www.elgenmfg.com/uploaded/files/msds/sds_elgen_seal_it.pdf?direct=1); Design Polymerics, *Fibered Water Base Duct Sealant (Safety Data Sheet)*, 2014, [designpoly.com/wp-content/uploads/SEALANT/DPI030/DP-1030-SDS.pdf](http://designpoly.com/wp-content/uploads/SEALANT/DPI030/DP-1030-SDS.pdf); ITW Polymers Sealants North America, Inc., *Ultraseal™ Green High Strength Duct Sealant/Mastic (Technical Data Sheet)*, 2015, [itmira.com/wp-content/uploads/bsk-pdf-manager/120\\_MIRACLE\\_ULTRASEAL\\_GREEN\\_TDS.PDF](http://itmira.com/wp-content/uploads/bsk-pdf-manager/120_MIRACLE_ULTRASEAL_GREEN_TDS.PDF).
- 125 National Association of Home Builders, *Codes*, [www.nahb.org/en/research/nahb-priorities/construction-codes-and-standards.aspx](http://www.nahb.org/en/research/nahb-priorities/construction-codes-and-standards.aspx) (May 5, 2017).
- 126 International Code Council, *International Residential Code For One- and Two-Family Dwellings*, 2015, <https://codes.iccsafe.org/public/document/toc/553/>; International Code Council, *International Building Code*, 2015, <https://codes.iccsafe.org/public/document/toc/542/>.
- 127 Vytenis Babrauskas et al., "Flame retardants in building insulation: a case for re-evaluating building codes," *Building Research & Information*, 26 (2012), [www.tandfonline.com/doi/abs/10.1080/09613218.2012.744533](http://www.tandfonline.com/doi/abs/10.1080/09613218.2012.744533).
- 128 International Code Council, *International Residential Code For One- and Two-Family Dwellings*, 2015; International Code Council, *International Building Code*, 2015.
- 129 See Common Product sources in the Pharos Building Product Library as well as the following: CertainTeed Corporation, *InsulSafe® SP Fiber Glass Blowing Insulation Specification Sheet*, 2016, [www.certainteed.com/resources/30-24-294.pdf](http://www.certainteed.com/resources/30-24-294.pdf); Knauf Insulation, *Jet Stream Ultra Data Sheet*, 2015, [https://web.archive.org/web/20160414133908/http://www.knaufinsulation.us/sites/us.knaufinsulation.com/files/BI-BWJ-DS\\_12-15.pdf](https://web.archive.org/web/20160414133908/http://www.knaufinsulation.us/sites/us.knaufinsulation.com/files/BI-BWJ-DS_12-15.pdf); Owens Corning Insulating Systems, LLC, *EcoTouch® PINK® FIBERGLAS™ Insulation with PureFiber® Technology Product Data Sheet*, 2014, [insulation.owenscorning.com/assets/0/428/429/431/b507cdf1-d1f4-4e08-930f-9d5e88c6b6ce.pdf](http://insulation.owenscorning.com/assets/0/428/429/431/b507cdf1-d1f4-4e08-930f-9d5e88c6b6ce.pdf); CertainTeed, *Basement Wall Blanket Insulation (Specification Sheet)*, 2016, [www.certainteed.com/resources/30-45-052.pdf](http://www.certainteed.com/resources/30-45-052.pdf); Knauf Insulation, *Basement Wall Insulation with Ecosse Technology (Data Sheet)*, 2016, [www.knaufinsulation.us/sites/us.knaufinsulation.com/files/BI-BWI-DS-new.pdf](http://www.knaufinsulation.us/sites/us.knaufinsulation.com/files/BI-BWI-DS-new.pdf); Owens Corning Insulating Systems, LLC, *Fiberglas™ Pipe Insulation SSL II® with ASJ Max|No-Wrap Product Data Sheet*, 2017, [commercial.owenscorning.com/assets/0/321/333/f57c2e78-bbd2-4fc8-bcfd-95fe92d2c62d.pdf](http://commercial.owenscorning.com/assets/0/321/333/f57c2e78-bbd2-4fc8-bcfd-95fe92d2c62d.pdf); US GreenFiber, LLC, *GreenFiber™ Cellulose Insulation C.S.I. 3-Part Specification*, 2013, [www.greenfiber.com/uploads/documents/WI-6.19-24-Rev-D-GreenFiber-CSI-3-Part-Spec-07-13.pdf](http://www.greenfiber.com/uploads/documents/WI-6.19-24-Rev-D-GreenFiber-CSI-3-Part-Spec-07-13.pdf); Applegate Insulation, *Applegate Insulation, Specifications*, 2001, [www.idi-insulation.com/wp-content/uploads/2015/11/Applegate.pdf](http://www.idi-insulation.com/wp-content/uploads/2015/11/Applegate.pdf).
- 130 National Association of Home Builders, *Floors above Crawl Spaces: Reducing the Risk of Moisture Accumulation within Wood Floor Assemblies*, 2014, [www.homeinnovation.com/-/media/Files/Reports/TechNotes-Floors-above-Crawl-Spaces-June-2014.pdf](http://www.homeinnovation.com/-/media/Files/Reports/TechNotes-Floors-above-Crawl-Spaces-June-2014.pdf); U.S. Department of Energy, *Types of Insulation*, [energy.gov/energysaver/types-insulation](http://energy.gov/energysaver/types-insulation) (May 16, 2017); Spray Polyurethane Foam Alliance, *Spray Foam - Frequently Asked Questions*, [www.sprayfoam.org/technical/faqs](http://www.sprayfoam.org/technical/faqs) (May 16, 2017); "Rigid Foam Insulation," *Green Building Advisor*, 9 August 2012, [www.greenbuildingadvisor.com/green-basics/rigid-foam-insulation](http://www.greenbuildingadvisor.com/green-basics/rigid-foam-insulation).
- 131 See Common Product sources in the Pharos Building Product Library. Links provided in citations for each product type in Sections III and IV of the Materials Encyclopedia.





 **ENERGY  
EFFICIENCY  
FOR ALL**

[energyefficiencyforall.org](http://energyefficiencyforall.org)