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FLAME RETARDANT ALTERNATIVES FOR HEXABROMOCYCLODODECANE (HBCD)

Chapter 5

Summary of Hazard Assessments, Considerations for Selecting Flame Retardants, and an Overview of Alternative Materials

FINAL REPORT

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5 Summary of Hazard Assessments, Considerations for Selecting Flame Retardants, and an Overview of Alternative Materials

This chapter outlines attributes that a decision-maker should consider in choosing an alternative to hexabromocyclododecane (HBCD), including hazard, social, performance, and economic considerations as they prepare to make substitution decisions. An overview of alternative insulation materials and the applications in which they may be used is also included.

5.1 Considerations for Selecting Flame Retardants

Design for the Environment (DfE) alternatives assessments provide extensive information on chemical hazards and discuss other general factors that are relevant to substitution decisions. When selecting flame retardants, decision-makers will consider performance and cost in combination with the human health and environmental information from this report.

This alternatives assessment considers three alternatives to HBCD. One of the alternatives, a butadiene styrene brominated copolymer, is a polymer with a molecular weight (MW) much greater than 10,000 daltons. The other two, a tetrabromobisphenol A (TBBPA)-bis brominated ether derivative and TBBPA bis(2,3-dibromopropyl) ether, are large molecules with a MWs close to 1,000 daltons. All three of these chemicals incorporate bromine as the mechanism for fire retardation and are the only known technically viable options for HBCD in polystyrene foam insulation. The limited number of alternatives is, at least in part, due to the requirement that flame retardants for expanded polystyrene (EPS) and extruded polystyrene (XPS) foam (1) allow the material to comply with fire safety codes, (2) not compromise the physical properties of the foam, and (3) be compatible with its manufacturing processes and formulas. The availability of flame retardants for polystyrene is described in Section 3.2.

5.1.1 Hazard Considerations

There are five general attributes evaluated in this assessment that can inform decision-making about the potential hazards associated with chemical alternatives: (1) human health hazard, (2) ecotoxicity, (3) persistence, (4) bioaccumulation potential, and (5) exposure potential. In general, a “safer” chemical alternative has lower potential for human health hazard, lower ecotoxicity, better degradability, low potential for bioaccumulation, and lower exposure potential compared to substances currently used. The hazard assessments are summarized below; readers are encouraged to review the individual detailed hazard profiles of each chemical in Chapter 4.

While experimental data were available for almost all hazard endpoints for HBCD (the exception is respiratory sensitization), experimental data for some or all of the hazard endpoints for the three alternatives were not available or were deemed inadequate. In these cases, hazard values were assigned using data for structural analogs, structure activity relationship (SAR) modeling, and professional judgment based upon physical-chemical properties and knowledge of data for similar chemicals. In some cases (e.g., respiratory sensitization), it was not possible to assign hazard values due to a lack of data, models, or structural analogs. It should be noted that those hazard designations based on estimated effect levels are regarded with a lower level of confidence compared to hazard designations based on measured data. Empirical data would allow for a more robust assessment that would confirm or refute professional judgment and thus support a more informed choice of alternatives. Estimated values in the report can, therefore, also be used to prioritize data needs.

Human health hazard: The DfE alternatives assessment criteria (U.S. EPA 2011a) address a consistent and comprehensive list of human health hazard endpoints for which DfE has established thresholds indicating levels of concern. These endpoints include acute toxicity, carcinogenicity, genotoxicity, reproductive toxicity, developmental toxicity, neurotoxicity, repeated dose toxicity, skin sensitization, respiratory sensitization, eye irritation, and dermal irritation.

HBCD has a High hazard designation for developmental toxicity, a Moderate hazard designation for reproductive and repeated dose effects, and an estimated Moderate hazard designation for carcinogenicity and neurotoxicity; other health endpoints have Low or Very Low hazard designations. Comparatively, the butadiene styrene brominated copolymer has Low hazard designations (either measured or estimated) for all health endpoints arising from its high MW and limited potential for absorption (U.S. EPA 2012b). The substance is marketed as greater than 60,000 daltons with negligible low MW components. U.S. Environmental Protection Agency (EPA) has regulated this polymer with a Significant New Use Rule (SNUR) that was finalized in June 2013. Manufacture (or import) of the polymer requires notification to EPA except in these cases: (1) the MW of the polymer is in the range of 1,000 to 10,000 daltons, or (2) the MW of the polymer is ≥10,000 daltons and less than 5 percent of the particles are in the respirable range of 10 microns or less (U.S. EPA 2013). The TBBPA-bis brominated ether derivative and TBBPA bis(2,3-dibromopropyl) ether have a Moderate hazard designation for carcinogenicity, genotoxicity, reproductive toxicity, developmental toxicity, and repeated dose toxicity; Low hazard designations were designated for acute toxicity, neurotoxicity, skin sensitization, eye irritation, and dermal irritation. Due to a lack of data for the substance, the hazard designations for the TBBPA-bis brominated ether derivative were all estimated. Available data for the structurally similar substance, TBBPA bis(2,3-dibromopropyl) ether (CASRN 21850-44-2), and a closely related confidential compound were used for the estimations based on analogy. Recently, TBBPA has been evaluated in a 2-year carcinogenicity study at the National Toxicology Program (NTP) (National Toxicology Program (NTP) 2013b). An updated DfE hazard profile for TBBPA may be published in 2014 as part of the report on Flame Retardants in Printed Circuit Boards (U.S. EPA 2008). Although derived from TBBPA, there are not any carcinogenicity data for TBBPA-bis brominated ether derivative or its analog TBBPA bis(2,3-dibromopropyl) ether. There is also a lack of data to determine if TBBPA might be a degradation product of TBBPA-bis brominated ether derivative. TBBPA bis(2,3-dibromopropyl) ether has been nominated for consideration for a 2-year cancer bioassay at NTP (Haneke 2002; National Toxicology Program (NTP) 2013a). Respiratory sensitization was not characterized for HBCD or the alternatives because no data were located, no suitable estimation methods were available, or no structural alerts were identified.

Ecotoxicity: Ecotoxicity includes adverse effects observed in wildlife. Aquatic organisms have historically been the focus of environmental toxicity considerations by industry and government during industrial chemical review. Surrogate species of fish, aquatic invertebrates, and algae are traditionally assessed to consider multiple levels of the aquatic food chain. HBCD is aquatically toxic. Aquatic toxicity for the three alternatives is low, driven by their lack of appreciable water solubility leading to no effects at saturation (NES). This analysis does not consider dietary exposure to substances since guideline tests are focused on exposure from the water column. For the butadiene styrene brominated copolymer, TBBPA-bis brominated ether derivative and TBBPA bis(2,3-dibromopropyl) ether, aquatic toxicity is estimated to be low (NES) based upon its physical-chemical properties (poor water solubility and estimated high octanol-water partition coefficient (K_{ow}). A number of publications identified the presence of HBCD in a variety of terrestrial and aquatic species. There were few terrestrial ecotoxicity studies; these studies were not associated with High hazard. Therefore, potential for impacts of HBCD on high trophic level and terrestrial wildlife is unclear. The butadiene styrene brominated copolymer is not expected to be bioavailable; impacts on wildlife from the TBBPA-bis brominated ether derivative or TBBPA bis(2,3-dibromopropyl) ether have not been studied.

Persistence: Persistence describes the tendency of a chemical to resist degradation and removal from environmental settings, such as air, water, soil, and sediment. Chemical flame retardants must be stable by design in order to maintain their flame retardant properties. HBCD and the TBBPA-bis brominated ether derivative have High persistence designations. The butadiene styrene brominated copolymer and TBBPA bis(2,3-dibromopropyl) ether have Very High persistence designations. Highly persistent chemicals may ultimately degrade in the right environmental conditions, but time to degradation is on the order of months to years and could be much longer. An ideal flame retardant would be stable in the material to which it is added and have low toxicity, but also be degradable at the end of the material's use (i.e., persistent in use but not after use). This quality has been difficult to achieve for flame retardants. Long-term degradation products, though beyond the scope of this assessment, are also important to consider as they might be more toxic, bioaccumulative or persistent (PBT) than the parent compound. The TBBPA-bis brominated ether derivative and TBBPA bis(2,3-dibromopropyl) ether have a tetrabromobisphenol A (TBBPA) backbone. TBBPA-bis brominated ether derivative and TBBPA bis(2,3-dibromopropyl) ether could theoretically release TBBPA, however, no experimental studies describing this degradation pathway were found. As mentioned on the previous page, an updated DfE hazard profile for TBBPA may be published in 2014. HBCD has been found to degrade to tetrabromocyclododecene, dibromocyclododecadiene, or 1,5,9-cyclododecatriene by aerobic and anaerobic processes (Davis, Gonsior et al. 2006).

Bioaccumulation Potential: The ability of a chemical to accumulate in living organisms is described by the bioconcentration, bioaccumulation, biomagnification, and/or trophic magnification factors. Each of these indices has a different definition and as such, a substance that bioaccumulates does not necessarily biomagnify. HBCD was assigned a Very High hazard designation for bioaccumulation based on standardized test results for bioconcentration factor (BCF). Based on structure activity relationships (SARs), the potential for a molecule to be absorbed by an organism tends to be lower when the molecule is larger than 1,000 daltons. This is reflected in the estimated Low hazard designation for bioaccumulation for the butadiene styrene brominated copolymer. The TBBPA-bis brominated ether derivative and TBBPA bis(2,3-dibromopropyl) ether have an estimated High bioaccumulation designation based on their lipophilic log K_{ow} and expected slow rate of metabolism.

Exposure Potential: For humans, chemical exposure may occur at different points throughout the chemical and product life cycle; by dermal contact, by inhalation, and/or by ingestion; and is affected by multiple physical-chemical factors. The DfE alternatives assessment assumes exposure scenarios to chemicals and their alternatives within a functional use class are roughly equivalent. The assessment also recognizes that, in some instances, chemical properties, manufacturing processes, chemical behavior in particular applications, or use patterns may affect exposure scenarios. Stakeholders should evaluate carefully whether and to what extent manufacturing changes, life-cycle considerations, and physical-chemical properties will result in different patterns of exposure. Large polymeric flame retardants and those that are reacted into a polymer backbone can decrease exposure potential.

Exposure potential can also be impacted by the persistence and bioaccumulation potential of chemicals and/or their degradation products. Chemicals with both higher persistence and higher bioaccumulation potential generally have a higher potential for exposure than chemicals that do not possess both of these attributes. As was described above, all four of the chemicals in this assessment were assigned High or Very High persistence potential and all were assigned High or Very High bioaccumulation potential except for the butadiene styrene brominated copolymer, which, based on its large size and insolubility, has Very High persistence but Low bioaccumulation potential. Since the butadiene styrene brominated copolymer and the TBBPA-bis brominated ether derivative are new to the market, environmental monitoring or biomonitoring information are not available to inform the exposure potential of these two alternatives. The higher exposure potential based on higher persistence and higher bioaccumulation for the TBBPA-bis brominated ether is supported by data for the analog TBBPA bis(2,3-dibromopropyl) ether (CASRN 21850-44-2), a chemical also evaluated in this report that has been detected in environmental media (Harju, Heimstad et al. 2009; Shi, Chen et al. 2009; Qu, Shi et al. 2011) and gull eggs (Letcher and Chu 2010). In general the exposure potential to the butadiene styrene brominated copolymer is expected to be lower than the other chemicals in this assessment because it is a large polymer and is unlikely to be released from the polystyrene, in addition to its low likelihood of bioaccumulation. However, long-term fate in the environment is not understood; degradation products could have greater exposure potential upon release of the substance to the environment.

5.1.2 Social Considerations

Social considerations may impact the choice of alternative chemicals. This section highlights occupational, consumer, and environmental justice considerations. Stakeholders may identify additional social considerations for application to their own decision-making processes.

Occupational Considerations: Workers might be exposed to relatively high concentrations of flame retardant chemicals from direct contact when conducting specific tasks related to manufacturing, processing, and application of chemicals. For example, tasks that involve heat and pressure where materials are aerosolized as they are mixed and reacted may result in direct contact with flame retardant chemicals. Many facilities have established risk management practices, which are required to be clearly communicated to all employees. The National Institute for Occupational Safety and Health (NIOSH) has established a hierarchy of exposure control practices[18]. Starting with the most protective, the practices are: elimination, substitution, engineering controls, administrative controls, and personal protection. Switching to inherently low hazard chemicals can benefit workers by decreasing workplace risks through the best exposure control practices: elimination and substitution of hazardous chemicals with safer alternatives.

Consumer and Lifestage Considerations: Consumers are potentially exposed to flame retardant chemicals through multiple pathways described in Chapter 2. Exposure research provides evidence that people carry body burdens of flame retardants, including HBCD. Individuals may also experience disproportionate impacts during certain lifestages resulting from higher exposures, increased susceptibility in response to exposure, or both conditions (National Academy of Sciences 2008). For example, children may be more susceptible to environmental exposures than adults because:

- Their bodily systems are still developing and exposures may occur during critical windows of susceptibility;
- Their bodies may absorb and process chemicals differently due to characteristics such as greater permeability of the blood-brain barrier, slower excretion from the kidneys, and alterations in the activity of metabolic enzymes;
- They eat more, drink more, and breathe more in proportion to their body size;
- Their behavior can expose them more to chemicals and organisms, for example, hand-to-mouth and object-to-mouth behaviors (Xue, Zartarian et al. 2007); and
- They may be exposed to chemicals, including HBCD, in human milk (Landrigan, Sonawane et al. 2002; Covaci, Gerecke et al. 2006; Arnot, McCarty et al. 2009).

Prenatal development represents a potential window of susceptibility whereby exposures to chemicals in the environment can contribute to adverse pregnancy and developmental outcomes (Stillerman 2008). During prenatal development, biological systems are forming, and disruption of these processes can have consequences later in life. While the placenta is designed to protect the fetus from stressors, including chemical exposures, chemicals (including HBCD) have been shown to pass through this organ resulting in prenatal exposures (Myren, Mose et al. 2006; Meijer, Weiss et al. 2008).

Environmental Justice Considerations: At EPA, environmental justice concerns refer to disproportionate impacts on minority, low-income, or indigenous populations. These disproportionate impacts arise because these population groups may experience higher exposures, are more susceptible in response to exposure, or experience both conditions. Factors that are likely to influence resilience/ability to withstand harm from a toxic exposure can vary with sociodemographics (e.g., co-morbidities, diet, metabolic enzyme polymorphisms, etc.) and are therefore important considerations. Adverse outcomes associated with exposure to chemicals

[18] http://www.cdc.gov/niosh/topics/engcontrols/

may be disproportionately borne by minority and low income populations. Additional information about EPA's environmental justice policy can be accessed at: www.epa.gov/compliance/ej/resources/policy/considering-ej-in-rulemaking-guide-07-2010.pdf.

Some populations have higher exposures to certain chemicals in comparison to the average member of the general population. A recent study has found that Hispanics, non-Hispanic African Americans, and non-Hispanic Asians generally experience greater exposure to certain chemical components associated with adverse health outcomes than non-Hispanic whites (Bell and Ebisu 2012). The same study found that populations with lower socioeconomic statuses generally experienced higher estimated exposures to certain chemicals based on education, unemployment, poverty, and earnings (Bell and Ebisu 2012). Higher exposures to environmental chemicals may also be attributable to atypical product use patterns and exposure pathways. This may be due to a myriad of factors such as cultural practices, language and communication barriers, and economic conditions. The higher exposures may also be a result of:

- The proximity of these populations to sources that emit the environmental chemical (e.g., manufacturing industries, industries that use the chemical as production input, hazardous waste sites, etc.);
- Access to and use of consumer products that may result in additional exposures to the chemical; or
- Higher employment of these groups in occupations associated with exposure to the chemical.

Finally, certain populations may experience high exposures to toxic chemicals due to geography, food sources, and cultural practices. For example, research shows that Alaska Natives are disproportionately impacted by certain flame retardants and other persistent organic pollutants (POPs), both because of atmospheric transport of persistent chemicals and because of the biomagnification of chemicals in traditional subsistence food webs (Arctic Monitoring and Assessment Program 2009).

5.1.3 Performance and Cost Considerations

The DfE approach allows companies to examine hazard profiles of potential replacement chemicals so they can consider the human health and environmental attributes of a chemical in association with cost and performance considerations. This is intended to allow companies to develop marketable products that meet performance requirements while reducing risk associated with potential hazard and exposure attributes. While DfE does not assess performance considerations, these attributes are critical to the overall function and marketability of flame retardants.

As was discussed in Chapter 2, the performance requirements for EPS and XPS foam used as insulation are governed by the American Society for Testing and Materials (ASTM) C578, *Standard Specification for Rigid, Cellular Polystyrene Insulation*.[19] In addition to meeting the required flammability standards, these requirements include density, R-value, compressive strength, flexural strength, water vapor transmission rate, water absorption, and dimensional stability. Alternatives must also be compatible with the manufacturing processes for EPS and XPS (e.g., the high pressures and temperatures of the XPS manufacturing process). Substituting chemicals can involve significant costs, as industries must adapt their production processes and have products re-tested for all required performance and product standards. Handling, disposal, and treatment costs may also be important considerations when evaluating alternatives. The expenses associated with initial alternative substitution may ultimately result in reduced costs associated with managing consumer concerns and public perceptions of hazardous chemicals.

Information on the cost and availability of butadiene styrene brominated copolymer is based on a 2012 report by the Persistent Organic Pollutants Review Committee (POPRC) (Persistent Organic Pollutants Review Committee 2012). According to the POPRC report, cost estimates for EPS and XPS containing this flame retardant versus HBCD have been made by various parties. One manufacturer does not anticipate EPS containing the butadiene styrene brominated copolymer to have a significant impact on its cost competitiveness with other products. However, other parties expect that the cost of using the butadiene styrene brominated copolymer instead of HBCD in EPS and XPS can lead to cost increases. One party suggests the costs of using the alternative are 90% (EPS) to 120% (XPS) higher than when using HBCD. The impact of the butadiene styrene brominated copolymer on the price of EPS and XPS will remain unclear until the alternative is fully commercialized. Regarding availability, the butadiene styrene brominated copolymer is currently commercially available through a single manufacturer but is expected to be available through two additional manufacturers in 2014. With this increased production capacity, it is anticipated that the butadiene styrene brominated copolymer suppliers will have sufficient capacity to replace HBCD in polystyrene foams in three to five years.

Consideration of economic factors is often better addressed by decision-makers within the context of their organization. Accurate cost estimations must be company-specific; the impact of substituting chemicals on complex product formulations can only be analyzed in-house and a company must determine for itself how changes will impact market share or other business factors.

5.2 Alternative Materials

This section is intended to provide a general overview of alternative insulation materials and their applications. The Partnership discussed alternative insulation materials and decided to include general information on this topic. This section is not a comprehensive comparison of alternative insulation materials. Some of these alternative materials may require flame retardants that are characterized in other DfE alternatives assessments. However, this section does not include a chemical hazard assessment of the alternatives. While this report provides general

[19] Likewise, ASTM D6817 applies to polystyrene foams in geotechnical engineering applications (“geofoam”). See www.astm.org/search/site-search.html?query=C578#84513999.

information about these potential alternatives, their inclusion here is informational only. Inclusion of a substance or material in a DfE report does not denote environmental preferability.

There are several insulation characteristics that should be considered when selecting alternative insulation materials. These include environmental considerations, material safety considerations, performance considerations, and economic considerations, as discussed below.

Environmental Considerations

Environmental considerations include whether the manufacturing process results in pollution, whether the material can be reused or recycled, and the environmental impacts of its end-of-life management. Another factor is the source of the insulation raw material: whether it is made from recycled or virgin materials and the environmental impacts associated with manufacturing the raw materials. It is important to consider the embodied energy of the product, such as the energy required to produce and transport materials (Wilson 1995), as well as the full range of environmental impacts (Wilson 1995; Wilson 2010a). All of these issues feed into the life-cycle considerations that should be taken into account when selecting insulation materials. Full life-cycle assessments (LCAs) are not within the scope of this report.

Material Safety Considerations

The material safety of the alternative insulation material is also a consideration. Insulation materials may use or contain hazardous chemicals, such as diisocyanates, or constituents such as blowing agents that may contribute to air pollution. Some materials pose health concerns as chemicals are released during processing, installation, or emitted throughout the life of the product. Whether the material contains PBT chemicals is also important, especially when the potential life-cycle impacts of the product are considered.

Performance Considerations

As discussed in Section 2.1.1, the primary desired properties of rigid foam and its alternatives include R-value, compressive strength, flexural strength dimensional stability, moisture resistance, and fire safety (e.g., flame spread index, smoke development index). In addition to these primary desired properties, other performance characteristics to consider when selecting alternatives include: water vapor transmission (permeance); corrosivity; weight of the material; resiliency; resistance to mold growth and microbial degradation; acoustical energy absorption; and whether the material can be used in retrofits and/or new construction. It is also important to note that for some materials, the R-value may decrease over the lifetime of the product (Minnesota Sustainable Housing Initiative 2007). Therefore, it is important to consider the expected lifespan of the product needed for the application.

Economic Considerations

Economic considerations, such as whether the material is readily available and its cost, will also impact the viability of alternative insulation materials. Return on investment, including payback through energy savings and net energy savings potential, are other economic considerations that may impact the decision to switch to alternative insulation materials.

The sections that follow provide information about specific insulation materials that could be used as substitutes for the functional uses of EPS and XPS. As was discussed in the previous section, the functional use of EPS and XPS is for continuous insulation applications such as in walls and roofs on the exterior of buildings. These applications include products such as insulating concrete forms (ICFs); structural insulated panels (SIPs); below grade and geotechnical applications for foundations and highways; and other dimensional stability or strength applications, e.g., insulated cold storage applications.

5.2.1 Rigid Board Alternatives

This section discusses alternative insulation materials identified by stakeholders that are available as rigid board and therefore can be used in many of the same applications as EPS and XPS. EPS and XPS are types of board insulation, which is typically made from plastic foams or fibrous materials, and is available in the form of board sheets (Minnesota Sustainable Housing Initiative 2007; U.S. Department of Energy 2008). Other materials readily available as board insulation include polyisocyanurate foams, perlite insulation, and mineral wool/rockwool insulation. These materials are described below.

Non-flame retarded EPS or XPS is a potential alternative to flame retarded EPS or XPS if used in conjunction with a thermal (fire resistant) barrier. In this case, the flame retardancy would be provided by a fire resistant covering or coating that isolates the insulation materials within the building (Sall 2010). While coatings face several technical and economic hurdles, separate non-adhered coverings that have sufficient flame barrier properties can be used to render the flame retardant properties of the insulation unimportant. For example, in some countries, non-flame retarded EPS is used in ground or floor insulation below a concrete layer, or in wall cavities with thermal barriers (COWI 2011). EPS is readily available with no flame retardants to the food or packaging industry. U.S. manufacturers generally only supply building insulation that contain flame retarded resins so that fire safety and construction codes can be met, and to reduce fire hazards of EPS and XPS after manufacturing and during transportation and construction.

Polyisocyanurate foams are manufactured from petrochemical feedstocks and a blowing agent (e.g., pentane), and are most commonly available as sprayed foam or board insulation with a facer on each surface (Wilson 1995; Wilson 2005; U.S. Department of Energy 2011). Polyisocyanurate foams typically use 5-14% by weight tris(chlorpropyl) phosphate (TCPP) as a flame retardant to meet building codes (Wilson 2005). The performance requirements for faced polyisocyanurate foam board insulation are specified in ASTM C1289. Its thermal resistance, which is subject to thermal drift over time, is cited by the National Roofing Contractors Association as having an in-service R-value of 5.0 or 5.6 per inch depending on whether the board is exposed to heating or cooling conditions (Graham 2010). It is primarily used as roof insulation, but is also used in cavity walls and sheathing (Polyisocyanurate Insulation Manufacturers Association 2011). Polyisocyanurate foam board insulation used in walls can have an R-value as high as 6.5 per inch (The Dow Chemical Company 2013; The Dow Chemical Company n.d.). It should be noted that the isocyanates (e.g., methylene diphenyl diisocyanate (MDI), polymeric methylene diphenyl diisocyanate (pMDI) and toluene diisocyanate (TDI), or other isocyanate oligomers) used in the manufacture of the foam pose human health hazards and are the subject of an EPA Action Plan and a separate DfE Best Practices Partnership (U.S. EPA 2011b).

Perlite insulation is manufactured from naturally occurring volcanic minerals (Sustainable Sources 2011). It is available as a rigid board, but is also often used as loose fill insulation or concrete aggregate (Healthy Building Network 2011; Sustainable Sources 2011). Perlite insulation is naturally fire resistant and does not require a flame retardant (COWI 2011). The performance requirements for perlite insulation are specified in ASTM C728 which lists its R-value as 2.7 per inch. It is most often used in roofs and walls, but can be used in all building applications, including floors (COWI 2011; Healthy Building Network 2011; Sustainable Sources 2011).

Mineral wool/rockwool is available as a semi-rigid or rigid board, batt, and blown-in loose fill insulation (Wilson 2005; Sustainable Sources 2011). It is made from recycled steel slag and/or basalt rock, uses a phenol-formaldehyde binder (Wilson 2005; Sustainable Sources 2011), and contains trace amounts of formaldehyde (ICA Fittings 2011). Formaldehyde poses human health hazards. EPA is currently developing regulations to implement the Formaldehyde Standards for Composite Wood Products Act. Mineral wool does not require a flame retardant (Ehrlich 2009). It has a typical R-value of 4 (Ehrlich 2009). It can be used in cavity walls, roofing, exterior insulation, and below grade (Wilson 2005; Ehrlich 2009).

5.2.2 Alternatives for Certain Functional Uses

This section describes alternative insulation materials identified by stakeholders that may be used for certain functional uses of EPS and XPS. These alternatives are generally not available as rigid board insulation, but may be used in certain applications where the properties such as dimensional stability or compressive strength are not integral to the performance of the insulation material. Types of insulation that may fulfill this purpose include:

- **Blanket insulation**, which is available in batts or rolls and is usually made from glass or mineral fibers (U.S. Department of Energy 2008). Blanket insulation is used in unfinished walls, foundations, floors, and ceilings and is fitted between studs, joists, and beams, or is laid on open horizontal surfaces (U.S. Department of Energy 2011). Blanket insulation may be used in place of some applications of board insulation in walls, floors, ceilings, and foundations.
- **Foamed-in-place insulation**, which is sprayed into cavities, reduces air leaks, and is usually made from polyurethane (Minnesota Sustainable Housing Initiative 2007; Wilson 2010b). Foamed-in-place insulation may be used in place of board insulation in applications such as walls or roofs where they can be sprayed to fill and seal cavities.
- **Loose-fill insulation**, **blown insulation**, and **sprayed insulation,** which are generally composed of loose fibers or fiber pellets that are blown into wall cavities or above horizontal ceiling surfaces using pneumatic equipment (U.S. Department of Energy 2008). Applications of loose-fill insulation include wall cavities, attic floors, irregularly shaped areas, and fill in around obstructions (U.S. Department of Energy 2008). Similar to foamed-in-place insulation, loose-fill, blown, and sprayed insulation may be used in place of board insulation in applications such as walls or roofs.

Alternative insulation materials within the categories of insulation types described above that may be used for certain functional uses of EPS and XPS are summarized below.

Cellulose is used as a type of blown-in loose-fill insulation and is made from recycled newspaper (Wilson 1995; COWI 2011). Ammonium sulfate, boric acid, and borax are typically used as flame retardants in cellulose insulation to meet building codes (Wilson 2005). It has a typical R-value of 3.7 and is not water resistant (Minnesota Sustainable Housing Initiative 2007; COWI 2011). There are also health concerns as printer ink in the newsprint may outgas as formaldehyde, as well as from inhalation of paper dust during installation (Greenspec 2010). Cellulose insulation is most commonly used as a loose-fill insulation in attic and wall cavities (Wilson 1993).

Cementitious foam is used as a foamed-in-place insulation and is made from magnesium oxide derived from seawater and talc (Wilson 2005). Cementitious foam does not require a flame retardant (Healthy Building Network 2011). It is has a typical R-value of 3.9 (AirKrete Inc 2009). Cementitous foam is friable, limiting its application (Wilson 2005). Currently, cementitious foam is manufactured by a single producer, limiting its distribution to the east coast of the United States (Wilson 2005; Healthy Building Network 2011). It is used to insulate walls, roofs, and ceilings (AirKrete Inc 2009).

Cotton insulation is available as a batt, and is made either from cotton and polyester mill scraps or from post-consumer recycled clothing, most often recycled denim scrap (Wilson 2005). It uses borate or ammonium sulfate flame retardants (Wilson 2005). Cotton insulation may absorb water and has a typical R-value of 3.4 (Healthy Building Network 2011; U.S. Department of Energy 2011). It can be used in the typical applications of batt insulation such as in walls, foundations, floors, and ceilings (U.S. Department of Energy 2011).

Fiberglass is available as a batt, blown-in loose fill, or semi-rigid board insulation material (Minnesota Sustainable Housing Initiative 2007). It is made from silica sand and may contain recycled glass content (Wilson 2005). Fiberglass insulation traditionally uses phenol formaldehyde binders, although some manufacturers are switching to acrylic or bio-based resins (Wilson 2005; Ehrlich 2010). Formaldehyde poses human health hazards and EPA is currently developing regulations to implement the Formaldehyde Standards for Composite Wood Products Act. Fiberglass does not require a flame retardant, although there are some specialty fiberglass batt products with halogenated flame retardants in the paper backing (Healthy Building Network 2011). It has a typical R-value of 3.2 (Minnesota Sustainable Housing Initiative 2007). It is used in masonry walls, cavity walls, roofs, attics, ceilings, and flooring (COWI 2011; Healthy Building Network 2011).

Polyurethane is most commonly available as a foam-in-place insulation (known as Spray Polyurethane Foam (SPF)) and is made from mixing two ingredients conventionally known as “Side A” and “Side B”. Side A is composed of isocyanates; Side B is a polyol blend that contains a refined petroleum (often some bio-based content) with a blowing agent (typically either water or chlorofluorocarbons (CFCs)/ hydrofluorocarbons (HFCs) (historically), more recently non-ozone depleting/low global warming potential substances) and other additives such as surfactants, amines, and flame retardants (Wilson 2005; U.S. Department of Energy 2011; U.S. EPA 2012a). Some polyurethane insulations may use some bio-based content, which is generally less than 15% of the total content (BioBased Insulation 2012). Polyurethane insulation uses TCPP or resorcinol-bis-diphenyl phosphate (RDP) as a flame retardant to meet building codes (Wilson 2005). Polyurethane has an R-value ranging from 3.6 to 7.5 (COWI 2011; U.S. Department of Energy 2011). It can be used to insulate cavities, walls, or roofs ("Foam-in-Place Polyurethane Insulation" 2008). It should be noted that exposures to diisocyanates (e.g., MDI) and other ingredients in SPF that may be found in vapors, aerosols, dust, or on surfaces during and for a period after installation may cause adverse health effects such as asthma (U.S. EPA 2011c). The EPA has issued an Action Plan for MDI and related compounds and performed separate DfE Best Practices Partnership on this topic (U.S. EPA 2011b). EPA has also developed an informational website addressing concerns for SPF use: http://www.epa.gov/dfe/pubs/projects/spf/spray_polyurethane_foam.html.

5.2.3 Specialty and Emerging Alternative Materials

The insulation materials presented in this section may be functional alternatives to EPS and XPS, but are not considered to be currently viable for large scale building applications, and so are constrained to specialty applications or limited geographic areas. This information is intended to provide context in case changes in manufacturing processes or economies of scale allow these products to become viable in the future.

Specialty and emerging alternative insulation materials identified by stakeholders include:

- **Aerogel** is available as a rigid board, roll, or loose-fill; and is used to insulate underfloors, rainscreens, roofing, cathedral ceilings, and interior walls (Madonik 2011). It is made from silica gel, polyethylene terephthalate (PET), fiberglass, and magnesium hydroxide (COWI 2011). Aerogel is lightweight and has a very high R-value of 10, but is costly.
- **Carbon foam** is a type of rigid board foam made from calcined coke. It is manufactured in limited quantities and is used primarily as a specialty insulation in the aeronautic, marine, and energy industries (Madonik 2011).
- **Foamglas** is a rigid board insulation made from sand, limestone, and soda ash that is primarily used for high-temperature industrial applications where extreme heat resistance is required but can be used to as insulation in roofs, walls, and below-grade. There is only one Foamglas manufacturer in the U.S. and Foamglas is costly compared to other rigid board insulation products (Wilson 2010c).
- **Phenolic foam** is a type of rigid foam and foamed-in-place insulation that may be used in roofing, wall cavities, external walls, and floors (COWI 2011). Currently, only foamed-in place phenolic insulation is available in the U.S (U.S. Department of Energy 2011). Rigid phenolic foams are no longer produced in the U.S. after corrosive breakdown products caused construction issues in the early 1990s, although they may be imported from Europe and Asia (Smith, Carlson et al. 1993; Schroer, Hudack et al. 2012).
- **Reflective insulation** is a foil-faced insulation material that incorporates a radiant barrier (normally highly reflective aluminum) with a kraft paper, plastic film, polyethylene bubble, or cardboard backing (U.S. Department of Energy 2012). Reflective insulation is used to reduce radiant heat flow across an open space, most usefully for downward radiant heat flow, and is typically used between roof rafters,

floor joists, and wall studs (U.S. Department of Energy 2008). The rest of the insulations described here are designed to reduce thermal heat conduction through solid surfaces in any direction. For this reason, reflective insulation is not an alternative for EPS and XPS, but rather works best in complement with other forms of insulation.

- **Agrifiber insulation** is manufactured from agricultural waste (e.g., rice hulls, fungal mycelia, wheat or rice straw) and is available as board insulation (Healthy Building Network 2011; Wilson 2011). Agrifiber typically uses borate as a flame retardant (Sustainable Sources 2011). New agrifiber insulations under development using mycelium as a binder are reported to have obtained a Class 1 fire rating without use of added chemical flame retardants (Wilson 2011). Agrifiber insulation has an R-value ranging from 3.0 to 3.5 and is not water resistant; it is currently available only in limited SIPs applications (Healthy Building Network 2011; Madonik 2011).

Further information about the alternative materials discussed in this section can be found in materials provided by the U.S. Department of Energy[20], Environmental Building News[21], The Pharos Project[22], GreenSpec[23], manufacturer websites, and the respective trade association websites, as well as the references cited above.

[20] http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm?mytopic=11510
[21] http://www.buildinggreen.com/news/index.cfm
[22] http://www.pharosproject.net/
[23] http://www.greenspec.co.uk/insulation-introduction.php

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