United States
Environmental Protection
Agency

FLAME RETARDANT ALTERNATIVES FOR HEXABROMOCYCLODODECANE (HBCD)

Chapter 3

Background on Flame Retardants

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3 Background on Flame Retardants

This chapter includes background information on flame retardants. Section 3.1 includes background on types of flame retardants and flammability test requirements. Section 3.2 presents information regarding flame retardants for polystyrene, Section 3.3 presents the flame retardants included in this assessment, and Section 3.4 discusses those flame retardants that were considered but excluded from the assessment.

3.1 General Information on Flame Retardants

Flame retardants are chemicals used to reduce risk of fire through reducing the ignitability of materials and/or the heat generated from materials. For polymers, the simplest way, in theory, of decreasing flammability is to design the polymer so that it is thermally stable. Thermally stable polymers are less likely to decompose into combustible gases under heat stress and thus often have higher ignition resistances. Because thermally stable polymers are often difficult and expensive to process, manufacturers use other means, such as adding flame retardant chemicals, to impart flame retardant properties to materials. Since there are a large number of flame retardants on the market and they often can be a cost-effective solution for providing fire safety, these chemicals are used in a broad range of products.

As plastics have become an integral part of modern life, fire risk is perceived to be elevated because plastics can burn hotter and faster than traditional materials such as wood (Underwriters Laboratories 2012). Flame retardants, which are often added to meet flammability standards, inhibit combustion and therefore contribute to a reduced fire risk when added to flammable plastics. However, some flame retardants are associated with environmental hazards e.g., polybrominated diphenyl ethers (PBDEs) (U.S. EPA 2003b; U.S. EPA 2003a; U.S. EPA 2004; U.S. EPA 2008; U.S. EPA 2012) and contribute to hazardous by-products from a smoldering or fully engaged fire (e.g., carbon monoxide and smoke (Nelson 1998; Peck 2011)) when inhibiting combustion. Some halogenated flame retardants will yield additional hazardous by-products (e.g., halogenated dioxins and furans) during incomplete combustion (Sidhu, Morgan et al. 2013). This incomplete combustion is too complex and variable for all potential combustion by-products to be adequately included in this report. Both halogenated and non-halogenated flame retardants may yield other toxic by-products that have not been identified in this report.

The use of flame retardants can be viewed as a risk-risk trade-off. Plastic product manufacturers are challenged with using chemical additives that reduce fire risk and may increase environmental risk. There are two risk reduction arguments put forth by the stakeholders of this Partnership. They are summarized here in simple terms: (1) flame retardants reduce fire risk and reduce smoke and toxicity caused by uninhibited fires thus enabling the use of beneficial plastic products, and (2) flame retardants increase environmental risk because they release from plastics into house dust and contribute to the toxicity of combustion by-products when they burn while not significantly increasing egress time from buildings during fires. One important approach in addressing this risk-risk trade-off is identifying the least hazardous flame retardant additives available for a given polymer-product combination. This report provides the environmental information necessary for product manufacturers to identify the flame retardants with the lowest hazard for their products. Although an analysis of fire safe assemblies that do not require additive flame retardants is outside of the scope of this report, Chapter 5 provides a general overview of alternative insulation materials and the applications in which they may be used.

Fire occurs in three stages: (1) thermal decomposition, where the solid, or condensed phase, breaks down into gaseous decomposition products as a result of heat, (2) combustion chain reactions in the gas phase, where thermal decomposition products react with an oxidant (usually air) and generate more combustion products, which then propagate the fire and release heat, and (3) transfer of the heat generated from the combustion process back to the condensed phase to continue the thermal decomposition process (Hirschler 1992; Beyler and Hirschler 2002). Those flame retardants which act in the gas phase do so by interacting with substances that are volatile. To function in the gaseous phase this way, these flame retardants themselves must become volatile and react with the substances that are being released from a product in turn making the volatile substances no longer combustible. Flame retardants that act in the condensed phase do so by forming a solid char, a glassy layer that acts by isolating the substrate from combustion, which interferes with the transfer of heat from the gas phase to the condensed phase and reduces the combustibility of the gases. The primary physical mode of flame retardancy is to reduce heat generation by forming a non-combustible layer or "diluting" the organic combustible material through the generation of water vapor and preventing the continued progression of the fire (Posner and Boras 2005). Therefore, in either state, flame retardants will act to decrease the release rate of heat (Hirschler 1994), thus reducing the burning rate, flame spread, and/or smoke generation (Morose 2006a). Flame retardant modes of action are further discussed in Chapter 3 of the report Flame-Retardant Alternatives for Decabromodiphenyl Ether (decaBDE)[11].

3.1.1 Flame Retardant Classification

Flame retardants are generally incorporated throughout a polymeric material, although they can also be coated on the external surface of the polymer to form a protective barrier. Flame retardants can be broadly classified into two types according to the method of incorporation into the polymer:

- *Reactive:* Reactive flame retardants are incorporated into the polymer during compounding and will become a permanent part of the polymer structure – i.e., the chemically-bound reactive flame retardant chemicals cease to exist as separate chemical entities. Compared to an additive flame retardant, reactive flame retardants can have a greater effect on a polymer's physical-chemical properties.

- *Additive:* Additive flame retardants are also incorporated into the polymer during compounding and may interact with the polymer, but they remain as an independent chemical species. Because they are not chemically bound to the polymer, additive flame retardants have a potential to migrate out of the polymer under certain conditions over time. Therefore plastic formulators must take this into account to avoid reducing polymer fire safety or causing exposure to humans and releases to the environment. A far greater number of additive flame retardants are offered for polymers compared to the number of

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[11] http://www.epa.gov/dfe/pubs/projects/decaBDE/index.htm

reactive flame retardants. Additive flame retardants are far more versatile because commodity plastics are made for many applications, not just those requiring flame retardants, and they can be incorporated into the product up until the final stages of manufacturing.

Due to the various physical and chemical properties of flame retardant chemicals, most are used exclusively as either reactive or additive flame retardants. Both reactive and additive flame retardants can significantly change the properties of the polymers into which they are incorporated. For example, they may change the viscosity, flexibility, density, electrical properties, tensile strength, and flexural strength; they may also increase the susceptibility of the polymers to photochemical and thermal degradation.

Flame retardants can also be classified into four main categories according to chemical composition (IPC 2003; Morose 2006a):

- *Halogenated*: Halogenated flame retardants are primarily based on chlorine and bromine. Hexabromocyclododecane (HBCD) and the three alternatives assessed in this report contain bromine. In 2006, brominated compounds represented approximately 18% by volume of the global flame retardant consumption (Cusack 2007). Typical halogenated flame retardants are halogenated aliphatic and aromatic compounds, halogenated polymeric materials, and halogenated paraffins. Some halogenated flame retardants also contain other elements, such as phosphorus or nitrogen. The effectiveness of halogenated additives is due to their interference with volatile substances that are created in the combustion process, decreasing their combustibility (see Section 3.2 for more detail).

- *Inorganic*: This category includes inorganic flame retardants and flame retardant synergists such as silicon dioxide, metal hydroxides (e.g., aluminum hydroxide and magnesium hydroxide), antimony compounds (e.g., antimony trioxide), boron compounds (e.g., zinc borate – which is often used as a synergist for both halogenated and non-halogenated flame retardants), and other metal compounds (molybdenum trioxide). As a group, these flame retardants represented the largest fraction (about 46-52%) of total flame retardants consumed in 2006 because they require high loading levels to impact the desired fire safety (Cusack 2007). Antimony trioxide is invariably used as a synergist for halogenated flame retardants since by itself antimony oxide has little flame retardant effect in the presence of most burning polymers. Inorganic synergists are sometimes used with HBCD.

- *Phosphorus-based*: This category represented about 16% by volume of the global consumption of flame retardants in 2006 and includes organic and inorganic phosphates, phosphonates, and phosphinates as well as red phosphorus, covering a wide range of phosphorus compounds with different oxidation states (Cusack 2007). There are also halogenated phosphate esters, often used as flame retardants for polyurethane foams or as flame retardant plasticizers, but not commonly used in electronics applications (Hirschler 1998; Green 2000; Weil and Levchik 2004). None of the potential HBCD alternatives identified in this assessment are phosphorus-based.

- *Nitrogen-based*: These flame retardants include melamine and melamine derivatives (e.g., melamine cyanurate, melamine polyphosphate). Nitrogen compounds were estimated to account for 3% of global flame retardant consumption in 2006 (Cusack 2007). Nitrogen-containing flame retardants are often used in combination with phosphorus-based flame retardants, often with both elements in the same molecule. None of the potential HBCD alternatives identified in this assessment are nitrogen-based.

3.1.2 Flammability Tests

HBCD is used as a flame retardant in polystyrene insulation foam to allow the foam to meet the fire safety requirements of various building codes, as set by national, state, county or municipal regulations. Flammability standards are developed by a variety of entities, including national regulatory agencies such as the Consumer Product Safety Commission (CPSC), state regulatory agencies such as the California Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation (BEARHFTI), or for-profit companies such as Underwriters Laboratories (UL).

In the U.S., building codes are adopted at the state or municipal level and not at the federal level (Morose 2006b; Grant 2011). The American Society for Testing and Materials (ASTM) E5 committee is responsible for developing voluntary consensus fire standards for materials, products, and assemblies that are often incorporated into state or municipal regulations. Specifically, ASTM standard E84 (*Standard Test Method for Surface Burning Characteristics of Building Materials*) is the overarching flammability test for building materials in the U.S. (Harscher 2011). ASTM E84 assesses the flame spread and smoke development of building materials by employing the Steiner Tunnel Test to compare the flame spread and smoke development against standard materials (Weil and Levchik 2009; Harscher 2011). Expanded polystyrene (EPS) and extruded polystyrene (XPS) foam also generally must meet the requirements of ASTM C578 (*Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation*), as well as comply with the International Building Code (IBC) and International Residential Code (IRC) (EPS Industry Alliance 2011; Extruded Polystyrene Foam Association 2011).

Other flammability tests apply to EPS and XPS insulation foam containing HBCD in specific building assemblies. A partial list of these tests includes:

- ASTM D2863 (*Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics*)
- ASTM E119 (*Standard Test Methods for Fire Tests of Building Construction and Materials*)
- ASTM E1354 (*Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*)
- Factory Mutual (FM) 4450 (*Approval Standard for Class 1 Insulated Deck Roofs*)
- FM 4470 (*Approval Standard for Single-Ply, Polymer-Modified Bitumen Sheet, Built-Up Roof (BUR) and Liquid Applied Roof Assemblies for use in Class 1 and Noncombustible Roof Deck Construction)*
- FM 4880 (*Approval Standard for Class 1 Fire Rating of Insulated Wall or Wall and Roof/Ceiling Panels, Interior Finish Materials or Coatings and Exterior Wall Systems*)

- National Fire Protection Association (NFPA) 225 (*Model Manufactured Home Installation Standard*)[12]
- NFPA 286 (*Standard Methods of Fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth*)
- Uniform Building Code (UBC) Standard 42-1 (*Flame Spread and Smoke Development*)[13]
- UL 94 (*Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances Testing*)

3.2 Brominated Flame Retardants for Polystyrene

At this time, brominated flame retardants are the only commercially and technically viable options for polystyrene foam insulation. Flame retardants for EPS and XPS must be compatible with manufacturing processes, allow the material to comply with fire safety codes, and not compromise the physical properties of the foam (Environment Canada 2011; EPS Industry Alliance 2011; Extruded Polystyrene Foam Association 2011). HBCD has been the flame retardant of choice for EPS and XPS because it imparts flame retardance at low concentrations without compromising the physical properties (e.g., thermal resistance) of the foam (EPS Industry Alliance 2009; Environment Canada 2011; Extruded Polystyrene Foam Association 2011). Based on currently available technology, using non-brominated flame retardants in polystyrene foam would require much higher concentrations of the flame retardant, which can alter the physical properties of the foam (IOM Consulting 2009).

Brominated flame retardants have the ability to interact with partial oxidation reactions that occur in the gas phase during the combustion of polystyrene, which leads to the extinction of the flame (Kaspersma, Doumen et al. 2002). Bromine-containing compounds form hydrogen bromide (HBr) and prompt the formation of hydrogen gas from radical hydrogen (Beach, Rondan et al. 2008). In addition to its ability to exhibit flame retardancy in the gas phase, HBCD has also been found to aid in polystyrene degradation through condensed-phase activity (Beach, Rondan et al. 2008).

Figure 3-1. Bromine Interaction Mechanism

$$\mathrm{HBr} + \mathrm{OH}\bullet \rightarrow \mathrm{H_2O} + \mathrm{Br}\bullet$$
$$\mathrm{HBr} + \bullet\mathrm{O}\bullet \rightarrow \mathrm{OH}\bullet + \mathrm{Br}\bullet$$
$$\mathrm{HBr} + \mathrm{H}\bullet \leftrightarrow \mathrm{H_2} + \mathrm{Br}\bullet$$
$$\mathrm{HBr} + \mathrm{RCH_2}\bullet \leftrightarrow \mathrm{RCH_3} + \mathrm{Br}\bullet$$
$$\mathrm{RBr} \leftrightarrow \mathrm{R}\bullet + \mathrm{Br}\bullet$$

Source: Kaspersma, Doumen et al. 2002

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[12] Based on ASTM E84.

[13] ibid

Although all halogens are capable of capturing free radicals produced during the combustion of polystyrene, the ability to do so effectively increases with the size of the halogen (F<Cl<Br<I) (Alaee, Arias et al. 2003). Fluorinated compounds are not used as flame retardants because they are very stable and decompose at very high temperatures, delaying the activation of the flame retardant's mechanism (Alaee, Arias et al. 2003). Iodine-based compounds are also not widely used because they decompose at slightly elevated temperatures and are unstable (Alaee, Arias et al. 2003). Brominated compounds, however, have a higher trapping efficiency and lower decomposing temperature than chlorinated compounds, making them ideal components in flame retardants (Alaee, Arias et al. 2003).

3.3 Flame Retardants Included in this Assessment

With the assistance of the multi-stakeholder partnership, U.S. Environmental Protection Agency (EPA) identified three alternatives to HBCD that fit the scope of this project: viable alternatives to HBCD for use in EPS and XPS foam insulation (see Chapter 1). A list of potential alternatives to HBCD was compiled based on information in open literature (Morose 2006b; Weil and Levchik 2009; pinfa 2011) and discussion with experts in chemical manufacturing and product development in industry, government, and academia. Through these discussions, the three alternatives shown in Table 3-1 were identified as potentially viable for use in EPS and XPS. Section 3.4 discusses other flame retardants that were considered but not included in the assessment. As was discussed in Chapter 1, while the project scope does not include alternatives to HBCD for its minor uses in textile back coatings and high-impact polystyrene

Chemical Alternatives and the Toxic Substances Control Act

EPA's Design for the Environment (DfE) program is administered by the Office of Pollution Prevention and Toxics (OPPT), which is charged with the implementation of the Toxic Substances Control Act (TSCA) and the Pollution Prevention Act (PPA).

Central to the administration of TSCA is the management of the TSCA Inventory. Section 8 (b) of TSCA requires EPA to compile, keep current, and publish a list of each chemical substance that is manufactured or processed in the United States. Companies are required to verify the TSCA status of any substance they wish to manufacture or import for a TSCA-related purpose. For more information, please refer to the TSCA Chemical Substance Inventory website: http://www.epa.gov/opptintr/existingchemicals/pubs/tscainventory/basic.html

TSCA and DfE Alternatives Assessments

Substances selected for evaluation in a DfE Alternatives Assessment generally fall under the TSCA regulations and therefore must be listed on the TSCA inventory, or be exempt or excluded from reporting before being manufactured in or imported to, or otherwise introduced in commerce in, the United States. For more information see http://www.epa.gov/oppt/newchems/pubs/whofiles.htm.

To be as inclusive as possible, DfE Alternatives Assessments may consider substances that may not have been reviewed under TSCA and therefore may not be listed on the TSCA inventory. DfE has worked with stakeholders to identify and include chemicals that are of interest and likely to be functional alternatives, ***regardless of their TSCA status.*** Chemical identities are gathered from the scientific literature and from stakeholders and, for non-confidential substances, appropriate TSCA identities are provided.

Persons are advised that substances, including DfE identified functional alternatives, may not be introduced into US commerce unless they are in compliance with TSCA. Introducing such substances without adhering to the TSCA provisions may be a violation of applicable law. Those who are considering using a substance discussed in this report should check with the manufacturer or importer about the substance's TSCA status. If you have questions about reportability of substances under TSCA, please contact the Industrial Chemistry Branch at 202-564-8740.

(HIPS) used in electronics housings, stakeholders interested in alternatives for these uses may refer to the flame retardants assessed in *An Alternatives Assessment For The Flame Retardant Decabromodiphenyl Ether (DecaBDE)*[14].

Table 3-1. Summary of Chemicals for Assessment

Chemical Name	CASRN	Status
Hexabromocyclododecane (HBCD)	25637-99-4; 3194-55-6	Action Plan chemical. Included for comparative purposes.
Benzene, ethenyl-, polymer with 1,3 butadiene, brominated; “butadiene styrene brominated copolymer”	1195978-93-8	Announced by The Dow Chemical Company and Great Lakes Solutions, A Chemtura Business on March 29, 2011 (Great Lakes Solutions, A Chemtura Business 2011). The chemical has also been licensed to ICL-IP and Albemarle.
Benzene, 1,1'-(1-methylethylidene)bis[3,5-dibromo-4-(2,3-dibromo-2-methylpropoxy)]; “TBBPA-bis brominated ether derivative”	97416-84-7	Proposed as an alternative by a chemical manufacturer.
Tetrabromobisphenol A Bis (2,3-dibromopropyl) Ether	21850-44-2	This flame retardant was submitted as an alternative to HBCD to the Stockholm Persistent Organic Pollutants Review Committee (POPRC) (Lorenzi and Garlaschi 2013).

3.4 Flame Retardants Not Included in this Assessment

In addition to the chemicals listed in Table 3-1, the Partnership considered other flame retardants for the assessment, including individual chemicals and materials. Section 3.4.1 describes chemicals that were identified as possible alternatives to HBCD and the reasons they were excluded from the assessment.

3.4.1 Specific Chemicals that were Excluded from this Assessment

The chemicals listed in this section were identified as possible alternatives to HBCD, but were not included in the alternatives assessment. Reasons for exclusion included:

- The chemical is not a flame retardant, but rather a blend of flame retardants and other additives intended to improve the performance of certain flame retardants through synergistic mixtures;
- Not functional in typical EPS and/or XPS manufacturing processes; and
- Interferes with ability of EPS and/or XPS to meet building codes or flammability standards.

A summary of the chemicals that were discussed but not included in this assessment is listed in Table 3-2 along with the reason for exclusion. It is possible that there are alternatives that the Partnership was not aware of or were under development at the time this report was compiled; therefore, Table 3-1 and Table 3-2 may not list all of the possible alternatives to HBCD.

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[14] http://www.epa.gov/dfe/pubs/projects/decaBDE/index.htm

Table 3-2. Chemicals Considered but Not Included in the Final Alternatives Assessment[1]

Chemical Name	CASRN	Reason for Exclusion
Brominated Flame Retardants		
Tetrabromocyclooctane	31454-48-5; 3194-57-8	This flame retardant is not functional in current EPS and XPS manufacturing processes. Its thermal stability does not meet operating temperature requirements for the manufacture of XPS foam.
Dibromoethyldibromocyclohexane	3322-93-8	Polystyrene manufacturers have noted insufficient thermal stability and an inferior persistent, bioaccumulative, and toxic (PBT) chemical assessment.
Chloropentabromocyclohexane	87-84-3	The manufacture of this flame retardant was discontinued in favor of HBCD due to an inferior environmental health and safety profile. This flame retardant may also interfere with the styrene polymerization process, resulting in a product with a lower average molecular weight (MW) and more residual unreacted styrene in the product. The resulting foam will lack the strength to meet building code requirements.
Cinnamalacetophenone tetrabromide	N/A[1]	This flame retardant was used for a time but discontinued. Its chemical structure is similar to that of 1,2-dibromoalkyl ketones. Referring to the patent literature, EPA identified this CAS name as expected to be 1-Pentanone, 2,3,4,5-tetrabromo-1,5-diphenyl-; CASRN 31611-84-4.
Hexabromohexene	125512-87-0	This flame retardant is recommended in patents as a potential alternative, but there is no information indicating that it is currently used by industry. It is also similar in structure to chloropentabromocyclohexane, so it may also interfere with the styrene polymerization process.
1,2-Dibromoalkyl ketones	N/A[1]	This flame retardant is recommended in patents as a potential alternative, but there is no information indicating that it is currently used by industry. Polystyrene foam manufacturers have observed insufficient functionality.
1,1,2,3,4,4-Hexabromo-2-butene	72108-73-7; 36678-45-2	This flame retardant is recommended in patents as a potential alternative, but there is no information indicating that it is currently used by industry. This flame retardant may also interfere with the styrene polymerization process, resulting in a product with a lower average MW and more residual unreacted styrene in the product. The resulting foam will lack the strength to meet building code requirements.
bis(2,3-dibromopropyl) tetrabromophthalate	N/A[1]	This flame retardant is not as effective per unit weight as other alkyl halides and polystyrene foam manufacturers have observed insufficient flame retardant activity. Referring to the patent literature, EPA identified this CAS name as 1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-, 1,2-bis(2,3-dibromopropyl) ester; CASRN 214216-08-7.
2,4,6-Tribromophenyl allyl ether	3278-89-5	This flame retardant is recommended in patents as a potential alternative. It is not a potential alternative for the use of HBCD in XPS foam because of its poor thermal stability at operating temperatures. It is not a cost-effective alternative in EPS because it is only viable in the less-economic two-step manufacturing process. This flame retardant may also interfere with the styrene polymerization process, resulting in a product with a lower average MW and more residual unreacted styrene in the product, resulting in foam that will lack the strength to meet building code requirements.
bis(allyl ether) of tetrabromobisphenol A	25327-89-3	This flame retardant is recommended in patents as a potential alternative, but in general only has limited use and availability. It does not work well in XPS manufacturing processes, and for EPS is only viable in the less-economic two-step manufacturing process. The lower brominated content and mixture of aliphatic and aromatic bromine affects the efficiency of the material.

Chemical Name	CASRN	Reason for Exclusion
N-(2,3-dibromopropyl)-4,5-dibromotetrahydrophthalimide	93202-89-2	This flame retardant is recommended in patents as a potential alternative, but feedback from polystyrene foam manufacturers indicated problems with its use, including insufficient flame retardant activity.
Dialkyl tetrabromophthalate	N/A[1]	This flame retardant is recommended in patents as a potential alternative, but polystyrene foam manufacturers have observed insufficient flame retardant activity. It is also known to have mutagenic affects. Referring to the patent literature, EPA identified this CAS name as 1,2-Benzenedicarboxylic acid, 3,4,5,6-tetrabromo-, 1,2-bis(2-ethylhexyl) ester; CASRN 26040-51-7.
tris(2,3-dibromopropyl) phosphate	126-72-7	This flame retardant was used for a time but discontinued due to its mutagenicity.
Blends		
Aluminum Hydroxide/Alumina Trihydrate (ATH) (recommended with further addition of phosphorus or brominated FRs)	21645-51-2	This flame retardant will require high loading in EPS and XPS. It has also already been assessed in Design for the Environment (DfE)'s *An Alternatives Assessment For The Flame Retardant Decabromodiphenyl Ether (DecaBDE).*
Brominated anionic styrene polymer + bis(pentabromophenyl) ethane	N/A[1] + 84852-53-9	These blends are synergistic mixtures used to improve performance of certain FRs. They are not potential alternatives to HBCD.
Bromoaliphatic FR + a more thermally stable bromine compound with an aromatic, vinylic, or neopentyl structure	N/A[1]	
Halogenated FR + P-N compound	N/A[1]	
Elemental sulfur + phosphorus additive	7704-34-9 + 7723-14-0	
Graphite particles (halogenated FR and (optional) antimony oxide, or with a phosphorus FR)	N/A[1]	Graphite is used to increase thermal properties rather than for flame retardancy. Expandable graphite has been used as a flame retardant in some polymers but is not expected to impart flame retardancy in EPS and XPS.
Epoxy resin containing reacted-in DOPO and phosphoric acid	N/A[1]	This flame retardant is unlikely to be a functional alternative in EPS and XPS due to insufficient flame retardant activity.
Other Classes		
Nano-particle coatings	N/A[1]	At low loading levels, these nanoparticle fire retardant coatings significantly reduce polyurethane foam flammability and can result in self-extinguishing fire behavior. National Institute of Standards and Technology (NIST) is evaluating this fire retardant technology that may have potential for XPS. The EPS industry processes material with hot wires, and particles that do not melt tend to create problems during this step.
Thiophosphates and dithiophosphates	N/A[1]	Polystyrene foam manufacturers observed insufficient flame retardant activity.
Flame resistant barrier - coating, laminate, foil	N/A[1]	Back coatings may not work with polystyrene foam because they will interfere with the ability of the foam to recede away from the fire. Additionally, the coating levels necessary to pass flammability tests are not economical.
Boric acid + binder	N/A[1]	This chemical is used as a smoke suppressant rather than as a flame retardant. It should also be noted that

Chemical Name	CASRN	Reason for Exclusion
		boric acid is a substance of very high concern in the European Union (EU).
Dimethyl methyl phosphonate (DMMP)	756-79-9	This chemical is too volatile for polystyrene foam.
Hypophosphite, calcium salt (with synergists)	7789-79-9	Polystyrene manufacturers have noted insufficient flame retardant activity.
Magnesium dihydroxide	1309-42-8	This flame retardant is not viable for polystyrene foam because it is not soluble and would require high loadings. It has also already been assessed in Design for the Environment (DfE)'s Flame Retardants in Printed Circuit Boards Partnership and the Flame Retardant Alternatives for DecaBDE Partnership.

Source: Personal Communication with members of the Partnership on Flame Retardant Alternatives for HBCD.

[1] A specific CASRN was not suitable for entries that cover a general group or larger class of chemicals.

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