United States
Environmental Protection
Agency

FLAME RETARDANT ALTERNATIVES FOR HEXABROMOCYCLODODECANE (HBCD)

Chapter 2

HBCD Uses, End-of-Life, and Exposure

FINAL REPORT

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2 HBCD Uses, End-of-Life, and Exposure

Hexabromocyclododecane (HBCD) is most commonly used in expanded polystyrene foam (EPS) and extruded polystyrene foam (XPS) produced for the building and construction industry to meet fire safety standards. HBCD also has minor uses as a flame retardant in textile back coatings and high-impact polystyrene (HIPS) used in electronics housings. As stated in Chapter 1, this alternatives assessment focuses on HBCD in EPS and XPS foam insulation and does not include alternatives to HBCD for its uses in textile back coatings and HIPS. Information on flame retardants in textile back coatings and HIPS can be found in Design for the Environment (DfE)'s Partnership on Alternatives to Decabromodiphenyl Ether (decaBDE)[6].

Chapter 2 presents the uses of HBCD with descriptions of EPS and XPS (Section 2.1), an overview of end-of-life scenarios for insulation (Section 2.2), and a summary of information pertaining to human and environmental exposure to HBCD (Section 2.3).

2.1 Uses of HBCD

Figure 2-1 shows the proportions of HBCD use in polystyrene foam, textile back coatings and HIPS in the European Union (EU). In 2001, the world market demand for HBCD was 16,700 tons, or 33.4 million pounds, 57% of which was attributed to Europe (Janak, Covaci et al. 2005). According to the Toxic Substances Control Act (TSCA) Inventory Update Reporting (IUR), a volume between 10 and 50 million pounds of HBCD was manufactured or imported in the U.S. in 2005 (U.S. EPA 2006). In the most recent TSCA reporting for 2011, now called Chemical Data Reporting (CDR), the volume of HBCD manufactured or imported in the U.S. was claimed confidential and cannot be described in this report (U.S. EPA 2013). More precise data for HBCD uses are available for the EU, where 96% of HBCD is used in EPS and XPS foam. Figure 2-1 reflects data for European markets, as similar information for the U.S. is not available. Although the EU market and industry for HBCD are considered to be similar to those in the U.S., differences do exist in building technologies, climate, and consumption patterns, limiting the comparison of the two markets.

The application of HBCD in EPS and XPS is discussed in Section 2.1.1 of this assessment; Section 2.1.2 provides a summary of the minor uses of HBCD in textiles and HIPS.

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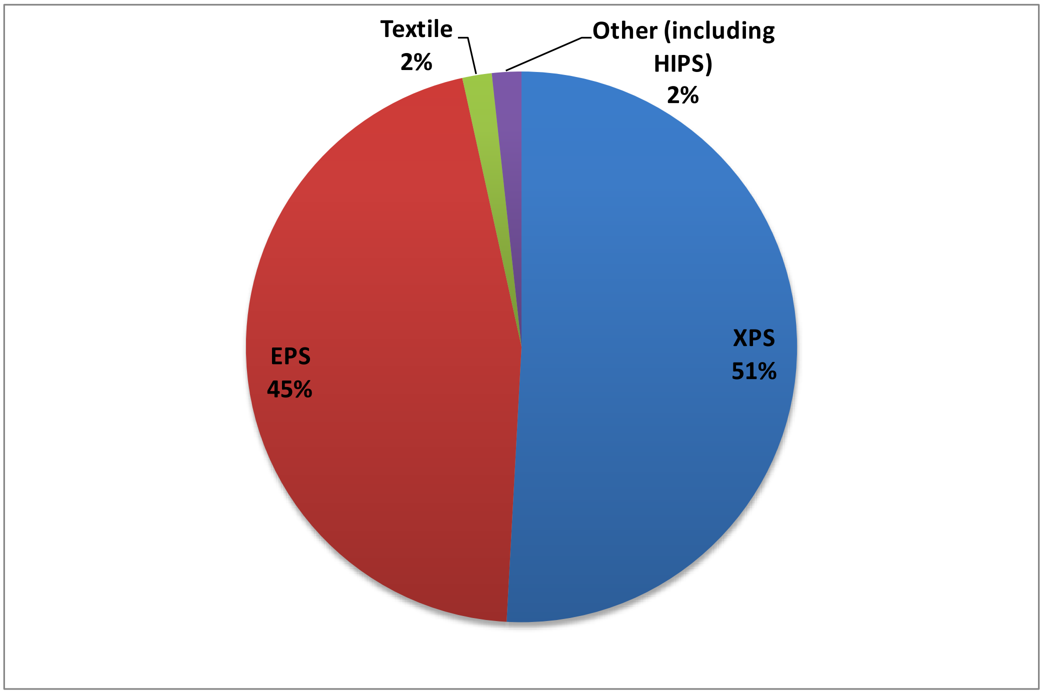
[6] www.epa.gov/dfe/pubs/projects/decaBDE/index.htm

Figure 2-1. Profile of HBCD Uses in European Markets for 2006/2007



(European Chemicals Agency 2009)

2.1.1 Building and Construction

Important properties of EPS and XPS include their energy efficiency, long-term performance (50-100 years), compressive strength, high moisture resistance and resistance to water absorption, versatility, durability, reusability, imperviousness to mold growth and microbiological, degradation, availability, and cost-effectiveness (EPS Industry Alliance 2011a; Extruded Polystyrene Foam Association 2011a; Fabian 2011).

EPS and XPS are used in buildings for insulation as well as to provide a moisture barrier, protect against damage from freezing, provide a stable fill material, and create high strength composite materials (Morose 2006). Typical applications include insulation in: attics, ceilings, roofs, walls, flooring, below grade applications, transportation, and cold storage (EPS Industry Alliance 2009a; EPS Industry Alliance 2011b; Extruded Polystyrene Foam Association 2011a; Extruded Polystyrene Foam Association 2011b). Other uses of polystyrene foam in consumer products (e.g., packaging) generally do not require the use of a flame retardant (European Commission 2008; EPS Industry Alliance 2011b). The use of HBCD in non-insulation applications of polystyrene foam was outside the scope of this alternatives assessment and was not researched.

Performance requirements for EPS and XPS foam used as thermal insulation are governed by American Society for Testing and Materials (ASTM) C578, *Standard Specification for Rigid, Cellular Polystyrene Insulation*.[7] In general, the performance requirements of foam insulation vary depending on the density of the foam. The ASTM C578 standards differentiate between classifications of insulation foam based on density and compressive strength. Table 2-1 below gives a broad range of properties covering the breadth of foam densities and compressive strengths cited in ASTM C578. The requirements are defined as follows:

- **Density:** Mass per unit volume.
- **R-value:** Thermal resistance. Higher R-values indicate a better ability to resist the flow of heat.
- **Compressive strength:** The compaction force (load per unit area) a material can withstand for a given change in dimensions (typically 10% reduction in thickness).
- **Flexural strength:** The breaking load applied to the neutral axis of a beam.
- **Water vapor transmission rate:** The steady state water vapor flow in unit time through unit area of a body, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface.
- **Water absorption:** Percentage, by volume, of water remaining within the specimen after immersion in water for a specified time.
- **Dimensional stability:** The ability of a material to maintain its original size, shape, and dimensions in response to thermal and humid aging.
- **Oxygen index:** The percent of oxygen necessary to support combustion of a polymer.

Typical Applications of EPS and/or XPS:

- Attics and Ceilings
- Roofs
  - Membrane roofs
  - Recovery/reroofing
  - Vegetative roofs
- Walls
  - Continuous insulation
  - Exterior Insulating and Finishing Systems (EIFS)
  - Garage door panels
  - Insulating Concrete Forms (ICFs)
  - Masonry cavity walls
  - One-coat stucco panels
  - Precast concrete
  - Steel Stud insulation
  - Structural Insulated Panels (SIPs)
- Flooring
- Below grade applications
  - Frost Protected Shallow Foundations (FPSF)
  - Geofoam
  - Geotechnical fill & stabilization
  - Highway insulation
- Cold Storage/Low temperature buildings
- Transportation
  - Recreational vehicle panels
  - Shipping containers

(EPS Molders Association, 2009a, 2011b; Extruded Polystyrene Foam Association, 2011a, 2011b)

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[7] Likewise, ASTM D6817 applies to polystyrene foams in geotechnical engineering applications ("geofoam"). See http://www.astm.org/Standards/D6817.htm.

- **Flame spread index:** The index rate expressed in distance and time at which a material will propagate flame on its surface.
- **Smoke development index:** An index indicating the potential for smoke generation during fire propagation.

Table 2-1. ASTM C578 Requirements for EPS and XPS Foam

	Unit	EPS	XPS
Classification Type		XI, I, VIII, II, IX, XIV, XV	XII, X, XIII, IV, VI, VII, V
Minimum Density	lbs per ft^3 (pcf)	0.70, 0.90, 1.15, 1.35, 1.80, 2.40, 3.00	1.20, 1.30, 1.60, 1.55, 1.80, 2.20, 3.00
Compressive strength	lbs per in^2 (psi)	5.0, 10.0, 13.0, 15.0, 25.0, 40,0, 60.0	15.0, 15.0, 20.0, 25.0, 40.0, 60.0, 100.0
Performance Requirement			
R-value	F-ft^2-h/BTU (75°F)	3.1-4.3	4.6-5
Flexural strength	lbs per in^2 (psi)	10-75	40-100
Water vapor transmission rate	Perm per inch	2.5-5.0	1.1-1.5
Water absorption	%	2.0-4.0	0.3-1.0
Dimensional Stability	%	2	2
Oxygen index	%	>24	>24
Flame spread index	Unitless index	<75	<75
Smoke development index	Unitless index	<450	<450

(International Code Council 2011a; International Code Council 2011b; American Society for Testing and Materials 2012)

To help ensure safety of occupants, building codes in the U.S. require use of materials that reduce the risk of fire. Flame retardants are used in EPS and XPS to raise ignition temperatures and to reduce the rate of burning, flame spread, and smoke, in turn potentially allowing building occupants more time to escape a life-threatening fire. HBCD is used because of its ability to impart flame retardancy at low concentrations (at a typical loading of 0.5% by weight in EPS (EPS Industry Alliance 2009b), 0.5-1% by weight in XPS (Extruded Polystyrene Foam Association 2011a), without the loss of thermal and physical property performance. HBCD is compatible with both EPS and XPS manufacturing processes (described in more detail below). Other valued characteristics include its low water solubility and retention in the foam, such that its fire safety contribution is maintained for decades, even after extended water contact (EPS Industry Alliance 2011a; Extruded Polystyrene Foam Association 2011a; Fabian 2011). Alternatives to HBCD in EPS and XPS foam must be able to meet fire safety and other regulatory requirements while avoiding negative impacts on human health and the environment, maintaining the thermal and physical properties of the material, being compatible with manufacturing processes, and being economically viable (EPS Industry Alliance 2011a; Extruded Polystyrene Foam Association 2011a; Fabian 2011). The EPS industry is making efforts to move away from the use of HBCD in building products and to implement alternatives by developing a test program to ensure that a new polymeric flame retardant complies with building code fire performance requirements for EPS applications in Canada and the U.S. (EPS Industry Alliance 2012). After commercial quantities of alternatives become available, in-house testing and quality control measures will be independently verified through third-party certification programs (EPS Industry Alliance 2012; ICC Evaluation Service 2012).

The remainder of this section discusses the manufacturing processes used to make EPS and XPS foam containing HBCD.

Manufacture of Expanded Polystyrene (EPS)

EPS is a rigid foam insulation produced by expansion and molding of expandable polystyrene resin beads. To manufacture EPS, first a polystyrene resin is produced via suspension polymerization by chemical manufacturers. Suspension polymerization is a polymerization process that uses agitation and suspending agents to suspend monomer and polymer particles (U.S. EPA 1997). The production of EPS resin beads for insulation is done by a limited number of chemical companies at a small number (<5) of production sites in the U.S. HBCD and a blowing agent, usually pentane, are added to the resin during the polymerization process. Synergists are often used with HBCD in EPS foam to allow the concentration of HBCD to be reduced, as is discussed in more detail below. There is also a less economical two-step technology for manufacturing EPS resin that for the most part has been replaced with the one-step process described here (Grant 2011).

Figure 2-2. EPS Insulation

The expandable resin is sold and transported to molders to create EPS foam. At the molding plant, the polystyrene resin is first expanded into foam beads via the direct application of steam, which causes the blowing agent in the resin to expand. Following an aging/maturing step of approximately 2 to 24 hours, the expanded foam beads are molded into rigid closed-cell foam. This process produces blocks of foam which are cut to desired shapes (such as insulation board) and thicknesses with hot wires (COWI 2011; EPS Industry Alliance 2011a). Alternatively, the expanded foam beads may be molded into custom shapes to produce rigid foam construction elements, such as ICFs. This process typically takes place at temperatures of 120°C (COWI 2011) or below. Trim scrap from the cutting operation can be recycled into the molding operation under controlled conditions while maintaining required properties. Molding plants are typically strategically located around the country to minimize the shipping costs of transporting the lightweight foams to end users. Additional information and resources regarding EPS foam and its manufacture may be found from chemical manufacturers, processors and formulators, and industrial association websites.

Manufacture of Extruded Polystyrene (XPS)

Figure 2-3. XPS Insulation

XPS is a rigid foam insulation board produced by an extrusion process. To manufacture XPS, polystyrene resin granules and additives, including blowing agents (typically hydrofluorocarbons (HFCs)) and flame retardants (i.e., HBCD), are mixed in an extruder. The resulting mixture is melted at high pressure and high temperatures (ranging from 180-230°C) into a viscous plastic fluid. Due to these high processing temperatures, HBCD is stabilized with chemical additives to limit effects of any HBCD decomposition during manufacture, as is discussed in more detail below. Next, the viscous fluid is forced through a die, expanded into a foam and shaped. The foamed mixture is cooled into continuous sheets (boards) of closed-cell insulation. The boards are cut to size and production waste is reprocessed (Wilson 2005; COWI 2011; Extruded Polystyrene Foam Association 2011a; Fabian 2011). Additional information and resources regarding XPS foam and its manufacture may be found from chemical manufacturers, processors and formulators, and their industrial association websites.

Synergists and Stabilizers used with HBCD in EPS and XPS

Synergists are often used with HBCD for the manufacture of EPS and stabilizers are used with HBCD in the manufacture of XPS. The Partnership discussed these additives but U.S. Environmental Protection Agency (EPA) did not include them in the hazard assessment (see Chapter 4) for several reasons: the additives were outside of the project scope that focuses on alternatives to HBCD; a comprehensive hazard assessment would require inclusion of the many different additives (beyond only synergists and stabilizers) that may be present in EPS and XPS foam; and as the transition to HBCD alternatives has not yet occurred, there is not certainty as to the synergists and stabilizers likely to be used with the alternatives. However, users of HBCD alternatives are encouraged to conduct hazard assessments on additives used with flame retardants to select the safest functional chemistries. The paragraphs that follow provide general information about synergists and stabilizers used with HBCD in EPS and XPS foam, respectively.

In EPS foam, synergists are often used along with HBCD for economic reasons, as they enable the concentration of HBCD to be reduced (Arch 2011). Synergists are typically added to the EPS resin by the EPS resin manufacturer; HBCD is generally not sold with synergists added. Common synergists used with HBCD in EPS foam are:

- 2,3-dimethyl-2,3-diphenyl butane (sold as Perkadox 30); and,
- dicumyl peroxide.

Synergists are typically not used with HBCD in XPS foam because most types (e.g., peroxides) are unstable at the high processing temperatures of the XPS manufacturing process (Arch 2011).

As was noted above, HBCD must be stabilized during the XPS manufacturing process because it may decompose at the high processing temperatures. Chemical manufacturers sell a stabilized grade of HBCD for use in the XPS manufacturing process. Commonly used thermal stabilizers for HBCD in XPS foam are:

- hydrotalcite;
- dibutyl tin maleate; and
- zeolites.

Other chemicals that have been proposed in the literature as stabilizers for XPS foam include:

- aminocrotonic acid esters;
- epoxy derivatives;
- metals;
- organotins;
- polymeric acrylic binders; and
- talc.

(Hahn, Hinselmann et al. 1981; Books and Landry 1998; Hallenback, Doumen et al. 2001; Maxwell 2008; Stobby 2008; Weil and Levchik 2009).

The formulations of stabilizers in the literature ranged from 0.1 to 30 weight percent based on the weight of the flame retardant (Hahn, Hinselmann et al. 1981; Books and Landry 1998; Hallenback, Doumen et al. 2001; Maxwell 2008; Stobby 2008). Available product literature about the butadiene styrene brominated copolymer indicates that the same stabilizers used with HBCD may also be used with the alternatives (Great Lakes Solutions 2011).

2.1.2 Other Uses

The remainder of this section includes information on the uses of HBCD in textiles and HIPS. Although the report only assesses alternatives for HBCD in insulation, this information is provided as background for the reader.

HBCD in Textiles

In the U.S., producers reported that less than 1% of the total HBCD used for commercial and consumer purposes in 2005 was used in the fabrics and textiles sector (U.S. EPA 2012). Based on information submitted to EPA, it is likely that HBCD use in textiles in the U.S. is restricted to use by the automotive industry and use in non-consumer textile applications (e.g., institutional, military, and aviation), such as firefighters’ suits (U.S. EPA 2012). EPA has proposed a Significant New Use Rule (SNUR) under TSCA Section 5(a)(2), which would designate the manufacture (which includes import) or processing of HBCD for use in consumer textiles as a significant new use, requiring manufacturers, importers and processors to notify EPA before manufacturing or processing HBCD for this use. In the EU, only 2% of HBCD is used in textile back coatings in applications such as flat and pile upholstered furniture, upholstery seating in transportation, draperies, wall coverings, and automobile interior textiles and car cushions (European Chemicals Agency 2009).

The global automotive industry uses HBCD in floor mats, roof interior coverings, and other interior fabrics of motor vehicles (U.S. EPA 2012). Additionally, in Europe it has been noted that EPS may be used in children's car seats or for insulation for transport vehicles (European Commission 2008). The EPS used in children's car seats may contain HBCD, as is evidenced by the bromine content found in tested car seats (Gearhart, Posselt et al. 2008). Some automakers plan to phase out these uses of HBCD in 2015, due to the addition of HBCD to the Annex XIV List of Substances Subject to Authorisation under the EU's Registration, Evaluation, Authorisation and Restriction of Chemical Substances (REACH) regulations.

For use in textiles, HBCD is formulated into polymer-based dispersions (e.g., acrylic or latex) of variable viscosity, which are then processed in the textile finishing industry (Harscher 2011). As HBCD is applied to textiles as a surface coating, it may be released during textile wear and washing (European Commission 2008). Antimony trioxide is often used as a synergist in combination with HBCD in the flame retardation of textiles (European Commission 2008). The typical loading of HBCD in textile back coatings is 10-25% (Harscher 2011).

The use of HBCD in textile back coatings is a source of HBCD in the environment. HBCD is expected to have greater mobility from textile coatings, where it is used in a surface coating, compared to EPS and XPS, where it is dispersed throughout the polymer matrix (European Commission 2008). Additionally, the HBCD particle size for textile applications is smaller than that used for insulation, which poses the potential of deep lung particulate exposure (Rozman and Klaassen 2001). The EU risk assessment of HBCD published in 2008 (European Commission 2008) estimated releases of HBCD during its production, formulation, and use in EPS, XPS, textiles, and HIPS. These estimates indicated that textile-related releases may constitute a significant share (approximately 86%) of total HBCD releases to the environment, however, textiles only accounted for 11% of the overall use of HBCD in Europe at the time of the study (European Commission 2008). Thus, EPS, XPS, and HIPS applications of HBCD only represented 14% of the releases despite accounting for 89% of the HBCD used. Industry information indicates that the use of HBCD in textiles in Europe has declined in recent years to 2% of total HBCD use (see Figure 2-1) (IOM Consulting 2009). For information on potential alternatives to HBCD in textile back coatings, refer to *An Alternatives Assessment For The Flame Retardant Decabromodiphenyl Ether (DecaBDE)*[8], which assessed alternatives for this use.

HBCD in HIPS

The use of HBCD in HIPS accounts for approximately 2% of HBCD usage in the EU (European Chemicals Agency 2009). Similar data for the U.S. are not available. HBCD is used as a flame retardant in HIPS enclosures for audio/video equipment and other appliances, typically in "Glow Wire" and Underwriters Laboratories (UL) 94 V2 rated applications (Harscher 2011). The use of

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[8] www.epa.gov/dfe/pubs/projects/decaBDE/index.htm

HBCD in these products allows for lower load levels, lower specific gravity, and non-antimony trioxide formulations (Harscher 2011). To use HBCD in HIPS, HIPS pellets are mixed with HBCD and other ingredients in an extruder; the resulting pellets then undergo granulation processes (European Commission 2008). The typical loading of HBCD in HIPS is 1-7% (European Commission 2008). For information on potential alternatives to HBCD in HIPS, refer to *An Alternatives Assessment For The Flame Retardant Decabromodiphenyl Ether (DecaBDE)*[9], which assessed alternatives for this use.

2.2 End-of-Life Scenarios

There are multiple end-of-life pathways for insulation products including reuse, recycling, landfilling or incineration. The manner in which a product is handled after use contributes to its environmental and human health impacts. The following sections consider end-of-life issues for insulation materials containing HBCD. As insulation boards comprise the majority of waste containing HBCD (Dawson 2011), they are the focus of this section.

For insulation materials, the end-of-life usually occurs when the building is altered, demolished (U.S. Department of the Interior n.d.), or burned down. During demolition, HBCD may be released in dust (European Commission 2008; Sall 2010). Common demolition techniques include implosion with explosives, use of a crane and wrecking ball, or deconstruction of the structure (European Commission 2008). Construction and demolition (C&D) debris in the U.S. is estimated to total approximately 160 million tons per year (U.S. EPA 2009). The amount of XPS and EPS insulation in this waste is unknown. In Europe, HBCD use in insulation began in the 1980s; therefore, the volume of waste containing HBCD is expected to increase after 2025, as buildings containing insulation flame retarded with HBCD are refurbished or demolished (Sall 2010).

Additionally, in some cases, insulation used on or under the soil may be left in the environment after use. For example, polystyrene insulation may be used under parking decks, rails, roads, or exterior insulation of cellars (European Commission 2008). Insulation used for these purposes often remains in the ground after its intended use is over (European Commission 2008).

The Agency’s concern about HBCD stems largely from its persistent, bioaccumulative, and toxic (PBT) characteristics. HBCD bioaccumulates and biomagnifies in the food chain (U.S. EPA 2010). Along with its high toxicity towards aquatic organisms, it persists and is transported long distances in the environment and is associated with human health concerns (U.S. EPA 2010).

2.2.1 Reuse and Recycling

The end-of-life for EPS and XPS often comes when buildings are demolished or altered. However, EPS and XPS insulation may remain functional as insulation even after a building is taken out of service. Polystyrene insulation can therefore be salvaged and reused, although the board must be protected and not broken during removal (Wilson 2005; U.S. Department of the

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[9] www.epa.gov/dfe/pubs/projects/decaBDE/index.htm

Interior n.d.). For example, during the re-roofing of the Dallas Fort Worth International Airport, approximately 90% of existing XPS material had maintained its thermal and physical properties over the past 17 years and was reused (Owens Corning 2007).

Additionally, polystyrene insulation board may be recycled into new polystyrene boards or other applications (European Commission 2008; Sall 2010). Polystyrene is easier to recycle compared to other foam insulation materials because it can be melted and reformed with minimal chemical modification (U.S. Department of the Interior n.d.). To do so, the polystyrene is melted and re-expanded into insulation or packaging (Wilson 2005). For example, used EPS insulation boards may be ground up and molded with virgin EPS to form new boards (European Commission 2008). Similarly, XPS may also be melted and reused in the manufacture of new insulation board (Herrenbruck n.d.). Due to the use of flame retardants (i.e., HBCD), as well as the dust and dirt accumulated during use and removal, used EPS and XPS can typically only be recycled into building insulation, and cannot be recycled into non-building applications, such as packaging (U.S. Department of the Interior n.d.). Although there is some recycling of polystyrene insulation in Europe – for example, Germany collects used polystyrene and recycles it into building insulation on a national level (European Commission 2008) – it is unclear to what extent the recycling of EPS and XPS takes place in the U.S. (Herrenbruck n.d.).

2.2.2 Landfilling

In the U.S., the majority of C&D waste is disposed of in municipal solid waste landfills or C&D landfills (U.S. EPA 1998; Dawson 2011; Sustainable Sources 2012). In landfills, weathering and degradation (via UV light, microorganisms, and physical impact) will cause these materials to release HBCD over time to the soil, and to a lesser extent to water and air (European Commission 2008; Environment Canada 2011b). However, HBCD is expected to remain largely immobile in landfills, due to its tendency to sorb to organic matter in particles and its low water solubility (Environment Canada 2011a). Therefore, the potential for groundwater contamination from landfill seepage is unlikely due to HBCD's physical-chemical properties and evidence that the chemical may undergo anaerobic biodegradation (Environment Canada 2011b).

2.2.3 Incineration

Insulation boards containing HBCD may also be incinerated, although this process is not commonly used in the U.S. (Herrenbruck n.d.). Although HBCD should be destroyed at the high temperatures found in properly functioning incinerators, releases of potentially hazardous combustion by-products such as polybrominated dibenzo-p-dioxins and dibenzofurans may occur from uncontrolled burns, accidental fires, and improperly functioning incinerators (Birnbaum, Staskal et al. 2003; Weber and Kuch 2003; Environment Canada 2011b). Recent studies also show that HBCD-containing EPS and XPS can be incinerated in advanced municipal solid waste incinerators with a very high destruction efficiency for HBCD (Plastics Europe 2014).

2.3 HBCD Exposure

Exposure can occur at many points in the life cycle of a flame retardant chemical. HBCD may be released to air, water, soil, and sediment during manufacture, processing, transportation, use, improper handling, improper storage or containment, product usage, and disposal of the substance or products containing the substance. HBCD has also been shown to be persistent and to bioaccumulate and biomagnify in food chains (U.S. EPA 2010). Occupational exposures may occur during raw material extraction, chemical and product manufacturing, handling of material containing HBCD (e.g., handling of insulation during installation and renovation of buildings), and product end-of-life (i.e., reuse, refurbishing, recycling, incinerating, landfilling, building demolition, or fire). Consumers have the potential to be exposed to HBCD while the flame retarded product is in use (e.g., releases to the air from flame retarded textiles), however the magnitude of this exposure is highly uncertain (IOM Consulting 2009). A quantitative exposure assessment is outside the scope of this project. For an overview of exposure considerations and routes of exposure, refer to Chapter 5 of the *An Alternatives Assessment For The Flame Retardant Decabromodiphenyl Ether (DecaBDE)*. Additionally, EPA's Exposure Factors Handbook[10] provides information on various physiological and behavioral factors commonly used in assessing exposure to environmental chemicals.

2.3.1 Human Exposures

Based on the uses of HBCD, humans may be exposed during its production, industrial use, from the use of products containing HBCD, and indirectly from household dust or the environment via food, soil, water, and air (European Commission 2008). The human population can be exposed to HBCD by inhaling airborne dust, ingestion, dermal contact (European Commission 2008) and, although unlikely, by inhaling vapor. It should be noted that HBCD exposure studies generally do not compare exposure resulting from the use of flame-retarded insulation to that from other uses (e.g., textiles), however, one study did indicate that the HBCD releases from insulation are minor in comparison to textile applications (European Commission 2008).

The primary occupational exposure to HBCD is through inhaling airborne dust (European Commission 2008). Ingestion may occur as a result of inhaling dust but is not expected to be a relevant route of occupational exposure (European Commission 2008). Workers may also be exposed through dermal deposition of airborne dust or direct handling of the chemical or products during chemical and product manufacturing and during construction (European Commission 2008). For insulation applications, HBCD is typically manufactured as a standard grade powder or granule with mean particle sizes that are not respirable (European Commission 2008). However, an occupational exposure study at an industrial plant in Europe producing EPS reported measured elevated airborne dust levels and measured HBCD in the blood of workers (Thomsen, Molander et al. 2007). Occupational HBCD exposure may also occur as a result of thermal cutting of EPS and XPS at production plants and construction sites. XPS is not typically thermally cut at production plants or construction sites. When XPS is cut at production plants, fan extraction is supplied and worker exposure is mitigated due to restricted access to the area during cutting. One small-scale simulation study suggests that over 60% of the HBCD particles released during the thermal cutting of EPS and XPS would penetrate the alveolar region of a worker's lung (Zhang, Kuo et al. 2012). No readily available HBCD occupational exposure information – including biomonitoring data – was found for U.S. workers (U.S. EPA 2010).

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[10] Available at http://www.epa.gov/ncea/efh/pdfs/efh-complete.pdf.

HBCD is incorporated at high temperatures and/or pressures in EPS and XPS manufacturing. In EPS, it is dissolved chemically in styrene monomer in a reactor. In XPS, it is added to viscous, molten polystyrene in an extruder. Room temperature solid state diffusion of HBCD out of polystyrene foams would be expected to be very slow and very low. Since HBCD is an additive flame retardant, it can potentially be released from its end products over time, as it is not chemically bound to the polymer matrix (Environment Canada 2011b).

HBCD has been detected in human adipose tissue, milk, and blood and has been shown to cross the placenta (Covaci, Gerecke et al. 2006; Johnson-Restrepo, Adams et al. 2008; Meijer, Weiss et al. 2008; Arnot, McCarty et al. 2009). General population exposure to HBCD is likely from its presence in food (e.g., fish and shellfish) due to biomagnification in food chains (Heibl and Vetter 2007; Fernandes, Dicks et al. 2008; van Leeuwen and de Boer 2008), outdoor air, particularly near sites where HBCD or HBCD flame retarded materials are produced (Covaci, Gerecke et al. 2006), and indoor air (Law, Herzke et al. 2008). HBCD has also been detected in indoor dust (Covaci, Gerecke et al. 2006; Law, Herzke et al. 2008; Roosens, Abdallah et al. 2009). If HBCD is present in household (e.g., furniture upholstery) and/or automotive (e.g., textiles in vehicles) applications, children could be exposed, especially given children's increased potential exposure via dust, mouthing behavior (e.g., object-to-mouth), and hand-to-mouth ingestion pathways (U.S. EPA 2010). While biomonitoring data for HBCD in children are not available, studies of other brominated flame retardants have found higher exposures in children than adults (Center for Disease Control and Prevention 2009; Toms, Sjödin et al. 2009).

2.3.2 Environmental Exposures

HBCD is not known to occur naturally, but may be released to air, water, soil, and sediment during manufacture, processing, transportation, use, improper handling, improper storage or containment, product usage, and disposal of the substance or products containing the substance (Environment Canada 2011a). Studies suggest that a significant portion of HBCD in the environment is released from textiles. As was noted in Section 2.1.2, the EU's 2008 risk assessment of HBCD (European Commission 2008) estimated releases of HBCD during its various life-cycle stages, finding that textile-related releases may constitute a significant share (approximately 86%) of total HBCD releases to the environment in Europe. Information from the United Kingdom indicates that the primary sources of HBCD in the environment are from fugitive emissions during its manufacture and use in subsequent products, potentially from leaching in landfills, and from incinerator emissions (United Kingdom Environment Agency 2009). Because HBCD is not covalently bound to the polymer, it is possible that it may migrate out of consumer or industrial end-use products into the indoor and/or outdoor environment (Environment Canada 2011a). It should be noted that HBCD exposure studies generally do not compare exposure resulting from the use of flame-retarded insulation to exposure resulting from other uses (e.g., textiles).

Limited data are available on the degradation of HBCD in soil, water, or sediment (U.S. EPA 2010). However, HBCD has been detected in biota over large areas and in remote locations (U.S. EPA 2010). The frequent detection of HBCD over a large geographic area, with increasing occurrence in remote locations such as the Arctic, where no demonstrable local sources exist that can account for these exposures, suggests that HBCD is persistent and undergoes long-range atmospheric transport (UNEP 2009).

HBCD has been measured in air and sediment in the Arctic, Scandinavian countries, North America and Asia (Covaci, Gerecke et al. 2006; Arnot, McCarty et al. 2009; UNEP 2009). HBCD has also been measured in marine and arctic mammals, freshwater and marine fish, aquatic invertebrates, birds and bird eggs, polar bears, and one plant species (Covaci, Gerecke et al. 2006; Arnot, McCarty et al. 2009; UNEP 2009). The majority of these studies are European; some are from North America, and a few are from Asia. Additionally, studies have shown that HBCD is bioavailable and bioaccumulative (Veith, Defoe et al. 1979; Drottar, MacGregor et al. 2001; Tomy, Budakowski et al. 2004). For example, a monitoring study by De Boer et al. (2002) included a wide variety of biota (invertebrates, fish, birds, and marine mammals) and showed that HBCD bioaccumulates easily and biomagnifies in food chains.

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