

Exposure and Use Assessment of Five Persistent, Bioaccumulative and Toxic Chemicals

Peer Review Draft

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1. Executive Summary

Section 6(h) of the Toxic Substance Control Act (TSCA), as amended by the Frank R. Lautenberg Chemical Safety for the 21st Century Act, directs the U.S. Environmental Protection Agency (EPA) to take expedited action to propose rules under TSCA with respect to chemicals identified in EPA's 2014 Update of the TSCA Work Plan for Chemical Assessments and meeting criteria relating to persistence, bioaccumulation and toxicity (PBT) and other factors. EPA must issue a proposed rule no later than June 22, 2019, with a final rule to follow no more than 18 months later.

EPA has developed this Exposure and Use Assessment for the five chemical substances it has identified for proposed action under TSCA section 6(h) ("PBT chemicals"). This Exposure and Use Assessment will be used by EPA in determining, under TSCA section 6(h)(1)(B), whether exposure to each identified PBT is likely.

EPA conducted a comprehensive literature review to identify, screen, extract, and evaluate exposure information for the five PBT chemicals addressed in this document. EPA also compiled physical-chemical properties and information on uses. Exposure information was categorized as core and/or supplemental. Core exposure data were defined as any environmental monitoring, biomonitoring, modeled environmental concentration, or modeled dose data. Supplemental exposure data were defined as any environmental fate or engineering data that provided information related to potential exposure sources and environmental pathways.

This document presents available exposure information and integrates the information by environmental media or biological matrix. EPA also provides some context for the sources and environmental pathways that may have contributed to concentrations detected in environmental and biological monitoring studies. EPA generated qualitative exposure scenarios for identified uses for these five PBT chemicals.

2. Background

Under the Toxic Substances Control Act (TSCA), as amended by the Frank R. Lautenberg Chemical Safety for the 21st Century Act, EPA has new authorities to regulate existing chemical substances. Section 6(h) of TSCA directs EPA to take expedited regulatory action under section 6(a) for certain PBT chemicals.

Chemical substances subject to TSCA section 6(h) are those:

- Identified in the 2014 update of the TSCA Work Plan for Chemical Assessments;
- That the Administrator has a reasonable basis to conclude are toxic and that, with respect to persistence and bioaccumulation, score high for one and either high or moderate for the other, under the 2012 TSCA Work Plan Chemicals Methods Document (or a successor scoring system);
- That are not a metal or a metal compound;

- For which the Administrator has not completed Work Plan Problem Formulation, initiated a review under section 5 (new chemicals), or entered into a consent agreement under section 4 (testing), prior to June 22, 2016;
- Exposure to which under the conditions of use is likely to the general population, to a potentially exposed or susceptible subpopulation, or the environment, on the basis of an exposure and use assessment; and
- That are not designated as a high priority substance by EPA and are not the subject of a manufacturer request for a risk evaluation.

Taking the above criteria into account, EPA has identified the following five PBT chemicals for proposed action under TSCA section 6(h):

- Decabromodiphenyl ether (DecaBDE) (CASRN 1163-19-5)
 - Scored high for hazard, high for persistence, and high for bioaccumulation on the 2014 update
- Hexachlorobutadiene (HCBd) (CASRN 87-68-3)
 - Scored high for hazard, high for persistence, and high for bioaccumulation on the 2014 update
- Phenol, isopropylated, phosphate (3:1) (PIP (3:1)) (CASRN 68937-41-7)
 - Scored high for hazard, high for persistence, and high for bioaccumulation on the 2014 update
- 2,4,6-Tris(tert-butyl) phenol (2,4,6 TTBP) (CASRN 732-26-3)
 - Scored high for hazard, moderate for persistence, and high for bioaccumulation on the 2014 update
- Pentachlorothiophenol (PCTP) (CASRN 133-49-3)
 - Scored high for hazard, high for persistence, and high for bioaccumulation on the 2014 update

This assessment follows the publication of and public comment on use documents for each of the five chemicals. The use documents were published by EPA in August 2017 and provide an overview of the Agency's information on uses of each chemical at the time. Relevant information from those use documents and the public comments is presented in each chemical's section in this document. The use documents and the public comments in response are in each chemical's docket.

Since the publication of the Use Documents in August 2017, EPA received public comments on the Use Document and communicated with companies, industry groups, chemical users, and other stakeholders to aid in identifying and verifying conditions of use for the five chemicals. These interactions and comments further informed EPA's understanding of the uses for the five chemicals. The information and input received from the public comments and stakeholder engagement has been incorporated into this document to the extent appropriate.

3. Approach

EPA used the following information for this exposure assessment. This information, where available, is presented for each of the five PBT chemicals:

- Chemistry and physical-chemical properties,
- Use descriptions,
- Expected environmental partitioning,
- Lifecycle and potential sources,
- Environmental monitoring,
- Biomonitoring,
- Modeled intake and doses,
- Trends,
- Information from completed exposure assessments and review articles, and
- Qualitative exposure scenarios.

This information helps to identify potential exposure scenarios which are the combination of sources/uses, environmental pathways, and receptors.

An exposure scenario is a set of facts, assumptions, and inferences about how exposure takes place that aids the exposure assessor in evaluating, estimating, or quantifying exposure [U.S. EPA \(2016b\)](#). A scenario is made up of combinations of the following:

- Sources/Context of Use: Conditions of use, translated into specific lifecycle stage and use descriptors
- Environmental Pathway: Information about presence of a chemical within media, transport form source to receptor and the route of exposure

Receptor: Information about presence of a chemical within a receptor (e.g., human workers or general population) or environmental (e.g. aquatic or terrestrial)

Questions that help refine exposure scenarios include:

Sources/Context of Use: What specifically is being manufactured, produced or used and in what manner? Has this changed over time? Is it an ongoing use? Is it a use that is generally controlled by existing environmental regulations? Which lifecycle stage(s) does the use apply to and how does that information provide context about the location of who is exposed during that use?

Environmental Pathway/Media: Within the context of the use, how does the chemical reach the receptor and enter the human body or organism? What environmental media are most likely to contribute to exposure? What are the associated routes of exposure (oral, inhalation, dermal) for these media?

Receptor: Who specifically may be exposed? Could the exposed receptor include specific susceptible subpopulations? How might the demographic or behavioral variability affect exposure?

An overview of the approach taken for each section is presented below.

Chemistry information was primarily obtained from EPA's Chemistry Dashboard ([U.S. EPA, 2018a](#)). The CAS number, structure, molecular formula, and select synonyms are presented. Note, EPA used a broader array of chemical synonyms in its search strategy and those chemical synonyms are listed in the Supplemental Exposure document. Physical-chemical property information was obtained through a combination of measured and estimated data. EPA's EPI-Suite model was used for estimation, when empirical data was not available ([U.S. EPA, 2012](#)). EPA presents the following physical-chemical properties for each chemical substance: molecular weight, density, molar volume, octanol-water partition coefficient Log K_{OW} , octanol-air partition coefficient Log K_{OA} , octanol-carbon partition coefficient Log K_{OC} , vapor pressure, Henry's law constant, and water solubility.

EPA compiled preliminary information on manufacturing, processing, distribution, use, and disposal for each of the five PBT chemicals in August 2017. Since that time, EPA reviewed public comments and engaged with many stakeholders which further informed EPA's understanding of uses. Use descriptions can be considered holistically to inform how a chemical is used in a given application across its lifecycle (manufacturing, processing, use, and disposal).

From these use descriptions, EPA developed lifecycle diagrams for each of the five PBT chemicals. EPA also completed a qualitative assessment describing relative potential for occupational exposure and relative potential for release to different media from industrial operations.

From available physical-chemical property information, EPA developed a qualitative assessment of expected environmental partitioning should a chemical be released to a given media. This section assumes that processes described in this section occur after release to all media. However, EPA notes that uses and processes for each of these five PBT chemicals are not expected to result in releases to all media.

EPA completed a comprehensive literature search and evaluation for environmental monitoring and biomonitoring data. Studies that contained primary, quantitative, readily extractable data in environmental media and in matrices of biological organisms were evaluated and integrated into this assessment. Note that for the five PBT chemicals found in air and water, no distinction was made during data extraction for chemical bound to particulate matter versus free chemical in air/water. For PIP (3:1) and 2,4,6 TTBP, few monitoring studies were reported. Consequently, EPA conducted a supplemental search on closely related chemicals with similar structures and physical-chemical properties. The list of closely related chemicals is provided in the Supplemental Exposure Document. Of this list, Triphenyl Phosphate (TPP) and Butyl Hydroxytoluene (BHT) were used as surrogate or read-across chemicals for PIP (3:1) and 2,4,6-TTBP, respectively.

EPA also completed a comprehensive literature search for and evaluation of studies reporting modeled intake or dose. Studies that contained primary, quantitative, readily extractable, modeled estimates of intake (mass chemical per day) or dose (mass chemical per mass body weight per day) of the five PBT chemicals were evaluated and integrated into this assessment.

Articles that contained spatial or temporal trend data were also evaluated and integrated into this assessment. Natural language processing algorithms were run to identify those that contained the words “temporal, time trend, time-trend, time varying, time-varying, time-dependent, time dependent, time activity, trend, spatiotemporal, or spatio-temporal” within either the title or abstract. These articles were then reviewed to determine if they contained spatial or temporal trend data. Additionally, various publicly available databases on environmental monitoring data previously identified by EPA were searched for data on the chemicals of interest; where this data was reported temporally, it was included with the extracted data identified in the systematic review. Note that some databases provided chemical concentrations by country. Monitoring data from developed countries with well-established and enforced environmental regulations may be more relevant for the U.S.

During the development of the literature search strategy, existing exposure and risk assessments were used as the basis for backwards searches to identify primary literature sources. Existing assessments were identified for four of the five PBT chemicals. The results from the assessments are summarized. Note, if these assessments summarized primary monitoring data, those data sources are not reported under existing assessments and are instead reported with other primary monitoring data. Secondary review articles were also identified during EPA’s systematic review. Data presented for review articles are limited to those that reported additional information on potential sources and/or environmental pathways in addition to environmental concentrations or doses. Note, if these review articles summarized primary monitoring data, those data sources are not reported under review articles are instead reported with other primary monitoring data.

EPA presented qualitative exposure scenarios for this exposure assessment. These qualitative scenarios provide additional context for likely exposures. These exposure scenarios may have relatively higher exposure potential and may represent a broader range of exposure scenarios. However, they are not intended to be comprehensive of every possible exposure scenario for these chemicals.

The literature search provides information about which of the data types are available and usable for different sources, pathways, and receptors to inform generation of exposure scenarios. Different types of data are needed to characterize the variety of chemical-specific exposure scenarios. A range of qualitative and quantitative data was available and usable for the five PBT chemicals in this exposure assessments across uses, releases, concentrations, intakes, and doses. Quantitative data are summarized for components of exposure scenarios while qualitative exposure scenario descriptions are provided.

Table 3-1. Overview of Qualitative and Quantitative Exposure Information used in this Exposure Assessment

Sources/Context of Use	Environmental Pathway	Receptor	Exposure Scenarios
Chemistry and physical-chemical properties (quantitative)	Fate and transport (qualitative)	Intake and uptake (quantitative)	Qualitative
Use information (qualitative)	Environmental monitoring data (quantitative)	Internal dose (quantitative)	
Emission/release information (qualitative)	Modeled estimates (quantitative)	Biomonitoring data (quantitative)	

In addition, EPA notes overarching uncertainties for consideration below.

Reported monitoring data does not necessarily reflect current or future conditions; but rather the conditions that were present at the time when samples were collected. Even very recent studies represent conditions when samples were collected, generally months to years before the publication of the study. Monitoring data can be heterogeneous in its reporting of free versus particle bound chemical concentrations in surface water and air. Supplementary contextualizing data such as lipid content, sample location, and even level of detection are not uniformly reported. There is uncertainty in both direct comparisons between two different monitoring studies and overall comparison across all monitoring studies. There may be less uncertainty, however, when comparing trends within one monitoring study.

Reported modeling data reflects the underlying assumptions about releases, environmental transport, and uptake. Modeled data also provides evidence of exposures that can be tailored to reflect many past, current, or future possible conditions and scenarios. EPA references modeling conducted by others in this assessment, but did not conduct its own exposure modeling from identified sources. Instead, EPA presents qualitative exposure scenarios and separately presents monitored and estimated concentrations and doses.

There are different approaches to construct exposure scenarios. There is overlap between qualitative exposure scenarios described by EPA and scenarios presented in completed assessments for some chemicals. Comparison of exposure scenarios can involve source attribution. The relative complexity of source attribution varies depending on the continuum of available uses/sources and the media considered. For example, total dust concentrations in a residence represent contributions from multiple different sources. Similarly, the internal dose represents total exposure from multiple media and sources. This source attribution can be qualitative or quantitative. EPA used qualifiers (e.g. higher, lower potential for exposure) throughout the document to describe exposures. EPA focused on describing qualitative exposure scenarios with higher potential. However, uncertainty is acknowledged when describing relative comparisons across exposure scenarios.

4. Decabromodiphenyl Ether (DecaBDE)

4.1. Chemistry and Physical-Chemical Properties

Chemical Name	Decabromodiphenyl Ether
CASRN	1163-19-5
Synonyms	DecaBDE, Deca, BDE209
Molecular Formula	C ₁₂ Br ₁₀ O
Structure	
MW	959.17
Density (g/cm³)	3.4 at 25°C (RSC, 2013)
Molar Volume (cm³/mol)	282 [Calculated based on the molar mass and density]
Log Kow	9.97 [(EU, 2002) citing (Watanabe and Tatsukawa, 1990)]
Log K_{OA}	16 [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Log K_{OC}	6.5 [Kow method, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Vapor Pressure (mm Hg)	3 × 10 ⁻⁸ [Extrapolated from (RSC, 2013)]
Henry's Law atm-m³/mole	4.5 × 10 ⁻⁸ [Group Method, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Water Solubility (mg/L)	0.02 (Chemicals Inspection and Testing Institute, 1992)
Water Solubility (mol/L)	2.1 × 10 ⁻⁸ [Calculated based on water solubility and molecular weight]

4.2. Uses

Since the publication of the Use Document in August 2017 for decabromodiphenyl ether (DecaBDE), EPA received 12 public comments on the Use Document and communicated with dozens of companies, industry groups, chemical users, and other stakeholders to aid in identifying and verifying conditions of use of DecaBDE ([U.S. EPA, 2017b](#)). These interactions and comments further informed EPA's understanding of the uses for DecaBDE. The information and input received from the public comments and stakeholder engagement has been incorporated into this document to the extent appropriate. Non-confidential public comments and stakeholder meeting summaries are available in EPA's docket at [EPA-HQ-OPPT-2016-0724](#).

DecaBDE is one congener in a class of chemicals known as polybrominated diphenyl ethers (PBDEs). PBDEs are a class of substances that contain an identical base structure but differ in the number of attached (1-10) bromine atoms. Commercial PBDEs are only used as flame retardants. PBDE flame retardants perform well in many products, preserving the durability and performance of the material while providing flame retardancy at a reasonable cost. These characteristics have resulted in their widespread use in hundreds of consumer products, including many plastics and textiles (upholstery). Flame retardants, in general, are incorporated into products in one of two ways. They are either chemically bound to the product matrix as "reactive" mixtures, or they are dissolved in the polymer materials as "additives." PBDEs are

additive flame retardants. Additive flame retardants are relatively unattached to the polymer matrix and may readily migrate from products to the surrounding environment during manufacture, normal use, and disposal ([Verslycke et al., 2005](#)). End of use for products containing PBDEs include disposal in landfills as well as recycling ([USGS, 2006](#)) or incineration ([Verslycke et al., 2005](#)).

DecaBDE specifically has a variety of uses as an additive flame retardant in plastic enclosures for televisions, computers, audio and video equipment, textiles and upholstered articles, wire and cables for communications and electronics, and other applications ([U.S. EPA, 2017b](#)). The primary use of DecaBDE is in high-impact polystyrene-based products and in the manufacture of textiles and plastics. The three major product categories in which DecaBDE has been used as a flame retardant are: textiles, electronic equipment, and building and construction materials ([U.S. EPA, 2017b](#)). DecaBDE is also used as a flame retardant for multiple applications in the aerospace and automotive industries, including replacement parts for cars and aircraft ([EPA-HQ-OPPT-2016-0724](#))([U.S. EPA, 2017b](#)).

The uses of DecaBDE that are considered within the scope of the exposure and use assessment during various life cycle stages (i.e., manufacturing, processing, use (industrial, commercial and consumer), distribution and disposal) are depicted in Table 4-1 and the life cycle diagram (Figure 4-1). The information is grouped according to Chemical Data Reporting (CDR) processing codes and internationally harmonized functional, product and article use categories from the Organisation for Economic Co-operation and Development (OECD) in combination with other data sources (e.g., published literature and consultation with stakeholders), to provide an overview of the uses.

Use categories are drawn from CDR definitions laid out in Instructions for Reporting for the 2016 CDR (U.S. EPA, 2016c) . “Commercial use” means the use of a chemical or a mixture containing a chemical (including as part of an article) in a commercial enterprise providing saleable goods or services. “Consumer use” means the use of a chemical or a mixture containing a chemical (including as part of an article, such as furniture or clothing) when sold to or made available to consumers for their use.

Table 4-1. Use Categories and Subcategories for DecaBDE

Life Cycle Stage	Category ^a	Subcategory ^b	References
Manufacture	Domestic manufacture	Domestic manufacture	U.S. EPA (2016a)
	Import	Import	U.S. EPA (2016a)
Processing	Processing – incorporation into formulation, mixture, or reaction	Flame retardant in: <ul style="list-style-type: none"> • Plastic product manufacturing • Textile, and apparel manufacturing 	U.S. EPA (2016a)

Life Cycle Stage	Category ^a	Subcategory ^b	References
	Processing-Incorporation into Article	Flame retardant in: <ul style="list-style-type: none"> • High impact polystyrene (HIP) – based products • Textiles • Electronic plastic casings • Rubber (wire casings) • Building and construction materials • Multiple automotive and aerospace components including adhesives, plastics, and fabrics 	U.S. EPA (2017b) ; EPA-HQ-OPPT-2016-0724
	Recycling	Flame retardant in: <ul style="list-style-type: none"> • Recycled plastic pallets 	EPA-HQ-OPPT-2016-0724
Commercial/Consumer Uses (includes imported articles)	Articles – Plastic articles (hard and soft, including HIP based products)	Flame retardant in: <ul style="list-style-type: none"> • Plastic electronic casings • Toys intended for children’s use 	U.S. EPA (2017b) ; EPA-HQ-OPPT-2016-0724
	Articles – Fabrics, textiles, and apparel	Flame retardant in: <ul style="list-style-type: none"> • Furniture and furnishings • Curtains • Construction and building materials 	U.S. EPA (2017b)
	Articles – Complex articles	Flame retardant in: <ul style="list-style-type: none"> • Vehicles (automotive and aerospace – includes replacement parts) 	U.S. EPA (2017b) ; EPA-HQ-OPPT-2016-0724
Distribution in commerce	Distribution	Distribution in commerce	U.S. EPA (2017b)
Disposal	Air Releases	Fugitive air emissions	U.S. EPA (2017f)
		Point source air emissions	
	Water Releases	Surface water discharge	U.S. EPA (2017f)
	Land releases	Solid wastes	U.S. EPA (2017f)
	Off-Site Releases	Transfers off-site	U.S. EPA (2017f)
Recycling	Recycled plastics articles containing DecaBDE not intended for use as a flame retardant (toy’s intended for children’s use, electronic casings, HIPs) ^c	EPA-HQ-OPPT-2016-0724	

^aThese categories of use appear in the Life Cycle Diagram, reflect CDR and OECD codes, and broadly represent the uses of decabromodiphenyl ether in commercial and/or consumer settings.

^bThese subcategories reflect more specific uses of decabromodiphenyl ether based on stakeholder outreach, and comments received on EPA’s Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal published in August 2017.

EPA plans to analyze the use of DecaBDE in recycled plastic pallets, as the flame retardant properties of DecaBDE are still utilized for this particular use. EPA does not expect to consider recycled articles, where those articles do not have intended flame retardant applications.

Descriptions of the commercial or consumer use categories identified from the 2017 OECD Harmonized Use Codes are summarized below ([OECD, 2017b](#)):

The “Plastic articles” category encompasses consumer products made of both hard and soft plastics, which includes DecaBDE as a flame retardant, including furniture & furnishings, foam in furniture or mattresses, computer casings, and toys intended for children’s products (such as play structures).

The “Fabrics, textiles, and apparel articles” category encompasses construction and building materials, furniture and furnishings, curtains, and other articles with routine direct contact during normal use.

The “Complex articles” category encompasses road vehicles and other vehicles for passengers and goods such as cars, trucks, and airplanes, and machinery, mechanical appliances, electrical and electronic articles such as computers and drills. It also encompasses replacement parts for both the automotive and aerospace industries.

4.3. Characterization of Expected Environmental Partitioning

If released to air, based on its vapor pressure (3×10^{-8} mm Hg) and Henry’s law constant (4.5×10^{-8} atm m³/mole), DecaBDE will generally partition into water rather than the air. Further, DecaBDE will tend to partition to soil and airborne particulates rather than air due to its vapor pressure and octanol-air partition coefficient ($\log K_{OA} = 16$). DecaBDE adsorbed to particulates in the air can be removed from the atmosphere via wet or dry deposition, but the presence of the compound at remote sites globally indicates that particulate-bound DecaBDE can undergo long-range transport in the atmosphere.

If released to water, DecaBDE in surface water is expected to partition to sediments and suspended particulates, based on its octanol-water partition coefficient ($\log K_{OW} = 9.97$) and organic carbon partition coefficient ($\log K_{OC} = 6.5$). Due to its vapor pressure and Henry’s law constant, DecaBDE is not likely to partition from water into air.

In wastewater treatment, DecaBDE is likely to sorb to biosolids due to its $\log K_{OC}$ and water solubility (0.02 mg/L) and is unlikely to volatilize to the air due to its Henry’s law constant. Due to its $\log K_{OC}$, most DecaBDE in wastewater is expected to be removed by adsorption to biosolids, which may later be landfilled, land-applied, or incinerated. Release of free DecaBDE in effluent water is expected to be limited, although DecaBDE adsorbed to small particles may be present in effluent.

If released to soil, due to its Henry’s law constant, vapor pressure, and $\log K_{OC}$, DecaBDE is not expected to volatilize from moist or dry soil. Further, DecaBDE is not likely to be mobile in groundwater, soil pore water, or the aqueous phase in other subsurface environments based

on its log K_{OC} and water solubility, although DecaBDE sorbed to colloids or other particles may be transported in subsurface environments.

If released to landfill, based on its water solubility and log K_{OC} , migration of DecaBDE from landfills into leachate is expected to be limited and slow. Volatilization of DecaBDE from solid waste is not likely due to its vapor pressure.

DecaBDE also may partition to the tissues of organisms that live in water, soil, and sediment via dermal or gill exposure and ingestion. Exposure to water column organisms is also possible via resuspension of the chemical from the sediment to water either sorbed to particulates or part of the dissolved phase. The above characterization is meant to describe the primary behavior or movement of the chemical through a generic environment, not the complete exclusion of the chemical from a given media (e.g., water) or elimination of the possibility for more complex behavior in a particular location.

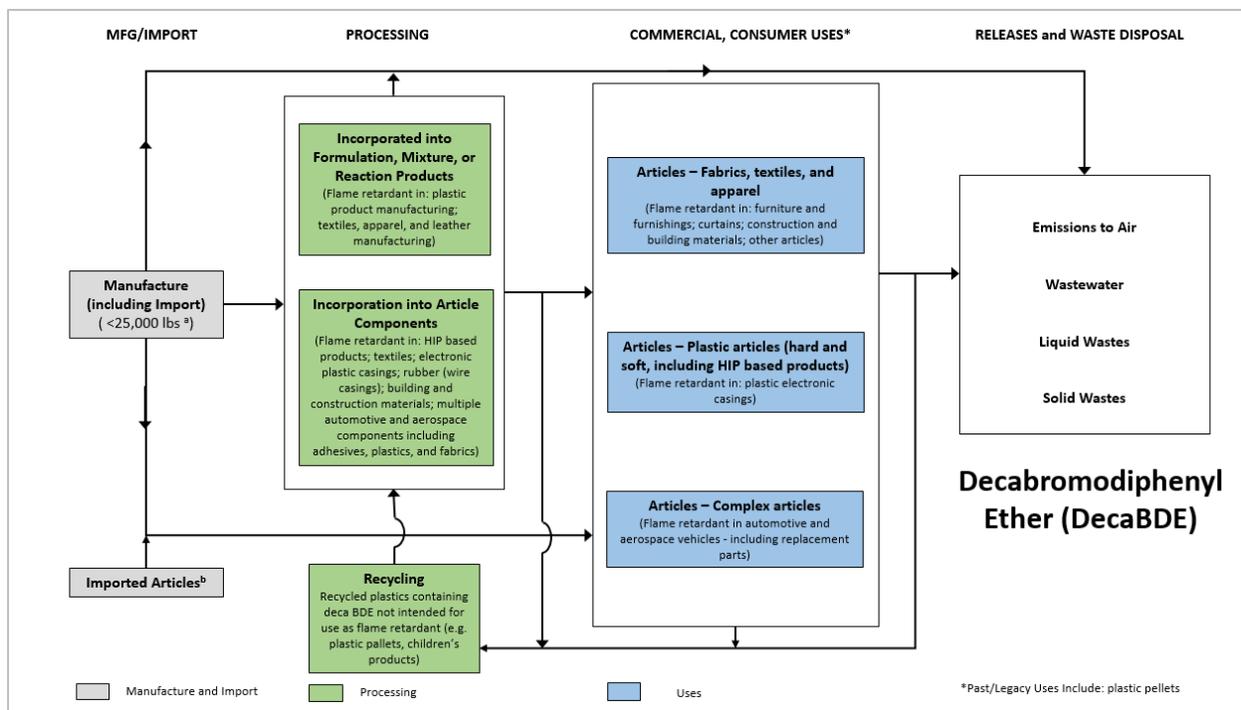
If released to the indoor environment, volatilization of DecaBDE from consumer products or articles, contaminated water, or other aqueous solutions is not likely due to its vapor pressure and Henry's law constant. Any potential emission to air would likely quickly partition to suspended dust. Due to its log K_{OA} and vapor pressure, DecaBDE is more likely emitted from solid articles through direct transfer to dust or abrasion, partitioning to dust and other particulates. The relationship between the initial concentration of DecaBDE in articles, emission of DecaBDE into indoor environments through various mechanisms and resulting indoor-dust levels, and the final concentration of DecaBDE in articles prior to disposal is not well characterized even though there is supporting data for some aspects of these processes for certain consumer articles.

4.4. Overview of Lifecycle and Potential Sources of Exposure

4.4.1. Background and Brief Description of Lifecycle

Flame retardants are incorporated into products in one of two manners. They are either chemically bound to the product matrix as "reactive" mixtures, or they are dissolved in the polymer materials as "additives." DecaBDE is an additive flame retardant. Additive flame retardants are not chemically bound and are relatively unattached to the polymer matrix. Therefore, they have the potential of migrating from products to the surrounding environment during manufacture, normal use, and disposal ([U.S. EPA, 2017b](#)).

DecaBDE's primary use is in high impact polystyrene-based products that are used in plastics, specifically in plastic enclosures for televisions, computers, audio and video equipment, and mobile phones. It is also used in textiles and upholstered articles (including carpets, upholstery fabric, back coatings, cushions, mattresses, and tents), wire and cables for communications and electronics, and other miscellaneous applications ([U.S. EPA, 2017b](#); [BSEF, 2007](#)).



^aChemical Data Reporting (CDR) data for 2015; U.S. manufacturers and importers agreed to voluntarily phase out domestic manufacture and import of the chemical no later than December 31, 2013. Preliminary data for the 2016 CDR indicates the total in 2015 is less than 25,000 lbs. The total volume of DecaBDE manufactured (including imported) in the United States was 16,696,951 lbs in 2012, between 1,000,000 and 10,000,000 lbs in 2013, between 100,000 and 500,000 lbs in 2014, and less than 25,000 lbs in 2015. Actual production volume for years 2013 through 2015 is claimed as confidential business information.

^bAn unknown but significant quantity of DecaBDE is expected to be imported in articles.

Figure 4-1. Lifecycle Diagram for DecaBDE

4.4.2. Manufacturing

The commercial production of DecaBDE involves bromination of diphenyl oxide to varying degrees. The degree of bromination is controlled either through stoichiometry or through control of reaction kinetics. The product is dried following reaction and separation steps to form a solid powder {ATSDR, 2004, 1004954}. DecaBDE is not expected to be manufactured or handled as a liquid during these operations. Therefore, the most likely sources of releases and occupational exposures are associated with fugitive dust. These include air releases from transfer and packaging operations (fugitive dust to ambient air as well as dust that is collected and channeled through a dedicated point as a stack release) and solid waste from floor sweepings, disposal of used transfer containers containing residual DecaBDE, and liquid waste from equipment cleaning. Fugitive vapor air releases are not expected due to the low vapor pressure. Releases to land are possible when floor sweepings and other solid waste are collected and disposed in landfills. Similarly, the collection and disposal of liquid equipment cleaning solutions has the potential of generating liquid waste containing DecaBDE (aqueous waste to surface waters and sent to publicly owned treatment works, and organic waste collected and sent for other disposal or waste treatment such as incineration). Historical and recent TRI data confirm primary releases are to air, followed by landfill and water {U.S. EPA, 2016, 3479565}{TRI 2016}. Occupational exposures from inhalation and dermal exposure to

dust are expected during transfer and packaging operations and from fugitive dust emissions from process operations. However, exposure to liquids is not anticipated.

Table 4-2. CDR Production Volumes 2010-2015

CDR Reporting Year	2010	2011	2012	2013	2014	2015
Production Volume (lb)	51,008,002	18,110,827	10,000,000– 50,000,000	1,000,000– 10,000,000	100,000– 500,000	<25,000

4.4.3. Imported Articles

The 2016 CDR data indicate that DecaBDE is manufactured (including import) in quantities less than 25,000 lbs ([U.S. EPA, 2017b](#)). However, significant quantities are also imported as a component of articles, including: plastics in televisions, computers, audio and video equipment; textiles and upholstered articles such as carpets, upholstery fabric, cushions, mattresses, and tents; wire and cables for communications and electronics; and other miscellaneous applications ([EPA-HQ-OPPT-2016-0724](#)). The quantity of DecaBDE in these articles is unknown; however, it may be substantial. Potential releases from these articles may occur when DecaBDE migrates from the articles during use, disposal, and waste management. Occupational dermal exposures are expected to be minimal, but possible from handling and repackaging articles. Inhalation and dermal exposures are possible during recycling operations (e.g. recycling of plastics) ([EPA-HQ-OPPT-2016-0724](#)).

4.4.4. Processing: Incorporated into Formulation, Mixture, or Reaction Products and Incorporation into Article Components

DecaBDE is combined with other ingredients (e.g., monomers) and then molded, extruded, formed into final products, or applied to a finished article, where curing may occur ([ACC, 2002](#)). Releases to air, land, and water are expected from DecaBDE and DecaBDE flame retardant formulations (solids and liquids) as well as from off-spec products containing the additive flame retardant. Air releases (fugitive dust and dust collected and channeled to a stack) are expected from transfer operations. Releases to land may occur during disposal of transfer containers containing residual material, collection and disposal of floor sweepings, and disposal of off-spec product. Equipment and general area cleaning with aqueous cleaning materials may result in releases to water. Current and historical TRI data indicate the primary releases are to air, followed by landfill and water ([U.S. EPA, 2016d](#)). Occupational exposures from inhalation and dermal exposure of dust is expected during transfer and packaging operations and from fugitive dust emissions from process operations. Dermal exposure to liquids is possible from incidental contact of liquid flame retardant formulations containing DecaBDE during transfer, loading, and mixing operations. Occupational exposures are most likely to occur when the bags of flame retardant are emptied into a hopper prior to mixing. Once formulated, DecaBDE is encased in the polymer matrix and worker exposure is unlikely ([ACC, 2002](#)).

4.4.5. Processing: Recycling

DecaBDE is present in plastic that may be recycled and subsequently reused ([EPA-HQ-OPPT-2016-0724](#)). Environmental releases from recycling facilities are expected from discarded material that cannot be recycled and reclaimed and is disposed in landfills. Releases to air and water are not expected. Limited occupational exposure to workers at recycling facilities is possible from dermal contact during handling of plastic material that is received and introduced into recycling operations, and from inhalation exposure to dust from grinding and shredding operations.

4.4.6. Industrial/Commercial Use: Fabrics, Textiles and Apparel (textile manufacturing)

DecaBDE is combined with other ingredients and incorporated into the back coating of various textiles via roll or dip coating processes. Releases are expected from disposal of transfer containers associated with DecaBDE formulations, waste from equipment and area cleaning, disposal of off-spec product, and bath dumps. Historical TRI data indicate most releases are associated with disposal to landfills, smaller quantities to air, and minimal releases to water. No releases to air or water from textile facilities reporting to TRI have occurred since 2013 ([U.S. EPA, 2016d](#)). Inhalation exposures may occur due to: fugitive dust generated from unloading and transfer of the solid flame retardant into mixing vessels; mist generated from the squeezing of the immersed fabric with rollers; from the roll coating application during back coating; and, after the coating operations are complete, during fabric cutting. Dermal exposures to solid and liquid DecaBDE mixtures in fabric finishing may occur from unloading operations, mixing finishing baths, equipment cleaning, and unintentional spilling ([ERG, 2004](#)).

4.4.7. Industrial/Commercial Use: Incorporation into Plastic Articles (wire and cable coatings)

DecaBDE is combined with other ingredients and then molded, extruded, formed into final products, or applied to wire or cable ([ACC, 2002](#)). Releases are expected from transfer operations, disposal of transfer containers, waste from equipment and area cleaning, and disposal of off-spec product. Historical TRI data indicate most releases are associated with disposal to landfills, smaller quantities to air, and minimal or no releases to water ([U.S. EPA, 2016d](#)). Inhalation exposure from fugitive dust that is generated from unloading and transfer of the flame retardant into mixing vessels may occur. Dermal exposure is most likely during formulation when the bags of flame retardant are emptied into a hopper prior to mixing. Once formulated, DecaBDE is encased in the cured coating and the potential for worker exposure is minimal.

4.4.8. Industrial/Commercial Use Articles – Complex articles

Article components containing DecaBDE such as fabrics and plastic parts are incorporated into finished products such as automobiles and aircraft. Releases to land are expected from disposal of off-spec products that contain DecaBDE. Releases to air and water are not expected.

Occupational exposure from dermal contact with article components during installation is possible. Inhalation exposure is not expected.

4.4.9. Consumer Articles

Articles treated with DecaBDE are used in the home, in business settings, and in the transportation sector. DecaBDE has also been found in children's products such as plastic play structures, and toys ([EPA-HQ-OPPT-2016-0724](#)). DecaBDE is also found in plastics used as components in electrical appliances and equipment such as stereos, computers, televisions, circuit boards, casings, and cable insulation. Other specified uses in the transportation and construction sector are in the fabrics of automobiles, aircrafts, and in wood used as building materials ([U.S. EPA, 2017b](#)). DecaBDE's primary use is in high impact polystyrene-based products that are used in plastics, specifically in plastic enclosures for televisions, computers, and audio and video equipment. It is also used in textiles and upholstered articles (including carpets, upholstery fabric, curtains, cushions, mattresses, and tents), wire and cables for communications and electronics, and other miscellaneous applications ([EPA-HQ-OPPT-2016-0724](#))([U.S. EPA, 2017b](#)). The end-of-life disposal and waste handling options for products containing DecaBDE include disposal in landfills, recycling ([USGS, 2006](#)) and incineration ([BSEF, 2007](#); [Janssen, 2005](#)).

4.4.10. Qualitative Trends Over Time for Releases and Occupational Exposures

DecaBDE was historically used as the flame retardant of choice in many commercial and consumer products including a wide variety of plastics, textiles, and other uses. Releases to all media and corresponding occupational exposures associated with manufacturing, processing, and use were significant. However, due to potential human health and environmental risks, the principle domestic manufacturers and importers of commercially-available DecaBDE agreed to voluntarily phase out domestic manufacture and import of the chemical no later than December 31, 2013. This resulted in a steady decrease in domestic production volume from millions of pounds per year to less than 25,000 pounds in 2015 ([U.S. EPA, 2017b](#)) and ([U.S. EPA, 2016a](#)).

TRI data show a corresponding decrease in releases that are reported in each industry sector using DecaBDE. The number of manufacturing facilities, textile manufacturing facilities, wire and cable manufacturing facilities, and other facilities reporting TRI releases has decreased from several dozen to only one manufacturer and 23 other facilities. The total yearly releases to all media and quantities managed as waste have seen a similar decline from millions to thousands of pounds ([U.S. EPA, 2016d](#)).

4.5. Environmental Monitoring

Hundreds of studies show that DecaDBE has been detected in a wide variety of media. Table 4-3 summarizes the monitoring data for DecaBDE identified in the peer-reviewed literature across all media considered. Also included in the count are available monitoring

database sources. Only studies or databases that reported measurements of the chemical of interest above the limit of detection were extracted and included in the “# of studies” count. The frequency of detection is provided as a measure, across all samples in all extracted studies, of the frequency that the chemical was measured above the limit of detection. Note, the frequency of detection is reported only for peer-reviewed sources, unless the only data sources available were database sources.

The patterns in Table 4-3 are generally consistent with the fate summary and physical-chemical properties in that DecaBDE was detected at relatively higher concentrations in indoor dust, soil, sediment, and sludge/biosolids. DecaBDE was detected at relatively lower concentrations in indoor air, ambient air, and surface water. Detection in ambient air reflects releases to air, which is an important environmental pathway to surface water and sediment. In addition, DecaBDE was reported in influent/effluent and landfill leachate, reflecting releases to water and land.

Table 4-3. Summary of DecaBDE Monitoring Data from the Peer-Reviewed Literature

Media	Presence	No. of Datasets	Frequency of Detection ^a
Indoor dust	Yes	75	96%
Indoor air	Yes	16	94%
Ambient air	Yes	34	94%
Surface/Ground water	Yes	11	100%
Drinking water	No	0	n/a
Soil	Yes	40	100%
Sediment	Yes	65	94%
Biosolids	Yes	19	98%
Wastewater (influent, effluent)	Yes	10	88%
Landfill leachate	Yes	2	97%
Vegetation/Diet	Yes	9	90%
Other	Yes	3	(varies by media)

^aFrequency of detection for peer reviewed studies only

The following chart provides the number of studies reporting DecaBDE monitoring data over time. For this chart, the year the study is published rather than the sampling timeframe is used as a proxy, though for most studies, samples were collected a few years prior to publication. Note, EPA recognizes that the sampling dates, rather than the publication date, would be a better reflection of temporal trends.

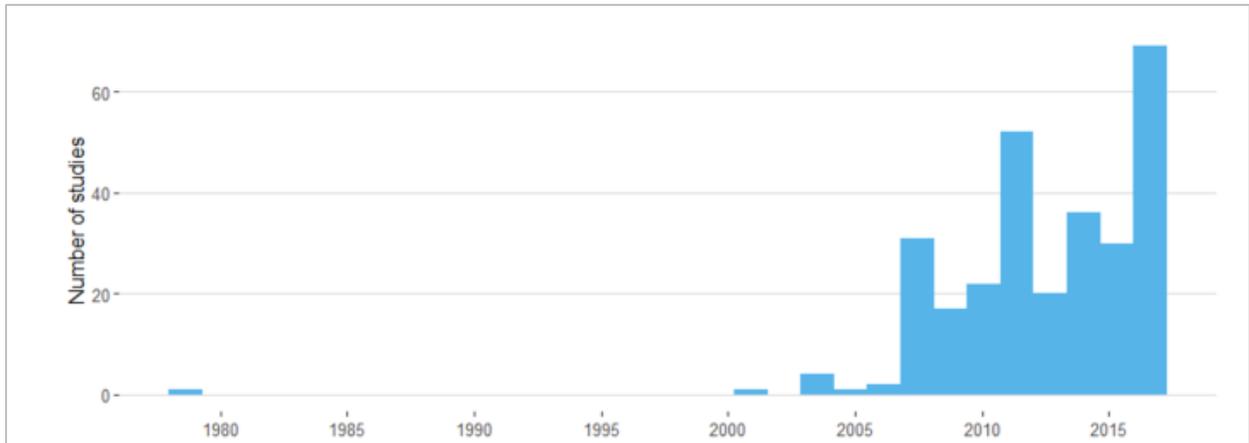


Figure 4-2. Frequency of peer-reviewed publications identified that contained DecaBDE monitoring data.

All environmental monitoring data that passed EPA’s evaluation criteria are presented graphically in the plots below. In short, EPA evaluated sampling methods, analytical approaches, quality assurance procedures, spatial and temporal representativeness, and clarity in reporting. These plots help visualize the data and are organized by study year and microenvironment, when reported. Note, some studies are discussed in 4.7, 4.9, and 4.11 as these studies integrate information on monitoring data and supplemental contextualizing information on uses, sources, and trends.

4.5.1. Indoor Dust

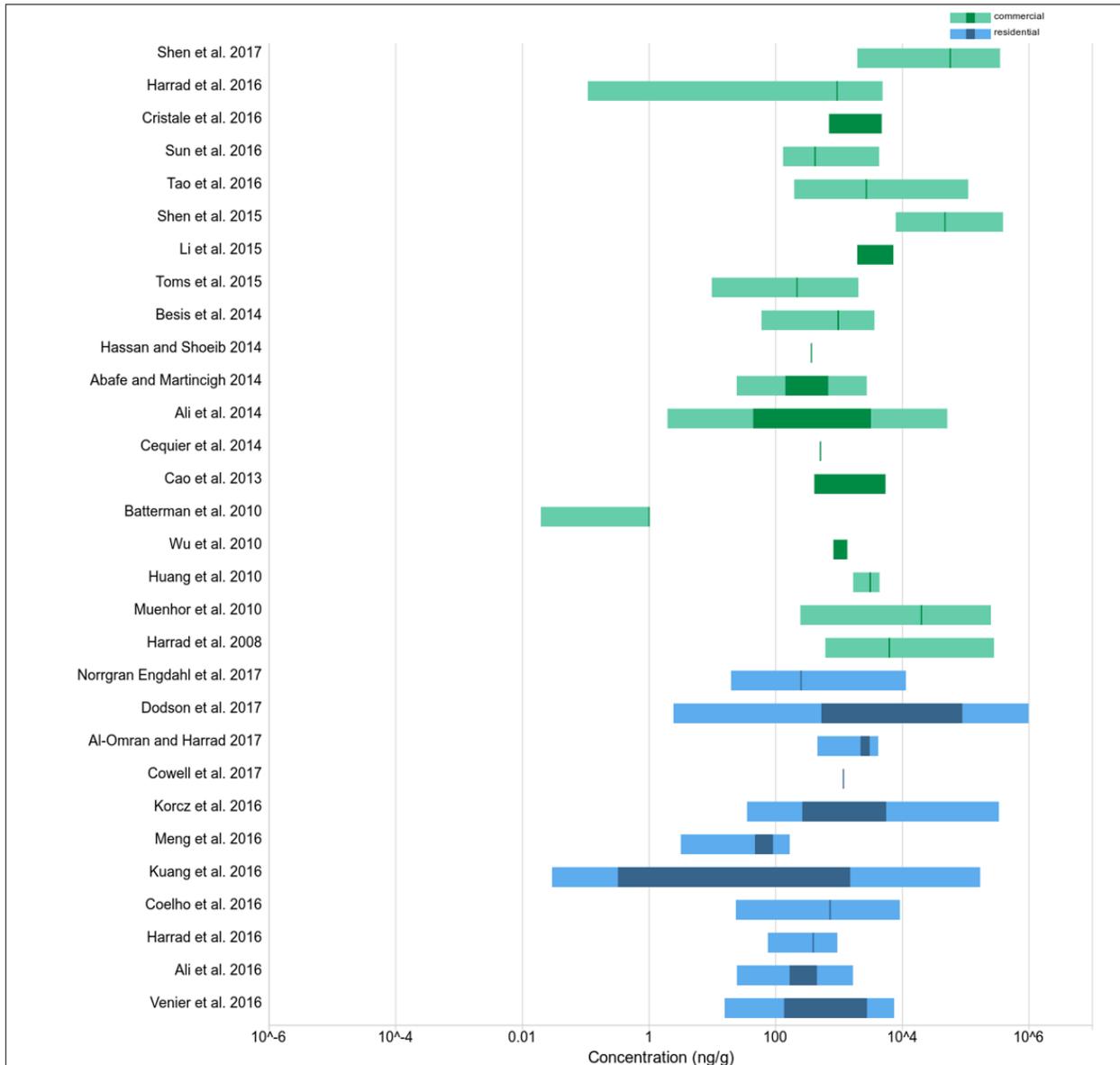


Figure 4-3. Concentration of DecaBDE (ng/g) in indoor dust for commercial (2008 to 2017) and residential (2016 and 2017) locations. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

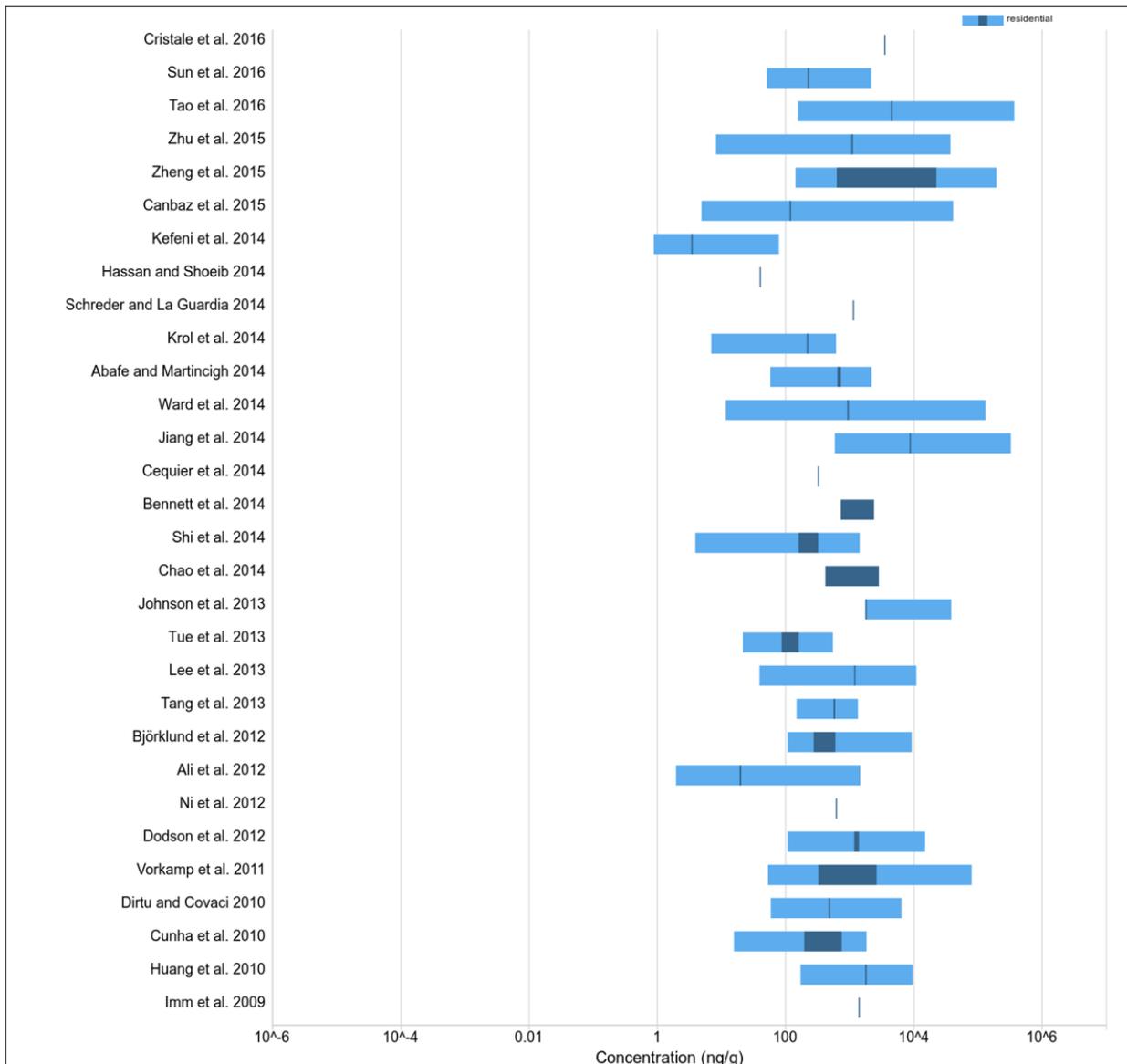


Figure 4-4. Concentration of DecaBDE (ng/g) in indoor dust for residential locations (2009 to 2016). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

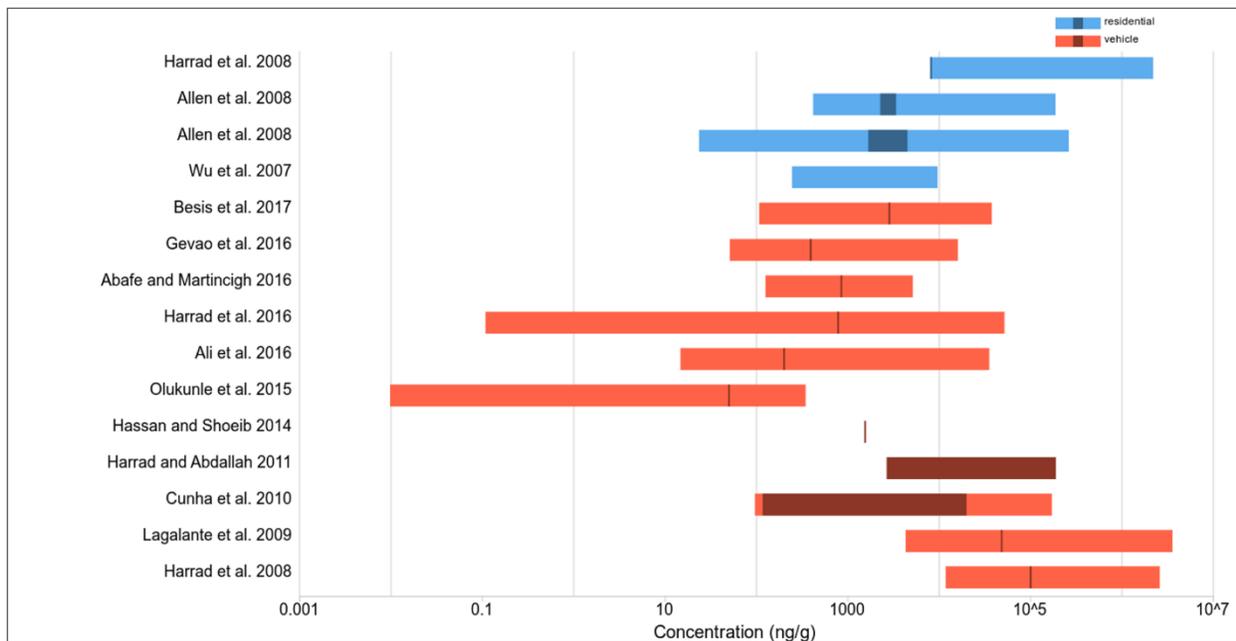


Figure 4-5. Concentration of DecaBDE (ng/g) in indoor dust for residential locations (2007 and 2008) and vehicles (2008 to 2017). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

The above figures for indoor dust contain data for the following: ([Al-Omran and Harrad, 2017](#); [Besis et al., 2017a](#); [Cowell et al., 2017](#); [Dodson et al., 2017](#); [Norrgran Engdahl et al., 2017](#); [Shen et al., 2017](#); [Abafe and Martincigh, 2016](#); [Ali et al., 2016](#); [Coelho et al., 2016](#); [Cristale et al., 2016](#); [Gevao et al., 2016](#); [Harrad et al., 2016](#); [Korczyk et al., 2016](#); [Kuang et al., 2016](#); [Meng et al., 2016b](#); [Sun et al., 2016](#); [Tao et al., 2016](#); [Venier et al., 2016](#); [Canbaz et al., 2015](#); [Li et al., 2015c](#); [Olukunle et al., 2015](#); [Shen et al., 2015](#); [Toms et al., 2015](#); [Zheng et al., 2015a](#); [Zhu et al., 2015](#); [Abafe and Martincigh, 2014](#); [Ali et al., 2014](#); [Bennett et al., 2014](#); [Besis et al., 2014](#); [Cequier et al., 2014](#); [Chao et al., 2014](#); [Hassan and Shoeib, 2014](#); [Jiang et al., 2014](#); [Kefeni et al., 2014](#); [Krol et al., 2014](#); [Schreder and La Guardia, 2014](#); [Shi et al., 2014](#); [Ward et al., 2014](#); [Cao et al., 2013](#); [Johnson et al., 2013](#); [Lee et al., 2013](#); [Tang et al., 2013](#); [Tue et al., 2013](#); [Ali et al., 2012b](#); [Björklund et al., 2012](#); [Dodson et al., 2012](#); [Ni et al., 2012](#); [Harrad and Abdallah, 2011](#); [Vorkamp et al., 2011](#); [Batterman et al., 2010](#); [Cunha et al., 2010](#); [Dirtu and Covaci, 2010](#); [Huang et al., 2010](#); [Muenhor et al., 2010](#); [Wu et al., 2010b](#); [Imm et al., 2009](#); [Lagalante et al., 2009](#); [Allen et al., 2008a, b](#); [Harrad et al., 2008](#); [Wu et al., 2007](#))

4.5.2. Indoor Air

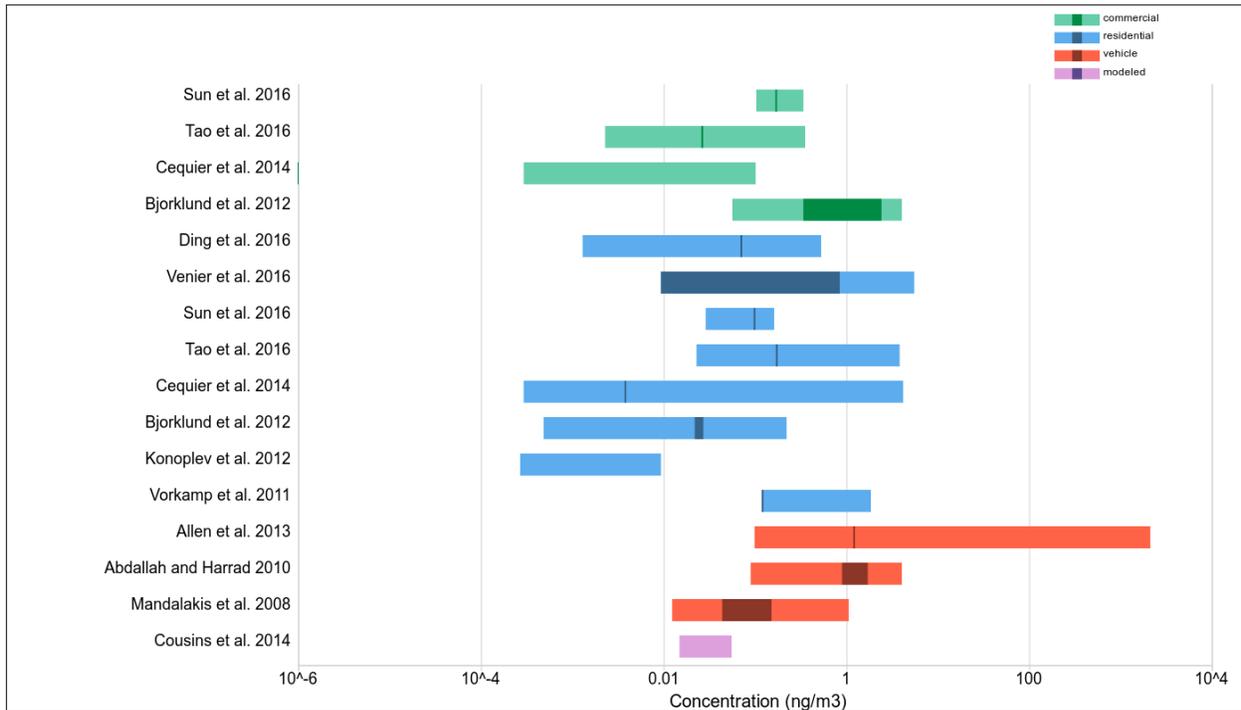


Figure 4-6. Concentration of DecaBDE (ng/m³) in indoor air for commercial locations (2012 to 2016), residential locations (2011 to 2016), vehicles (2008 to 2013), and modeled data (2014). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Ding et al., 2016](#); [Sun et al., 2016](#); [Tao et al., 2016](#); [Venier et al., 2016](#); [Cequier et al., 2014](#); [Cousins et al., 2014](#); [Allen et al., 2013](#); [Bjorklund et al., 2012](#); [Konoplev et al., 2012](#); [Vorkamp et al., 2011](#); [Abdallah and Harrad, 2010](#); [Mandalakis et al., 2008](#))

4.5.3. Ambient Air

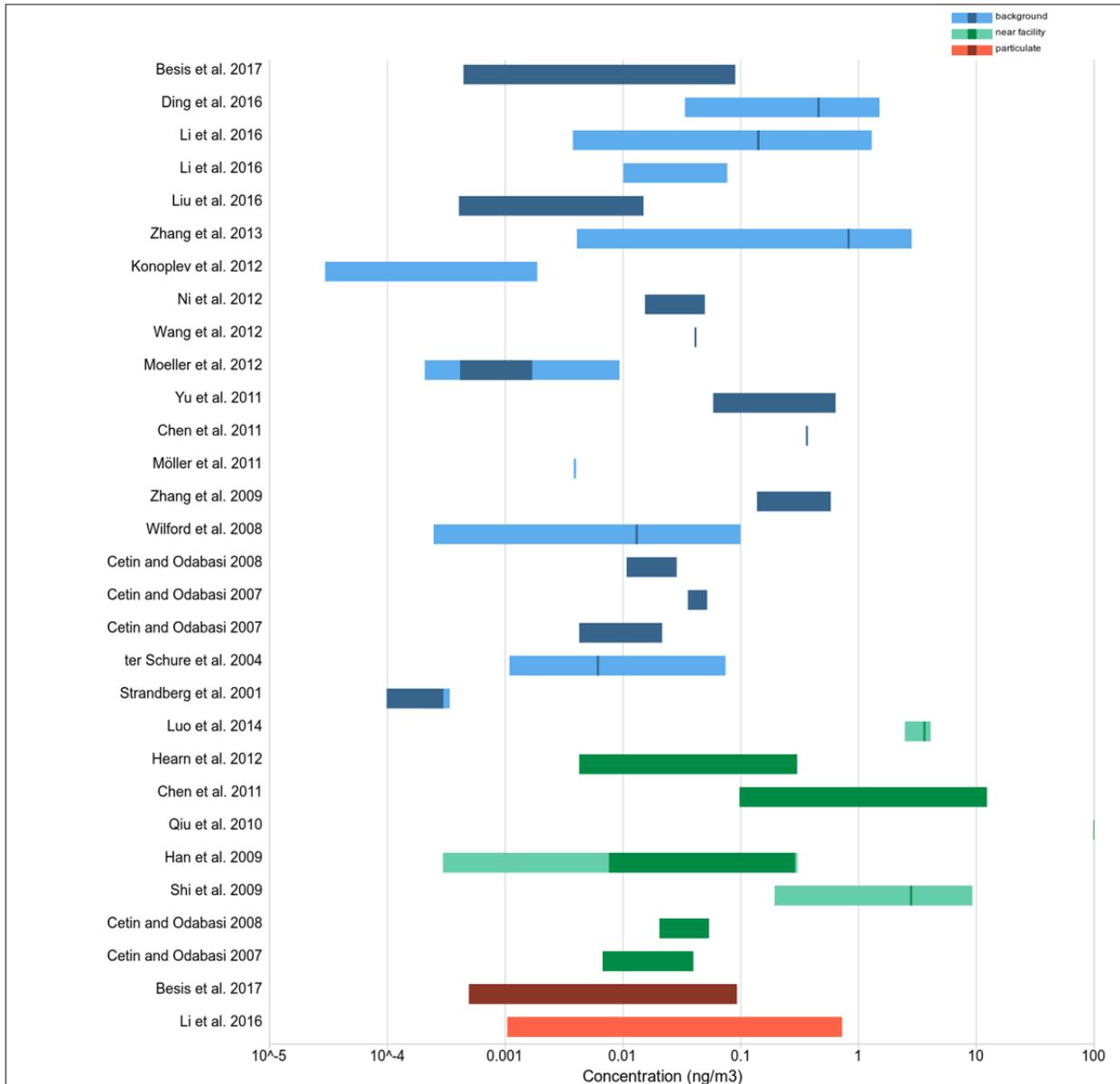


Figure 4-7. Concentration of DecaBDE (ng/m³) in ambient air for background locations (2001 to 2017), near facility locations (2007 to 2014), and particulate data (2016 and 2017). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

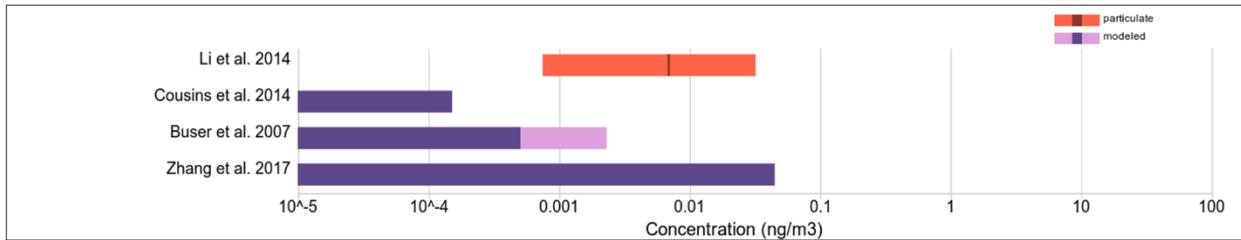


Figure 4-8. Concentration of DecaBDE (ng/m³) in ambient air for particulate data (2014) and modeled data (2014 to 2017). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

The above figures for ambient air contain data for the following: ([Besis et al., 2017b](#); [Zhang et al., 2017](#); [Ding et al., 2016](#); [Li et al., 2016d](#); [Li et al., 2016c](#); [Liu et al., 2016](#); [Li et al., 2015b](#); [Cousins et al., 2014](#); [Luo et al., 2014](#); [Zhang et al., 2013](#); [Hearn et al., 2012](#); [Konoplev et al., 2012](#); [Moeller et al., 2012](#); [Ni et al., 2012](#); [Wang et al., 2012a](#); [Chen et al., 2011a](#); [Möller et al., 2011](#); [Yu et al., 2011b](#); [Qiu et al., 2010](#); [Han et al., 2009](#); [Shi et al., 2009](#); [Zhang et al., 2009](#); [Cetin and Odabasi, 2008](#); [Wilford et al., 2008](#); [Buser et al., 2007](#); [Cetin and Odabasi, 2007a, b](#); [ter Schure et al., 2004](#); [Strandberg et al., 2001](#))

4.5.4. Surface Water

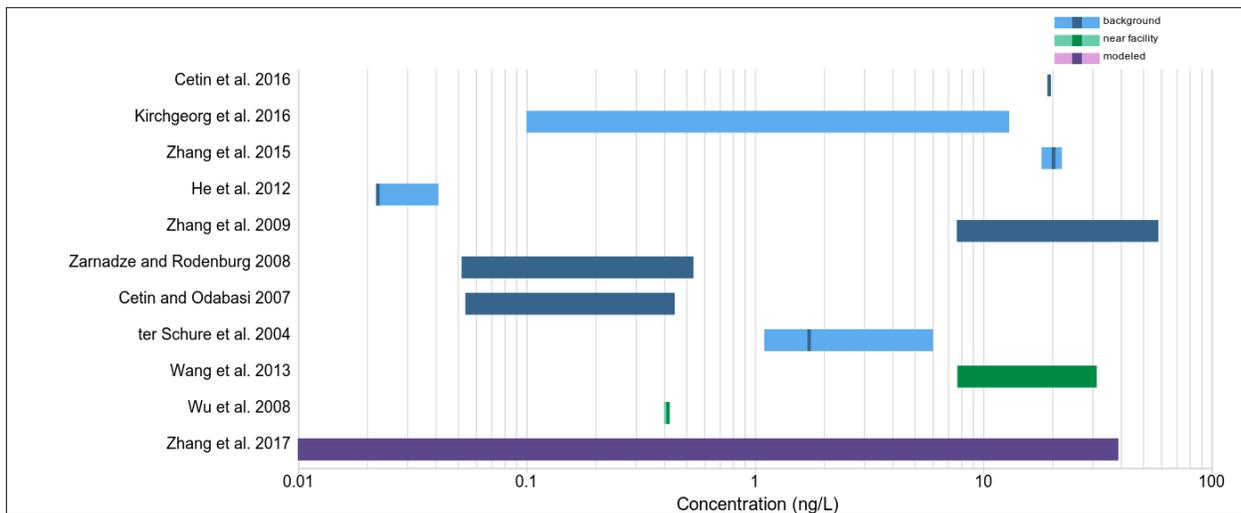


Figure 4-9. Concentration of DecaBDE (ng/L) in surface water for background locations (2004 to 2016), near facility locations (2008 and 2013), and modeled data (2017). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Zhang et al., 2017](#); [Cetin et al., 2016](#); [Kirchgeorg et al., 2016](#); [Zhang et al., 2015a](#); [Wang et al., 2013](#); [He et al., 2012](#); [Zhang et al., 2009](#); [Wu et al., 2008](#); [Zarnadze and Rodenburg, 2008](#); [Cetin and Odabasi, 2007a](#); [ter Schure et al., 2004](#))

4.5.5. Drinking Water

Of the studies searched, EPA did not identify any studies that reported extractable DecaBDE data in drinking water. DecaBDE is expected to adsorb to suspended particulates, based on its octanol-water partition coefficient ($\log K_{ow} = 9.97$) and organic carbon partition coefficient ($\log K_{oc} = 6.5$). As a result, DecaBDE is not expected to be present in drinking water.

4.5.6. Soil

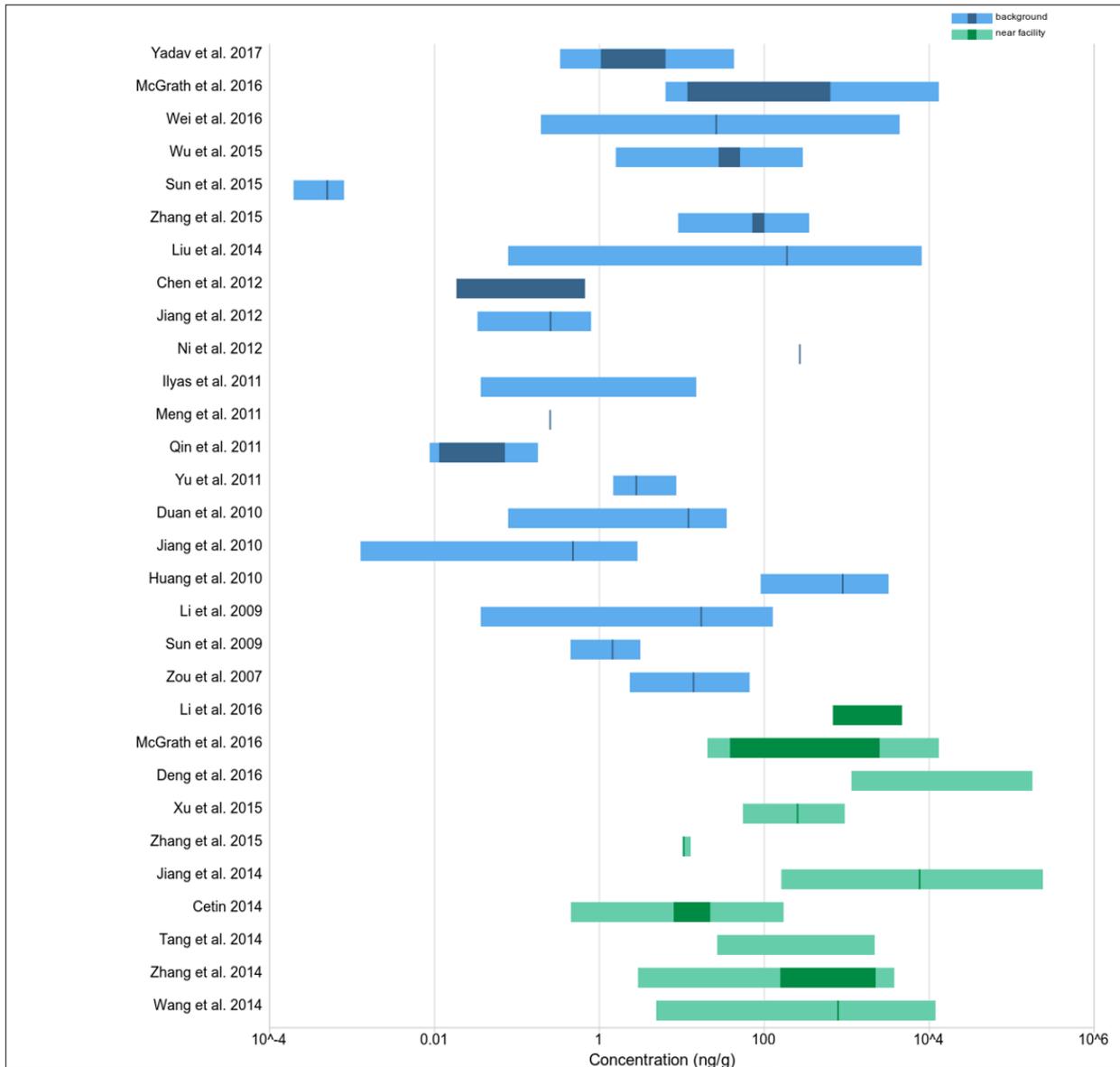


Figure 4-10. Concentration of DecaBDE (ng/g) in soil for background (2007 to 2017) and near facility (2014 to 2016) locations. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

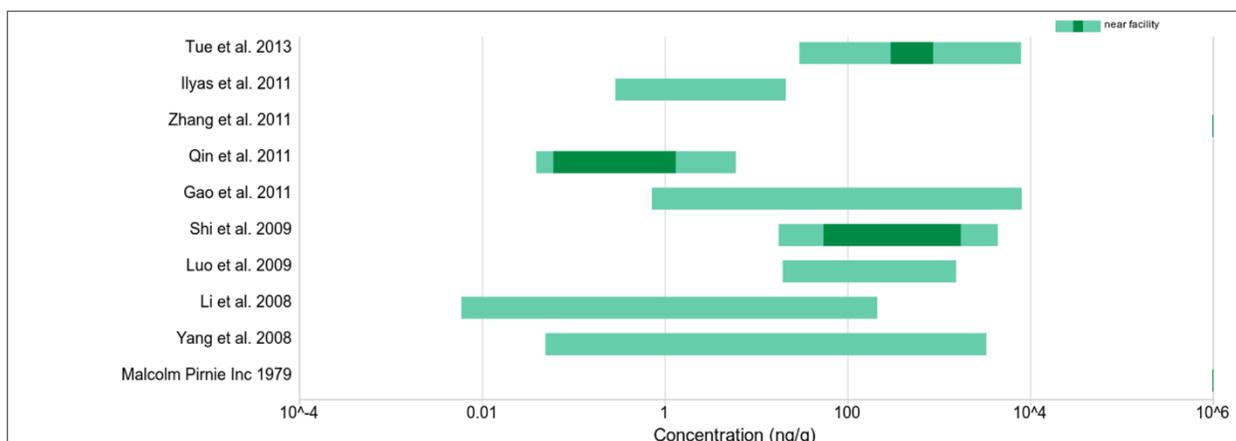


Figure 4-11. Concentration of DecaBDE (ng/g) in soil for near facility locations from 1979 to 2013. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

The above figures for soil contain data for the following: ([Yadav et al., 2017](#); [Deng et al., 2016](#); [Li et al., 2016b](#); [McGrath et al., 2016](#); [Wei et al., 2016](#); [Sun et al., 2015](#); [Wu et al., 2015](#); [Xu et al., 2015a](#); [Zhang et al., 2015b](#); [Zhang et al., 2015a](#); [Cetin, 2014](#); [Jiang et al., 2014](#); [Liu et al., 2014a](#); [Tang et al., 2014a](#); [Wang et al., 2014](#); [Zhang et al., 2014b](#); [Tue et al., 2013](#); [Chen et al., 2012a](#); [Jiang et al., 2012](#); [Ni et al., 2012](#); [Gao et al., 2011](#); [Ilyas et al., 2011a](#); [Meng et al., 2011](#); [Qin et al., 2011](#); [Yu et al., 2011a](#); [Zhang et al., 2011b](#); [Duan et al., 2010](#); [Huang et al., 2010](#); [Jiang et al., 2010](#); [Li et al., 2009](#); [Luo et al., 2009](#); [Shi et al., 2009](#); [Sun et al., 2009](#); [Li et al., 2008](#); [Yang et al., 2008](#); [Zou et al., 2007](#); [Malcolm Pirnie Inc, 1979](#))

4.5.7. Sediment

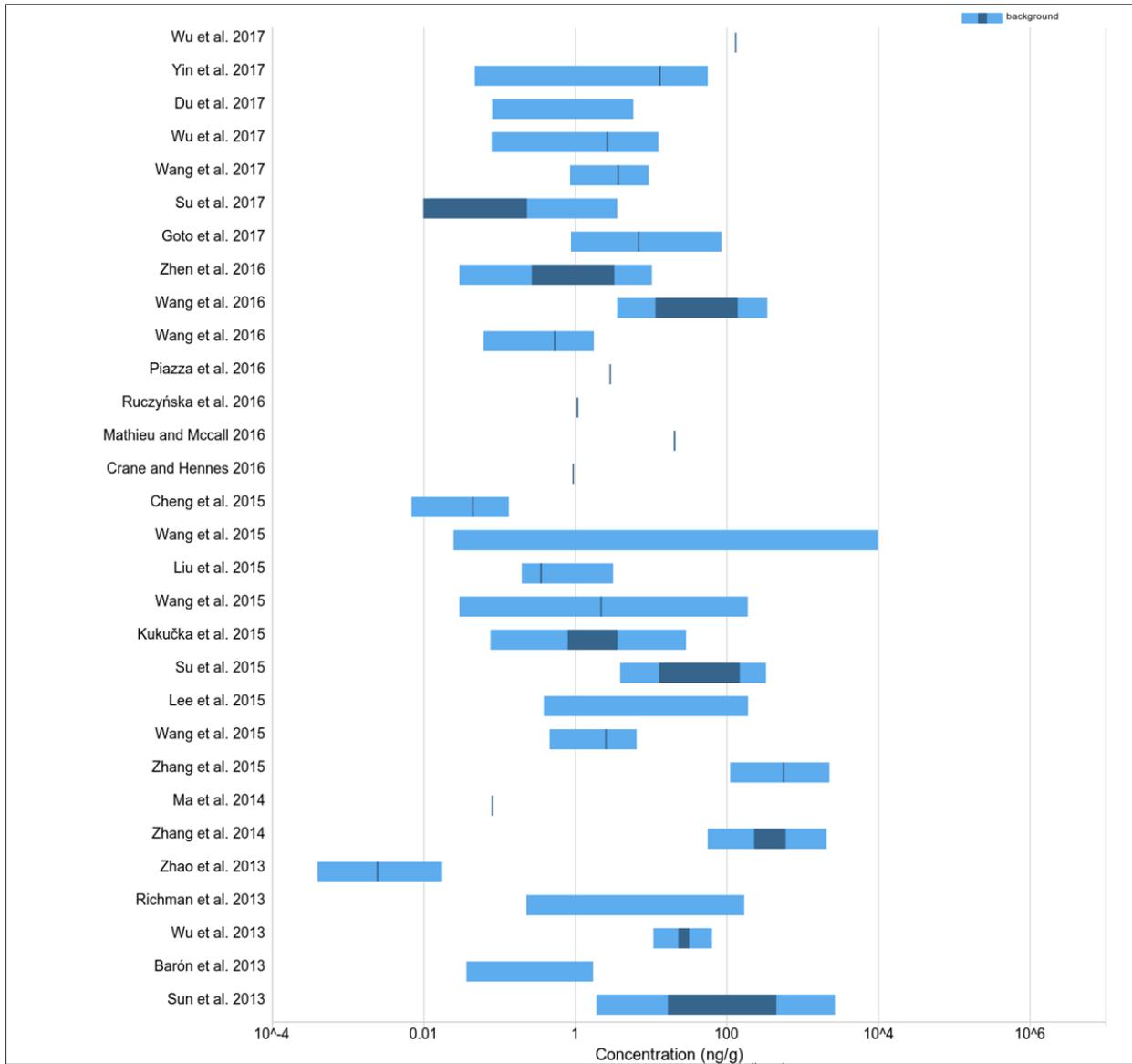


Figure 4-12. Concentration of DecaBDE (ng/g) in sediment for background locations from 2013 to 2017. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

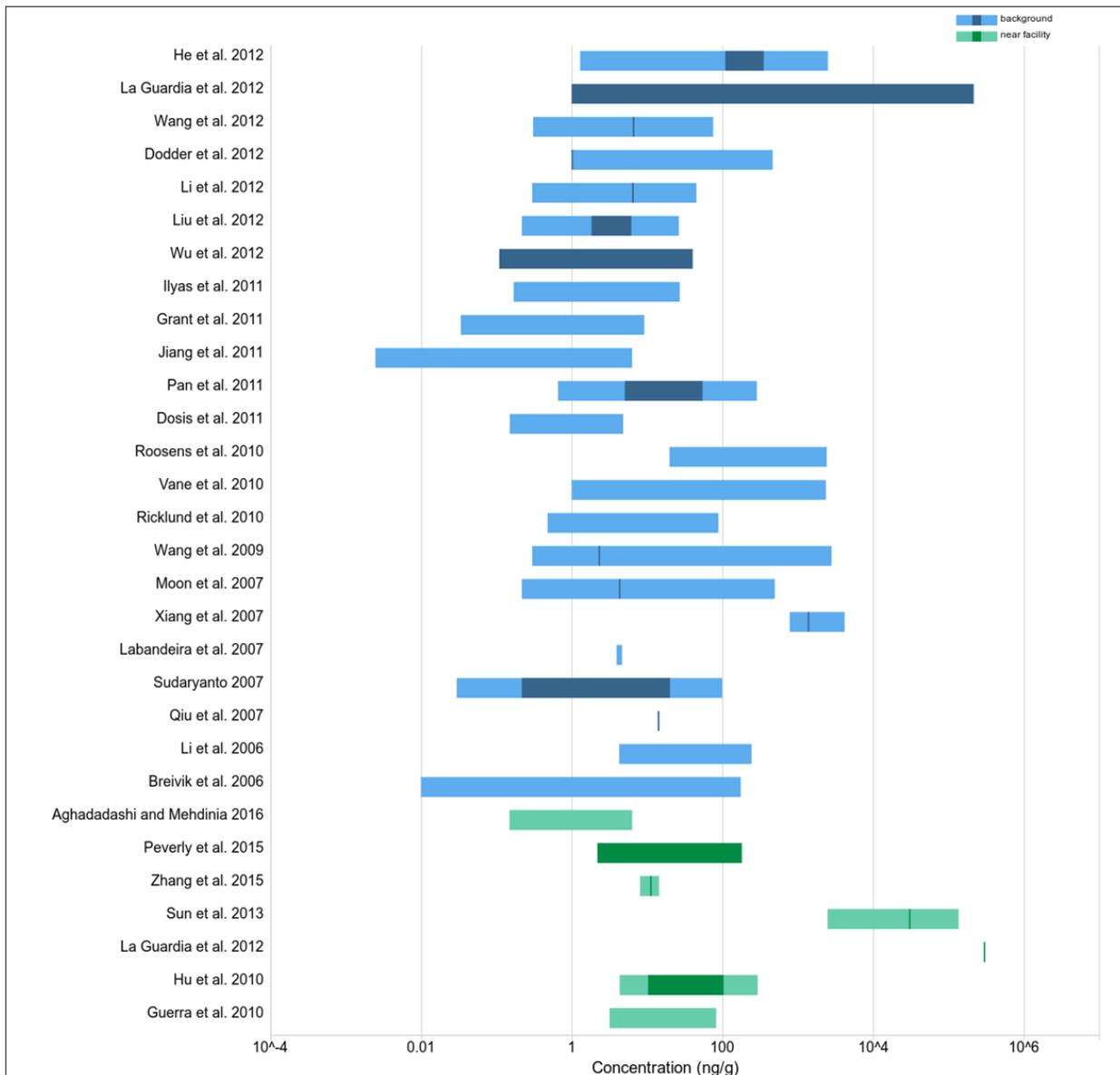


Figure 4-13. Concentration of DecaBDE (ng/g) in sediment for background (2006 to 2012) and near facility (2010 to 2016) locations. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

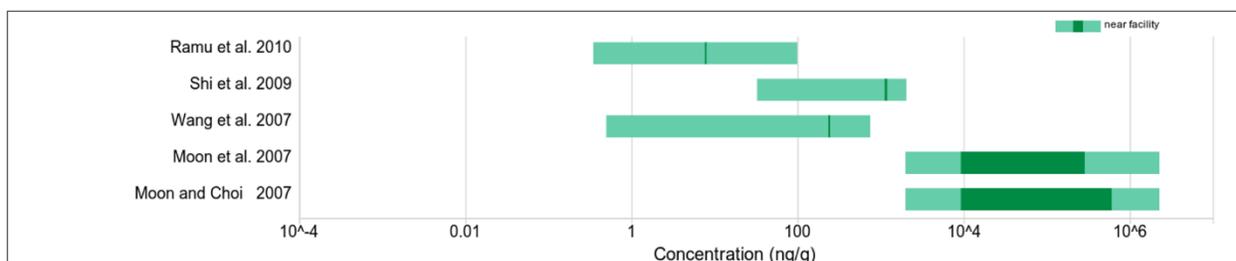


Figure 4-14. Concentration of DecaBDE (ng/g) in sediment for near facility locations from 2007 to 2010. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

The above figures for sediment contain data for the following: ([Du et al., 2017](#); [Goto et al., 2017](#); [Su et al., 2017](#); [Wang et al., 2017](#); [Wu et al., 2017c](#); [Wu et al., 2017a](#); [Yin et al., 2017](#); [Aghadadashi and Mehdinia, 2016](#); [Crane and Hennes, 2016](#); [Mathieu and Mccall, 2016](#); [Piazza et al., 2016](#); [Ruczyńska et al., 2016](#); [Wang et al., 2016a](#); [Wang et al., 2016b](#); [Zhen et al., 2016](#); [Cheng et al., 2015](#); [Kukučka et al., 2015](#); [Lee et al., 2015](#); [Liu et al., 2015](#); [Pevery et al., 2015](#); [Su et al., 2015b](#); [Wang et al., 2015a](#); [Wang et al., 2015c](#); [Wang et al., 2015b](#); [Zhang et al., 2015b](#); [Zhang et al., 2015a](#); [Ma et al., 2014](#); [Zhang et al., 2014c](#); [Barón et al., 2013](#); [Richman et al., 2013](#); [Sun et al., 2013](#); [Wu et al., 2013](#); [Zhao et al., 2013a](#); [Dodder et al., 2012](#); [He et al., 2012](#); [La Guardia et al., 2012](#); [Li et al., 2012](#); [Liu et al., 2012a](#); [Wang et al., 2012b](#); [Wu et al., 2012](#); [Dosis et al., 2011](#); [Grant et al., 2011](#); [Ilyas et al., 2011b](#); [Jiang et al., 2011](#); [Pan et al., 2011](#); [Guerra et al., 2010](#); [Hu et al., 2010](#); [Ramu et al., 2010](#); [Ricklund et al., 2010](#); [Roosens et al., 2010b](#); [Vane et al., 2010](#); [Shi et al., 2009](#); [Wang et al., 2009](#); [Labandeira et al., 2007](#); [Moon et al., 2007a](#); [Moon et al., 2007b](#); [Moon and Choi, 2007](#); [Qiu et al., 2007](#); [Sudaryanto, 2007](#); [Wang et al., 2007a](#); [Xiang et al., 2007](#); [Breivik et al., 2006](#); [Li et al., 2006b](#))

4.5.8. Sludge/Biosolids

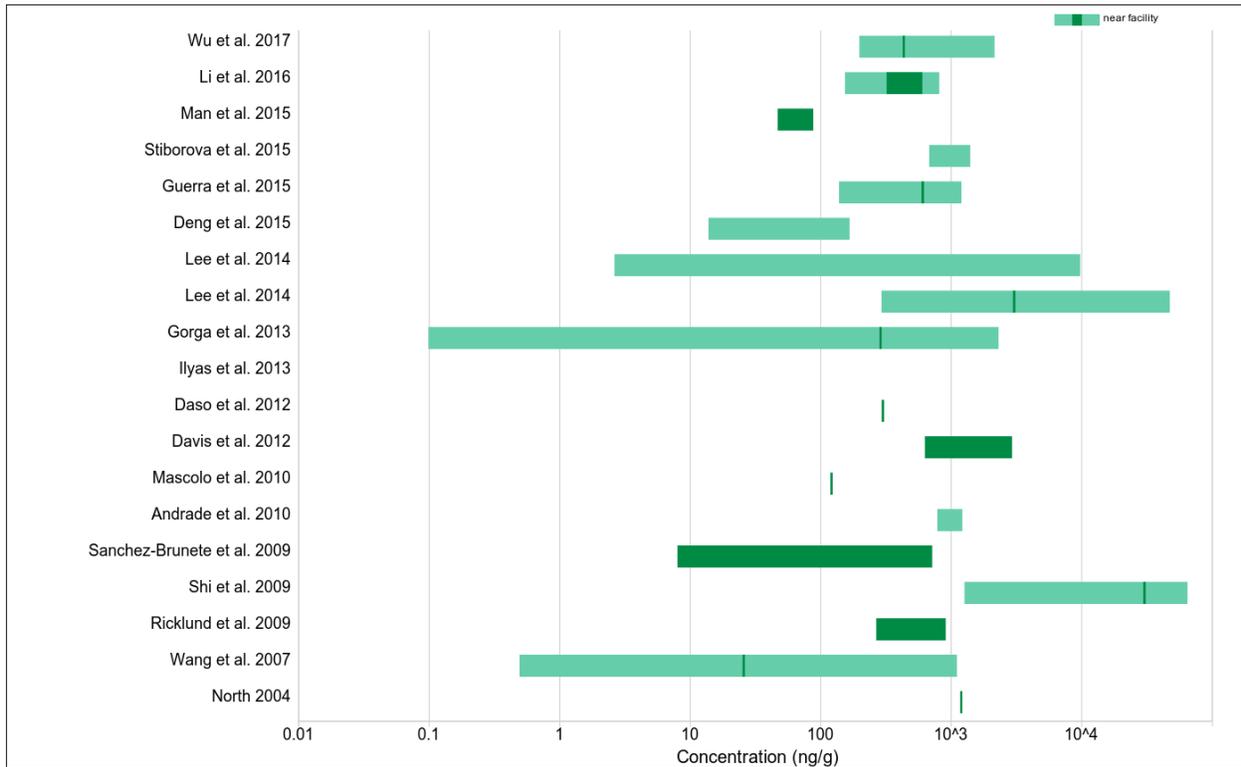


Figure 4-15. Concentration of DecaBDE (ng/g) in sludge/biosolids for near facility locations from 2004 to 2017. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Wu et al., 2017b](#); [Li et al., 2016a](#); [Deng et al., 2015](#); [Guerra et al., 2015](#); [Man et al., 2015](#); [Stiborova et al., 2015](#); [Lee et al., 2014a](#); [Lee et al., 2014b](#); [Gorga et al., 2013](#); [Ilyas et al., 2013](#); [Daso et al., 2012](#); [Davis et al., 2012](#); [Andrade et al., 2010](#); [Mascolo et al., 2010](#); [Ricklund et al., 2009](#); [Sanchez-Brunete et al., 2009](#); [Shi et al., 2009](#); [Wang et al., 2007b](#); [North, 2004](#))

4.5.9. Influent/Effluent

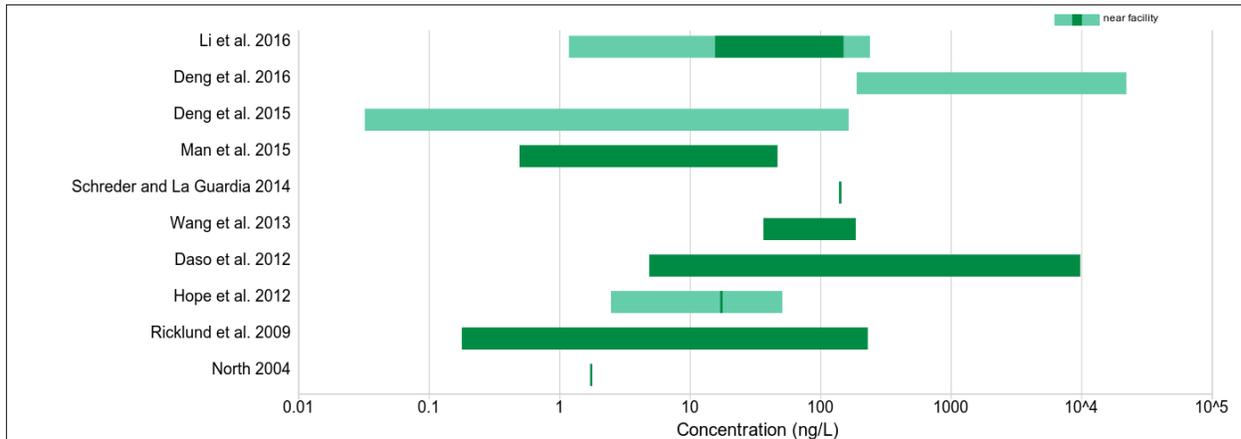


Figure 4-16. Concentration of DecaBDE (ng/L) in influent/effluent for near facility locations from 2004 to 2016. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Deng et al., 2016](#); [Li et al., 2016a](#); [Deng et al., 2015](#); [Man et al., 2015](#); [Schreder and La Guardia, 2014](#); [Wang et al., 2013](#); [Daso et al., 2012](#); [Hope et al., 2012](#); [Ricklund et al., 2009](#); [North, 2004](#))

4.5.10. Landfill Leachate

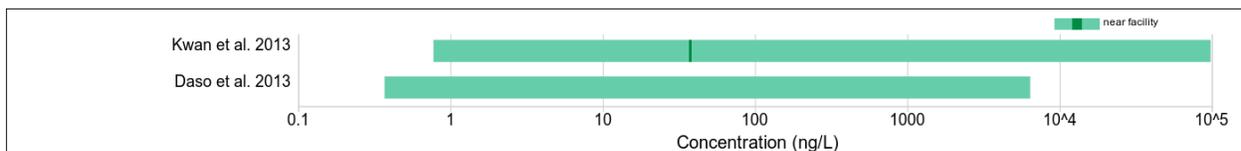


Figure 4-17. Concentration of DecaBDE (ng/L) in landfill leachate for near facility locations in 2013. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Daso et al., 2013](#); [Kwan et al., 2013](#))

4.5.11. Vegetation/Diet

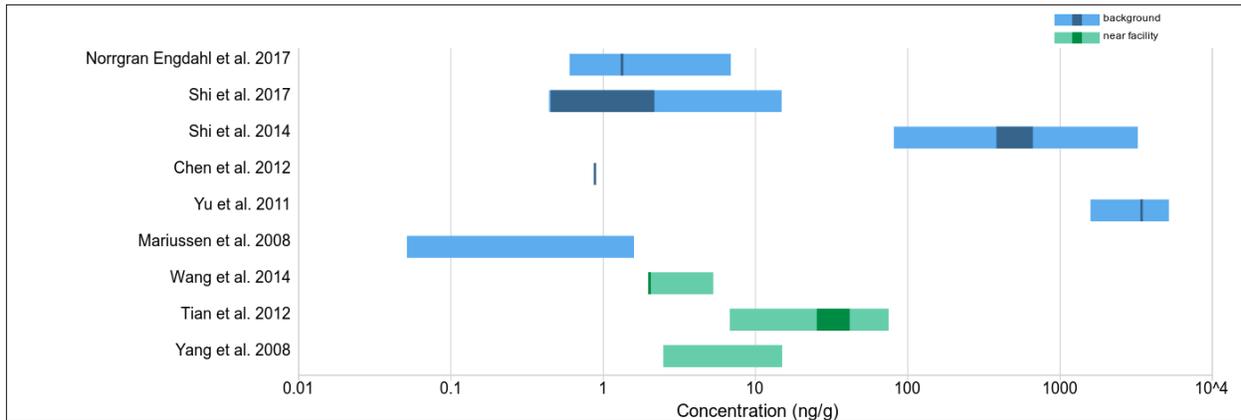


Figure 4-18. Concentration of DecaBDE (ng/g) in vegetation/diet for background (2008 to 2017) and near facility (2008 to 2014) locations. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Norrgran Engdahl et al., 2017](#); [Shi et al., 2017](#); [Shi et al., 2014](#); [Wang et al., 2014](#); [Chen et al., 2012c](#); [Tian et al., 2012](#); [Yu et al., 2011a](#); [Mariussen et al., 2008](#); [Yang et al., 2008](#))

4.5.12. Other

Three studies were identified that reported DecaBDE concentrations in incinerator waste and in seawater.

4.5.12.1. Incinerator Waste

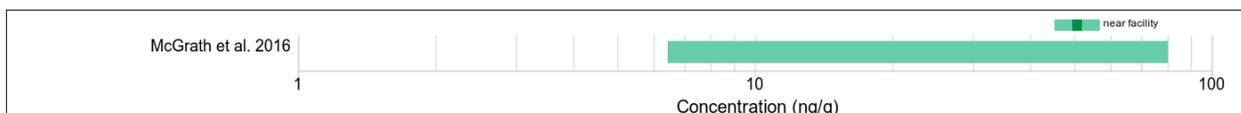


Figure 4-19. Concentration of DecaBDE (ng/g) in incinerator waste for near facility locations in 2016. The range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([McGrath et al., 2016](#))

4.5.12.2. Seawater

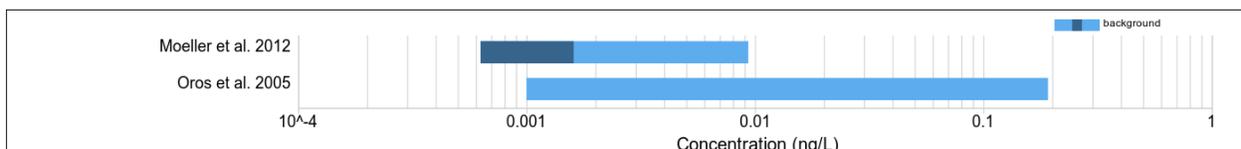


Figure 4-20. Concentration of DecaBDE (ng/L) in seawater for background locations in 2005 and 2012. The range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([Moeller et al., 2012](#); [Oros et al., 2005](#))

4.6. Biomonitoring

Many studies show that DecaBDE has been detected in a wide variety of matrices. Table 4-4 summarizes the biomonitoring data for DecaBDE identified in the peer-reviewed literature across all matrices considered. Also included in the count are available monitoring database sources. Only studies or databases that reported measurements of the chemical of interest above the limit of detection were extracted and included in the “# of studies” count. The frequency of detection is provided as a measure, across all samples in all extracted studies, of the frequency that the chemical was measured above the limit of detection. Note, the frequency of detection is reported only for peer-reviewed sources, unless the only data sources available were database sources.

DecaBDE was detected in all matrices, which is generally consistent with the fate summary and physical-chemical properties. Dietary exposure through the food-chain and trophic transfer may contribute to presence in biological matrices.

Table 4-4. Summary of DecaBDE Biomonitoring Data from the Peer-Reviewed Literature and Monitoring Databases

Matrix	Presence	No. of Datasets	Frequency of Detection
Human blood (serum)	Yes	30	66%
Human (other)	Yes	36	87%
Fish	Yes	20	91%
Birds	Yes	18	84%
Terrestrial invertebrates	Yes	2	86%
Aquatic invertebrates	Yes	10	90%
Terrestrial mammals	Yes	11	79%
Aquatic mammals	Yes	1	100%
Other	Yes	2	100%

The following chart provides the number of studies that have reported DecaBDE biomonitoring data over time. For this chart, the year the study is published rather than the sampling timeframe is used as a proxy, though for most studies, samples were collected a few years prior to publication. Note, EPA recognizes that the sampling dates, rather than the publication date, would be a better reflection of temporal trends.

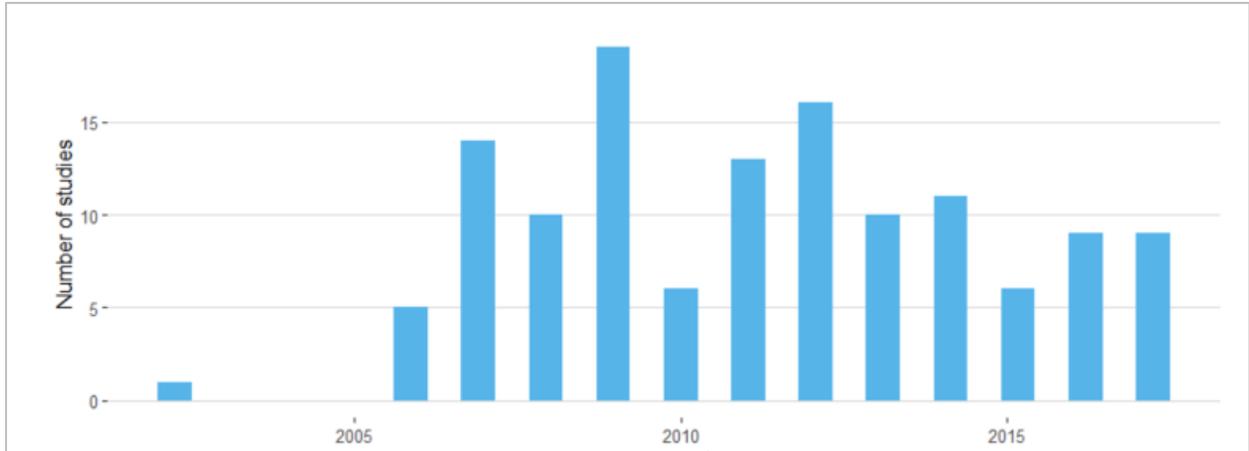


Figure 4-21. Frequency of peer-reviewed publications identified that contained DecaBDE biomonitoring data.

All biomonitoring data that passed EPA’s evaluation criteria are presented graphically in the plots below. These plots help visualize the data and are organized by study year and microenvironment, when reported. Note, some studies are discussed in Sections 4.7 and 4.11 as they pulled together information on monitoring data alongside supplemental contextualizing information on uses, sources, and trends.

4.6.1. Human blood (serum)

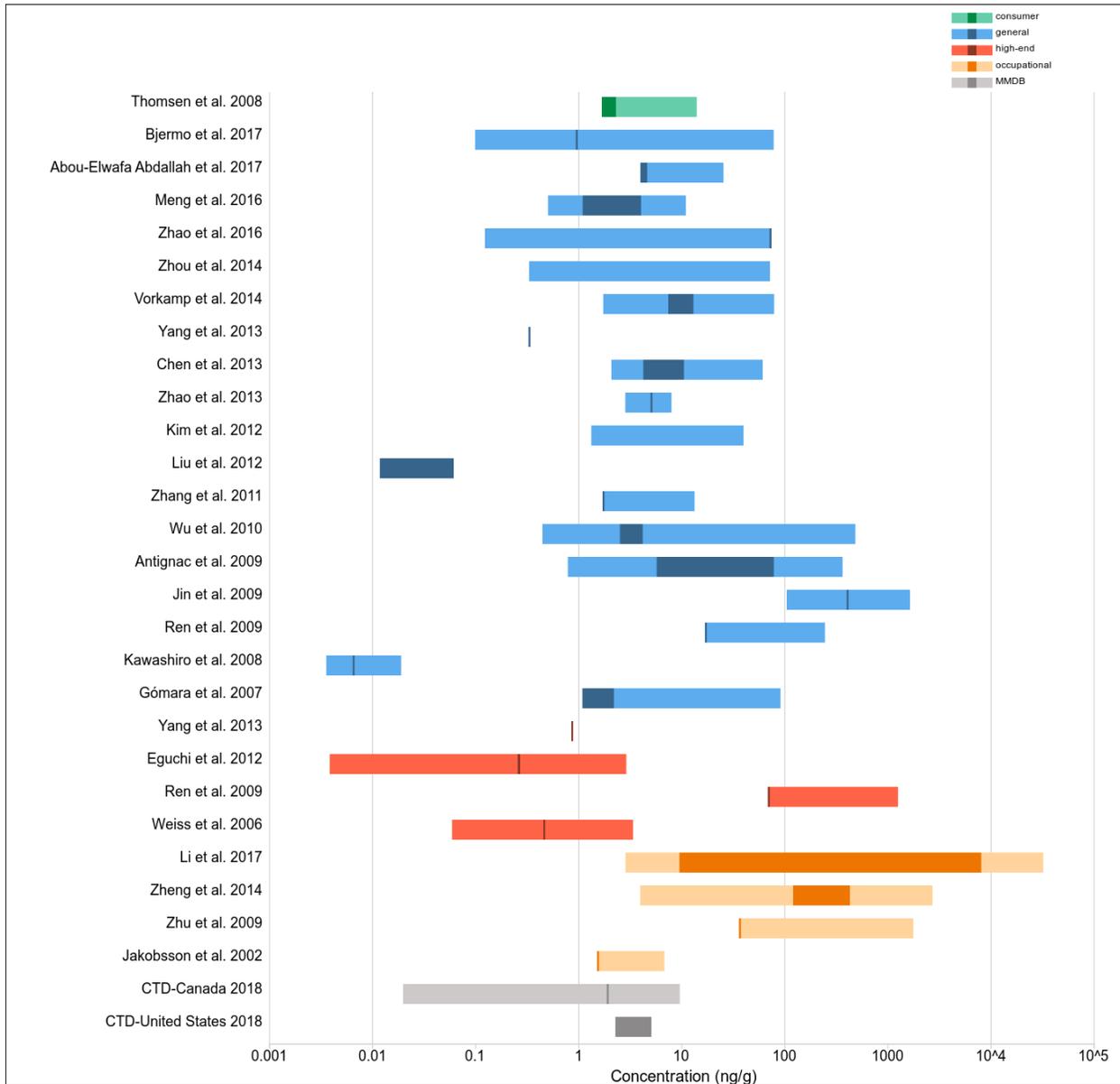


Figure 4-22. Concentration of DecaBDE (ng/g) in human blood (serum) for consumer (2008), general (2007 to 2017), high-end (2006 to 2013), and occupational (2002 to 2017) populations, as well as monitoring database results (MDI, 2002). For each year/database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Abou-Elwafa Abdallah et al., 2017](#); [Bjermo et al., 2017](#); [Li et al., 2017](#); [Meng et al., 2016a](#); [Zhao et al., 2016b](#); [Vorkamp et al., 2014](#); [Zheng et al., 2014](#); [Zhou et al., 2014](#); [Chen et al., 2013](#); [Yang et al., 2013](#); [Zhao et al., 2013b](#); [Eguchi et al., 2012](#); [Kim et al., 2012](#); [Liu et al., 2012b](#); [Zhang et al., 2011a](#); [Wu et al., 2010a](#); [Antignac et al.,](#)

[2009](#); [Jin et al., 2009](#); [Ren et al., 2009](#); [Zhu et al., 2009](#); [Kawashiro et al., 2008](#); [Thomsen et al., 2008](#); [Gómara et al., 2007](#); [Weiss et al., 2006](#); [Jakobsson et al., 2002](#)), ([MDI, 2002](#))

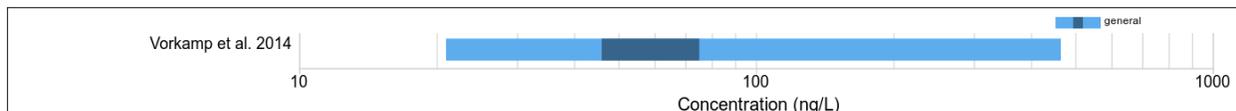


Figure 4-23. Concentration of DecaBDE (ng/L) in human blood (serum) for the general population in 2014. The range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Vorkamp et al., 2014](#))

4.6.2. Human (other)

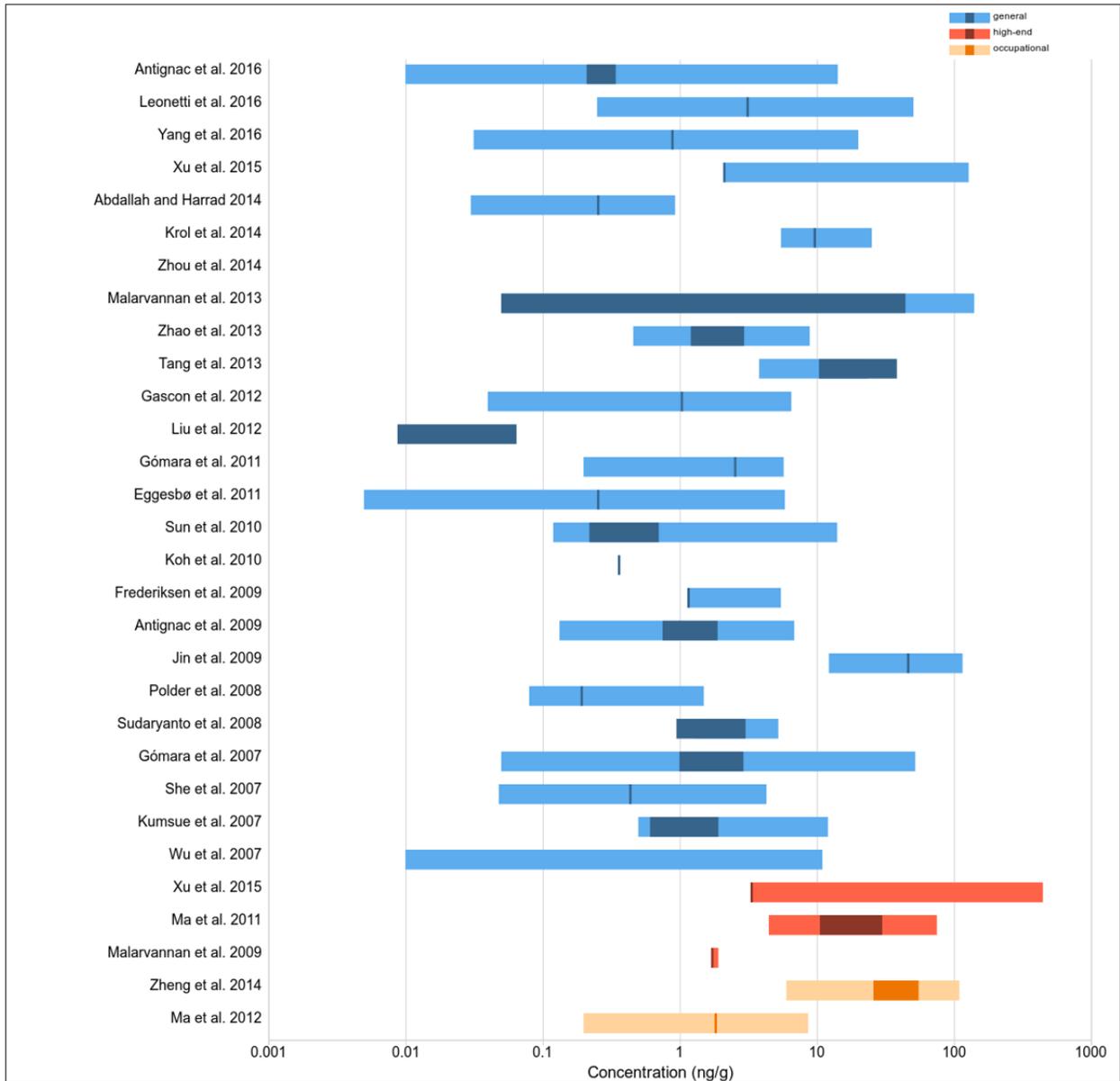


Figure 4-24. Concentration of DecaBDE (ng/g) in human (other) for general (2007 to 2016), high-end (2009 to 2015), and occupational (2012 to 2014) populations. For each year/database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

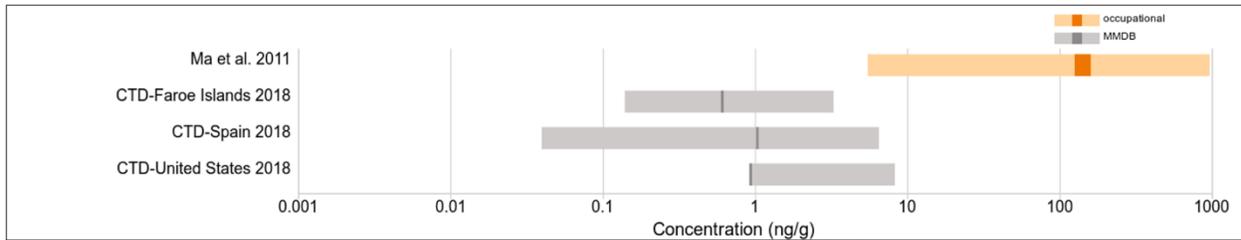


Figure 4-25. Concentration of DecaBDE (ng/g) in human (other) for occupational populations in 2011, as well as monitoring database results. For each year/database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

The above figures for human (other) contain data for the following: ([Antignac et al., 2016](#); [Leonetti et al., 2016](#); [Yang et al., 2016b](#); [Xu et al., 2015b](#); [Abdallah and Harrad, 2014](#); [Krol et al., 2014](#); [Zheng et al., 2014](#); [Zhou et al., 2014](#); [Malarvannan et al., 2013](#); [Tang et al., 2013](#); [Zhao et al., 2013b](#); [Gascon et al., 2012](#); [Liu et al., 2012b](#); [Eggesbø et al., 2011](#); [Gómara et al., 2011](#); [Ma et al., 2011](#); [Koh et al., 2010](#); [Sun et al., 2010](#); [Antignac et al., 2009](#); [Frederiksen et al., 2009](#); [Jin et al., 2009](#); [Malarvannan et al., 2009](#); [Polder et al., 2008](#); [Sudaryanto et al., 2008](#); [Gómara et al., 2007](#); [Kumsue et al., 2007](#); [She et al., 2007](#); [Wu et al., 2007](#)),² ([Ma et al., 2012](#); [Ma et al., 2011](#); [MDI, 2002](#))

4.6.2.1. Dermal Wipes



Figure 4-26. Concentration of DecaBDE (ng/cm²) in dermal wipes for the general population in 2017. The minimum and maximum of reported central tendency estimates are shown.

This figure contains data for the following: ([Cowell et al., 2017](#))

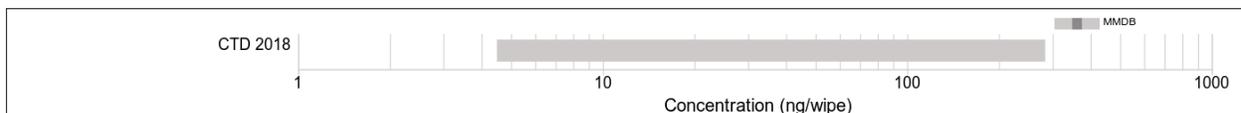


Figure 4-27. Concentration of DecaBDE (ng/wipe) in dermal wipes from a monitoring database (CTD). The range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([MDI, 2002](#))

4.6.3. Aquatic invertebrates

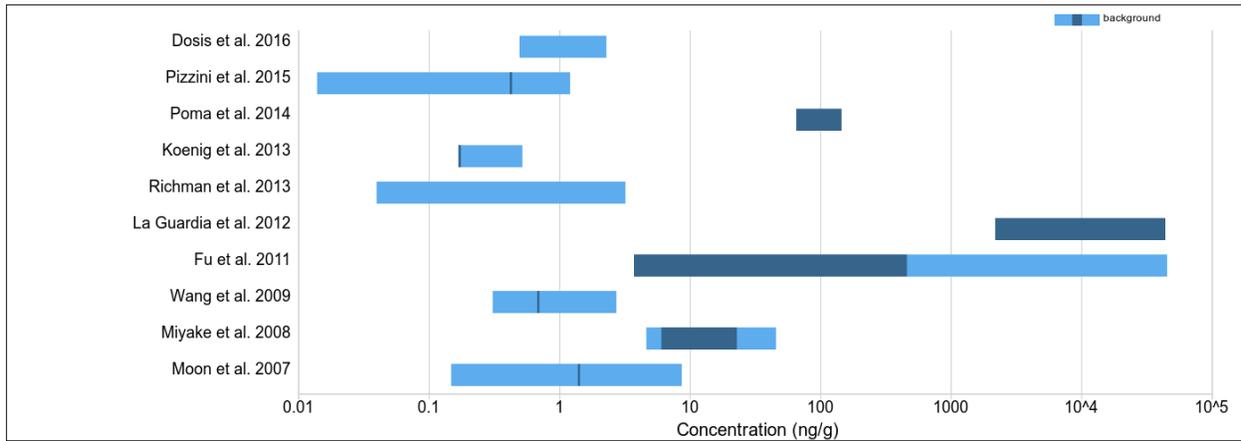


Figure 4-28. Concentration of DecaBDE (ng/g) in aquatic invertebrates for background locations from 2007 to 2016. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Dosis et al., 2016](#); [Pizzini et al., 2015](#); [Poma et al., 2014](#); [Koenig et al., 2013](#); [Richman et al., 2013](#); [La Guardia et al., 2012](#); [Fu et al., 2011](#); [Wang et al., 2009](#); [Miyake et al., 2008](#); [Moon et al., 2007b](#))

4.6.4. Fish

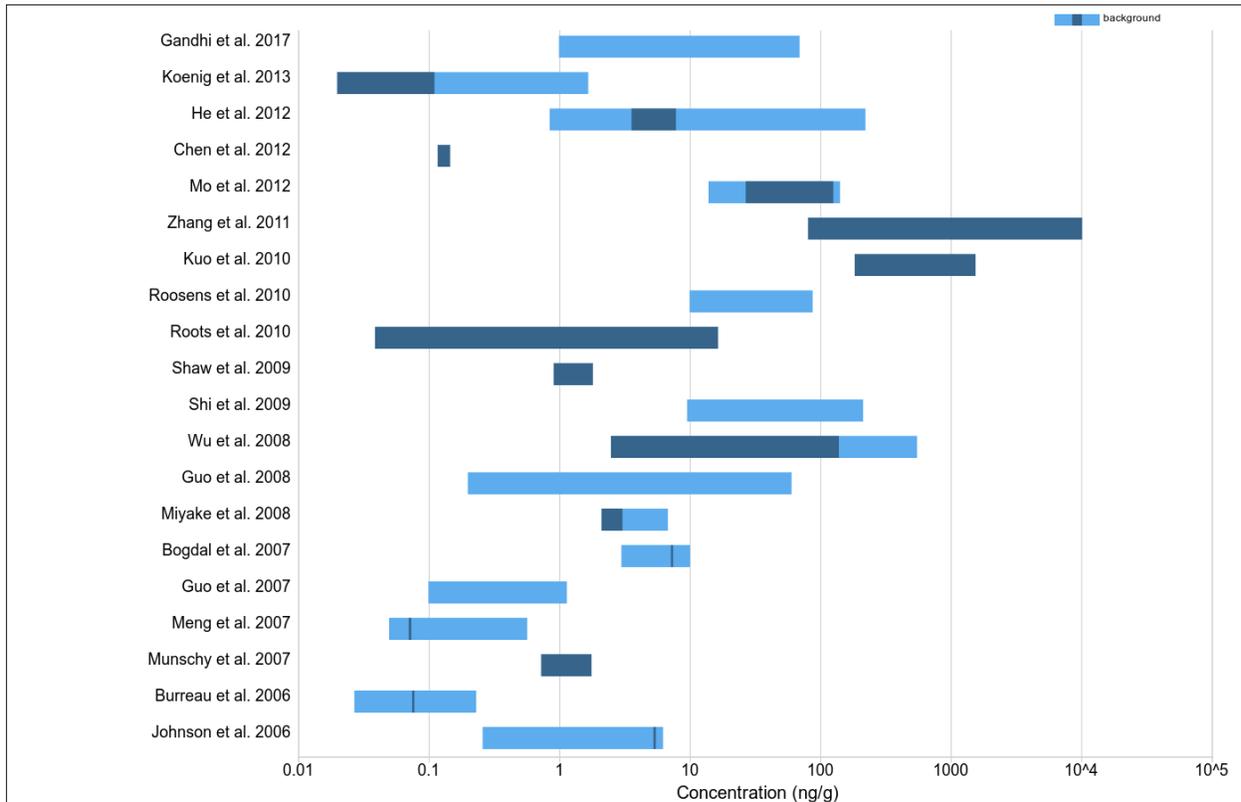


Figure 4-29. Concentration of DecaBDE (ng/g) in fish for background locations from 2006 to 2017. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Gandhi et al., 2017](#); [Koenig et al., 2013](#); [Chen et al., 2012c](#); [He et al., 2012](#); [Mo et al., 2012](#); [Zhang et al., 2011b](#); [Kuo et al., 2010](#); [Roosens et al., 2010b](#); [Roots et al., 2010](#); [Shaw et al., 2009](#); [Shi et al., 2009](#); [Guo et al., 2008](#); [Miyake et al., 2008](#); [Wu et al., 2008](#); [Bogdal et al., 2007](#); [Guo et al., 2007](#); [Meng et al., 2007](#); [Munschy et al., 2007](#); [Burreau et al., 2006](#); [Johnson et al., 2006](#))

4.6.5. Aquatic mammals

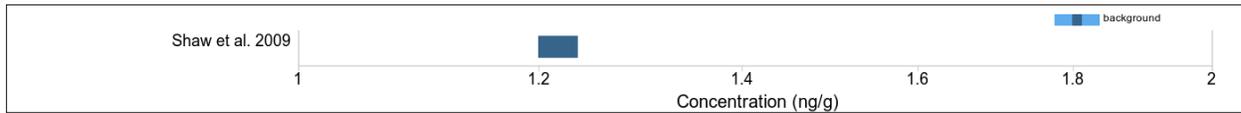


Figure 4-30. Concentration of DecaBDE (ng/g) in aquatic mammals for background locations in 2009. The minimum and maximum of reported central tendency estimates are shown.

This figure contains data for the following: ([Shaw et al., 2009](#))

4.6.6. Terrestrial invertebrates

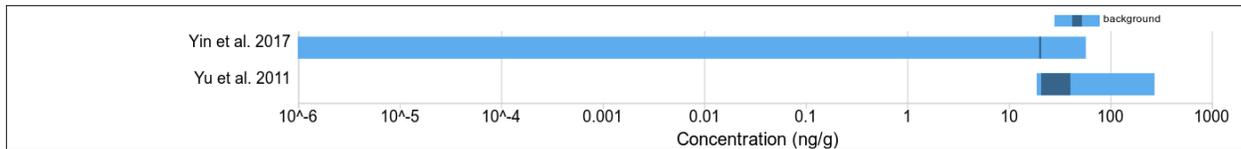


Figure 4-31. Concentration of DecaBDE (ng/g) in terrestrial invertebrates for background locations in 2011 and 2017. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Yin et al., 2017](#); [Yu et al., 2011a](#))

4.6.7. Birds

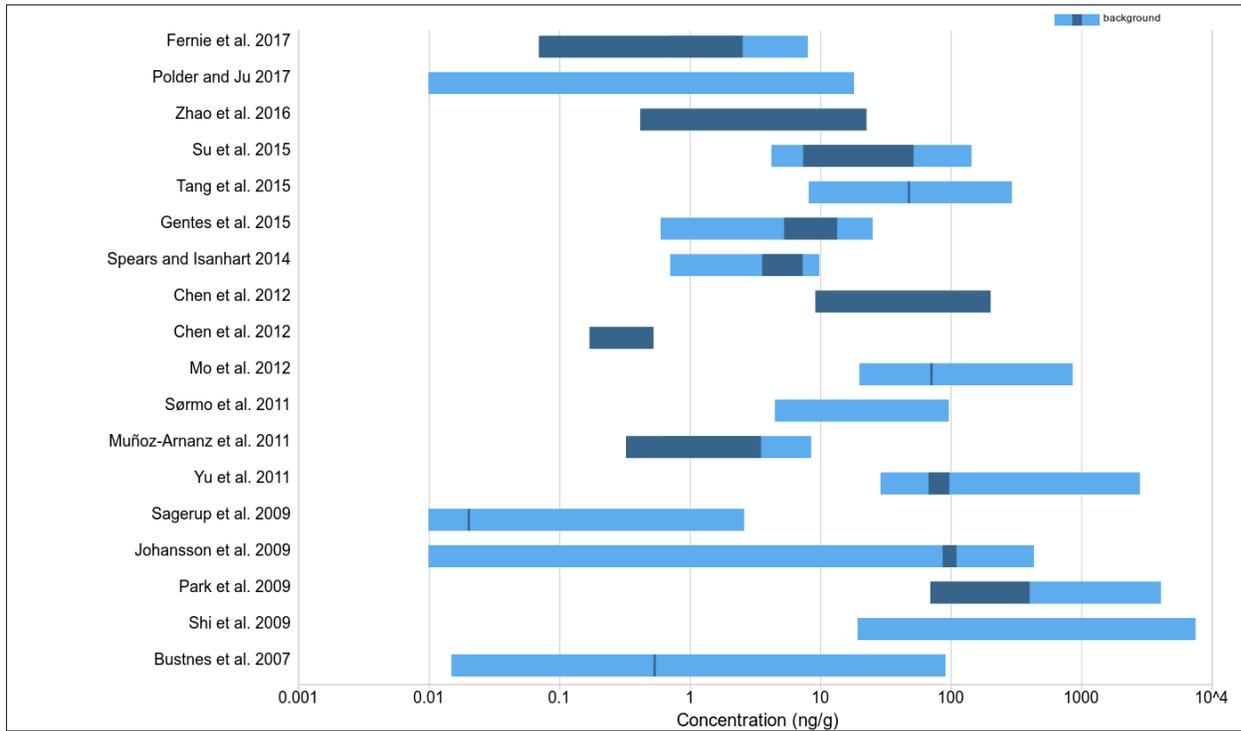


Figure 4-32. Concentration of DecaBDE (ng/g) in birds for background locations from 2007 to 2017. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Fernie et al., 2017](#); [Polder et al., 2017](#); [Zhao et al., 2016a](#); [Gentes et al., 2015](#); [Su et al., 2015a](#); [Tang et al., 2015](#); [Spears and Isanhart, 2014](#); [Chen et al., 2012b](#); [Chen et al., 2012c](#); [Mo et al., 2012](#); [Muñoz-Arnanz et al., 2011](#); [Sørmo et al., 2011](#); [Yu et al., 2011a](#); [Johansson et al., 2009](#); [Park et al., 2009](#); [Sagerup et al., 2009](#); [Shi et al., 2009](#); [Bustnes et al., 2007](#))

4.6.8. Terrestrial mammals

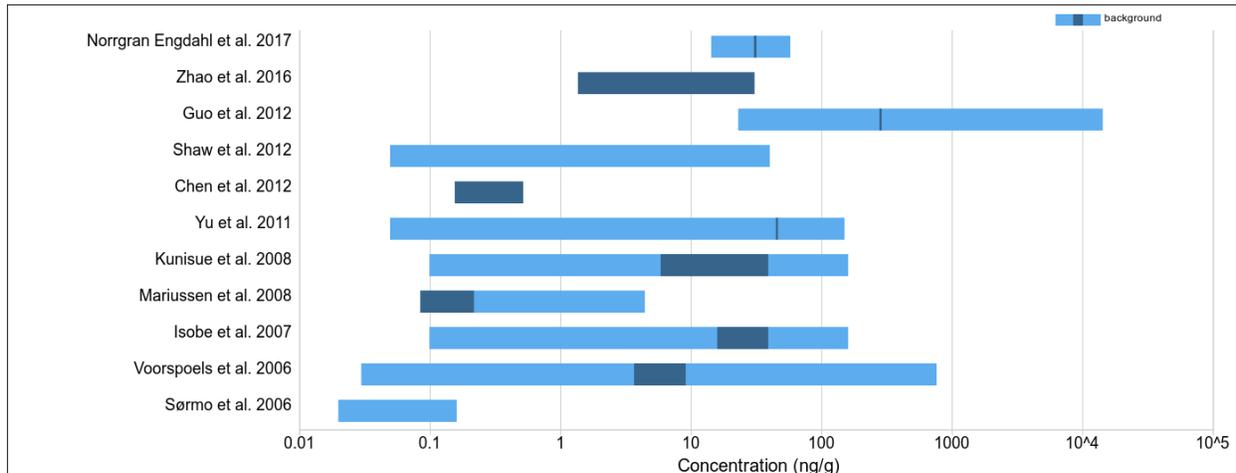


Figure 4-33. Concentration of DecaBDE (ng/g) in terrestrial mammals for background locations from 2006 to 2017. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Norrgran Engdahl et al., 2017](#); [Zhao et al., 2016a](#); [Chen et al., 2012c](#); [Guo et al., 2012](#); [Shaw et al., 2012](#); [Yu et al., 2011a](#); [Kunisue et al., 2008](#); [Mariussen et al., 2008](#); [Isobe et al., 2007](#); [Sørmo et al., 2006](#); [Voorspoels et al., 2006](#))

4.6.9. Other

Two studies were identified that reported concentrations of DecaBDE in amphibians.

4.6.9.1. Amphibians

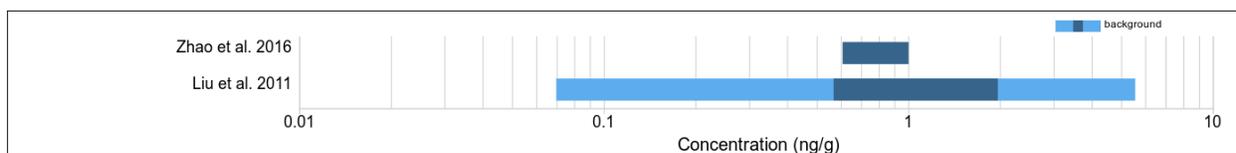


Figure 4-34. Concentration of DecaBDE (ng/g) in amphibians for background locations in 2011 and 2016. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Zhao et al., 2016a](#); [Liu et al., 2011](#))

4.7. Trends in Monitoring Data

Several studies reported temporal trends for DecaBDE in the following media:

- Indoor Dust

- Ambient Air
- Soils
- Sediments
- Biosolids
- Humans
- Aquatic Invertebrates
- Fish
- Birds

Those studies are summarized below.

4.7.1. Indoor Dust

Two studies reported DecaBDE levels in dust from 2004 to 2010 ([Whitehead et al., 2013](#)) and ([Yu et al., 2012](#)). The difference between the studies appears to be greater than any trends that are seen with time.

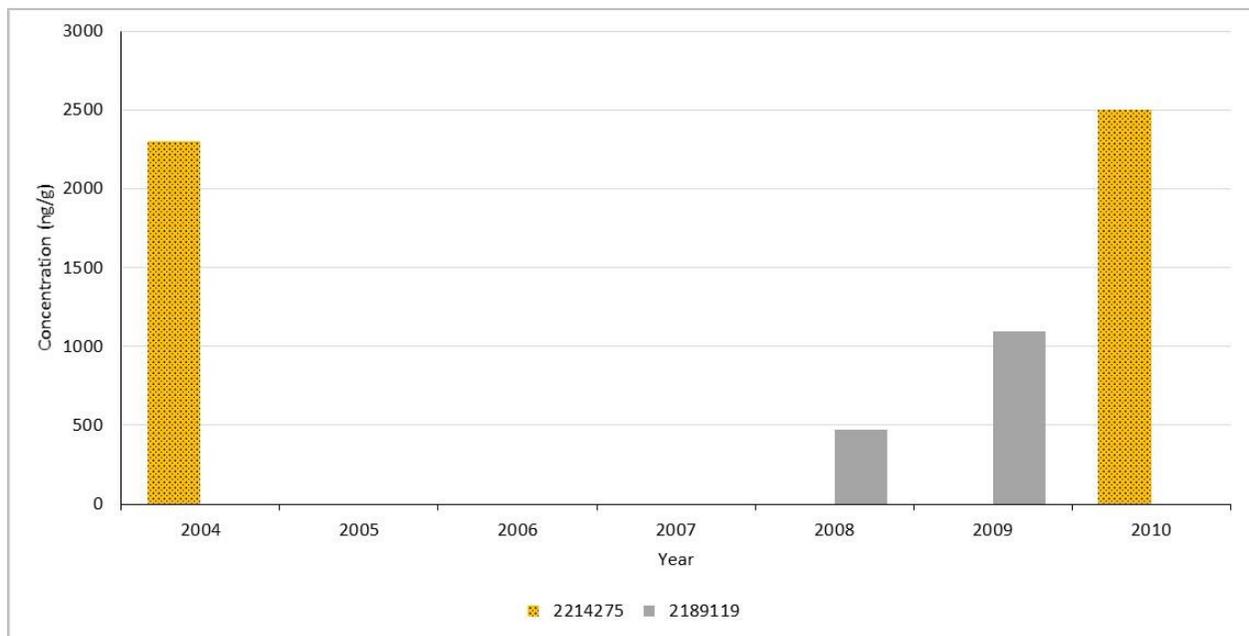


Figure 4-35. Concentration of DecaBDE (ng/g) in indoor dust from 2004 to 2010.

4.7.2. Ambient Air

One study ([Strandberg et al., 2001](#)) reported DecaBDE levels in ambient air across 4 locations and 3 years. Again, no strong temporal trends were observed.

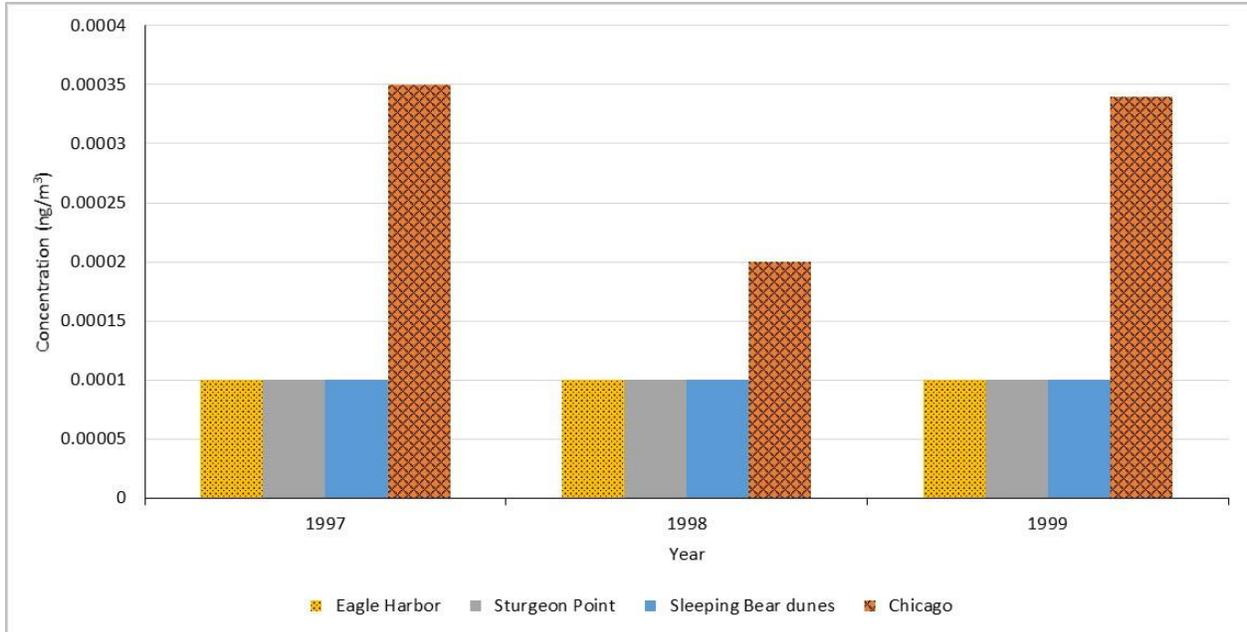


Figure 4-36. Concentration of DecaBDE (ng/m³) in ambient air from 1997 to 1999.

4.7.3. Soils

One study measured DecaBDE in soils ([Yu et al., 2012](#)). Over the short, 2 year, time period of observation, levels did appear to be increasing.

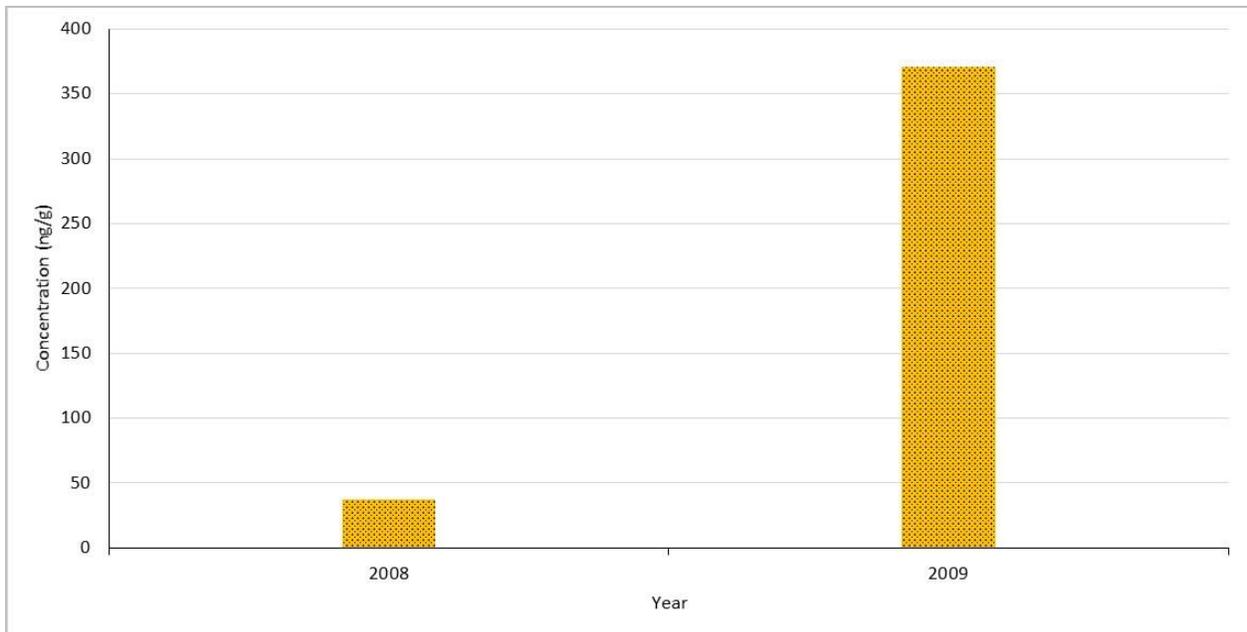


Figure 4-37. Concentration of DecaBDE (ng/g) in soils from 2008 to 2009.

4.7.4. Sediments

Two studies reported DecaBDE concentrations in sediments from 1974 to 2005 [Kohler et al. \(2008\)](#) and [Chen et al. \(2007\)](#). Within the second study, data were provided for three core samples. A general increasing trend was observed.

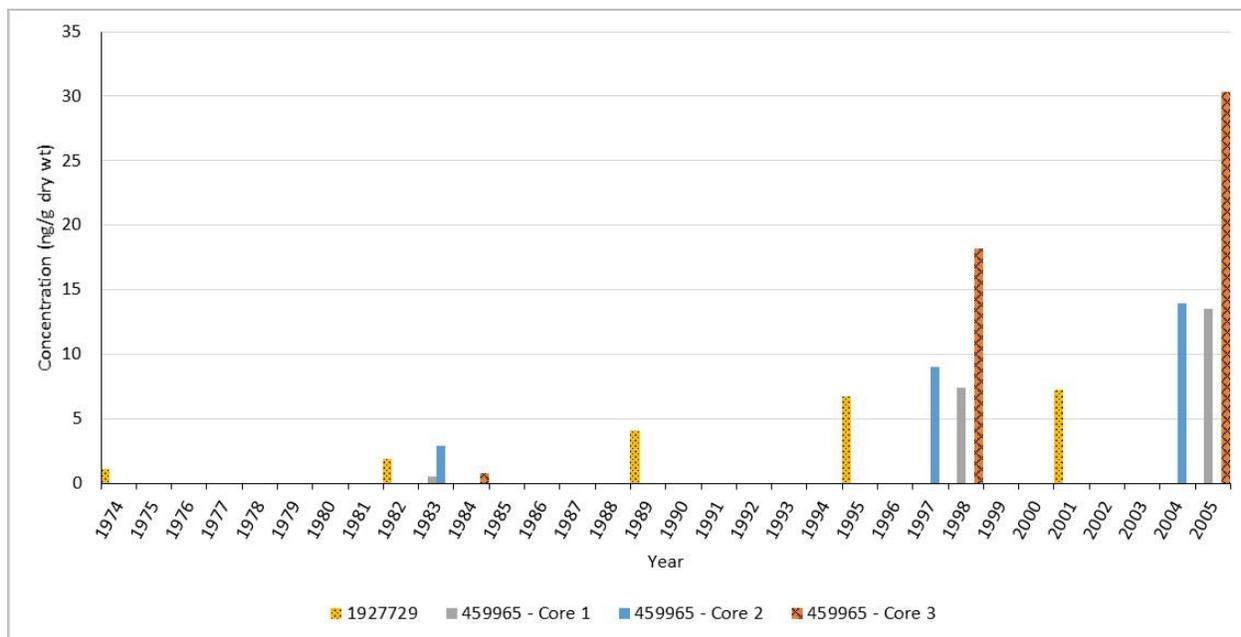


Figure 4-38. Concentration of DecaBDE (ng/g dry weight) in sediments from 1974 to 2005.

This is corroborated by Figure 1 in Yang et al. ([Yang et al., 2016a](#)) that presents DecaBDE monitoring data from lake sediment cores collected throughout the United Kingdom from 1955 through 2010. DecaBDE concentrations increased steadily from 1955 to 1990, followed by a greater rate of increase between 1990 and 2010. In addition to levels increasing with time, DecaBDE levels were also higher in more urban lake sediments.

Increasing DecaBDE levels with time was also seen in Figures 7 and 2 of [Mathieu and Mccall \(2016\)](#) and [Li et al. \(2006a\)](#), respectively, for lake sediment cores collected throughout Washington state and the Great Lakes. Specifically, [Mathieu and Mccall \(2016\)](#) showed a sharp increase in DecaBDE levels from the 1990s through 2010 for sediment cores from three lakes. In [Li et al. \(2006a\)](#), total DecaBDE annual load to the sediment of all the Great Lakes showed a steady increase from 1980 to 2005.

4.7.5. Biosolids

No studies were identified that could be extracted temporally. However, Figure 3 from [Andrade et al. \(2015\)](#) presents time trends of DecaBDE in biosolids collected in waste water treatment plants from the U.S. Over the time period of 2005 to 2011, levels in biosolids appear relatively stable.

4.7.6. Humans

One longitudinal study was identified ([Darnerud et al., 2015](#)), which reported human blood concentrations of DecaBDE from 1996 through 2010. Levels appear relatively stable, with a possible peak in the early 2000's.

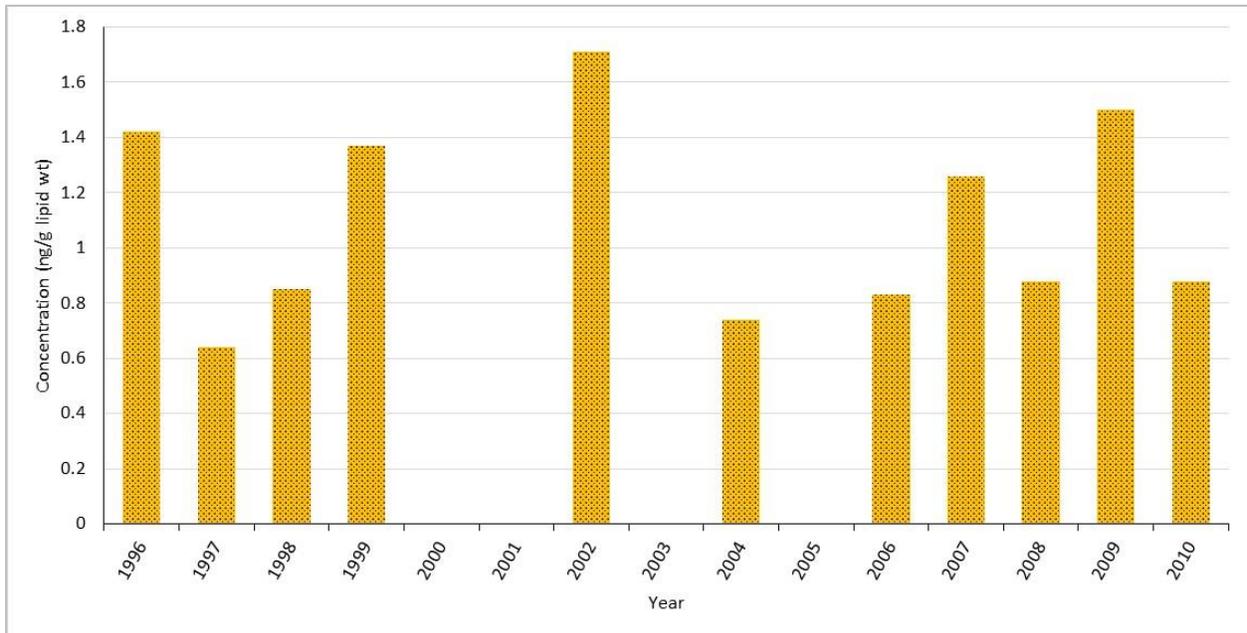


Figure 4-39. Concentration of DecaBDE (ng/m³) in human blood from 1996 to 2010.

4.7.7. Aquatic Invertebrates

One monitoring database (USGS) provided three years of data for DecaBDE concentrations in aquatic invertebrates from 2004 through 2006. No apparent trend was observed, with central tendency concentrations decreasing and then increasing through the 3-year period. The same lack of trend was observed for the minimum and maximum concentrations.

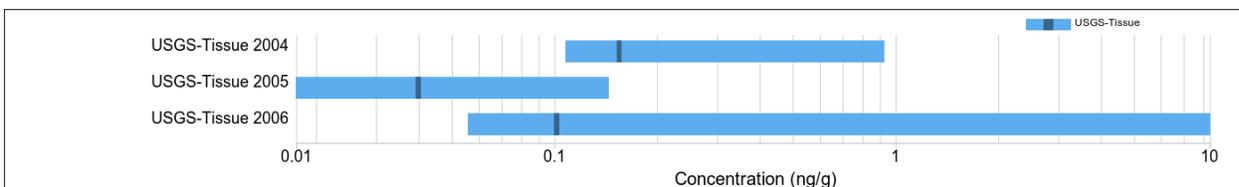


Figure 4-40. Concentration of DecaBDE (ng/g) in aquatic invertebrates from 2004 to 2006. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate color within (dark blue).

4.7.8. Fish

Figure 1 from [de Boer et al. \(2004\)](#) reported DecaBDE levels in Lake Ontario lake trout from 1979 through 2004. While levels appeared relatively stable until the late 1990's, a large increase was seen in 2004.

The large increase between 2000 and 2005 was corroborated by results from one monitoring database (USGS) which showed a similar increase after 2000 and a maximum DecaBDE concentration in 2004. DecaBDE levels in fish were stable between 2005 and 2007 with a decrease in 2010 and 2012.

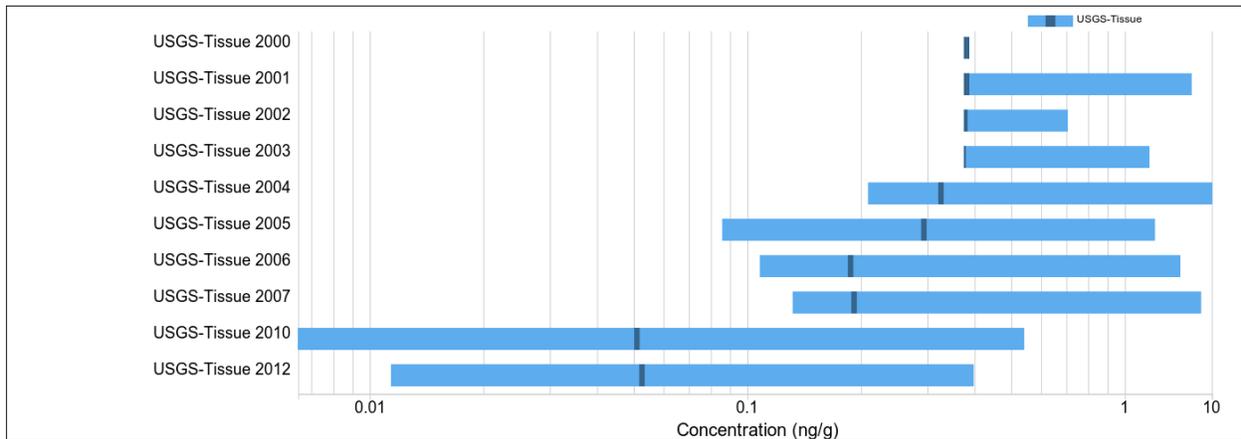


Figure 4-41. Concentration of DecaBDE (ng/g) in fish from 2000 to 2012. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate color within (dark blue).

4.7.9. Birds

Two studies were identified that measured levels in 4 types of bird eggs over 30 years ([Baron et al., 2015](#); [Johansson et al., 2011](#)). Dramatic increases in concentrations were seen from the beginning of study (1974) through the early 2000's, when levels appeared to peak.

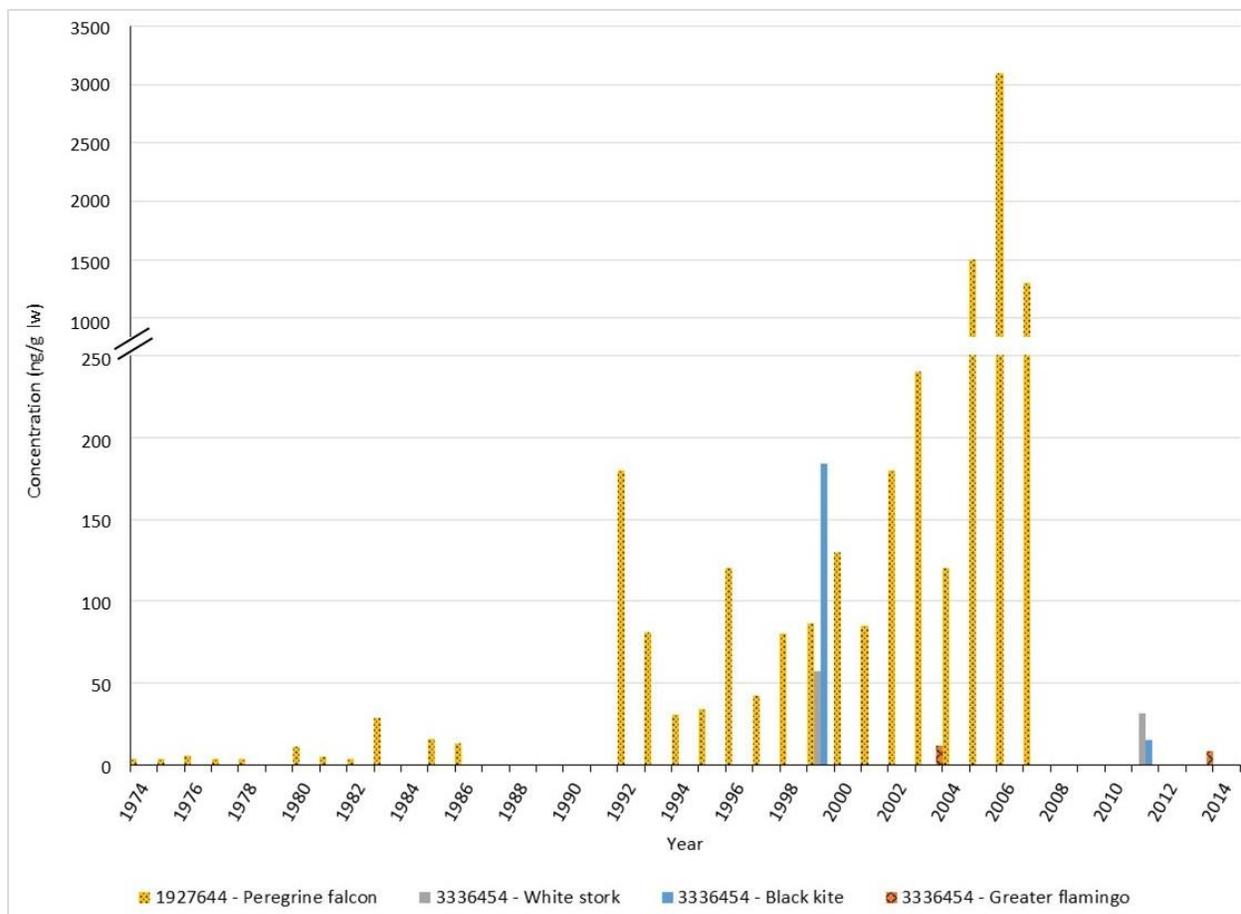


Figure 4-42. Concentration of DecaBDE (ng/g lw) in bird eggs from 1974 to 2014.

This is corroborated by Figure 1 from [Ismail et al. \(2009\)](#) who studied DecaBDE levels in peregrine falcon eggs in the United Kingdom. Levels appeared to increase from 1980 until the late 1990's and then begin to decrease.

4.8. Modeled Intake and Dose Data

Eleven studies that modeled DecaBDE dose were identified: ([Ali et al., 2016](#); [Civan and Kara, 2016](#); [Gou et al., 2016b](#); [Gou et al., 2016a](#); [Polder et al., 2016](#); [Li et al., 2015a](#); [Chao et al., 2014](#); [Asante et al., 2011](#); [Trudel et al., 2011](#); [Roosens et al., 2010a](#); [Chen et al., 2009](#)). On average, estimated doses were below 5 ng/kg/day. The highest estimated average daily dose resulted from ingestion, followed by inhalation. Dermal exposure had a negligible contribution to estimated doses.

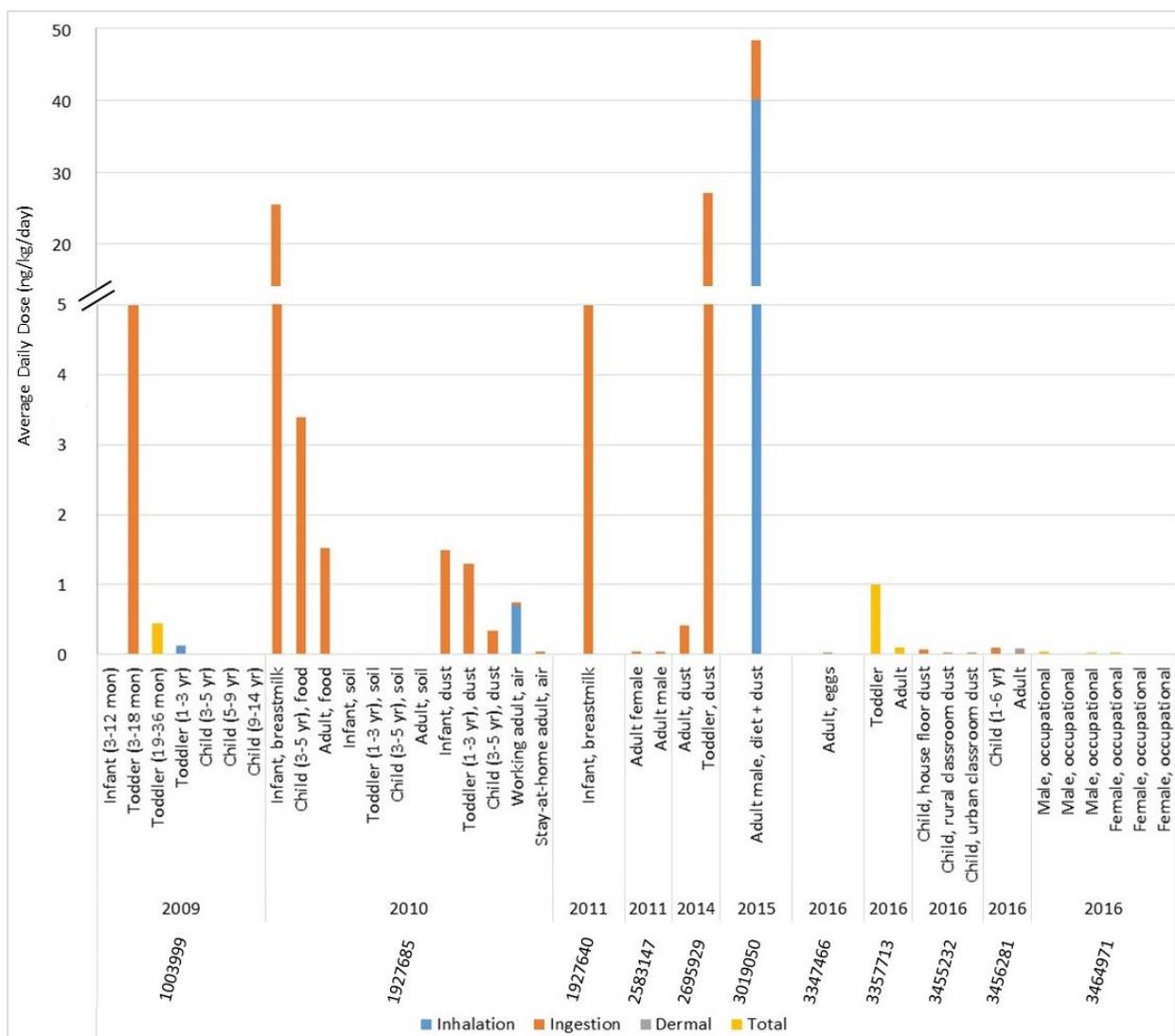


Figure 4-43. Estimated average daily dose (ng/kg/day) of DecaBDE for inhalation (blue), ingestion (orange), dermal (grey), and total (gold) exposure. Data are presented for infants, toddlers, children, and adults. If available, information on the age range, exposure media, and location of exposure are provided in the x axis description. The study year and HERO ID (diagonal text below the year) are also provided.

In addition to modeled doses, 14 studies were identified that estimated intake of DecaBDE ([Anh et al., 2017](#); [Han et al., 2016](#); [Harrad et al., 2016](#); [Tao et al., 2016](#); [Sahlström et al., 2015](#); [Jiang et al., 2014](#); [Liu et al., 2014b](#); [de Wit et al., 2012](#); [Chen et al., 2011b](#); [D'Hollander et al., 2010](#); [Jin et al., 2010](#); [U.S. EPA, 2010](#); [Covaci et al., 2009](#); [Roosens et al., 2009](#)). Similar to modeled doses, inhalation and ingestion exposures resulted in the highest estimates, with one toddler inhalation estimate ([Jiang et al., 2014](#)) exceptionally high at over 4,000 ng/day. The Vietnamese receptor group ([Anh et al., 2017](#)) showed higher ingestion estimates than other receptor groups from the UK, U.S., China, Belgium, and Sweden.

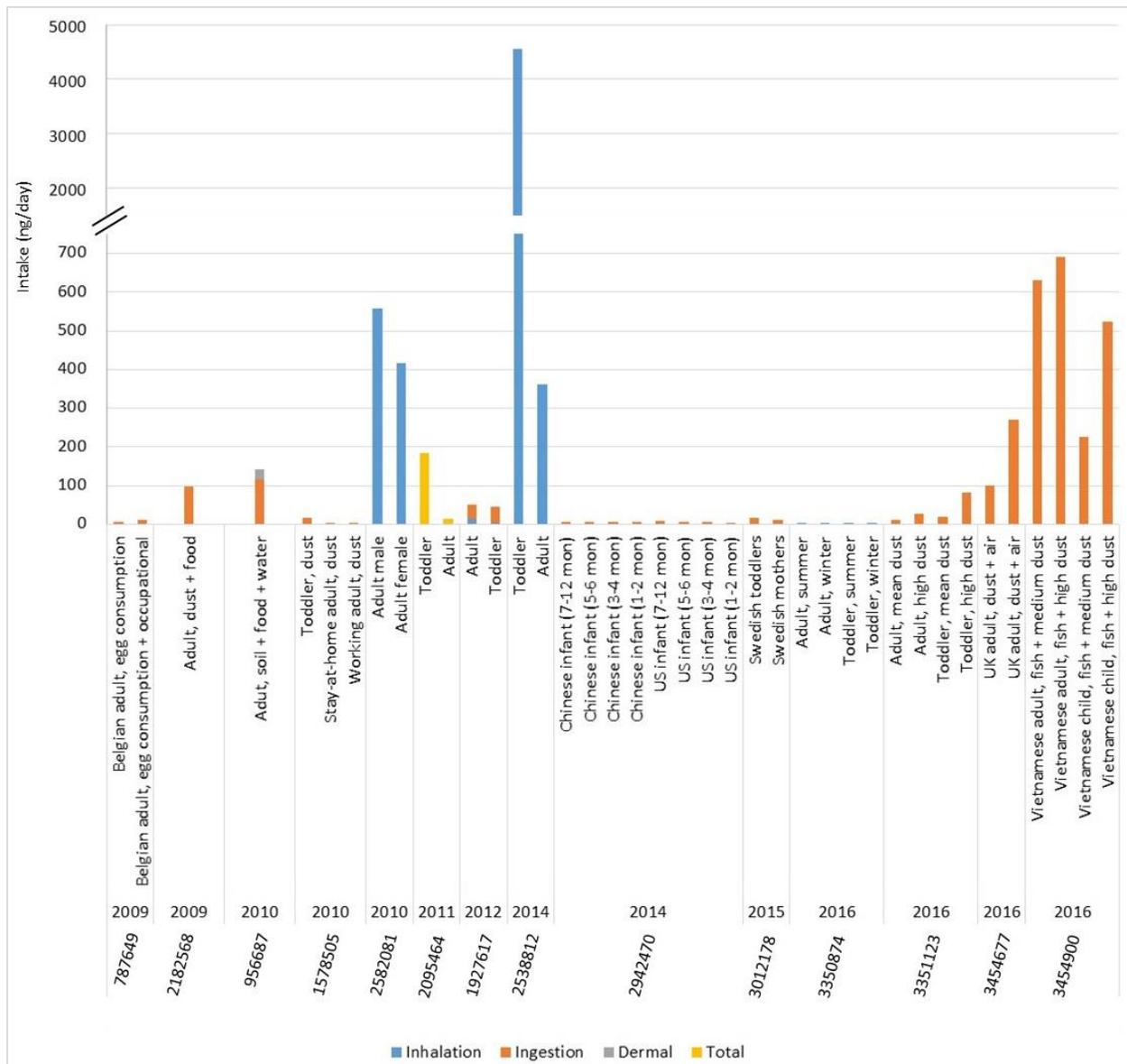


Figure 4-44. Estimated average intake (ng/day) of DecaBDE for inhalation (blue), ingestion (orange), dermal (grey), and total (gold) exposure. Data are presented for infants, toddlers, children, and adults. If available, information on the age range, exposure media, season, and location of exposure are provided in the x axis description. The study year and HERO ID (diagonal text below the year) are also provided.

4.9. Overview of Existing Exposure Assessments

Multiple DecaBDE assessments have been conducted, including by EPA, other U.S. and international government agencies, and industry groups, and have been identified as authoritative sources.

EPA's Exposure Assessment of Polybrominated Diphenyl Ethers (PBDEs) ([U.S. EPA, 2010](#)), which included DecaBDE, describes the PBDE exposure potential for adults, children, and infants considering the following pathways: house dust ingestion, house dust dermal contact, inhalation, breastmilk ingestion, milk ingestion, dairy ingestion, egg ingestion, beef ingestion, pork ingestion, poultry ingestion, other meat ingestion, freshwater/marine fin fish ingestion, and freshwater/marine shellfish ingestion. Adult and child exposures were dominated by dust ingestion and dermal contact with dust, while infant exposures were dominated by breastmilk ingestion. The next highest adult exposure pathways included milk ingestion, dairy ingestion, and inhalation of indoor air (Table 4-5). [U.S. EPA \(2010\)](#) estimated a total adult intake for DecaBDE of 1.4×10^2 ng/day, but reported only total PBDE intakes for children and infants; DecaBDE intakes were not reported. The assessment identified household consumer products as the main source of PBDEs in house dust.

Table 4-5. Total Adult Intake Estimates of DecaBDE ([U.S. EPA, 2010](#)), Sorted Highest to Lowest

Exposure Pathway	Estimate in ng/day
House dust ingestion	1.0×10^2
House dust dermal contact	2.5×10^1
Dairy ingestion	6.3×10^0
Milk ingestion	3.0×10^0
Inhalation	1.5×10^0
Egg ingestion	5.7×10^{-1}
Pork ingestion	2.5×10^{-1}
Other meats	1.9×10^{-1}
Beef ingestion	1.5×10^{-1}
Poultry ingestion	1.4×10^{-1}
Fresh/marine finfish	9.0×10^{-2}
Water ingestion	6.0×10^{-2}

In its 2010 exposure assessment, EPA discussed the American Chemistry Council's Brominated Flame Retardant Industry Panel's assessment of DecaBDE developed for the Voluntary Children's Chemical Evaluation Program (VCCEP). The VCCEP assessment estimated DecaBDE exposures for infants breastfed by a mother who worked in a DecaBDE formulation site, infants breastfed by a mother who is involved in the disassembling of electronic monitors, children mouthing DecaBDE-containing plastic electronic products, children inhaling DecaBDE particulates released from plastic electronic products, and children exposed to DecaBDE in the general environment [e.g., soil and dust, diet, ambient air, and water ([Hays and Pyatt, 2006](#))]. See Table 4-6 for the estimated intakes calculated for the pathways addressed in the VCCEP assessment. The highest estimated exposure scenario in this assessment was the upper estimated aggregate estimated exposure for a breast-fed infant of a mother involved in the formulation of DecaBDE. The aggregate exposure for this scenario included the intake for ingestion of breast milk combined with ingestion from consumer electronic products, ingestion from mouthing fabric, and general exposures. EPA reviewed the VCCEP DecaBDE assessment in 2005 and expressed concern about dust ingestion by children via hand-to-mouth activity ([U.S. EPA, 2005b](#)).

Table 4-6. Intakes of DecaBDE by Children Estimated by Hays and Pyatt (2006)

Age (years) or Lifestage	Exposure Pathway Specific	Mid-Range Estimate (ng/kg/day)	Upper Estimate (ng/kg/day)
0 to 2	Ingesting breast milk from a mother who is involved in the formulation of DecaBDE (bagging operation)	1.9×10^4 (birth to 3 months)	3.4×10^5 (birth to 2 years)
0 to 2	Ingesting breast milk from a mother who is involved in the disassembling of electronics	3.3×10^0 (birth to 3 months)	2.5×10^1 (birth to 2 years)
0 to 2	Mouthing DecaBDE-containing plastic electronic products	4.3×10^0	2.5×10^2
0 to 2	Inhaling DecaBDE particulates released from plastic electronic products	3.1×10^{-1}	6.3×10^{-1}
Children of all ages	Exposed to DecaBDE via the general environment (e.g., soil and dust, diet, ambient air, and water)	1.2×10^3	3.9×10^5
Aggregate			
Infant	Intakes for ingestion of breast milk from a mother who is involved in the formulation of DecaBDE, plus ingestion from consumer electronic products, ingestion from mouthing fabric, and general exposures	4.6×10^4	7.6×10^5
Infant	Intakes for ingestion of breast milk from a mother who is involved in disassembling DecaBDE-containing products, plus ingestion from consumer electronic products, ingestion from mouthing fabric, and general exposures	2.7×10^4	4.1×10^5
Child	Intake from general exposures	1.2×10^3	3.9×10^5

Hays and Pyatt, in the VCCEP assessment ([Hays and Pyatt, 2006](#)), included estimates of occupational exposures for breast-feeding women. For the scenario involving disassembling electronic monitors, they used serum levels from a study of Swedish workers; the upper level for the analysis was 9.9 ng/g serum lipid and median level was 4.8 ng/g serum lipid ([Sjodin et al., 1999](#)). They used the air-serum level ratio from this study and ([Sjodin et al., 2001](#)) to estimate serum levels for the formulation scenario. This scenario, which was thought to be the highest occupational exposure, was for a woman engaged in bagging DecaBDE during manufacture or in emptying bags of DecaBDE into hoppers for formulators and compounders. [Hays and Pyatt \(2006\)](#) selected as the upper air concentration level the American Industrial Hygiene Association Workplace Environmental Exposure Level (WEEL) of 5 mg/m³ and a mid-range estimate of 1 mg/m³ based on a European Union study that concluded that the majority of workplace air levels were below 1 mg/m³ ([ECB, 2007](#)).

[Health Canada \(2012\)](#) evaluated infant, child, and adult DecaBDE exposures via inhalation of ambient air, inhalation of indoor air, ingestion of drinking water, ingestion of food and beverages, ingestion of dust, infant ingestion of breastmilk, and children’s oral exposure from mouthing of hard plastic toys. Infants and children had the highest total intakes among the age groups. [Health Canada \(2012\)](#) concluded that the predominant sources of exposure are breast milk for breast-fed infants, mouthing of hard plastic toys for children ages 0.5 to 4 years of age, and ingestion of indoor dust and food for all other age groups.

Table 4-7. Estimated Exposure of the General Population to DecaBDE from Health Canada Assessment ([Health Canada, 2012](#))

Age Group	Estimated Total Intake (ng/kg/bw per day)
0 to 0.5 years (breast milk fed)	5×10^1 to 1.9×10^2
0 to 0.5 years (formula fed)	4.1×10^1
0 to 0.5 years (not formula fed)	7.9×10^1
0.5 to 4 years	8.9×10^1
5 to 11 years	3.6×10^1
12 to 19 years	1.3×10^1
20 to 59 years	9.3×10^0
60+ years	7.9×10^0

The National Academy of Sciences ([NRC, 2000](#)) developed “conservative” estimates of exposure to flame retardants, including DecaBDE, for comparison with a reference toxicity dose considering the following exposure pathways: adult dermal contact with DecaBDE on fabric, adult inhalation of DecaBDE particles from eroded upholstery, adult inhalation of DecaBDE vapor, and 1-year-old child oral exposure from repeated sucking on upholstery fabric treated with DecaBDE. In this assessment, NAS estimated two adult dermal absorbed doses using different assumptions regarding the absorption of DecaBDE. The first estimate of dermal-absorbed dose assumed immediate absorption of DecaBDE (9.8×10^5 ng/kg-day), i.e., that the skin and clothing of the person sitting on the treated fabric would offer no barrier to movement of a non-ionic substance and there would be adequate water present (e.g., sweat) to dissolve the nonionic substance and transfer to the skin and into the body of the person. This estimate assumes that all of the substance that dissolves is immediately absorbed by the body. NAS calculated an alternative iteration of dermal exposure, which had the same assumptions as the first estimate, with the exception of the assumption of 100% immediate absorption, which was replaced with an estimate of the rate at which the substance could penetrate the skin and assuming the substance dissolved up to its solubility limit in water. The second dermal exposure estimate resulted in a considerably lower dose (1.33×10^{-3} ng/kg-day). NAS’ estimate of particle time-averaged inhalation exposure concentration for a person was higher (4.8×10^2 ng/m³) compared to its vapor inhalation estimate (3.8×10^2 ng/m³). NAS also estimated a dose for children mouthing fabric back-coated with DecaBDE to be 2.6×10^4 ng/kg-day. They calculated this dose based on the following exposure parameters: area density of the substance (i.e., the mass per unit surface area), area of the fabric sucked on each occasion, fractional rate (per unit time) of substance extraction by saliva, fraction of time a child sucks the treated fabric, and the average body weight of a 1-year-old child. This assessment did not report total intakes.

The European Chemicals Agency (ECHA) in its proposal for a restriction of DecaBDE ([ECHA, 2014](#)) concluded that the indoor environment is an important exposure pathway for consumers. This ECHA assessment stated that the main routes of human exposure to DecaBDE include exposure from food consumption, inhalation of particulate-bound DecaBDE in indoor and outdoor air, and through skin uptake. Children aged 1 to 3 years were identified as the age group with the highest exposures, and breastfed infants were also anticipated to be highly exposed on a body weight basis. The assessment said that fetuses are exposed to DecaBDE through transport across the placental barrier. That said, occupational exposures were found to be significantly higher than consumer exposures.

The United Nations Environment Programme (UNEP) Persistent Organic Pollutants Review Committee's risk profile of DecaBDE ([UNEP, 2014](#)) cited U.S. EPA's exposure assessment ([U.S. EPA, 2010](#)) to support their conclusion that ingestion and dermal contact with dust, inhalation of indoor air, and breastmilk are the dominant exposure pathways. It also noted food as a lesser but still important pathway based on the [Health Canada \(2012\)](#) analysis that identified food and dust as the main sources of exposure in adults.

4.10. Representative Exposure Scenarios

DecaBDE was produced and released at higher levels in the past, but continues to be released under current conditions of use. Across the lifecycle, while releases from manufacturing and processing may be declining over time, releases associated with use, disposal, and recycling are likely to increase over time until the stock of available materials with DecaBDE is depleted. This depletion may take several years because of how long articles are typically used before being disposed and/or recycled. Historical and recent TRI data confirm primary releases are to air, followed by landfill and water. When released to air, DecaBDE is likely to partition to particulates where it can be deposited to nearby waterbodies and catchments. A large number of monitoring studies frequently report DecaBDE in sediment.

Experimental product testing studies suggest that DecaBDE can be emitted from articles during use through abrasion and direct transfer to dust on surfaces ([Rauert and Harrad, 2015](#); [Rauert et al., 2014a](#); [Kemmlin et al., 2006](#)). There are a wide range of studies that have reported DecaBDE in dust (see Section 4.5.1). Only a subset of dust-monitoring studies considers potential indoor sources, which could contribute to levels reported in dust. However, some studies note associations between emission rates from articles and increased levels in dust ([Liagkouridis et al., 2016](#); [Rauert et al., 2014b](#)).

Human exposure to DecaBDE has been documented. Several biomonitoring studies have reported levels in serum and breast milk (see Sections 4.6.1 and 4.6.2). Only a subset of these studies considers source attribution and includes exposure assessments. Those that do suggest that indoor dust and dietary exposures are primary exposure pathways. Based on its physical-chemical properties, ingestion is likely the primary exposure route. Inhalation would likely be comprised of particles which could be swallowed, and dermal absorption is likely low.

Exposure to ecological receptors has been documented. Several biomonitoring studies have reported levels in tissues of fish, birds, and invertebrates (see Section 4.6.3 through Section 4.6.9). Only a subset of these studies considers source attribution and includes exposure assessments. Those that do suggest that environmental and biological levels can be higher near point sources. However, DecaBDE has also been detected in remote areas far away from point sources indicating potential for long-range transport.

Representative Exposure Scenarios:

Ecological: Recycled electronics containing DecaBDE results in releases to air, which deposit to nearby waterbodies and catchments, leading to increased concentrations in sediment and uptake into organisms who ingest or reside within sediment.

Ecological: Direct releases to water and indirect releases to water (deposition from air) from industrial processing facilities is treated at a local wastewater treatment plant. Sludge containing elevated concentrations of DecaBDE is then land-applied where exposure to terrestrial organisms can occur.

Consumer: Residential homes contain several electronic and textile articles with DecaBDE. These articles can emit DecaBDE into indoor air and indoor dust through direct transfer, abrasion, and diffusion. Indoor dust is ingested by children and leads to increased internal dose of DecaBDE.

General Population: Air releases and deposition to soil from industrial facilities and land application of sludge to soil result in uptake to vegetation and other edible terrestrial food sources. Individuals who consume these dietary sources may have increased internal dose of DecaBDE.

General Population: Direct releases to water and indirect releases to water (deposition from air) from industrial facilities lead to elevated uptake and concentrations in edible fish species. Individuals who consume these fish (recreational fishers) may have increased internal dose of DecaBDE.

Occupational and General Population: Workers who are in direct contact with DecaBDE during industrial operations breathe occupational air with elevated concentrations of DecaBDE. These particulates are primarily ingested after inhalation leading to elevated internal dose. Workers in this scenario who are breast-feeding may have elevated concentrations of DecaBDE in breast-milk which can be transferred to infants during breast-feeding.

Occupational: Manufacturing of DecaBDE results in particulates that are transferred to workplace air during transfer and packaging operations. Workers at the remaining manufacturing facility can inhale these particulates and the particles can settle on exposed skin. Both inhalation and dermal exposures are possible.

Occupational: Processing of DecaBDE into plastic articles results in particulates that are transferred to workplace air when bags of solid (powder or granular) flame retardant are emptied into hoppers during process operations. Workers at plastic processing facilities can inhale these particulates and the particles can settle on exposed skin. Workers can also be exposed to liquid flame retardant formulations when small quantities of the liquid are spilled during transfer operations. Inhalation and dermal exposures are possible from solid DecaBDE formulations and dermal exposure is possible from liquid flame retardant formulations.

Occupational: Processing of DecaBDE into formulation, mixture, or reaction products and subsequent incorporation into article components results in particulates that are transferred to workplace air when bags of solid (powder or granular) flame retardant are emptied into hoppers during process operations. Workers can inhale these particulates and the particles can settle on exposed skin. Workers can also be exposed to liquid flame retardant formulations when small quantities of the liquid are spilled during transfer operations. Inhalation and dermal exposures are possible from solid DecaBDE formulations and dermal exposure is possible from liquid flame retardant formulations.

Occupational: Recycling of plastic articles containing DecaBDE results in particulates that are transferred to workplace air during grinding and shredding operations. Workers at recycling facilities can inhale these particulates and the particles can settle on exposed skin. Both inhalation and dermal exposures are possible.

Occupational: Processing of DecaBDE into textiles results in mist generated from squeezing immersed fabric with rollers and from roll coating applications and results in particulates generated from transfer of solid DecaBDE flame retardant formulations into mixing vessels. Workers at these textile processing facilities can inhale these mists and particulates and droplets or particulates can settle on exposed skin. Both inhalation and dermal exposure are possible.

4.11. Summary of Review Articles

Many review articles for DecaBDE were identified, including several conducted in the past 2-3 years. One of the most recent reviews was a 2017 ATSDR toxicological review of PBDEs ([ATSDR, 2017](#)). ATSDR reported concentrations of DecaBDE in ambient air ($<1.0 \times 10^{-4}$ -0.9 ng/m³), airplane air (<detection limit-2,100 ng/m³), sediment (<0.51-16,000 ng/g), soil (geometric mean of 15.3 ng/g), indoor dust (up to 29,000 ng/g), food (meat with a mean of 0.05 ng/g wet weight and fish with a mean of 0.1 ng/g), sewage sludge (140-1,470 ng/g), human blood (<0.1-4.8 ng/g lipid weight) and breast milk (0.25-8.24 ng/g lipid weight). ATSDR also summarized the findings of existing exposure assessments on PBDEs, concluding that house dust (ingestion and dermal exposure) is the primary pathway of exposure in the U.S., with dietary exposure being more important in Europe.

4.11.1. Dust

[Bramwell et al. \(2016\)](#) conducted a systematic review of studies published between 2007 and 2015 on human exposure to PBDEs in dust and diet and internal dose. DecaBDE was not measured in any of the studies on dietary exposure to PBDEs, but DecaBDE was the predominant congener found in dust in almost of all the studies. The median dust concentration of DecaBDE in the studies ranged from 106-2,574 ng/g dry weight, with a maximum concentration of 310,000 ng/g dry weight. Serum measurements were sparse but ranged from below detect to 11 ng/g. However, none of the studies reported significant associations between DecaBDE in dust and internal dose. The authors stated that this may be due to recent advances in the ability of laboratories to more accurately measure DecaBDE, because DecaBDE adsorbs to a much greater extent than other PBDEs increasing the difficulty of quantification.

[Coelho et al. \(2014\)](#) also reviewed available published literature describing PBDE concentrations in indoor dust from different regions of the world and different locations from 2003 to 2013. Data from houses close to e-waste centers (high exposure) and airplanes (occasional exposure) were excluded as the authors aim was to describe normal exposure. The highest levels of DecaBDE were reported in car interiors (190,000 ng/g) and in the trunks of cars (2,700 ng/g) in the U.K. Also in the U.K., the highest median level of DecaBDE in house dust was observed at 10,000 ng/g. In general, median concentrations of 1,000 ng/g were observed. The authors also reviewed literature that matched indoor dust and human biological samples (ie serum, hair, breast milk, cord blood) which demonstrated that indoor dust is an important exposure pathway.

These findings are higher than those reported by [Akortia et al. \(2016\)](#) who report median concentrations of DecaBDE of 141-180 ng/g dry weight in dust, but similar to [ATSDR \(2017\)](#) who report dust levels up to 29,000 ng/g.

These findings are generally consistent with the monitoring data presented in Section 7.1.

4.11.2. Soil

[McGrath et al. \(2017\)](#) reviewed soil contamination data on PBDEs presented in English language peer-reviewed scientific literature published up until May 2017. PBDEs have been ubiquitously detected in soils across the world with DecaBDE as the most prevalent congener in all land-use categories, with concentrations ranging from 0.11-8,060 ng/g dry weight. Industrial contamination via production of PBDEs or PBDE-containing products was identified as having the strongest potential to contaminate surrounding soils, followed by disposal via landfill, dumping, incineration and recycling of Deca-BDE containing products. Electronic waste appears to be one of the greatest contributors to contamination in regions where the practice is widespread. High levels of contamination have been indicated in China and other parts of Asia and Africa where informal methods such as burning or acid-stripping of electrical components may enhance release of PBDEs. PBDEs have also been determined in almost all background soils assessed including remote areas of Antarctica and northern polar regions.

[Akortia et al. \(2016\)](#) reports relatively lower levels with median measurements ranging from 10.8-28.6 ng/g dry weight in soil to 1,430 ng/g dry weight in soil.

In general, central tendency soil measurements ranged from 100 to 1,000 ng/g in the monitoring data presented in Section 4.5.

4.11.3. Surface Water and Sediments

[Iqbal et al. \(2017\)](#) reviewed available published literature describing DecaBDE levels in freshwater environments. Levels in riverine water are increasing, from below detection in the 1970's and 1980's to 2 to 200 ng/L in North American and European rivers in the 2000's. A recent study found levels of DecaBDE in two rivers in France ranging from 2.1-295 ng/L. DecaBDE is expected to be found bound to sediments, rather than in freshwater. Sediments concentrations worldwide vary greatly from below the limit of detection to 100's of ng/g. This is supported by the ATSDR findings of sediment concentrations from < 0.51-16,000 ng/g ([ATSDR, 2017](#)). DecaBDE was detected in aquatic sediments in a European river at 84 ng/g dry weight. A study in this river reported that DecaBDE represented almost 80% of the total BDEs in surface sediment samples. Temporally, DecaBDE concentrations have been steadily increasing in all media across the period studied. Temporally, higher levels were detected across all media near manufacturing sites and urban areas, but levels were also measured in remote and Arctic environments.

[Lee and Kim \(2015\)](#) reviewed the available literature on the occurrence of PBDEs in the marine environment and found concentrations ranging from 0.005-7,340 ng/g dry weight, much lower than the levels measured in fresh waters. The authors also noted low levels of DecaBDE in biota, and attribute this to its low potential to bioaccumulate versus to sorb to sediments.

[Akortia et al. \(2016\)](#) reports relatively lower levels with median sediment levels of 0.819-27,419 ng/g dry weight in fish levels of 0.01-8.2 ng/g lipid weight.

4.11.4. Human Biomonitoring

[Tang and Zhai \(2017\)](#) reviewed the published literature describing PBDE levels in placentas, cord blood, and breast milk from 1996 to 2016. They reported median concentrations of DecaBDE of up to: 45.6 ng/g lipid weight in breast milk, 27.11 ng/g lipid weight in cord blood, and 3.3 ng/g lipid weight in placentas in countries in North America, Asia, Europe, Oceania and Africa. The highest levels of PBDEs in human biological samples were detected at e-waste recycling sites in South China, East China and South Korea. This is supported by reviews aimed primarily at understanding impacts at e-waste facilities, including [Sepulveda et al. \(2010\)](#). The authors also examined temporal trends and determined DecaBDE levels reached a peak in 2006 worldwide.

These findings are higher than those reported by other studies, including [Akortia et al. \(2016\)](#) who report median concentrations of DecaBDE of 0.06 ng/g lipid weight in breast milk and 0.90 ng/g lipid weight in human serum and [ATSDR \(2017\)](#) who report levels in human blood (<0.1-4.8 ng/g lipid weight) and breast milk (0.25-8.24 ng/g lipid weight).

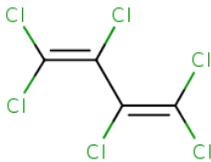
4.11.5. Dose

[Malliari and Kalantzi \(2017\)](#) reviewed children's non-dietary exposure to brominated flame retardants in indoor environments by searching peer-reviewed literature published between 2002 and 2017. They identified spatial variability, with higher DecaBDE exposure via indoor dust in the U.S. and Europe (highest median concentration of 190,000 ng/g), and lower exposure in the Middle East, Australia, and Africa (highest median concentration of 1,540 ng/g). In Asia, exposure was highest near e-waste recycling areas (highest median concentration of 22,500 ng/g). By combining air and dust concentrations with accepted media intake rates, the authors report that dust ingestion was the dominant exposure pathway for PBDEs, followed by inhalation of indoor air. The authors reported mean daily intakes for ingestion from dust exposure for DecaBDE: these ranged from 0.092 ng/kg bw/day in Turkey to 610 ng/kg bw/day in the U.K. in homes, and from 0.0069 ng/kg bw/day in the U.S. to 28 ng/kg/ bw/day in the U.K. in early childhood facilities and schools. The authors also cite studies showing dermal contact and mouthing of toys also contribute to total exposure, however, at a lower rate than dust ingestion.

These estimates generally align with those of [U.S. EPA \(2010\)](#) and [Health Canada \(2012\)](#) who estimate daily intake from dust ingestion at 10 ng/day and 10-90 ng/kg/day.

5. Hexachlorobutadiene (HCBD)

5.1. Chemistry and Physical-Chemical Properties

Chemical Name	Hexachlorobutadiene
CAS RN	87-68-3
Synonyms	HCBD; Hexachloro-1,3-butadiene; 1,3-Butadiene, hexachloro-; 1,3-Butadiene, 1,1,2,3,4,4-hexachloro-; 1,1,2,3,4,4-Hexachloro-1,3-butadiene; 1,3-Hexachlorobutadiene; Perchlorobutadiene; Perchloro-1, 3-butadine; Perchlorobutadiene; 1,3-butadiene, hexachloro-; Hexachlorobuta-1,3-diene
Molecular Formula	C ₄ Cl ₆
Structure	
Source: (UNEP, 2012 ; HSDB, 2005)	
MW	260.76
Density (g/cm³)	1.556 at 25°C (Haynes et al., 2014)
Molar Volume (cm³/mol)	168 [Calculated based on the molar mass and density]
Log K_{ow}	4.78 (Hansch et al., 1995)
Log K_{OA}	5.2 [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Log K_{oc}	4.1 [Kow method, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Vapor Pressure (mm Hg)	0.22 (Daubert and Danner, 1989)
Henry's Law (atm-m³/mol)	0.01 at 20°C (Warner et al., 1987)
Water Solubility (mg/L)	3.2 (Banerjee et al., 1980)
Water Solubility (mol/L)	1.2 × 10 ⁻⁵ [Calculated based on water solubility and molecular weight]

5.2. Uses

Since the publication of the Use Document in August 2017 for HCBd, EPA received 11 public comments and communicated with several companies, industry groups, chemical users, and other stakeholders to aid in identifying and verifying conditions of use of HCBd ([U.S. EPA, 2017c](#)). These interactions and comments further informed EPA’s understanding of the uses for HCBd. The information and input received from the public comments and stakeholder engagement has been incorporated into this document to the extent appropriate. Non-confidential public comments and stakeholder meeting summaries can be found in EPA’s docket at [EPA-HQ-OPPT-2016-0738](#).

HCBd is primarily generated as a by-product of the manufacture of chlorinated hydrocarbons, particularly perchloroethylene, trichloroethylene, and carbon tetrachloride, but it can also be produced during magnesium manufacturing via electrolysis ([POPRC, 2013](#); [U.S. EPA, 2003](#)). According to recent reports to the UN Environmental Programme, HCBd does not appear to be intentionally manufactured in Europe, Japan, Canada, or the United States. Intentional production in Europe ceased as early as the late 1970s; in various other parts of the world, production of HCBd has been restricted or banned in subsequent years; however, the chemical continues to be manufactured as a byproduct of chemical manufacturing ([Working Group of the Basel Convention, 2016](#)).

Table 5-1. Use Categories and Subcategories for HCBd

Life Cycle Stage	Category ^a	Subcategory ^b	References
Manufacture	Domestic manufacture	Manufactured byproduct	U.S. EPA (2017c)
Processing	Specialty chemical formulation and packaging	Specialty chemical formulation and packaging	U.S. EPA (2017c)
	Recycling	Recycling	U.S. EPA (2016d)
Industrial, Commercial, Consumer Uses	Clothing	Children’s clothing	U.S. EPA (2017c)
	Solvents	Solvents used as analytical standards	U.S. EPA (2017c)
	Waste fuel	Waste fuel for cement kilns	U.S. EPA (2017c)
	Other	Manufacture of drywall or carbon spheres	U.S. EPA (2017c)
Releases and Waste Disposal	Emissions to air	Fugitive emissions	U.S. EPA (2016d)
		Point source emissions	U.S. EPA (2016d)
	Water Releases	Surface water discharge	U.S. EPA (2016d) ; EPA-HQ-OPPT-2016-0738
	Liquid Wastes		U.S. EPA (2016d)
	Solid Waste		U.S. EPA (2016d)

^aThese categories of conditions of use appear in the Life Cycle Diagram, broadly represent conditions of use of HCBd in commercial and/or consumer settings.

^bThese subcategories reflect more specific uses of HCBd based on stakeholder outreach, and comments received on EPA's Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal published in August 2017.

5.3. Characterization of Expected Environmental Partitioning

If released to air, with a vapor pressure of 0.22 mm Hg, HCBd is expected to exist solely as a vapor in the ambient atmosphere.

If released to water, based on its log K_{OW} (4.78) and log K_{OC} (4.1), HCBd is likely to adsorb to sediments and suspended particulates. Its Henry's law constant of 0.01 atm m³/mole and vapor pressure of 0.22 mm Hg indicate HCBd may partition from water into air, although adsorption to organic matter in sediments and suspended particles may inhibit volatilization, based on the compound's log K_{OC} .

In wastewater treatment plants, the majority of HCBd in wastewater is expected to be removed through adsorption to sludge and volatilization to air based on its log K_{OC} and Henry's law constant, but some fraction of HCBd will likely remain in the wastewater treatment plant effluent. Biosolids containing adsorbed HCBd may be landfilled, applied to soil, or incinerated. Effluent is typically released to surface water, where HCBd may further partition to sediments or suspended particles or volatilize to air.

If released to soil, HCBd may volatilize from moist or dry soil due to its Henry's law constant and vapor pressure, but volatilization from soil may be limited by adsorption to organic matter based on the log K_{OC} of HCBd. Based on its log K_{OC} and water solubility (3.2 mg/L), most HCBd in soils and groundwater will adsorb to soil or particulate organic matter but free HCBd may be somewhat mobile in soil pore water or groundwater in subsurface environments.

If released to landfill, HCBd is expected to migrate slowly into landfill leachate based on its log K_{OW} , and may volatilize from solid waste based on its vapor pressure.

HCBd also may partition to the tissues of organisms that live in water, soil and sediment via dermal or gill exposure and ingestion. Exposure to water column organisms is also possible via resuspension of the chemical from the sediment to water either sorbed to particulates or part of the dissolved phase. The above characterization is meant to describe the primary behavior or movement of the chemical through a generic environment, not the complete exclusion of the chemical from a given media (e.g., water) or elimination of the possibility for more complex behavior in a particular location.

If released to indoor environment, HCBd in consumer products or articles, contaminated water, or other solutions is likely to volatilize based on its vapor pressure, Henry's law constant, and log K_{OA} . HCBd in indoor air is not likely to adsorb to dust or other particles due to its log K_{OA} .

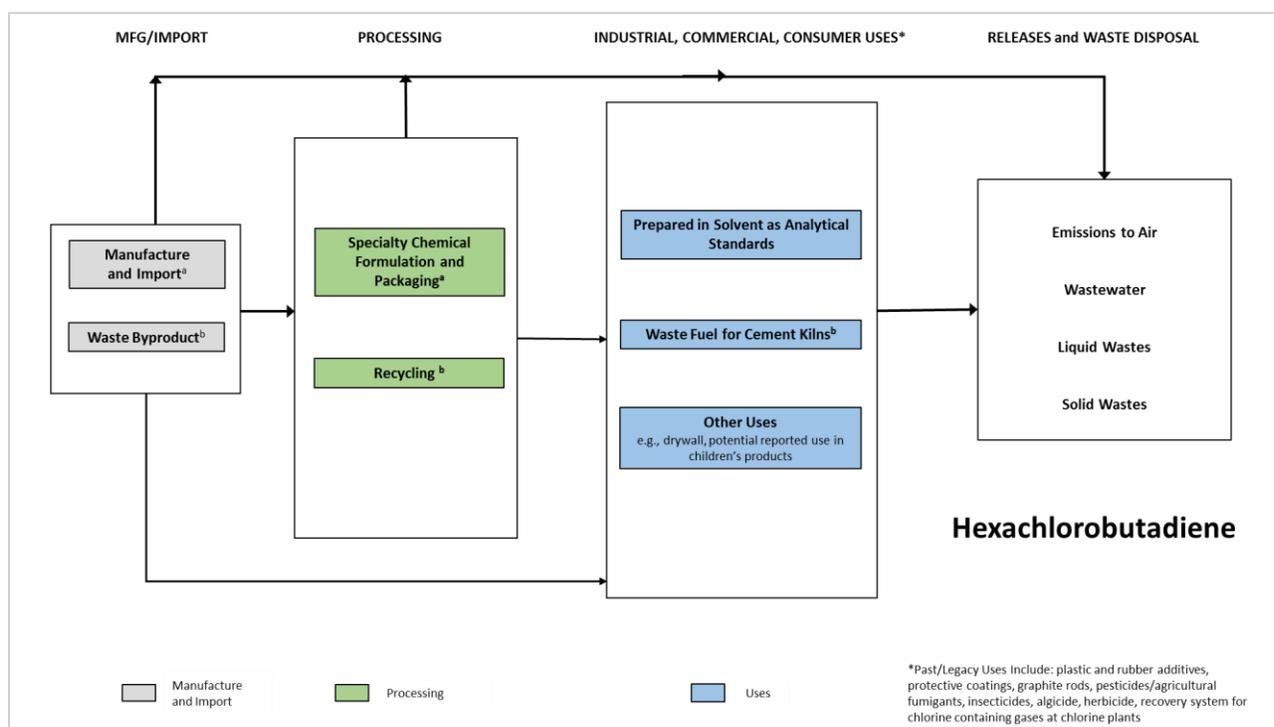
Based on its water solubility and log K_{OC} , HCBd subjected to down-the-drain disposal is expected to enter wastewater treatment or surface water either adsorbed to organic matter or free in the water column.

5.4. Overview of Lifecycle and Potential Sources of Exposure

5.4.1. Background and Brief Description of Lifecycle

HCBD is an organic compound. It is a clear, colorless, oily liquid with a mild turpentine-like odor. It does not naturally occur. HCBD is poorly soluble in water. When released to the environment, it is expected to volatilize quickly. Further, its vapor pressure indicates that it will evaporate from surfaces.

HCBD is manufactured as a by-product ([U.S. EPA, 2017c](#)). It is processed as a chemical intermediate for products including plastic additives. It is used as a waste fuel, as an analytical standard, and as a component of consumer products and drywall. The primary end-of-life disposal options for HCBD include combustion for energy recovery in cement kilns and incineration on-site.



^aNo data were submitted by manufacturers (including importers) under the CDR rule for the 2016 reporting period. HCBD is manufactured as an impurity or byproduct in the manufacture of plastic additives. It is also available for purchase from distributors based in the United States, Europe, and Asia and may be domestically manufactured in small quantities as a specialty chemical below the IUR reporting threshold ([U.S. EPA, 2017c](#)).

^bHCBD is produced as a waste byproduct during the manufacture of certain chemicals. Per 2016 TRI data, approximately 12 million pounds of HCBD was collected and managed on-site (300,000 pounds recycled and 11.7M pounds treated) during manufacturing and processing operations; and 27,000 pounds were collected and transferred off site as a waste fuel by cement kilns.

Figure 5-1. Lifecycle Diagram for HCBD

5.4.2. Manufacturing and Import

HCBD is primarily generated as a by-product of the manufacture of chlorinated hydrocarbons, particularly perchloroethylene, trichloroethylene, and carbon tetrachloride, but it can also be produced during magnesium manufacturing via electrolysis. According to recent reports to the UN Environmental Programme, HCBD does not appear to be intentionally manufactured in Europe, Japan, Canada, or the United States. Intentional production in Europe ceased as early as the late 1970s; in various other parts of the world, production of HCBD has been restricted or banned in subsequent years; however, the chemical continues to be manufactured as a byproduct of chemical manufacturing.

Various methods for HCBD synthesis have been described in two patents. HCBD can be directly synthesized through the chlorination of butadiene or butane or produced as a by-product of chlorinated hydrocarbon manufacturing, including perchloroethylene, trichloroethylene, and carbon tetrachloride. It appears that HCBD generated as a by-product during the synthesis of other compounds of interest may be recovered or recycled for commercial purposes.

Occupational dermal exposures are possible from liquid residue during transfers in process operations. Occupational inhalation exposure to fugitive vapors are possible.

5.4.3. Processing: Plastic Additive and Chemical Intermediate

HCBD may be processed as a plastic additive and as an intermediate for a variety of products. Releases and occupational exposures associated with intermediates are expected from unloading and loading operations and disposal of empty transfer containers. Releases and exposures after completion of reactions is limited to potential contact with low concentrations of unreacted HCBD from incomplete reactions. Specific release sources and exposure pathways to all intermediate uses of HCBD may be similar to those observed from additives in plastic compounding and finishing operations.

Releases of additives from plastic compounding and finishing operations are possible to water, air, and land. Releases to water can occur from the release of cooling water from forming and molding processes where water may have direct contact with plastics, and from equipment and general area cleaning when aqueous cleaning solutions are used ([U.S. EPA, 2014a](#)). Land releases are possible from the disposal of off-spec product and empty transfer containers. Air releases are expected to be minimal but are possible from fugitive releases from transfer operations. Occupational inhalation exposures from fugitive vapors and dermal exposure from incidental contact with liquids may occur from unloading and transfer operations when the HCBD is added to process equipment. Once incorporated into the plastic formulation, the potential for worker exposure is not expected.

5.4.4. Industrial/Commercial Use: Solvent as an Analytical Standard

HCBD is available for purchase from distributors in the U.S., Europe, and Asia. Laboratories are the only known direct U.S. consumers of high purity HCBD. Most distributors sell the product in

small quantities and specify its intended purpose as an analytical standard or reagent [ATSDR, 1995 as cited in the ([U.S. EPA, 2017c](#))].

Potential releases to all media are possible from use and disposal of unused experimental reagents and laboratory equipment that may contain residual HCBD. However, releases directly to the environment are expected to be minimal due to handling and disposal requirements at laboratories. Similarly, inhalation and dermal exposure to laboratory personnel is possible from the handling of laboratory reagents; however, it is expected to be reduced by from the use of engineering controls such as fume hoods and personal protective equipment.

5.4.5. Industrial/Commercial Use: Waste Fuel

Waste containing HCBD is blended with conventional fuels and burned in cement kilns for energy recovery ([U.S. EPA, 2017c, 2016d](#)). The destruction and removal efficiency of these kilns and incinerators is expected to be significant but not complete, resulting in air releases from incinerator flue gas and land releases from disposal of ash and slag. Minor water releases from equipment cleaning are possible. Current and historical TRI data and 2017 Discharge Monitoring Report data confirm the primary releases are to air, with minor releases to surface water and land ([U.S. EPA, 2017c, 2016d](#)). Occupational exposures to HCBD at cement kilns and related incinerator facilities are expected to be minimal.

5.4.6. Consumer Use: Consumer Products

Reports from manufacturers to the State of Washington's Department of Ecology under the Children's Safe Product Act indicate that HCBD was detected in 5 of 88 consumer products ([WSDE, 2018a](#)). In testing completed by the State of Washington, HCBD was not detected above method reporting limits for 80 similar consumer products ([WSDE, 2018b](#)). Reports indicate that HCBD was detected in jewelry, surface coatings of headwear, homogenous mixtures (likely adhesive) in underwear, and surface coatings of dolls or soft toys ([WSDE, 2018a](#)). No function was identified for four of the five products, while protective coating was identified as a function for the headwear product. Manufacture of these products may lead to occupational exposures. For example, occupational exposures in the textile manufacturing industry (inhalation and dermal exposure to organic dust and chemicals) are expected during production and packaging operations. Use of these products, if HCBD is present, may lead to consumer exposures (inhalation and dermal exposure) when products are worn or used.

5.4.7. Qualitative Trends Over Time for Releases and Occupational Exposures

According to the U.N., emissions of HCBD from domestic chlor-alkali plants dropped by 93% from 1990 to 2005. Technological changes, more effective emission controls, and the end of HCBD use as a solvent to scrub chlorine from exhaust gasses contributed to the decline. Euro Chlor, a trade association representing the European Chlor-Alkali industry, stated that historically HCBD was used in agriculture (e.g., seed dressing and fungicide) as well as in the production of aluminum and graphite rods, but its use has "virtually ceased" in response to concerns about how persistent, bioaccumulative, and toxic it might be ([U.S. EPA, 2017c](#)).

Data pertaining to occupational exposure have not been identified. However, TRI data confirm the number of reporting facilities and the total domestic release quantities to all media have remained relatively constant since 2000 ([U.S. EPA, 2016d](#)). These data show 14 facilities submitted reports for HCBd in 2016. Of these, 9 facilities reported manufacture in the United States, 0 reported import, 5 reported processing operations of some type, and 9 reported other uses. Most waste was treated on site, with significant amounts being recycled. Historical TRI data indicate that releases to air have remained the primary medium of release with minor releases to land, and quantities have remained constant for many years. Releases to surface water and quantities transferred to POTWs for wastewater treatment have decreased to minimal levels over time such that total releases to water were less than one pound in 2016 ([U.S. EPA, 2016d](#)).

5.5. Environmental Monitoring

Dozens of studies show that HCBd has been detected in a wide variety of media. Table 5-2 summarizes the monitoring data for HCBd identified in the peer-reviewed literature across all media found. Also included in the count are available monitoring database sources. Only studies or databases that reported measurements of the chemical of interest above the limit of detection were extracted and included in the “# of studies” count. The frequency of detection is provided as a measure, across all samples in all extracted studies, of the frequency that the chemical was measured above the limit of detection. Note, the frequency of detection is reported only for peer-reviewed sources, unless the only data sources available were database sources.

Generally consistent with the fate summary and physical-chemical properties of HCBd, higher concentrations were reported in ambient air, surface water, soil, and sediment. Lower concentrations were reported in drinking water, indoor air, and sludge/biosolids. HCBd was not reported in indoor dust or landfill leachate. HCBd was reported in influent, effluent, and in ambient air. This is consistent with release patterns that show primary releases to air, minor releases to water, and no or limited indoor sources of HCBd. It is of particular note that the bulk of monitoring studies are older and represent exposures when HCBd was used more broadly or when past use as a byproduct in the chlor-alkali industry likely resulted in higher releases.

Table 5-2. Summary of HCBd Monitoring Data from the Peer-Reviewed Literature and Monitoring Databases

Media	Presence	No. of Datasets	Frequency of Detection
Indoor dust	No	0	n/a
Indoor air	Yes	2	100%
Ambient air	Yes	5	100%
Surface/Ground water	Yes	45	83%
Drinking water	Yes	2	100%
Soil	Yes	8	75%
Sediment	Yes	38	88%
Biosolids	Yes	1	76%
Wastewater (influent, effluent)	No	1	n/a

Landfill leachate	No	0	n/a
Vegetation/Diet	Yes	1	60%
Other	Yes	1	n/a

The following chart provides the number of studies that have reported HCBd monitoring data over time. For this chart, the year the study is published rather than the sampling timeframe is used as a proxy, though for most studies, samples were collected a few years prior to publication. Note, EPA recognizes that the sampling dates, rather than the publication date, would be a better reflection of temporal trends.

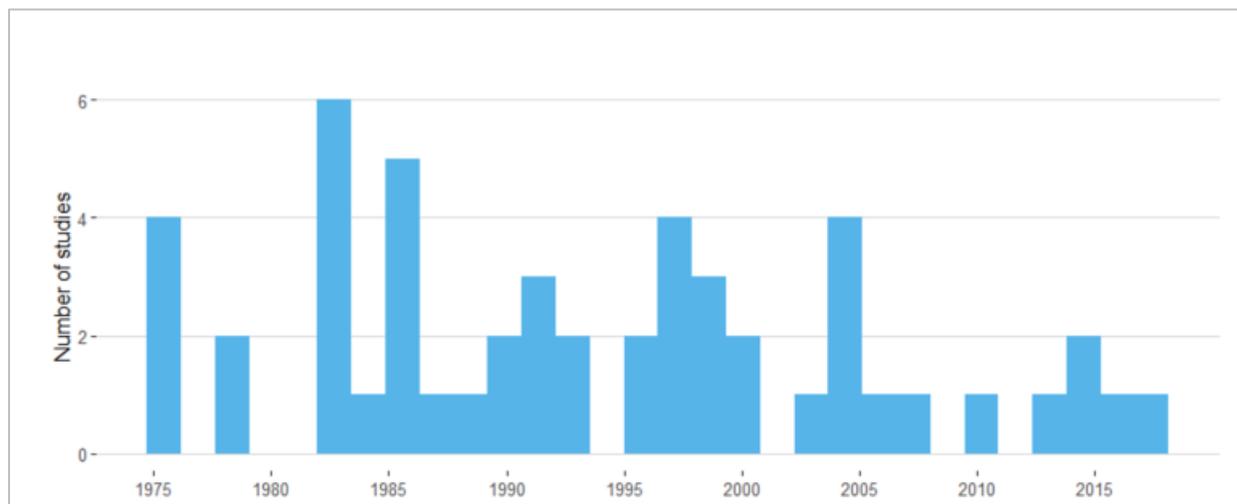


Figure 5-2. Frequency of peer-reviewed publications identified that contained HCBd monitoring data.

All environmental monitoring data that passed EPA’s evaluation criteria are presented graphically in the plots below. These plots help visualize the data and are organized by study year and microenvironment, when reported. Note, some studies are discussed in Sections 5.7 and 5.11 as they integrate information on monitoring data alongside supplemental contextualizing information on uses, sources, and trends.

5.5.1. Indoor Dust

EPA did not identify any studies with extractable HCBd data in indoor dust. There are not expected to be indoor sources of HCBd (e.g. consumer products or building materials). HCBd present in indoor air may be related to HCBd from outdoor air sources. HCBd in indoor air is not likely to adsorb to dust or other particles due to its log K_{OA} . As a result, HCBd is not expected to be present in indoor dust.

5.5.2. Indoor Air

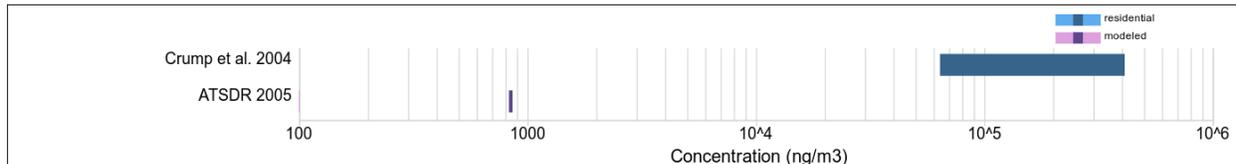


Figure 5-3. Concentration of HCBd (ng/m³) in indoor air for residential locations (2004) and modeled data (2005). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([ATSDR, 2005b](#); [Crump et al., 2004](#))

5.5.3. Ambient Air

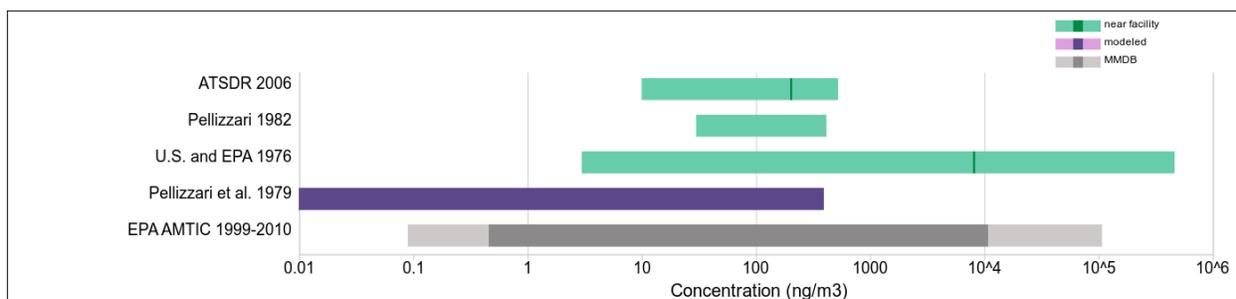


Figure 5-4. Concentration of HCBd (ng/m³) in ambient air for near facility locations (1976 to 2006), modeled data (1979), and from monitoring databases (EPA AMTIC). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This chart contains data for the following: ([ATSDR, 2006](#); [U.S. EPA, 1990](#); [Pellizzari, 1982](#); [Pellizzari et al., 1979](#); [U.S. EPA, 1976](#))

5.5.4. Surface Water

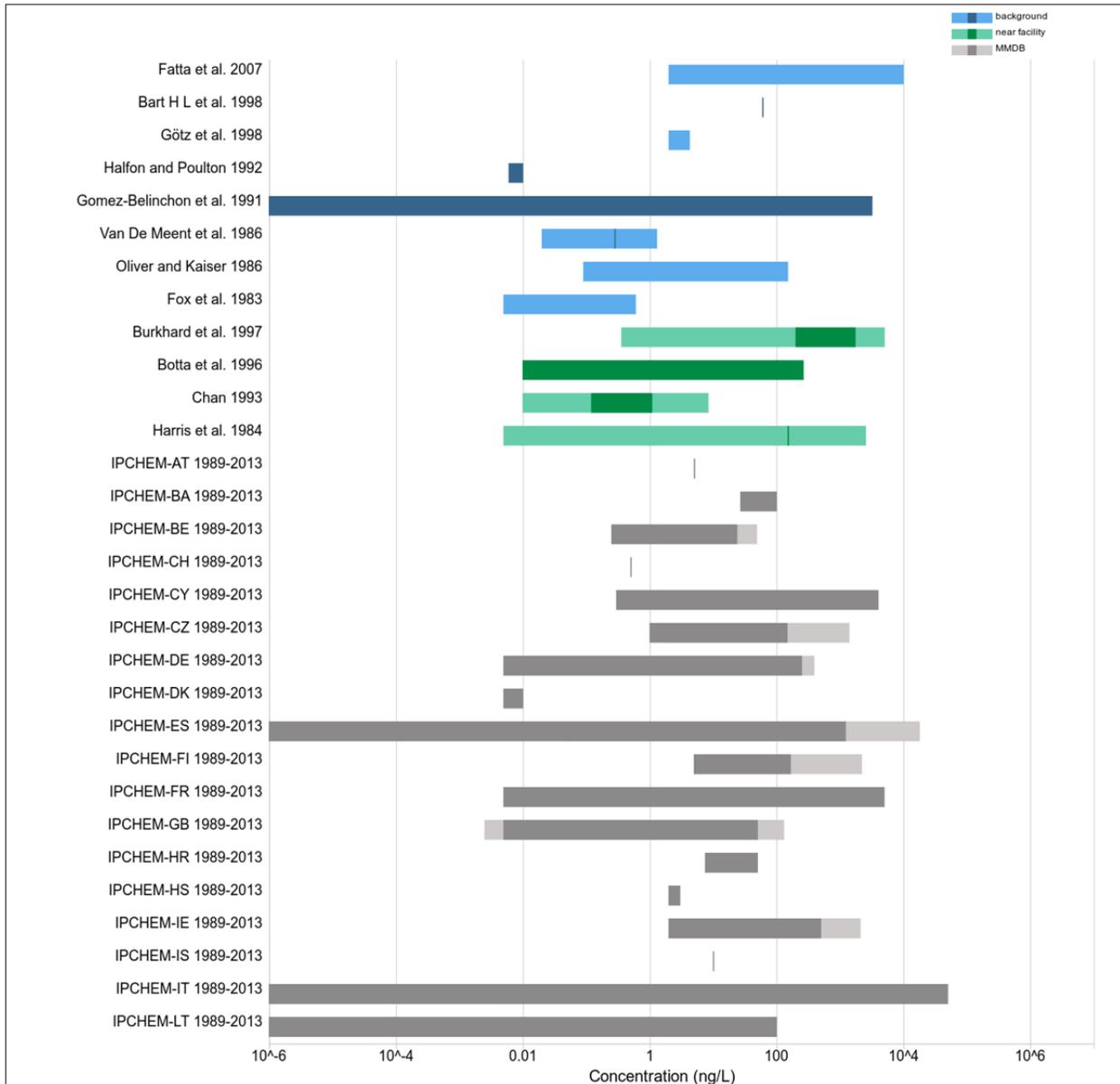


Figure 5-5. Concentration of HCBd (ng/L) in surface water for background locations (1983 to 2007), near facility locations (1984 to 1997), and from monitoring databases (IPCHEM). For each year/database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

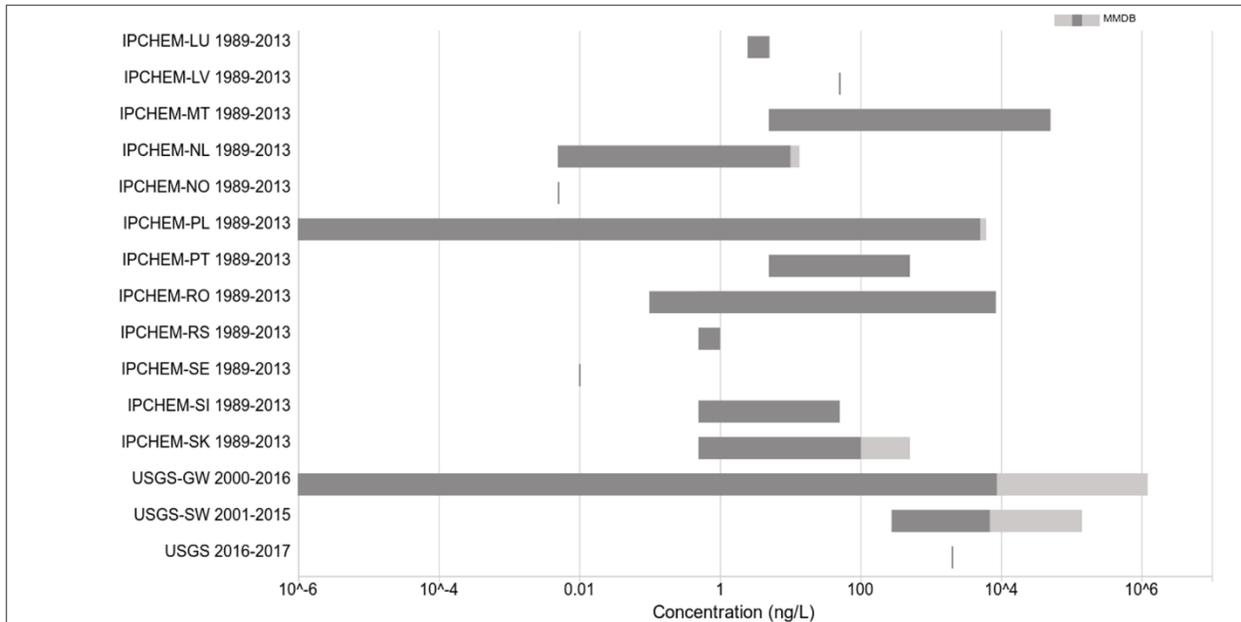


Figure 5-6. Concentration of HCBD (ng/L) in surface water from monitoring databases (IPCHEM, USGS). For each database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

The above figures for surface water contain data for the following: ([EC, 2018](#); [Fatta et al., 2007](#); [Bart H L et al., 1998](#); [Götz et al., 1998](#); [Burkhard et al., 1997](#); [Botta et al., 1996](#); [Chan, 1993](#); [Halfon and Poulton, 1992](#); [Gomez-Belinchon et al., 1991](#); [USGS, 1991](#); [Oliver and Kaiser, 1986](#); [van de Meent et al., 1986](#); [Harris et al., 1984](#); [Fox et al., 1983](#))

5.5.5. Drinking Water

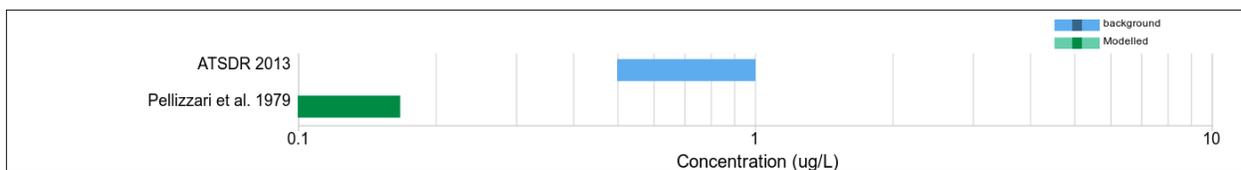


Figure 5-7. Concentration of HCBD (µg/L) in drinking water for background locations (2013) and modeled data (1979). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([ATSDR, 2013](#); [Pellizzari et al., 1979](#))

5.5.6. Soil

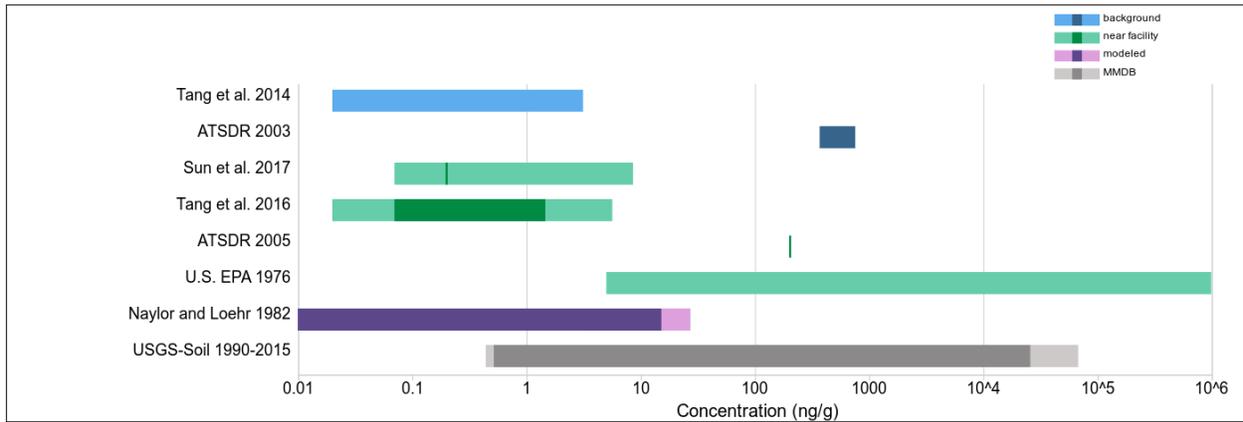


Figure 5-8. Concentration of HCBD (ng/g) in soil for background locations (2003 and 2014), near facility locations (1976 to 2017), modeled data (1982), and from monitoring databases (USGS). For each year/database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Sun et al., 2017](#); [Tang et al., 2016](#); [Tang et al., 2014b](#); [ATSDR, 2005a](#), [2003](#); [USGS, 1991](#); [DOE, 1989](#); [Naylor and Loehr, 1982](#); [U.S. EPA, 1976](#))

5.5.7. Sediment

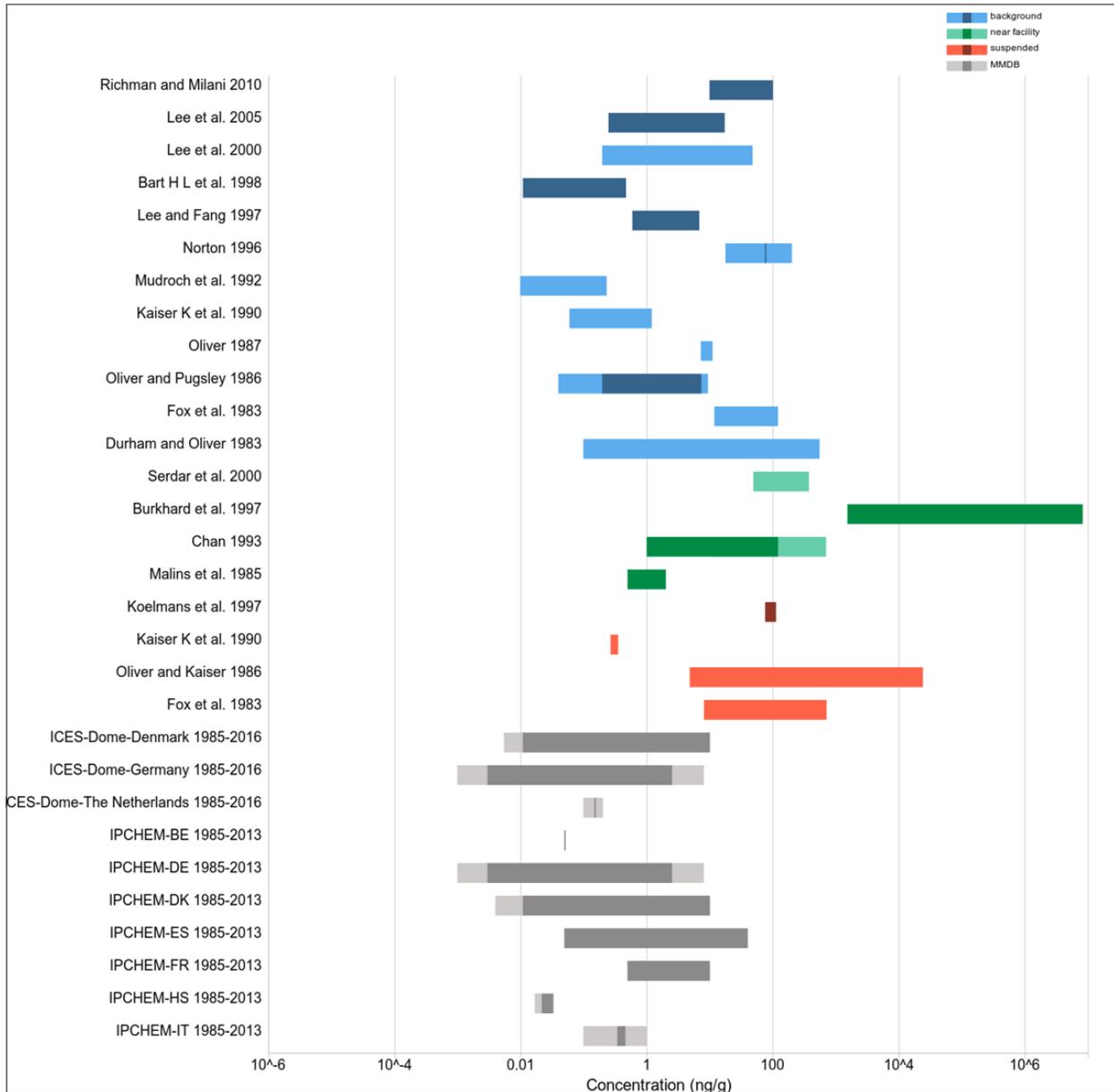


Figure 5-9. Concentration of HCBd (ng/g) in sediment for background locations (1983 to 2010, near facility locations (1985 to 2000), suspended sediments (1983 to 1997), and from monitoring databases (ICES, IPCHEM). For each year/database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

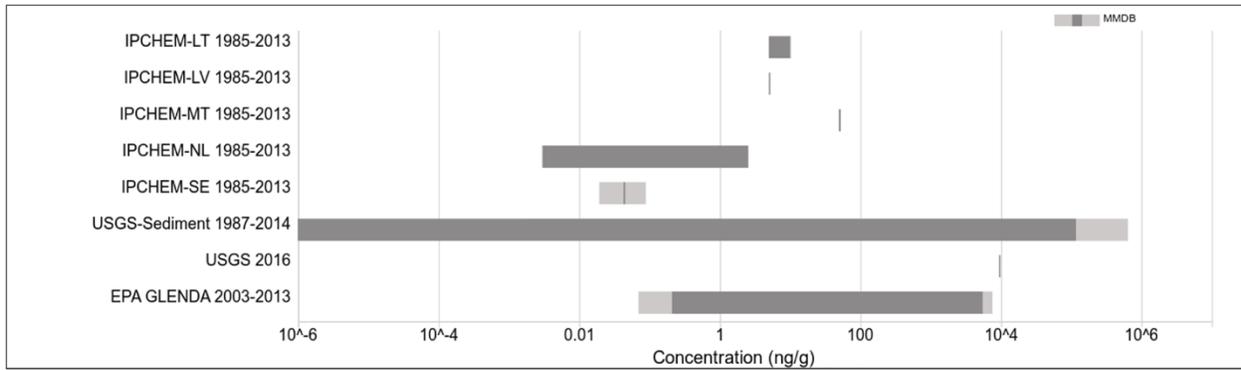


Figure 5-10. Concentration of HCBd (ng/g) in sediment from monitoring databases (IPCHEM, USGS, EPA GLENDa). For each year/database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

The above figures for sediment contain data for the following: ([EC, 2018](#); [U.S. EPA, 2018b](#); [Richman and Milani, 2010](#); [Lee et al., 2005, 2000](#); [Serdar et al., 2000](#); [Bart H L et al., 1998](#); [Burkhard et al., 1997](#); [C-L and M-D, 1997](#); [Koelmans et al., 1997](#); [Norton, 1996](#); [Chan, 1993](#); [Mudroch et al., 1992](#); [USGS, 1991](#); [Kaiser K et al., 1990](#); [Oliver, 1987](#); [Oliver and Pugsley, 1986](#); [Oliver and Kaiser, 1986](#); [Malins et al., 1985](#); [Durham and Oliver, 1983](#); [Fox et al., 1983](#))

5.5.8. Sludge/Biosolids

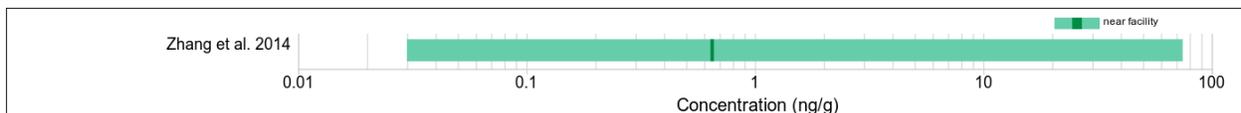


Figure 5-11. Concentration of HCBd (ng/g) in sludge/biosolids for near facility locations in 2014. The range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Zhang et al., 2014a](#))

5.5.9. Influent/Effluent

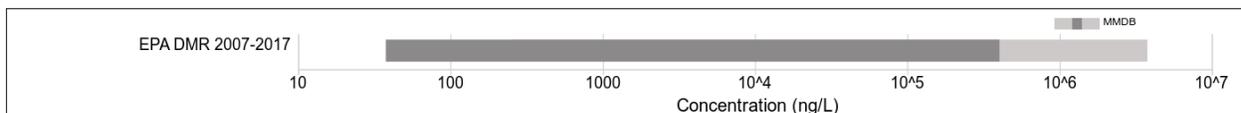


Figure 5-12. Concentration of HCBd (ng/L) in influent/effluent from monitoring databases (EPA DMR). For each database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([U.S. EPA, 2007](#))

5.5.10. Landfill Leachate

Of the studies searched, we did not identify any studies with detectable levels of HCBd in landfill leachate.

5.5.11. Vegetation/Diet

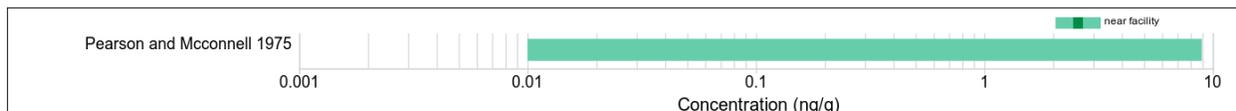


Figure 5-13. Concentration of HCBd (ng/g) in vegetation/diet for near facility locations in 1975. The range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([Pearson and Mcconnell, 1975](#))

5.5.12. Other

One study was identified that reported concentrations of HCBd in seawater.

5.5.12.1. Seawater

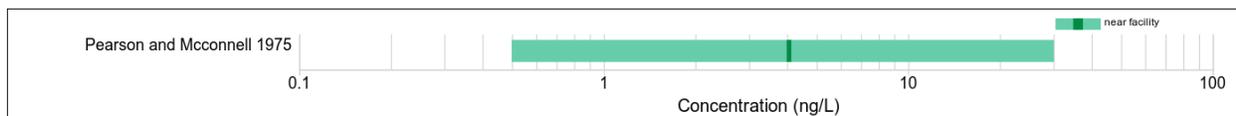


Figure 5-14. Concentration of HCBd (ng/L) in seawater for near facility locations in 1975. The range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Pearson and Mcconnell, 1975](#))

5.6. Biomonitoring

Dozens of studies show that HCBd has been detected in a wide variety of matrices. Table 5-3 summarizes the biomonitoring data for HCBd identified in the peer-reviewed literature across all matrices. Also included in the count are available monitoring database sources. Only studies or databases that reported measurements of the chemical of interest above the limit of detection were extracted and included in the “# of studies” count. The frequency of detection is provided as a measure, across all samples in all extracted studies, of the frequency that the chemical was measured above the limit of detection. Note, the frequency of detection is reported only for peer-reviewed sources, unless the only data sources available were database sources.

Table 5-3. Summary of HCBd Biomonitoring Data from the Peer-Reviewed Literature and Monitoring Databases

Matrix	Presence	No. of Datasets	Frequency of Detection
Human blood (serum)	No	0	n/a
Human (other)	No	0	n/a
Fish	Yes	25	48%
Birds	Yes	2	27%
Terrestrial invertebrates	Yes	3	78%
Aquatic invertebrates	Yes	17	37%
Terrestrial mammals	Yes	2	66%
Aquatic mammals	No	1	n/a
Other	No	0	n/a

The following chart provides the number of studies that reported HCBd biomonitoring data over time. For this chart, the year the study is published rather than the sampling timeframe is used as a proxy, though for most studies, samples were collected a few years prior to publication. Note, EPA recognizes that the sampling dates, rather than the publication date, would be a better reflection of temporal trends.

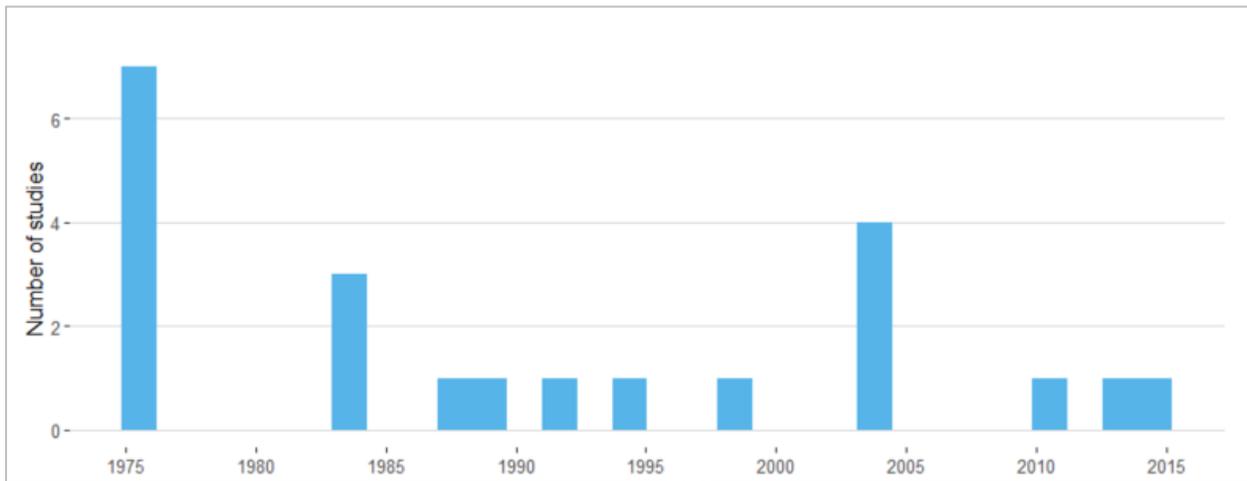


Figure 5-15. Frequency of peer-reviewed publications identified that contained HCBd biomonitoring data.

5.6.1. Human blood (serum)

EPA did not identify any studies with detectable levels of HCBd in human blood.

5.6.2. Aquatic invertebrates

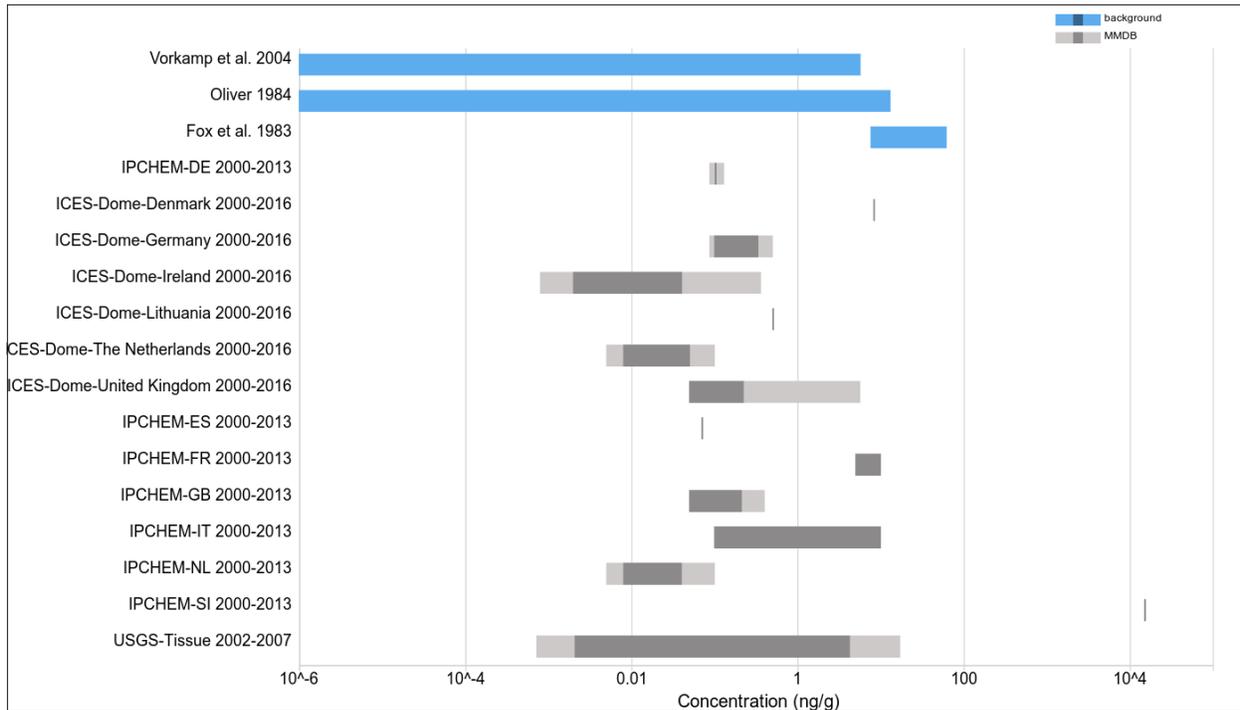


Figure 5-16. Concentration of HCBd (ng/g) in aquatic invertebrates for background locations (1983 to 2004) and from monitoring databases (IPCHEM, ICES, USGS). For each year/database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([EC, 2018](#); [ICES, 2018](#); [Vorkamp et al., 2004](#); [USGS, 1991](#); [Oliver, 1984](#); [Fox et al., 1983](#))

5.6.3. Fish

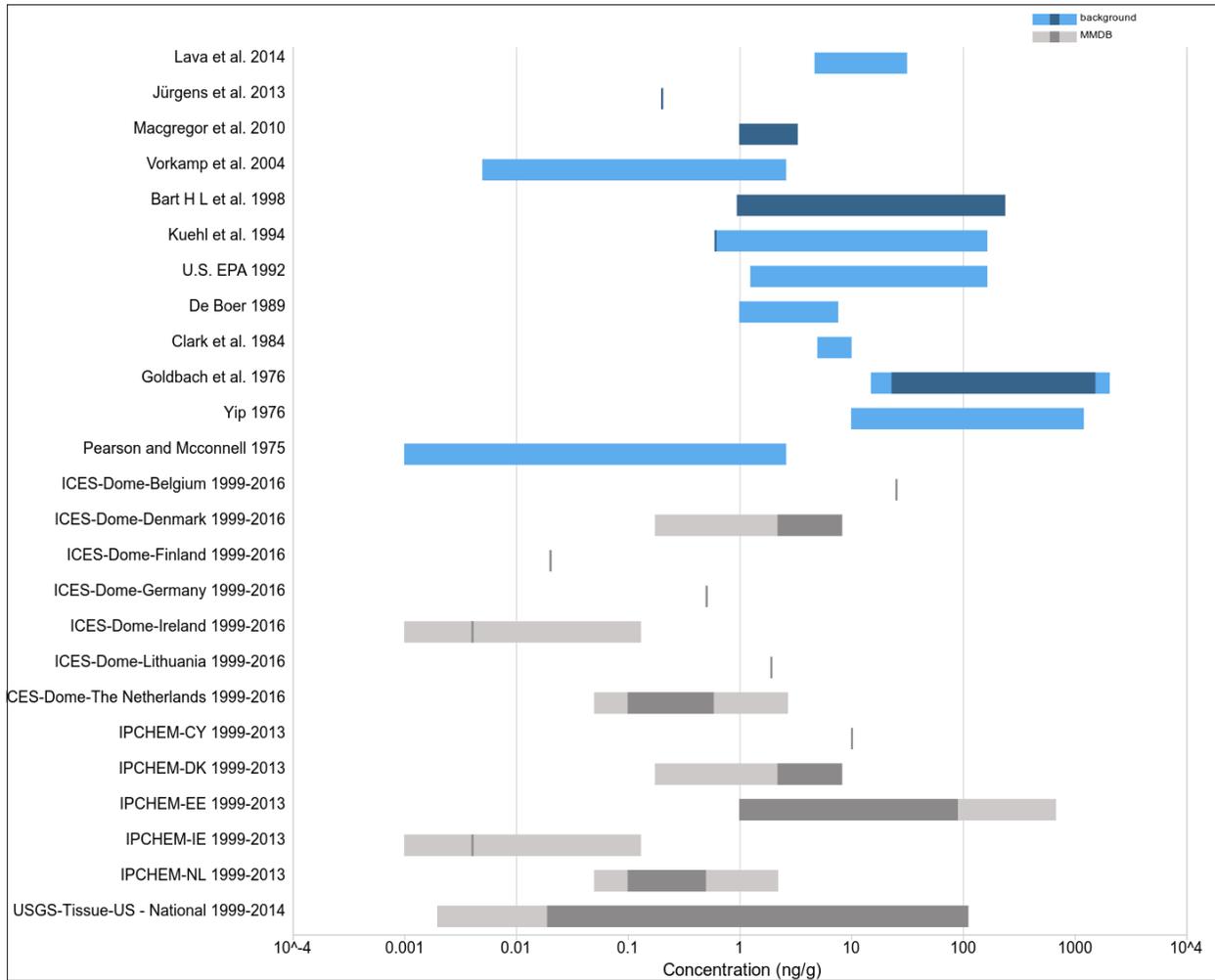


Figure 5-17. Concentration of HCBd (ng/g) in fish for background locations (1975 to 2014) and from monitoring databases (ICES, IPCHEM, USGS). For each year/database, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([EC, 2018](#); [ICES, 2018](#); [Lava et al., 2014](#); [Jürgens et al., 2013](#); [Macgregor et al., 2010](#); [Vorkamp et al., 2004](#); [Bart H L et al., 1998](#); [Kuehl et al., 1994](#); [U.S. EPA, 1992](#); [USGS, 1991](#); [De Boer, 1989](#); [Clark et al., 1984](#); [Goldbach et al., 1976](#); [Yip, 1976](#); [Pearson and Mcconnell, 1975](#))

5.6.4. Aquatic mammals

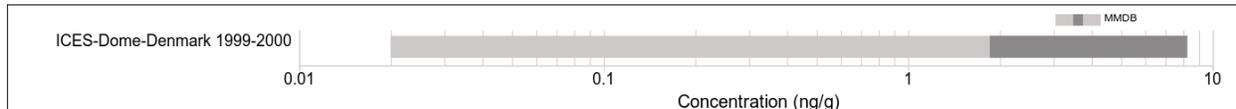


Figure 5-18. Concentration of HCBd (ng/g) in aquatic mammals from one monitoring database (ICES). The range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([ICES, 2018](#))

5.6.5. Terrestrial invertebrates

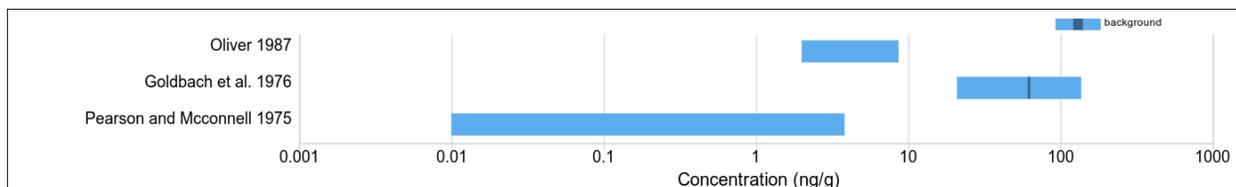


Figure 5-19. Concentration of HCBd (ng/g) in terrestrial invertebrates for background locations from 1975 to 1987. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Oliver, 1987](#); [Goldbach et al., 1976](#); [Pearson and Mcconnell, 1975](#))

5.6.6. Birds

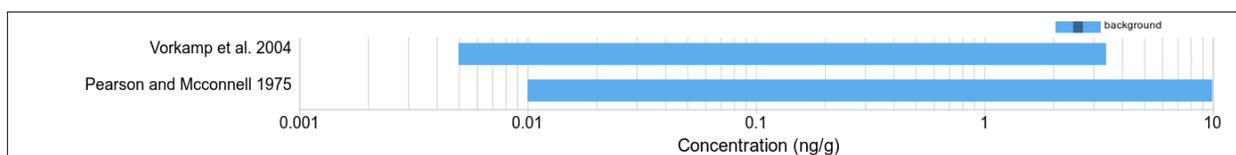


Figure 5-20. Concentration of HCBd (ng/g) in birds for background locations in 1975 and 2004. For each year, the range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([Vorkamp et al., 2004](#); [Pearson and Mcconnell, 1975](#))

5.6.7. Terrestrial mammals

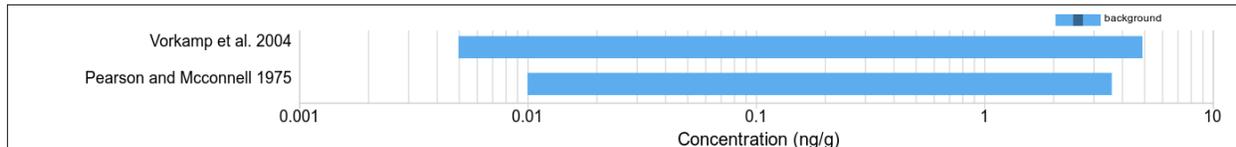


Figure 5-21. Concentration of HCBD (ng/g) in terrestrial mammals for background locations in 1975 and 2004. For each year, the range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([Vorkamp et al., 2004](#); [Pearson and McConnell, 1975](#))

5.7. Trends in Monitoring Data

Several studies reported temporal trends for HCBD in the following media:

- Ambient Air
- Soils
- Sediments
- Influent/Effluents
- Aquatic Invertebrates
- Fish
- Aquatic Mammals

Those studies are summarized below.

5.7.1. Ambient Air

One monitoring database (EPA AMTIC) reported HCBD levels in ambient air from 1990 through 2014 ([U.S. EPA, 1990](#)). In general, HCBD concentrations spanned three orders of magnitude, from 10^1 to 10^4 ng/m³, with no strong temporal trends observed. From 2004 to 2006, greater variability was observed with a larger range of concentrations detected and/or higher maximum concentrations.

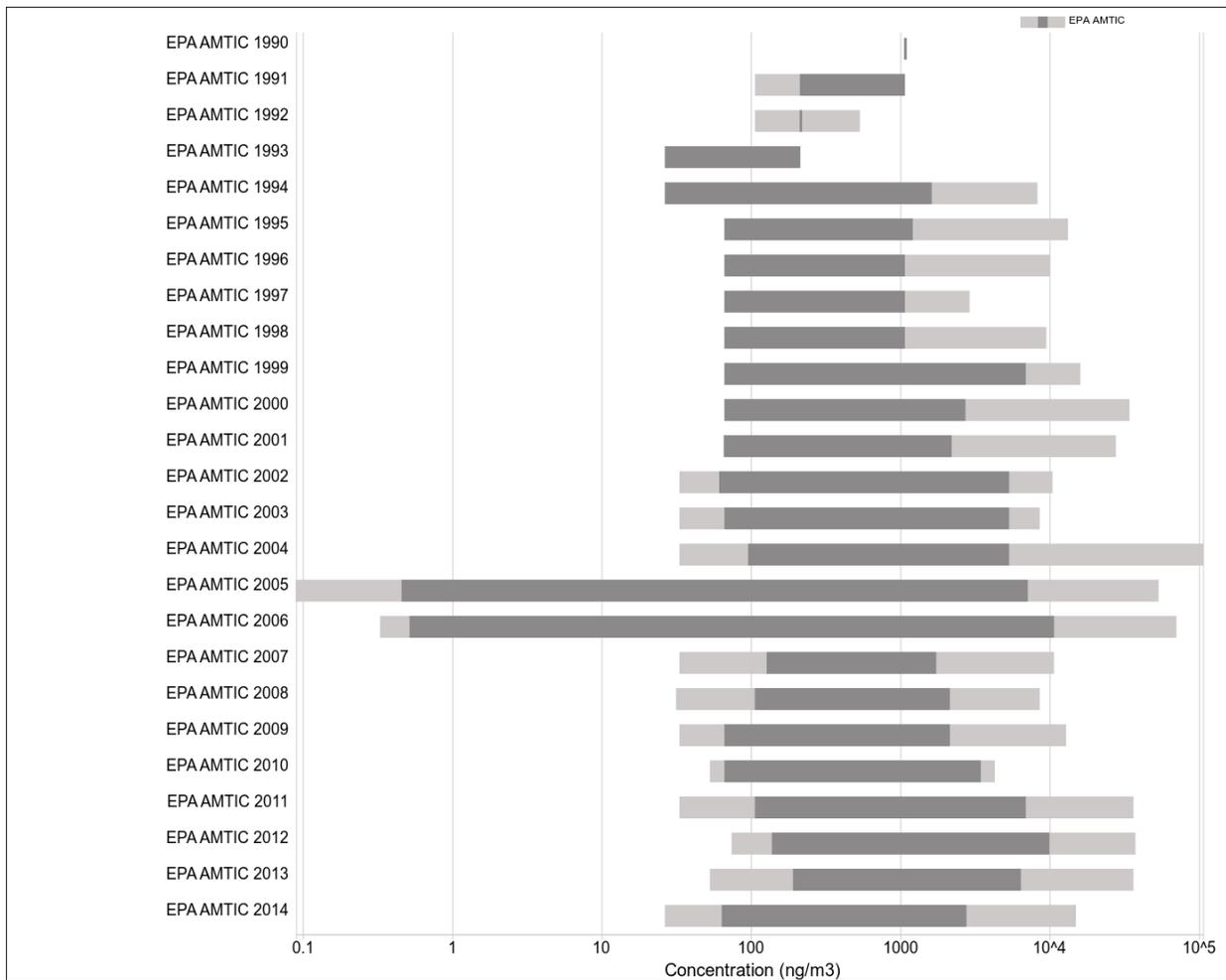


Figure 5-22. Concentration of HCBd (ng/m³) in ambient air from 1990 to 2014. For each row of data, the entire length of the bar represents the range of values reported. The darker color within the bar shows the minimum and maximum of reported central tendency estimates.

5.7.2. Soils

Eleven years of monitoring data were reported in the USGS database for HCBd concentrations in soils. From 1990 to 2015, no strong temporal trends were observed, with concentrations ranging over five orders of magnitude.

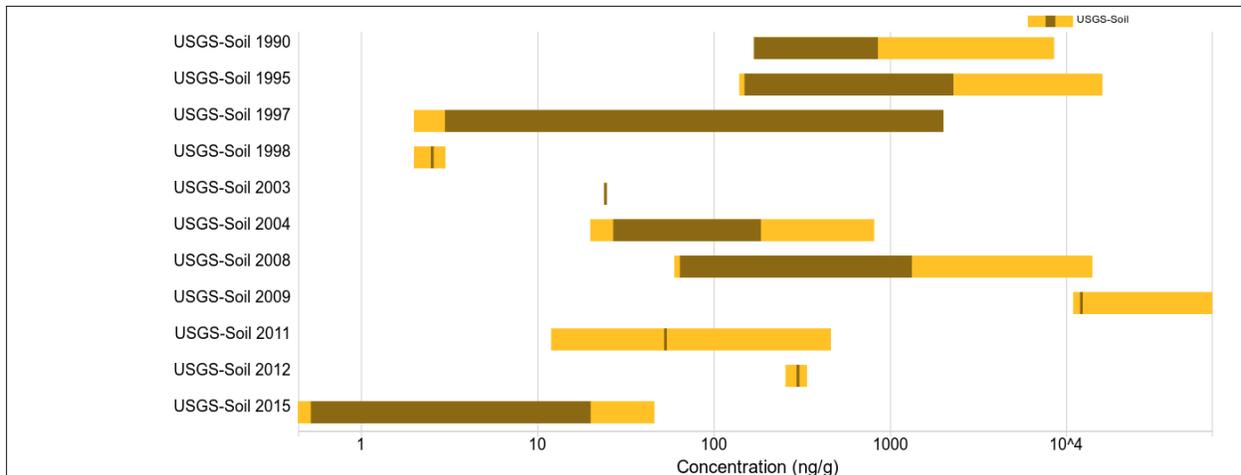


Figure 5-23. Concentration of HCBd (ng/g) in soils from 1990 to 2015. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate color within (dark brown).

5.7.3. Sediments

Four monitoring databases (ICES, IPCHEM, USGS, EPA GLENDa) reported concentrations of HCBd in sediments from 1985 through 2016 ([EC, 2018](#); [ICES, 2018](#); [U.S. EPA, 2018b](#); [USGS, 1991](#)). Data presented in Figure 5-24 to **Error! Reference source not found.** were obtained by filtering by media and desired date range. No strong temporal trends were observed when all databases were considered together or when databases were individually considered. From 1985 through 2008, US sediments reported higher concentrations of HCBd than sediment concentrations from The Netherlands, Germany, Belgium, France, Malta, Spain, and Denmark. The latter group of seven countries are part of the European Union and subject to different regulations than the US, which may contribute to the differences observed.

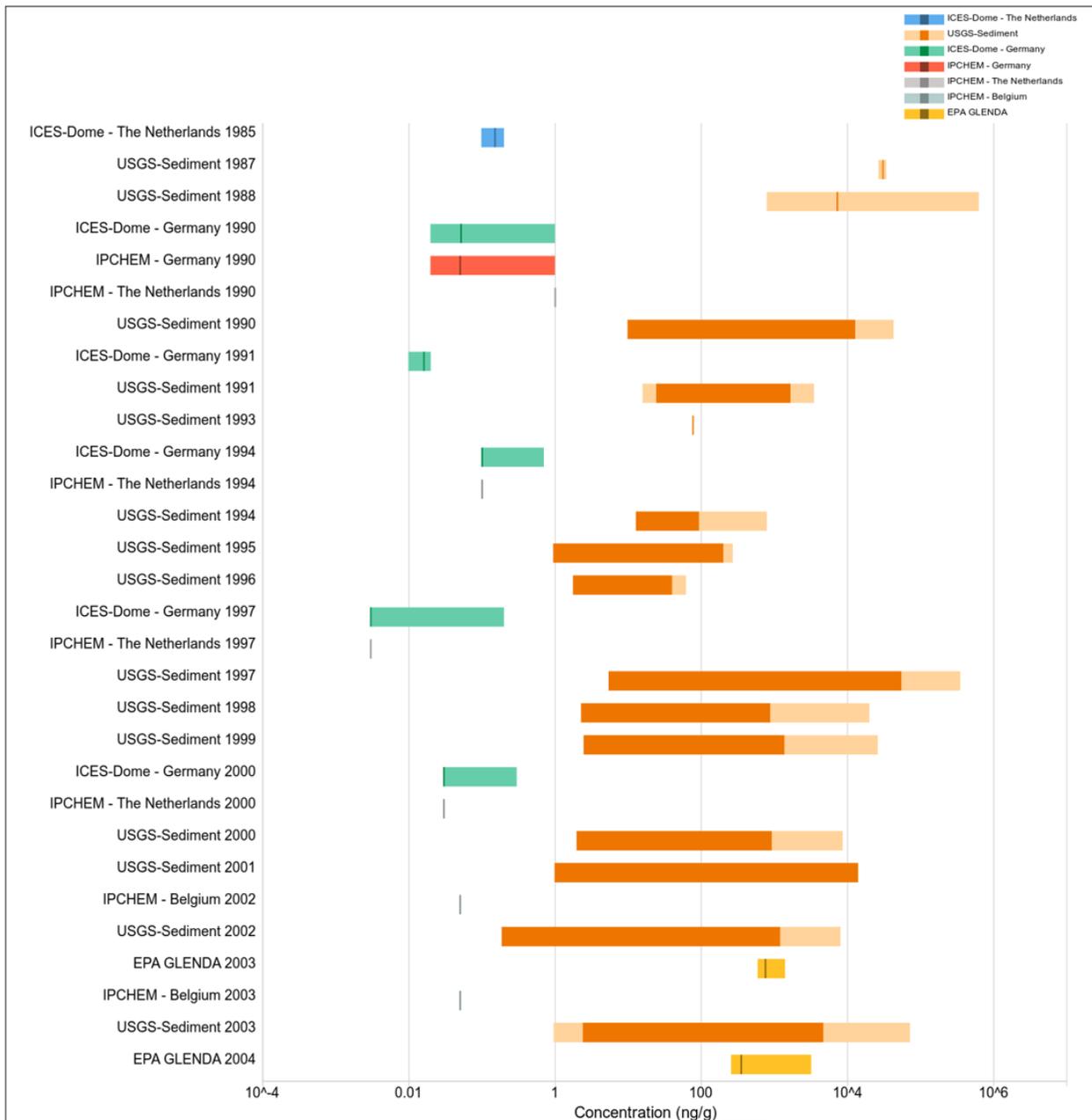


Figure 5-24. Concentration of HCBd (ng/g) in sediments from 1985 to 2004. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

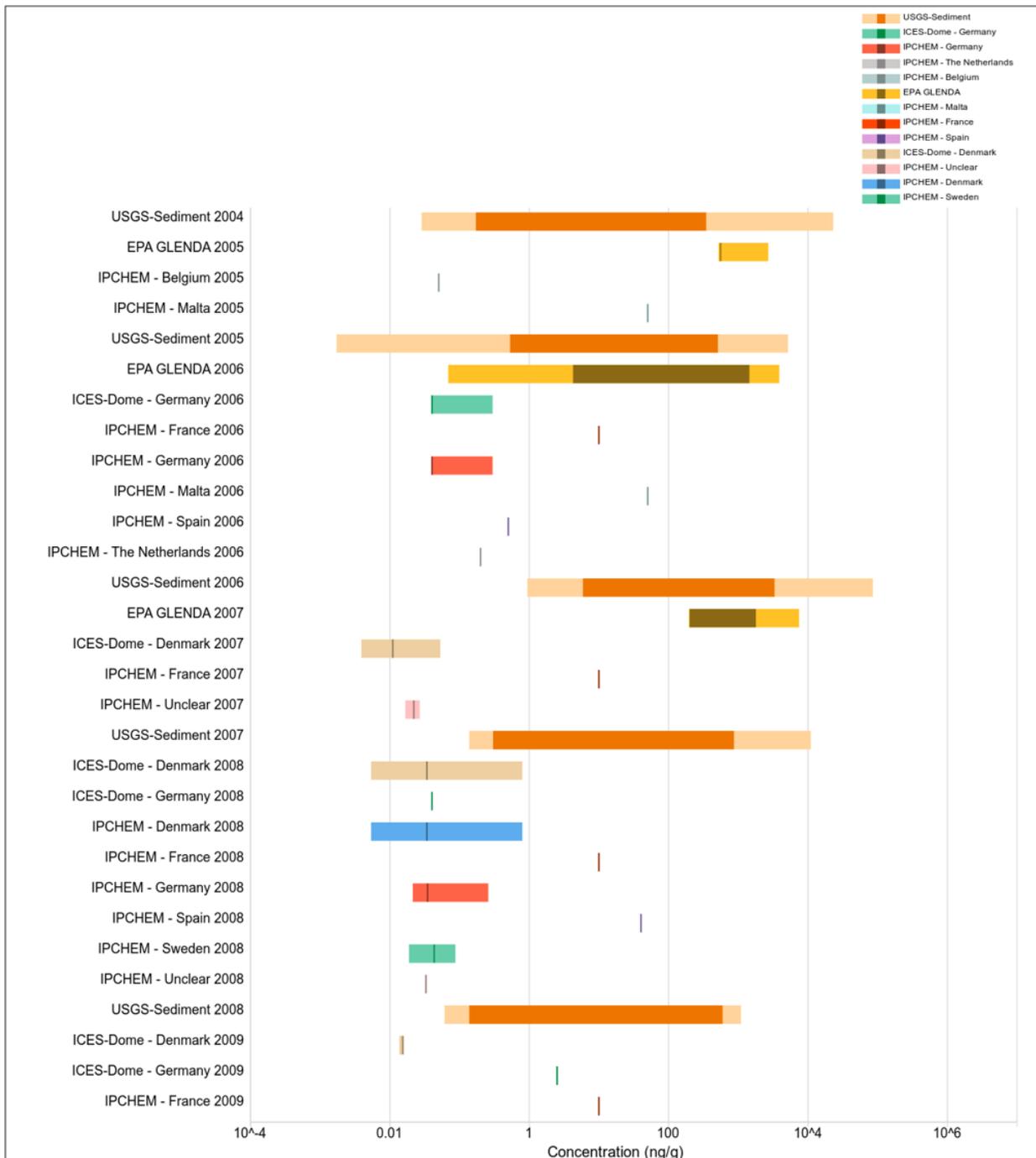


Figure 5-25. Concentration of HCBd (ng/g) in sediments from 2004 to 2009. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate color within (darker color).

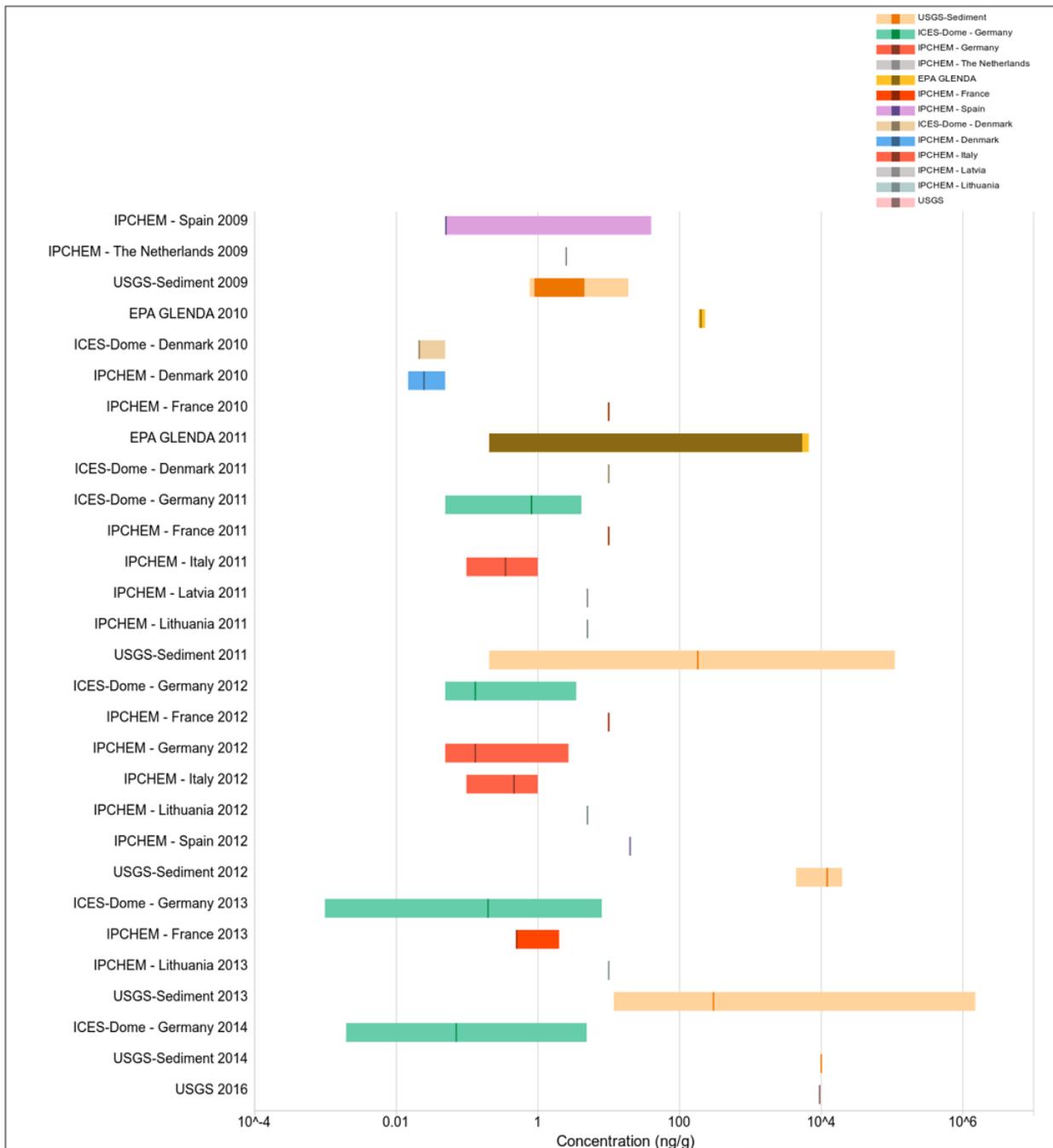


Figure 5-26. Concentration of HCBd (ng/g) in sediments from 2009 to 2016. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

5.7.4. Influent/Effluents

One monitoring database (EPA DMR) reported HCBd levels in the influent/effluents of wastewater from 2007 through 2017 ([U.S. EPA, 2007](#)). A decrease in concentration was observed between 2007 and 2011, with levels steady between 2011 and 2017.

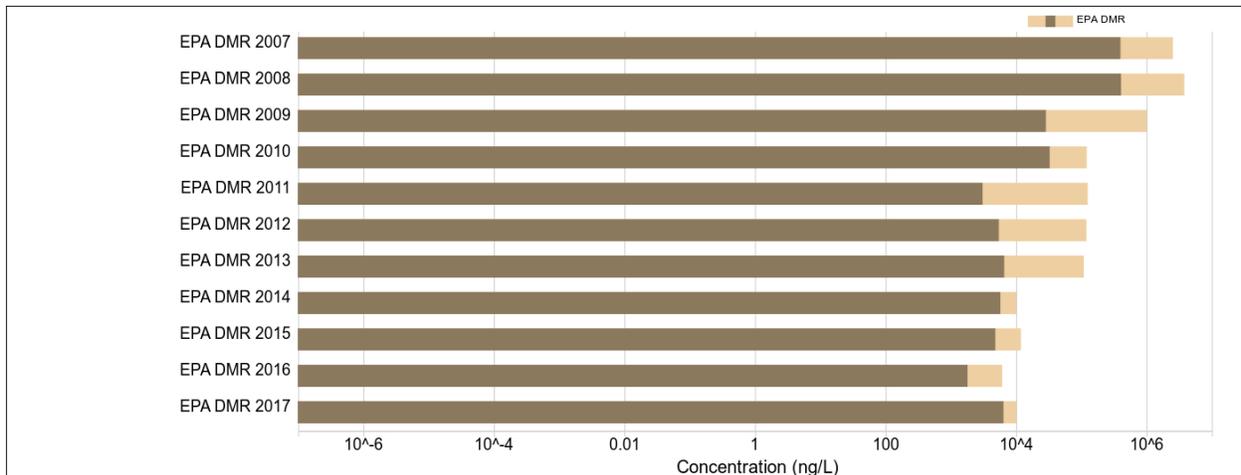


Figure 5-27. Concentration of HCBD (ng/g) in influent/effluents from 2007 through 2017. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

5.7.5. Aquatic Invertebrates

Three monitoring databases (ICES, IPCHEM, USGS) reported concentrations of HCBD in aquatic invertebrates from 2000 through 2016 ([EC, 2018](#); [ICES, 2018](#); [USGS, 1991](#)). Data presented in Figure 5-28 and Figure 5-29 were obtained by filtering by media and desired date range. No strong temporal trends were observed when all databases were considered together or when databases were individually considered. Concentrations of HCBD in aquatic invertebrate were all lower than 100 ng/L with the exception of the IPCHEM results reported in 2012 from Slovenia, which had a median reported concentration of 15,000 ng/L.

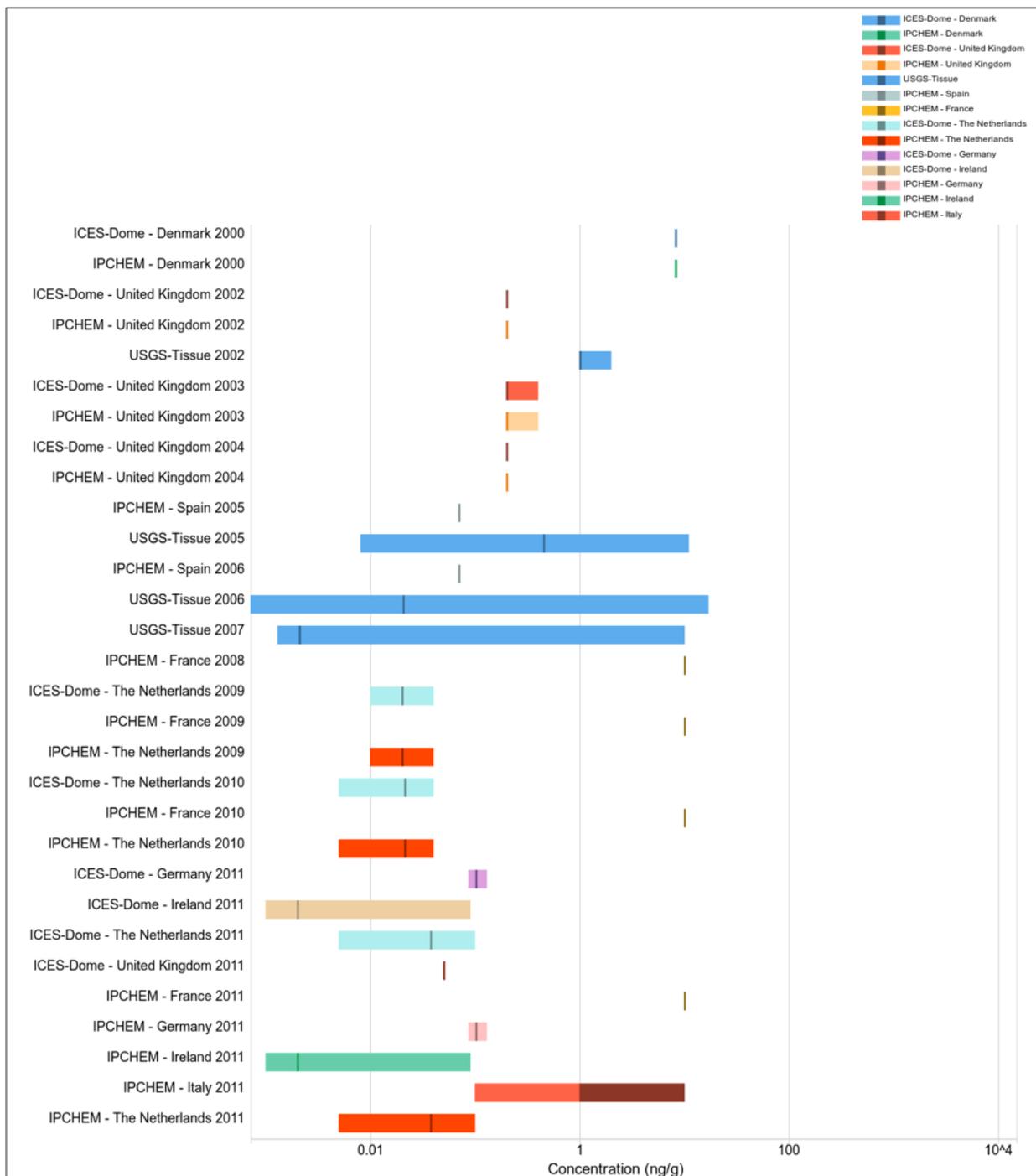


Figure 5-28. Concentration of HCBd (ng/g) in aquatic invertebrates from 2000 through 2011. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

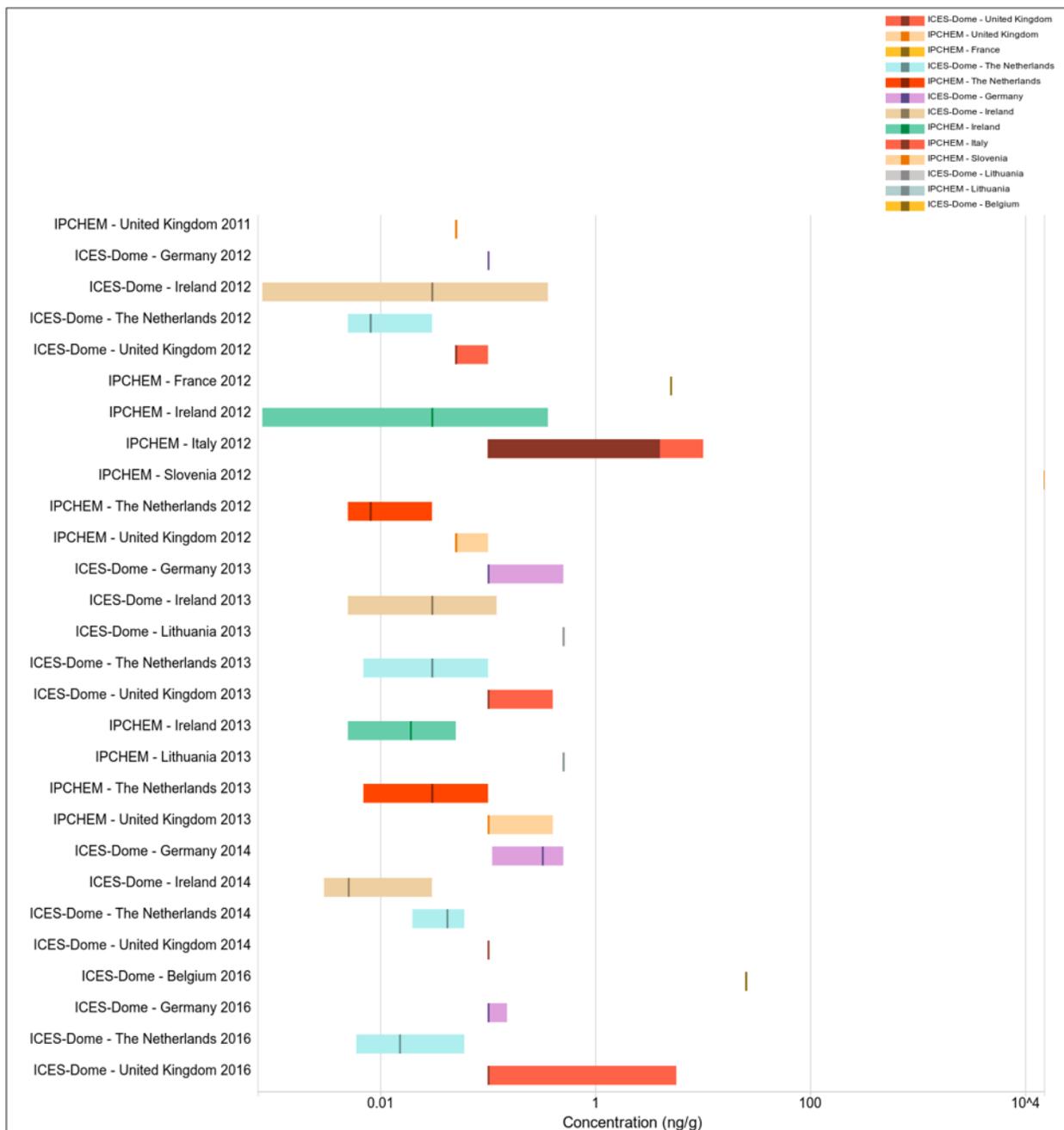


Figure 5-29. Concentration of HCBd (ng/g) in aquatic invertebrates from 2011 through 2016. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

5.7.6. Fish

Three monitoring databases (USGS, ICES, IPCHEM) reported concentrations of HCBd in fish from 1999 through 2016 (EC, 2018; ICES, 2018; USGS, 1991). Data presented in Figure 5-30 and Figure 5-31 were obtained by filtering by media and desired date range. When considering the

median reported concentrations, HCBd concentrations were stable in fish from the U.S. from 1999 to 2003, followed by a decrease from 2005 to 2007. No other strong temporal trends were observed.

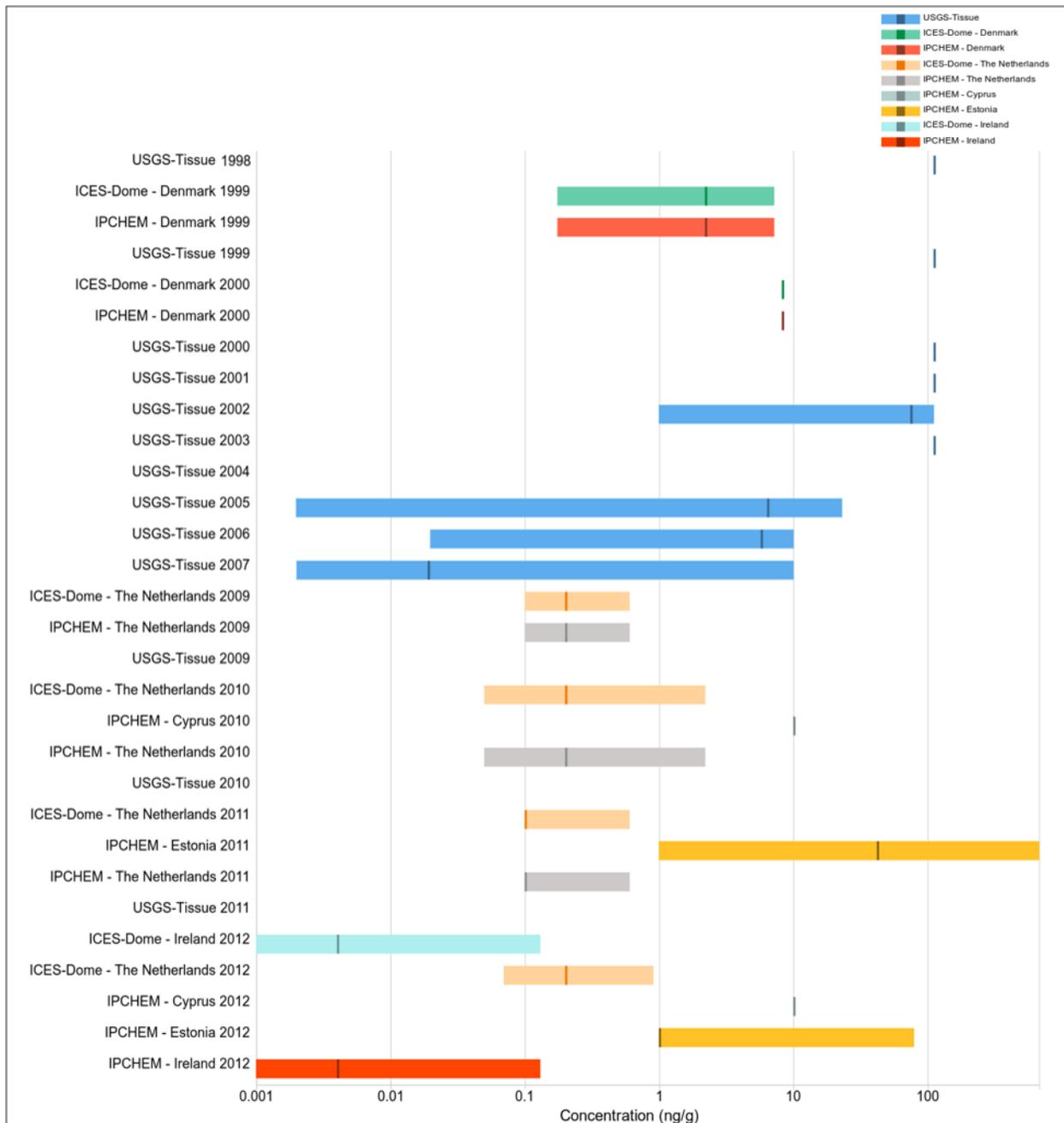


Figure 5-30. Concentration of HCBd (ng/g) in fish from 1998 through 2012. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

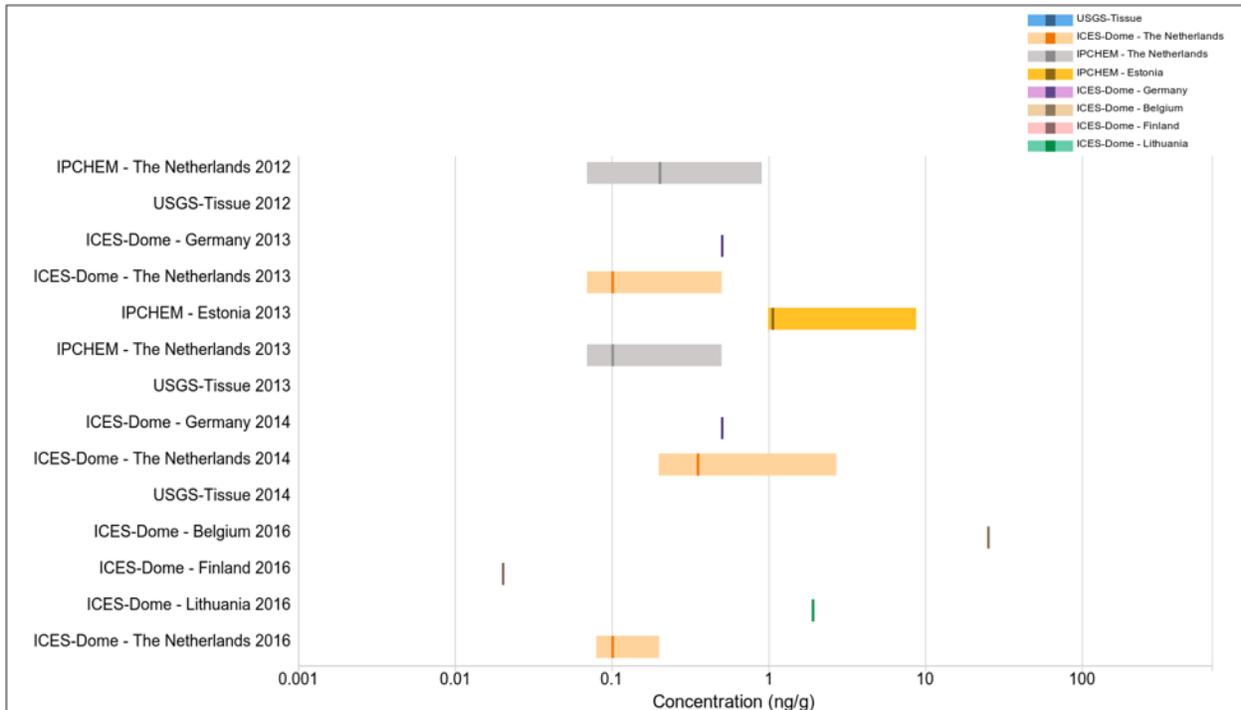


Figure 5-31. Concentration of HCBd (ng/g) in fish from 2012 through 2016. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

5.7.7. Aquatic Mammals

Two monitoring databases (ICES and IPCHEM) reported concentrations of HCBd in aquatic mammals in Denmark for two years, 1999 and 2000 ([EC, 2018](#); [ICES, 2018](#)). Results from both databases showed an increase from 1999 to 2000.

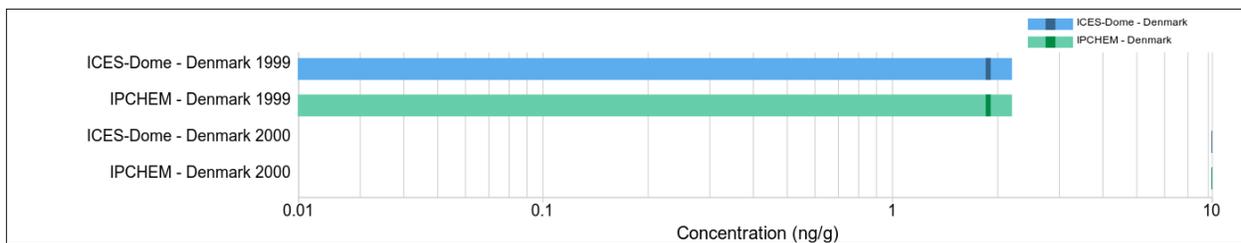


Figure 5-32. Concentration of HCBd (ng/g) in aquatic mammals in 1999 and 2000. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

5.8. Modeled Intake and Dose Data

One study was identified that modeled dermal dose of HCBd ([HHS, 2005](#)). Adults were found to have a slightly higher estimated dose than children ages 2-16 although all estimates were 0.04 ng/kg/day or lower.

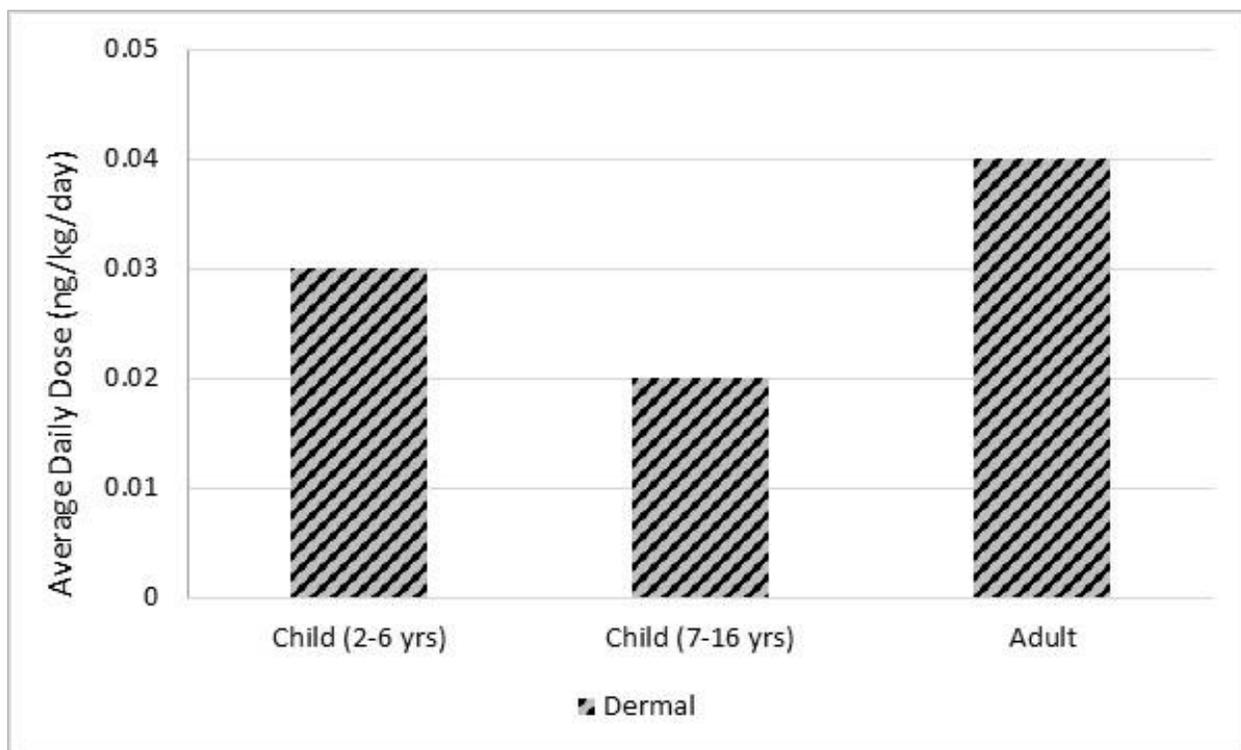


Figure 5-33. Estimated average daily dose (ng/kg/day) of HCBd for dermal exposure. Data are presented for adults and two groups of children between 2-6 and 7-16 years of age.

5.9. Overview of Existing Exposure Assessments

EPA identified two risk assessments of HCBd. An assessment by Environment Canada and Health Canada ([Canada, 2000](#)), *Priority Substances List Assessment Report: Hexachlorobutadiene*, stated that food and air appear to be the major routes of general population exposure for HCBd. Sources of HCBd included releases during refuse combustion and transboundary movement from foreign sources. This Canadian assessment estimated child and adult exposures from air, drinking water, and food as well as the total intake from these exposures; see Table 5-4. Data were insufficient to estimate intake from soil. The assessment also identified a conservative environmental exposure value for pelagic organisms of 0.0027 µg/L, which was the highest reported concentration of HCBd detected in the St. Clair River in 1994.

Table 5-4. Estimated Exposure of the General Population to HCBD (Environment Canada and Health Canada (2000))

Age Group	Estimated Total Intake (ng/kg/bw per day)
0 to 0.5 years	5.0×10^1 to 9.0×10^1
0.5 to 4 years	4.0×10^1 to 2.0×10^2
5 to 11 years	3.0×10^1 to 9.0×10^1
12 to 19 years	1×10^1 to 5×10^1
20 to 70 years	1×10^1 to 5×10^1

An assessment by [Euro Chlor \(2002\)](#) of risks to marine (North Sea) ecological receptors also identified food as being a potentially significant source of HCBD. This assessment did not provide unique concentrations or doses.

5.10. Representative Exposure Scenarios

HCBD is a highly regulated chemical. In tandem with increased regulation, releases of HCBD have declined over time. This is likely due to many factors including improved control technologies, increased use of processes that minimize waste, and required processing of waste at hazardous waste facilities which have more stringent control technologies to reduce emissions.

Human exposure to HCBD has limited documentation from one biomonitoring study. [Choudhary \(1995\)](#) provide a review of HCBD exposure to humans and notes potential for general population and occupational exposure at that time. The overall magnitude of exposures has likely decreased due to lower releases and control technologies within facilities. However, potential for human exposure remains. Based on its physical-chemical properties, inhalation is likely the primary exposure route although ingestion and dermal exposure are possible.

Exposure to ecological receptors has been documented. Several biomonitoring studies have reported levels in tissues of fish, birds, and invertebrates. Only a subset of these studies considers source attribution and includes exposure assessments. Those that do suggest that environmental and biological levels can be higher near point sources. In addition, the majority of these monitoring studies is older and represents conditions when HCBD was likely released to the environment in higher amounts. However, potential for ecological exposure remains as some current releases still occur as documented through reporting to TRI, DMR, and AMTIC databases.

Representative Exposure Scenarios:

Occupational: Byproduct generation of HCBD during manufacture of other chlorinated solvents results in fugitive vapors during processing operations. Workers at these manufacturing facilities can inhale these vapors. Both inhalation and dermal exposures are possible.

Occupational: Processing of HCBD into plastic articles results in fugitive vapors during unloading and transfer operations when the formulations containing HCBD are added to process

equipment. Workers at these processing facilities can inhale these vapors. Both inhalation and dermal exposures are possible.

Occupational: Industrial and commercial use of HCBP as a solvent in analytical standards results in fugitive vapors. Laboratory workers may inhale these vapors and incidental contact with exposed skin may occur from accidental spills during use of the standards. However, the use of engineering controls such as fume hoods and personal protective equipment is expected to reduce these exposures.

Occupational: Industrial and commercial use of waste derived fuel containing HCBP can result in fugitive vapors during loading and unloading operations. Workers can inhale these vapors and may be exposed due to accidental spills during transfer operations. However, these exposures are expected to be minimized due to small concentrations of HCBP in the fuel and when closed-system transfer operations are used.

Ecological: Releases to water from industrial operations during processing of HCBP into plastic articles leads to elevated concentrations of HCBP in surface water and sediment, where exposure to aquatic and terrestrial organisms can occur.

General Population: Releases of HCBP to air near industrial facilities from industrial and commercial use as a waste fuel can lead to elevated concentrations of HCBP in ambient air, where exposure to residents living near these facilities can occur.

5.11. Summary of Review Articles

Four review articles presented exposure and doses for HCBP. However, each of the review articles was relatively dated, with publication dates ranging from 1975 to 2001.

[Mumma and Lawless \(1975\)](#) conducted a study between June 1973 and October 1974 to identify possible sources and effects of a number of chemicals, including HCBP. At that time, HCBP was only imported to the U.S., primarily as by-product, contaminant, or component of waste materials from production of tetrachloride, perchloroethylene, and trichloroethylene. Due to its lack of degradation, the authors recommended disposal via incineration.

The International Programme on Chemical Safety ([IPCS, 1994](#)) identified emissions from waste and dispersive use as the main source of HCBP. Environmental transport occurs by volatilization, adsorption to particulate matter, and subsequent deposition or sedimentation. HCBP was predominantly found to be in sediment and biota. HCBP has been measured in urban air below $0.5 \mu\text{g}/\text{m}^3$ and below $1 \text{ pg}/\text{m}^3$ in remote areas. European freshwater concentrations were recorded up to $2 \mu\text{g}/\text{L}$ with mean levels below $100 \text{ ng}/\text{L}$. In the Great Lakes area of Canada, much lower levels (around $1 \text{ ng}/\text{L}$) were measured; however, sediment levels were as high as $120 \mu\text{g}/\text{kg}$ dry weight. Older sediment layers from around 1960 contained higher concentrations (up to $550 \mu\text{g}/\text{kg}$ wet weight). Concentrations of HCBP in aquatic organisms, birds, and mammals indicate bioaccumulation but not biomagnification. The concentrations of HCBP in freshwater biota measured since 1980 generally do not exceed $100 \mu\text{g}/\text{kg}$ fresh weight,

but in a polluted area can reach 120 mg/kg in the lipid of fish. HCBd has also been detected in human urine, blood, and tissues. One study reported occupational exposures of 1.6-12.2 mg/m³ and urine levels of up to 20 mg/L. Exposure of the general public mainly occurs indirectly via ingestion of drinking water and food of high lipid content. Assuming a maximum concentration of 2.5 µg/L in contaminated drinking-water and 10 µg/kg wet weight in contaminated fatty food items (meat, fish, milk) and daily intakes of 2 L drinking-water, 0.3 kg meat, 0.2 kg fish and 0.5 kg milk, the authors noted a maximum total daily intake of 0.2 µg/kg body weight can be calculated for a 70-kg person.

[Choudhary \(1995\)](#) reported HCBd in 72 ambient air samples collected from urban and other areas with expected high concentrations of HCBd at 3.6 ppt. HCBd was also detected in some surface waters, but the incidence of detection was low (12 of 593 ambient water samples in the EPA's STORET database). Additionally, HCBd was detected in some groundwater samples, coastal waters of the Gulf of Mexico, and fish samples. In addition, it was detected in drinking water at low levels and some foodstuffs in the UK and Germany, but not in the U.S. Exposures to HCBd are also likely from occupationally related use of this compound where inhalation and dermal contact are the most common routes of exposure.

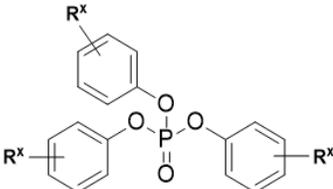
[Farrar \(2001\)](#) described a study conducted by ICI (the chemical company) investigating the fate, transport, and potential health implications resulting from the migration of HCBd in homes near its sandstone quarries located on the bluff of the Mersey estuary close to Weston village in England. As part of an extensive indoor monitoring program conducted by ICI, indoor air in a small number of properties was shown to have HCBd levels greater than 0.6 ppb (24 hour time-weighted average, the proposed toxicity benchmark), but the vast majority of properties in the vicinity of the quarries were shown to be much lower.

More recently, Environment Canada and Health Canada ([Canada, 2000](#)), conducted an HCBd exposure assessment and estimated daily intakes on the order of 10¹ to 10² ng/kg/day.

6. Phenol, Isopropylated, Phosphate (3:1)-PIP (3:1)

6.1. Chemistry and Physical-Chemical Properties

Chemical Name	Phenol, isopropylated, phosphate (3:1)
CASRN	2502-15-0
Synonyms	ITPP, PIP (3:1)
Molecular Formula	...

Structure	 <p>Where R^x = H or CH(CH₃)₂ and all three rings have at least one -CH(CH₃)₂ group.</p>
W	452.53
Density (g/cm³)	CAS 26967-76-0: 1.159 at 20°C (Kirk, 1982)
Molar Volume (cm³/mol)	390 [Calculated based on the molar mass and density]
Log K_{ow}	9.07 [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Log K_{OA}	14 [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Log K_{oc}	5.7 [K _{ow} method, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Vapor Pressure (mm Hg)	2.1 × 10 ⁻⁸ [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Henry's Law (atm-m³/mole)	2.9 × 10 ⁻⁷ [Bond Method, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Water Solubility (mg/L)	2.6 × 10 ⁻⁵ [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Water Solubility (mol/L)	5.8 × 10 ⁻¹¹ [Calculated based on water solubility and molecular weight, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]

6.2. Uses

Since the publication of the Use Document in August 2017 for PIP (3:1), EPA received 15 public comments on the Use Document and communicated with dozens of companies, industry groups, chemical users, and other stakeholders to aid in identifying and verifying conditions of use of PIP (3:1) ([U.S. EPA, 2017e](#)). These interactions and comments further informed EPA's understanding of the uses for PIP (3:1). The information and input received from the public comments and stakeholder engagement has been incorporated into this document to the extent appropriate. Non-confidential public comments and stakeholder meeting summaries are available in EPA's docket at [EPA-HQ-OPPT-2016-0730](#).

As reported to the 2016 CDR, the types of processes using PIP (3:1) include incorporation into articles, use as a chemical processing or manufacturing aid, and incorporation into a formulation, mixture or reaction product. Because PIP (3:1) is a liquid, processing into lubricant products and liquid flame retardants involves adding it into formulated mixtures.

PIP (3:1) is included in various formulations, where it may serve a functional purpose as a flame retardant, plasticizer, anti-compressibility additive, anti-wear additive, or some combination of these functions. PIP (3:1) is in hydraulic fluid, both in aviation and industrial machinery ([EPA-HQ-OPPT-2016-0730](#)). In these hydraulic fluids, PIP (3:1) acts as a flame retardant and as an anti-compressibility additive. It is also added to various lubricating oils, where it may act as a flame retardant or an anti-compressibility additive. In some cases, such as lubricating oils used in helicopter gear boxes and other circulating oils and grease for industrial equipment, its functional purpose is as an anti-wear additive ([EPA-HQ-OPPT-2016-0730](#)).

PIP (3:1) is also added to various industrial products where it acts as both a plasticizer and flame retardant. This includes epoxy coatings on the decks of shipping vessels, coatings for pipes and insulation in construction, adhesives and sealants in insulation for pipes in chemical plants and other manufacturing facilities ([U.S. EPA, 2017e](#))([EPA-HQ-OPPT-2016-0730](#)). PIP (3:1) has been generally identified, by commenters and others, as a possible component in plastic products and articles, including children’s products, automotive, and aerospace products ([U.S. EPA, 2017e](#))([EPA-HQ-OPPT-2016-0730](#)).

The uses of PIP (3:1) that are considered within the scope of the use and exposure assessment during various life cycle stages (i.e. manufacturing, processing, use (industrial, commercial and consumer), distribution and disposal) are depicted in Table 6-1 and the life cycle diagram (Figure 6-1). The information is grouped according to Chemical Data Reporting (CDR) processing codes and internationally harmonized functional, product and article use categories from the Organisation for Economic Co-operation and Development (OECD) in combination with other data sources (e.g., published literature and consultation with stakeholders), to provide an overview of conditions of use.

Use categories are drawn from Instructions for Reporting for the 2016 CDR. “Industrial use” means use at a site at which one or more chemicals or mixtures are manufactured (including imported) or processed. “Commercial use” means the use of a chemical or a mixture containing a chemical (including as part of an article) in a commercial enterprise providing saleable goods or services. “Consumer use” means the use of a chemical or a mixture containing a chemical (including as part of an article, such as furniture or clothing) when sold to or made available to consumers for their use ([U.S. EPA, 2016c](#)).

Table 6-1. Use Categories and Subcategories for PIP (3:1)

Life Cycle Stage	Category ^a	Subcategory ^b	References
Manufacturing	Manufacturing	Domestic manufacturing	U.S. EPA (2016a)
		Import	U.S. EPA (2016a)
Processing	Incorporated into formulation, mixture, or reaction product	Flame retardant in: <ul style="list-style-type: none"> • Plastic material and resin manufacturing • Plastics product manufacturing 	U.S. EPA (2016a) ; U.S. EPA (2017e)
		Aviation hydraulic fluid	U.S. EPA (2017e) ; EPA-HQ-OPPT-2016-0730
		Other industrial hydraulic fluid	U.S. EPA (2017e) ; EPA-HQ-OPPT-2016-0730
		Petroleum lubricating oils and grease manufacturing	U.S. EPA (2016a) ; EPA-HQ-OPPT-2016-0730
		Paints and coatings manufacturing – PIP 3:1 may act as a plasticizer, flame retardant, or both	U.S. EPA (2016a) ; EPA-HQ-OPPT-2016-0730
		Adhesives and sealants	U.S. EPA (2017e) ; U.S. EPA (2016a) ; EPA-HQ-OPPT-2016-0730

Life Cycle Stage	Category ^a	Subcategory ^b	References
	Processing, incorporation into an article	Flame retardant in <ul style="list-style-type: none"> • Adhesive manufacturing • Paint and coating manufacturing • Plastic material resin manufacturing • Transportation equipment (PIP 3:1 may serve multiple functional uses in these sectors, including as a plasticizer) 	U.S. EPA (2016a) ; EPA-HQ-OPPT-2016-0730
		Petroleum lubricating oil and grease manufacturing	U.S. EPA (2017e) ; U.S. EPA (2016a) ; EPA-HQ-OPPT-2016-0730
		Synthetic rubber manufacturing	U.S. EPA (2016a)
Distribution in commerce	Distribution	Distribution in commerce	U.S. EPA (2017e) ; U.S. EPA (2016a)
Industrial and commercial use	Hydraulic fluid	Aviation hydraulic fluid used in airplanes	U.S. EPA (2017e) ; U.S. EPA (2016a) ; EPA-HQ-OPPT-2016-0730
		Hydraulic fluid for other industrial functions such as mining equipment	U.S. EPA (2017e) ; CDR 2016, EPA-HQ-OPPT-2016-0730
	Lubricants and grease	Liquid lubricants and greases, for example – helicopter gear box oil	U.S. EPA (2017e) ; U.S. EPA (2016a) ; EPA-HQ-OPPT-2016-0730
	Paints and coatings	Solvent based paint, water based paint. PIP (3-1) may be incorporated into paints and coatings as a flame retardant and plasticizer	U.S. EPA (2017e) ; U.S. EPA (2016a) ; EPA-HQ-OPPT-2016-0730
	Adhesives and sealants	Single component adhesive such as – Vimasco industrial insulation adhesive – fasttack sealant spray	U.S. EPA (2017e) ; U.S. EPA (2016a)
Consumer Use	Complex articles	Road vehicles for passengers and goods	U.S. EPA (2017e) ; EPA-HQ-OPPT-2016-0730
		Other machinery, mechanical appliances, electronic/electronic articles	EPA-HQ-OPPT-2016-0730
	Plastic articles (hard and soft)	Furniture & furnishings, including furniture coverings	U.S. EPA (2017e) ; EPA-HQ-OPPT-2016-0730
		Toys intended for children's use (and child dedicated articles)	U.S. EPA (2017e) ; EPA-HQ-OPPT-2016-0730
Other	Insulation products not covered elsewhere	U.S. EPA (2017e) ; EPA-HQ-OPPT-2016-0730	
Disposal	Recycling	Incineration of lubricating oils containing PIP (3:1) for base oil recovery	EPA-HQ-OPPT-2016-0730

^aThese categories of conditions of use appear in the Life Cycle Diagram, reflect CDR codes and OECD codes, and broadly represent conditions of use of PIP (3:1) ether in industrial and/or commercial settings.

^bThese subcategories reflect more specific uses of phenol, isopropylated, phosphate (3:1) ether based on stakeholder outreach, and comments received on EPA's Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal published in August 2017.

Descriptions of the industrial, commercial, or consumer use categories identified from the 2017 OECD Harmonized Use Codes are summarized below ([OECD, 2017b](#)).

The “hydraulic fluid” category encompasses chemical substances, typically liquid, used for transmitting pressure and Extreme pressure (EP)-additives; and to transfer power in hydraulic machinery. This includes phosphate ester based hydraulic fluids for aircraft and other machinery.

The “lubricants and greases” category encompasses chemical substances used to reduce friction, heat generation and wear between solid surfaces. PIP (3:1) is in some lubricants and greases in small quantities as an anti-wear additive.

The “paints and coatings” category encompasses chemical substances used to paint or coat substrates. Phenol isopropylated phosphate is present in coatings in the insulation industry and marine industry as a plasticizer and flame retardant, and may be found in industrial coatings more widely. This includes paints that have been formulated with water or solvent as the main vehicle.

The “adhesives and sealants” category encompasses chemical substances used to fasten other materials together or prevent the passage of liquid or gas. PIP (3:1) is found as a flame retardant and plasticizer in adhesives and sealants in the insulation industry. This includes products that are single component adhesives and one component caulks which are premixed in their final product formulations.

The “complex articles” category encompasses road vehicles for passengers and goods such as cars and trucks, and machinery, mechanical appliances, electrical and electronic articles such as computers and drills.

The “plastic articles” category encompasses consumer products made of both hard and soft plastics, which include PIP (3:1) as a flame retardant or plasticizer, including toys intended for children's use, and furniture and furnishings, including furniture coverings such as computer casing and foam in furniture or mattresses.

The “other” category encompasses consumer articles not covered elsewhere, which contain PIP (3:1) as a flame retardant.

6.3. Characterization of Expected Environmental Partitioning

If released to air, the Henry's law constant (2.9×10^{-7} atm m³/mole) and log K_{OA} (14) of PIP (3:1) indicate it is likely to partition from the air into water and soil or airborne particles,

respectively. Particulate-bound PIP (3:1) may be removed from the atmosphere via wet or dry deposition.

If released to water, its log K_{ow} (9.07) and log K_{oc} (5.7), indicate PIP (3:1) released to surface water will adsorb to sediments and particulates suspended in the water column. PIP (3:1) is not likely to volatilize from surface water due to its Henry's law constant.

Due to its log K_{ow} and log K_{oc} , PIP (3:1) in wastewater is likely to be removed via adsorption to biosolids, which may then be landfilled, land-applied, or incinerated. PIP (3:1) is not expected to be removed from wastewater by volatilization due to its Henry's law constant. Although release of free PIP (3:1) with wastewater treatment plant effluent is expected to be limited, some PIP (3:1) may be adsorbed to small particles present in effluent.

If released to soil, PIP (3:1) is not expected to volatilize from moist or dry soils due to its Henry's law constant and vapor pressure (2.1×10^{-8} mm Hg). Based on its log K_{oc} and water solubility (2.6×10^{-5} mg/L), PIP (3:1) is likely to adsorb to soil and particulate organic matter. Free PIP (3:1) is not expected to be mobile in soil pore water or groundwater, but may be absorbed to colloids and other small particles which are mobile in subsurface environments.

If released to landfill, PIP (3:1) is expected to undergo limited, slow migration from solid waste into landfill leachate due to its log K_{oc} and water solubility. Based on its vapor pressure and log K_{OA} , PIP (3:1) is not likely to volatilize from solid waste.

PIP (3:1) also may partition to the tissues of organisms that live in water, soil, and sediment via dermal or gill exposure and ingestion. Exposure to water column organisms is also possible via resuspension of the chemical from the sediment to water either sorbed to particulates or part of the dissolved phase. The above characterization is meant to describe the primary behavior or movement of the chemical through a generic environment, not the complete exclusion of the chemical from a given media (e.g., water) or elimination of the possibility for more complex behavior in a particular location.

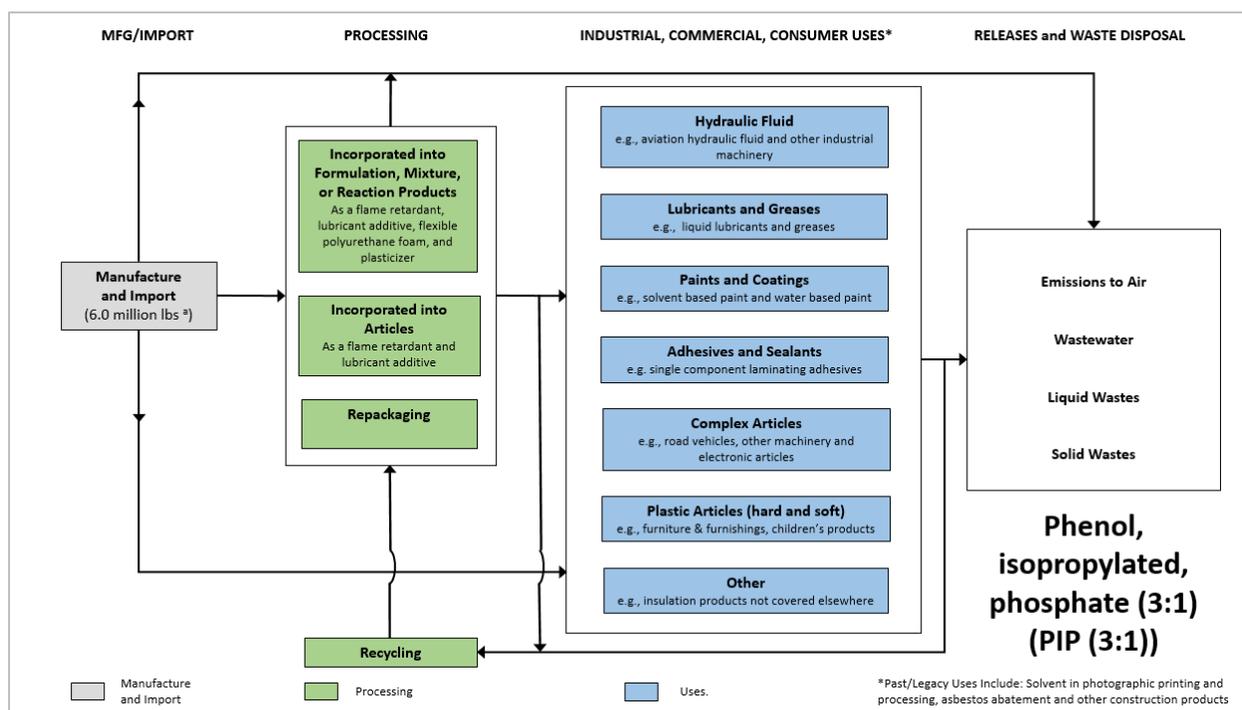
If released to the indoor environment, based on its vapor pressure and Henry's law constant, PIP (3:1) is not likely to volatilize from consumer products or articles, contaminated water, or other solutions. Any phenol, isopropylated, phosphate (3:1) that is emitted to indoor air is expected to partition to organic matter including dust due to its log K_{OA} . PIP (3:1) is most likely to be emitted from consumer products via abrasion or direct partitioning to dust and other particulates.

PIP (3:1) that is disposed down the drain with wastewater is expected to be associated with organic matter in the wastewater based on its log K_{oc} , and concentrations of free PIP (3:1) in the water column will be limited.

6.4. Overview of Lifecycle and Potential Sources of Exposure

6.4.1. Background and Brief Description of Lifecycle

PIP (3:1) belongs to the group of triaryl phosphates and is a type of organophosphate ester. It is a mixture of as many as 50 unspecified isomers. PIP (3:1) is primarily incorporated into flexible polyurethane foam, plasticizers, and lubricants as a flame retardant. It is used as a component in consumer products such as furniture and furnishings. It is also used in a variety of industrial or commercial liquids such as hydraulic fluid, greases, paints, coatings, and adhesives. The end-of-life disposal options for products containing PIP (3:1) include disposal in landfills, recycling, and incineration ([EPA-HQ-OPPT-2016-0730](#)).



^aCDR data for 2015.

Figure 6-1. Lifecycle Diagram for PIP (3:1)

6.4.2. Manufacturing

Triaryl phosphates are manufactured from phosphorous oxychloride and phenol. The manufacturing process is carried out in closed reactors and the hydrogen chloride gas generated during the reaction absorbed in water. One manufacturer indicated the process has three stages of reaction followed by a distillation stage. From distillation, PIP (3:1) can be recycled back to the first reactor as needed. The product is sent through a batch washing step to remove small contaminants. Dehydration and filtration steps then remove water and any further solids to make a clear product. The final product is transferred to temporary storage until use or sale. This process occurs in continuous, closed operations except during the batch

washing step, which is performed under vacuum. Hydration and filtration is also a closed system.

Generally, there is no waste produced in the manufacture of the chemical with almost 100 percent of the material recycled back into the reactors. However, fugitive air releases from various process steps, water releases from separation and drying steps as well as equipment and area cleaning, and land releases from disposal of spent filters are expected ([EPA-HQ-OPPT-2016-0730](#)). Inhalation exposures from fugitive emissions during the reaction, drying, and transfer operations may occur. Incidental dermal exposure from product sampling and transfer operations may also occur ([EPA-HQ-OPPT-2016-0730](#)).

Table 6-2. Production Volume of Phenol, Isopropylated, Phosphate (3:1)

CDR Reporting Year	2010	2011	2012	2013	2014	2015
Production Volume (lb)	12,362,683	14,932,040	3,191,017	2,968,861	5,632,272	5,951,318

6.4.3. Processing: Incorporation into Formulation, Mixture, or Reaction Products

PIP (3:1) is used as a formulation component and incorporated into mixtures for a variety of products including plastic resins, hydraulic fluids, lubricating oils and grease, and adhesives and sealants. Releases to air, water, and land are expected from the associated unit operations. The primary sources of release include container residue, process equipment cleaning, and off-spec products ([OECD, 2009](#)). Although PIP (3:1) has a low vapor pressure, fugitive air emissions may occur from unloading, transfer into process equipment, and packaging of the final product. Releases to water may result from equipment and general area cleaning with aqueous cleaning materials. Land releases may occur from disposal of empty transport containers and off-spec product. Inhalation exposure to fugitive vapors is expected to be minimal due to the low vapor pressure, but inhalation exposure to plastic resins containing PIP (3:1) may occur during unloading, transfer, and processing. Dermal exposure is possible from incidental contact during unloading and transfer operations and from product packaging ([OECD, 2009](#)).

6.4.4. Processing: Incorporation into Articles

PIP (3:1) is an additive flame retardant that is used in a variety of articles including plastic resins, foam, and synthetic rubber. Flame retardants in general are incorporated into products in one of two manners. They are either chemically bound to the product matrix as “reactive” mixtures, or they are dissolved in the polymer materials as “additives.” Additive flame retardants are not chemically bound and are relatively unattached to the polymer matrix. Therefore, they have the potential of migrating from products to the surrounding environment during manufacture, normal use, and disposal ([Verslycke et al., 2005](#)).

Flexible polyurethane foam is manufactured in “slabstock” or “molded” forms. The slabstock manufacturing process generates continuous slabs of foam or buns which are cut to shape for the finished product. Typically, buns cure for 24 hours before fabrication or shipping and off

gassing may occur. Fugitive and stack (or point) air releases of PIP (3:1) may occur from gasses generated from this and other processes. Releases to land are expected from disposal of waste foam generated from cutting operations, floor sweepings, and disposal of empty transport containers. Releases to water are possible from equipment and general area cleaning operations. Inhalation exposure to volatile emissions from curing and unloading operations may occur. Inhalation and dermal exposure to particulates may also occur during the cutting and finishing steps that can generate fugitive dust. Molded foam is produced when the polymerization occurs in a closed mold resembling the shape of the final product. Similar releases and occupational exposures are expected ([U.S. EPA, 2005a](#)).

Releases of additives from rubber manufacturing are possible to water, air, and land. Water releases are expected to be most prevalent. Sources include processed wastewater from cooling or heating medium and vulcanization, where water has direct contact with the rubber mixture. Releases to water can also occur from equipment and general area cleaning with aqueous cleaning solutions ([OECD, 2004](#)). Land releases are possible from the disposal of off-spec product and empty transfer containers. Air releases are expected to be minimal; however, fugitive air releases are possible. Occupational inhalation exposure to fugitive vapors is possible, and incidental dermal exposure is expected during unloading and transfer operations when the PIP (3:1) is added to process equipment. Once incorporated into the rubber formulation and reacted, worker exposure is not expected ([OECD, 2004](#)).

6.4.5. Industrial Use: Hydraulic Fluid / Lubricants and Greases

Organophosphate esters are among the most widely used classes of synthetic compounds in hydraulic fluids, in part because they impart better fire resistance than mineral oils and are better lubricants than water. PIP (3:1) is used in aviation and industrial machinery hydraulic fluid [EPA-HQ-OPPT-2016-0730](#). In these hydraulic fluids, PIP (3:1) acts as a flame retardant and as an anti-compressibility additive. After the useful life of the hydraulic oils, the used oil is recovered for reuse or incinerated. PIP (3:1) is also added to various lubricating oils, where again it may act as a flame retardant or an anti-compressibility additive. In some cases, such as lubricating oils used in helicopter gear boxes and other circulating oils and grease for industrial equipment, its functional purpose is as an anti-wear additive (Akin Gump; Shell).

PIP (3:1) is added to formulations during the manufacture of hydraulic fluids, lubricants, and greases in batch blending processes and incorporated into equipment for use (e.g., aircraft and automotive) ([EPA-HQ-OPPT-2016-0730](#)). Fugitive air releases of PIP (3:1) are expected to be minimal due to its low vapor pressure. Water and land releases are not expected from waste hydraulic fluids and greases because used fluids and grease are typically collected for reuse or incineration ([EPA-HQ-OPPT-2016-0730](#)). Dermal exposure to PIP (3:1) (full hand immersion, splashing, or spraying) is expected from handling hydraulic fluids, lubricants and greases. Inhalation exposure to fugitive vapors is expected to be minimal, but possible; inhalation exposure to mist is possible if the fluid is spray-applied. Transportation workers aside from those who regularly handle these fluids can also be exposed to hydraulic fluid vapor; for example, airline crews exposed to hydraulic or engine oil smoke or fumes ([Austrian Federal Ministry of Agriculture, 2013](#)).

6.4.6. Industrial/Commercial Use: Paints and Coatings / Adhesives and Sealants

PIP (3:1) is added to coatings, adhesives, and sealants for a variety of industrial uses. This includes epoxy coatings on the decks of shipping vessels, coatings for pipes and insulation in construction, and adhesives and sealants in pipe insulation in chemical plants and other manufacturing facilities (Akzo Nobel; Vimasco). Potential application methods of these coatings to industrial substrates may include roll, dip, and spray processes. The quantity of releases and level of occupational exposures varies with each process; however, each presents possible releases to all media (air, water, land) and exposure to all routes (inhalation to vapors or mists and dermal exposure to liquids). Release sources include: fugitive air emissions of vapors from transfer operations and the application process, and overspray if spray application is used; water releases from equipment cleaning with aqueous cleaning solutions and waste from bath dumps; and land releases from empty transfer containers and substrate trimming or other finishing processes. Inhalation exposure to fugitive vapors from transfer operations, equipment cleaning, and application processes may occur. Inhalation exposure to mists is expected if a spray or roll coating application process is used. Each of these processes is also expected to result in dermal exposure ([OECD, 2009](#)).

6.4.7. Consumer Use: Complex Articles / Plastic Articles / Other

PIP (3:1) has been generally identified by commenters and others as a possible component in plastic products and articles, including children's, automotive, and aerospace products ([EPA-HQ-OPPT-2016-0730](#)).

6.4.8. Qualitative Trends Over Time for Releases for Releases and Occupational Exposures

PIP (3:1) is not reported to the Toxics Release Inventory and no release data over time were identified. However, the production and use of PIP (3:1) may have increased since the flame retardant pentabromodiphenylether was banned and phased out of production in 2013. Since that time, a prominent flame retardant formulation with PIP (3:1) as a component began to be used in increasing quantities in upholstered furniture, infant products, and other items, such that it became one of the most commonly detected flame retardants in the U.S. ([NTP, 2013](#)). Releases to various media of this flame retardant may have increased proportionally with an increase in production and use volume. Conversely, some products identified in August 2017, including intumescent firestop and asbestos abatement products, are no longer in commerce, or no longer include PIP (3:1) in their formulations ([EPA-HQ-OPPT-2016-0730](#)).

6.5. Environmental Monitoring

PIP (3:1) was detected in relatively few environmental monitoring studies. A supplemental search for PIP (3:1) was conducted to determine if any studies co-reported information on aryl phosphate chemicals. A few studies reported PIP (3:1) itself in environmental media. The chemical most reported in environmental media from the supplemental search is Triphenyl

Phosphate (TPP). TPP and PIP (3:1) can be found in the same mixture, formulation, or article. Instead, Table 6-3 provides a summary of the monitoring data for PIP (3:1) and TPP identified in the peer-reviewed literature across all media considered. Also included in the count are available monitoring database sources. Only studies or databases that reported measurements of the chemical of interest above the limit of detection were extracted and included in the “# of studies” count. The frequency of detection is provided as a measure, across all samples in all extracted studies, of the frequency that the chemical was measured above the limit of detection. Note, the frequency of detection is reported only for peer-reviewed sources, unless the only data sources available were database sources.

This is generally consistent with the fate summary and reported physical-chemical properties in that PIP (3:1) was detected in indoor dust, soil, ambient air, and sediment in higher concentrations and was not reported in other media. However, reported uses indicate higher likelihood of release to water and no detections in water were found.

Table 6-3. Summary of PIP (3:1) and TPP Monitoring Data from the Peer-Reviewed Literature

Media	Presence	No. of Datasets	Frequency of Detection
Indoor dust	Yes	29	95%
Indoor air	Yes	9	62%
Ambient air	Yes	2	87%
Surface/Ground water	No	0	n/a
Drinking water	No	0	n/a
Soil	Yes	2	38%
Sediment	Yes	3	66%
Biosolids	No	0	n/a
Wastewater (influent, effluent)	No	0	n/a
Landfill leachate	No	0	n/a
Vegetation/Diet	No	0	n/a
Other	No	0	n/a

The following chart provides the number of studies that have reported PIP (3:1) monitoring data over time. For this chart, the year the study is published rather than the sampling timeframe is used as a proxy, though for most studies, samples were collected a few years prior to publication. Note, EPA recognizes that the sampling dates, rather than the publication date, would be a better reflection of temporal trends.

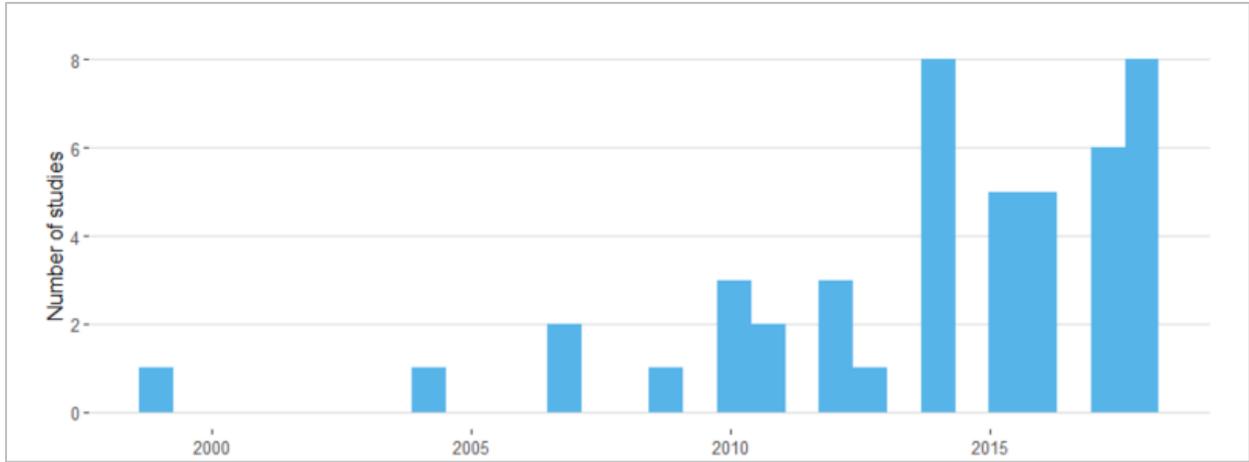


Figure 6-2. Frequency of peer-reviewed publications identified that contained PIP (3:1) and TPP monitoring data.

All environmental monitoring data that passed EPA’s evaluation criteria are presented graphically in the plots below. These plots help visualize the data and are organized by study year and microenvironment, when reported. Note, some studies are discussed in Sections 6.7 and 6.11 as they pulled together information on monitoring data alongside supplemental contextualizing information on uses, sources, and trends.

6.5.1. Indoor Dust

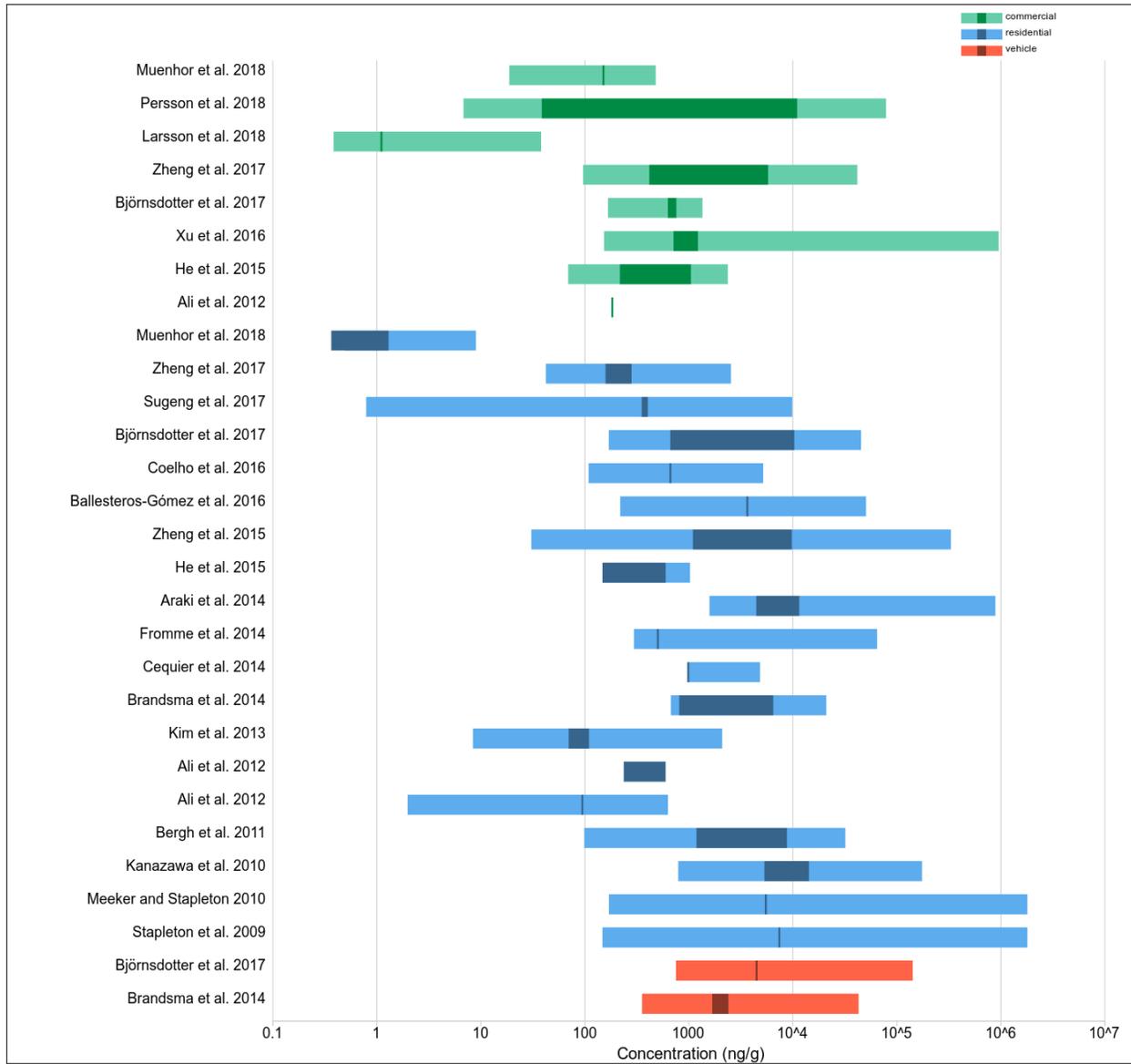


Figure 6-3. Concentration of PIP (3:1) and TPP (ng/g) in indoor dust for commercial locations (2012 to 2018), residential locations (2009 to 2018), and vehicles (2014 and 2017). For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Larsson et al., 2018](#); [Muenhor et al., 2018](#); [Persson et al., 2018](#); [Björnsdotter et al., 2017](#); [Sugeng et al., 2017](#); [Zheng et al., 2017](#); [Ballesteros-Gómez et al., 2016](#); [Coelho et al., 2016](#); [Xu et al., 2016](#); [He et al., 2015](#); [Zheng et al., 2015a](#); [Araki et al., 2014](#); [Brandsma et al., 2014](#); [Cequier et al., 2014](#); [Kim et al., 2013](#); [Ali et al., 2012b](#); [Ali et al., 2012a](#); [Bergh et al., 2011](#); [Kanazawa et al., 2010](#); [Meeker and Stapleton, 2010](#); [Stapleton et al., 2009](#))

6.5.2. Indoor Air

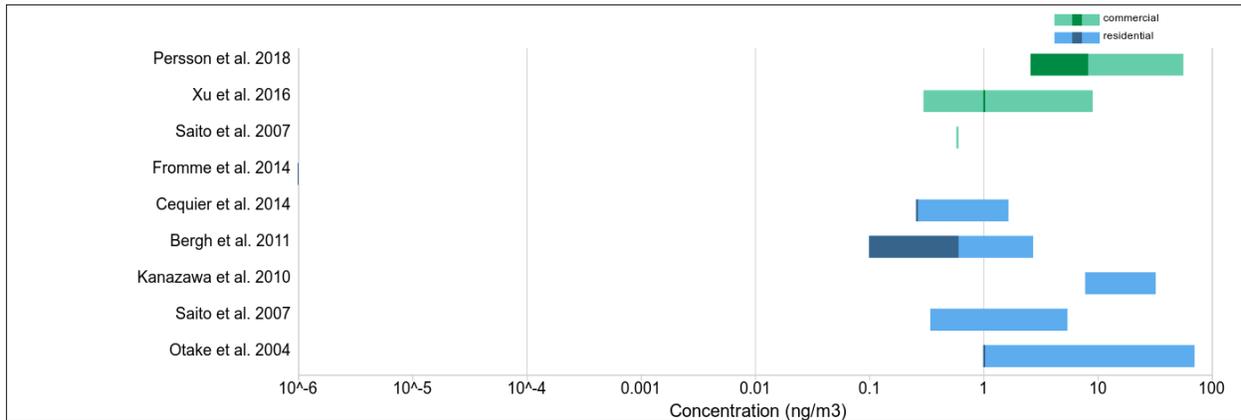


Figure 6-4. Concentration of PIP (3:1) and TPP (ng/m³) in indoor air for commercial (2007 to 2018) and residential (2004 to 2014) locations. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Persson et al., 2018](#); [Xu et al., 2016](#); [Cequier et al., 2014](#); [Fromme et al., 2014](#); [Bergh et al., 2011](#); [Kanazawa et al., 2010](#); [Saito et al., 2007](#); [Otake et al., 2004](#))

6.5.3. Ambient Air

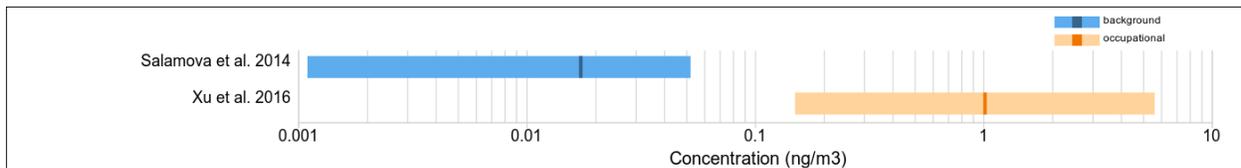


Figure 6-5. Concentration of PIP (3:1) and TPP (ng/m³) in ambient air for background (2014) and occupational (2016) locations. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Xu et al., 2016](#); [Salamova et al., 2014](#))

6.5.4. Soil

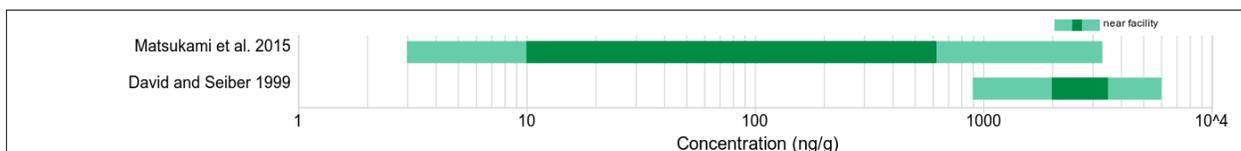


Figure 6-6. Concentration of PIP (3:1) and TPP (ng/g) in soil for near facility (1999 and 2015) locations. For each year, the range of values reported is presented by the entire length of the

bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Matsukami et al., 2015](#); [David and Seiber, 1999](#))

6.5.5. Sediment

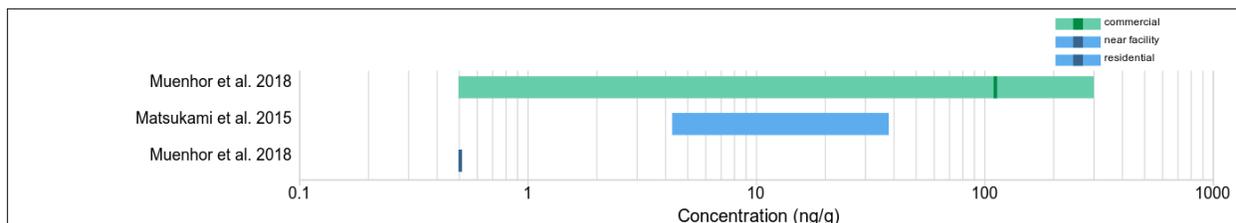


Figure 6-7. Concentration of PIP (3:1) and TPP (ng/g) in sediment for commercial (2018), near facility (2015), and residential (2018) locations. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Muenhor et al., 2018](#); [Matsukami et al., 2015](#))

6.5.6. Other

EPA did not identify any studies with extractable PIP (3:1) nor TPP data in surface water, drinking water, wastewater treatment plants influent or effluent, or landfill leachate. PIP (3:1) is not expected to be present in these media due to the following:

- For surface water, PIP (3:1) is expected to adsorb to sediments and particulates suspended in the water column based on its log K_{ow} (9.07) and log K_{oc} (5.7).
- For drinking water, PIP (3:1) is expected to adsorb to suspended particulates based on its log K_{ow} (9.07) and log K_{oc} (5.7).
- For wastewater treatment plants influent or effluent, due to its log K_{ow} and log K_{oc} , PIP (3:1) in wastewater is likely to be removed via adsorption to biosolids, which may then be landfilled, land-applied, or incinerated.
- For landfill leachate, PIP (3:1) is expected to undergo limited, slow migration from solid waste into landfill leachate due to its log K_{oc} and water solubility.

Of the studies searched, EPA did not identify any studies with detectable levels of PIP (3:1) nor TPP in sludge/biosolids or vegetation/diet.

6.6. Biomonitoring

A small number of studies show PIP (3:1) detected in any biological matrix. No monitoring data were identified for PIP (3:1). Instead, Table 6-4 summarizes the biomonitoring data for TPP identified in the peer reviewed literature across all matrices considered. Also included in the count are available monitoring database sources. Only studies or databases that reported

measurements of the chemical of interest above the limit of detection were extracted and included in the “# of studies” count. The frequency of detection is provided as a measure, across all samples in all extracted studies, of the frequency that the chemical was measured above the limit of detection. Note, the frequency of detection is reported only for peer-reviewed sources, unless the only data sources available were database sources.

PIP (3:1) was detected in matrices where it was expected due to physical-chemical properties; however, for many matrices, PIP (3:1) data has not been collected.

Table 6-4. Summary of TPP, a Surrogate for PIP (3:1), Biomonitoring Data from the Peer-Reviewed Literature

Matrix	Presence	No. of Datasets	Frequency of Detection
Human blood (serum)	Yes	1	100%
Human (other)	Yes	5	85%
Fish	No	0	n/a
Birds	Yes	1	84%
Terrestrial invertebrates	No	0	n/a
Aquatic invertebrates	No	0	n/a
Terrestrial mammals	Yes	1	100%
Aquatic mammals	No	0	n/a
Other	No	0	n/a

The following chart provides the number of studies that reported TPP biomonitoring data over time. For this chart, the year the study is published rather than the sampling timeframe is used as a proxy, though for most studies, samples were collected a few years prior to publication. Note, EPA recognizes that the sampling dates, rather than the publication date, would be a better reflection of temporal trends.

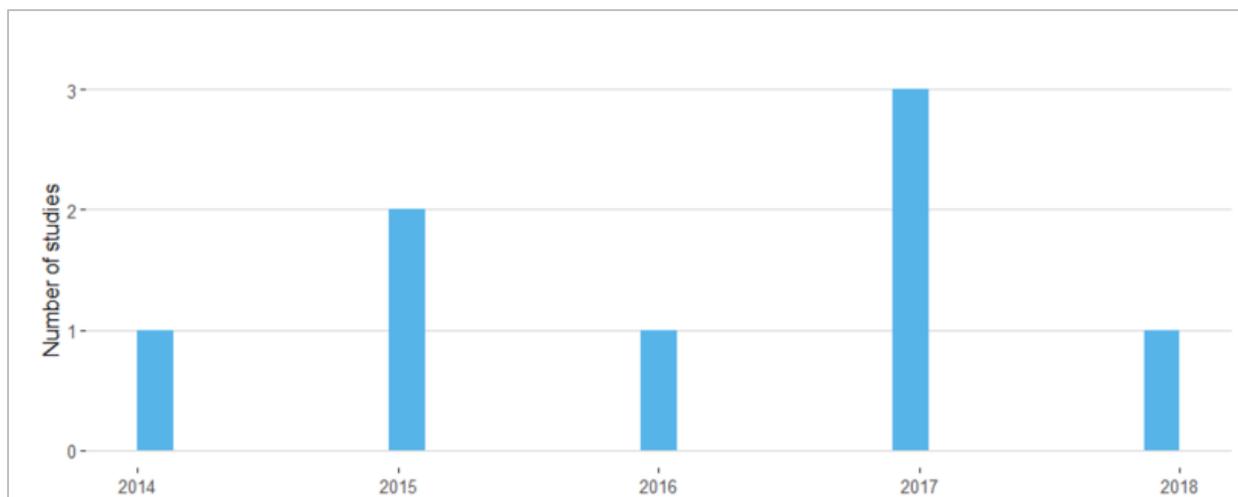


Figure 6-8. Frequency of peer-reviewed publications identified that contained TPP, a surrogate for PIP (3:1), biomonitoring data.

6.6.1. Human blood (serum)



Figure 6-9. Concentration of TPP (ng/g), a surrogate for PIP (3:1), in human blood (serum) for the general population in 2017. The minimum and maximum of reported central tendency estimates are shown.

This figure contains data for the following: ([Henríquez-Hernández et al., 2017](#))

6.6.2. Human (other)

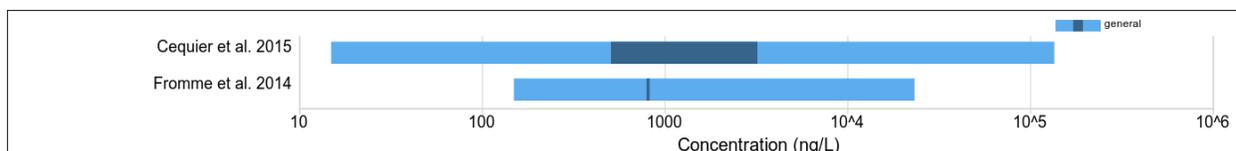


Figure 6-10. Concentration of TPP (ng/L), a surrogate for PIP (3:1), in human (other) for the general population in 2014 and 2015. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Cequier et al., 2015](#); [Fromme et al., 2014](#))

6.6.2.1. Dermal Wipes

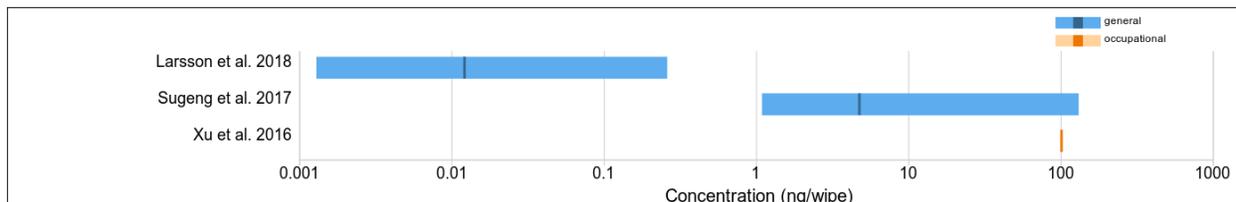


Figure 6-11. Concentration of TPP (ng/wipe), a surrogate for PIP (3:1), in dermal wipes for the general (2017 and 2018) and occupational (2016) populations. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Larsson et al., 2018](#); [Sugeng et al., 2017](#); [Xu et al., 2016](#))

6.6.3. Birds

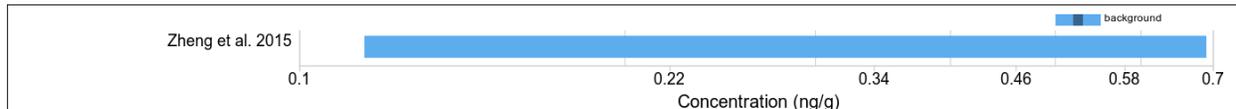


Figure 6-12. Concentration of TPP (ng/g), a surrogate for PIP (3:1), in birds for background locations in 2015. The range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([Zheng et al., 2015b](#))

6.6.4. Terrestrial mammals



Figure 6-13. Concentration of TPP (ng/g), a surrogate for PIP (3:1), in terrestrial mammals for background locations in 2017. The minimum and maximum of reported central tendency estimates are shown.

This figure contains data for the following: ([Henríquez-Hernández et al., 2017](#))

6.6.5. Other

EPA did not identify any studies with detectable levels of PIP (3:1) nor TPP in aquatic invertebrates, fish, aquatic mammals, or terrestrial invertebrates.

6.7. Trends in Monitoring Data

EPA did not identify any studies that reported trends for PIP (3:1) nor closely-related chemicals. Of the monitoring databases searched, no monitoring data was available for PIP (3:1).

6.8. Modeled Intake and Dose Data

Five studies modeled the average daily dose for TPP, a closely-related chemical to PIP (3:1) ([Larsson et al., 2018](#); [Muenhor et al., 2018](#); [Zheng et al., 2017](#); [Coelho et al., 2016](#); [He et al., 2015](#)). Estimated doses were generally less than 2 ng/kg/day, with a few exceptions seen. For [He et al. \(2015\)](#), the average daily dose calculated using the average concentration in dust is presented in the figure below. The error bars represent the daily dose corresponding to maximum concentrations in dust samples.

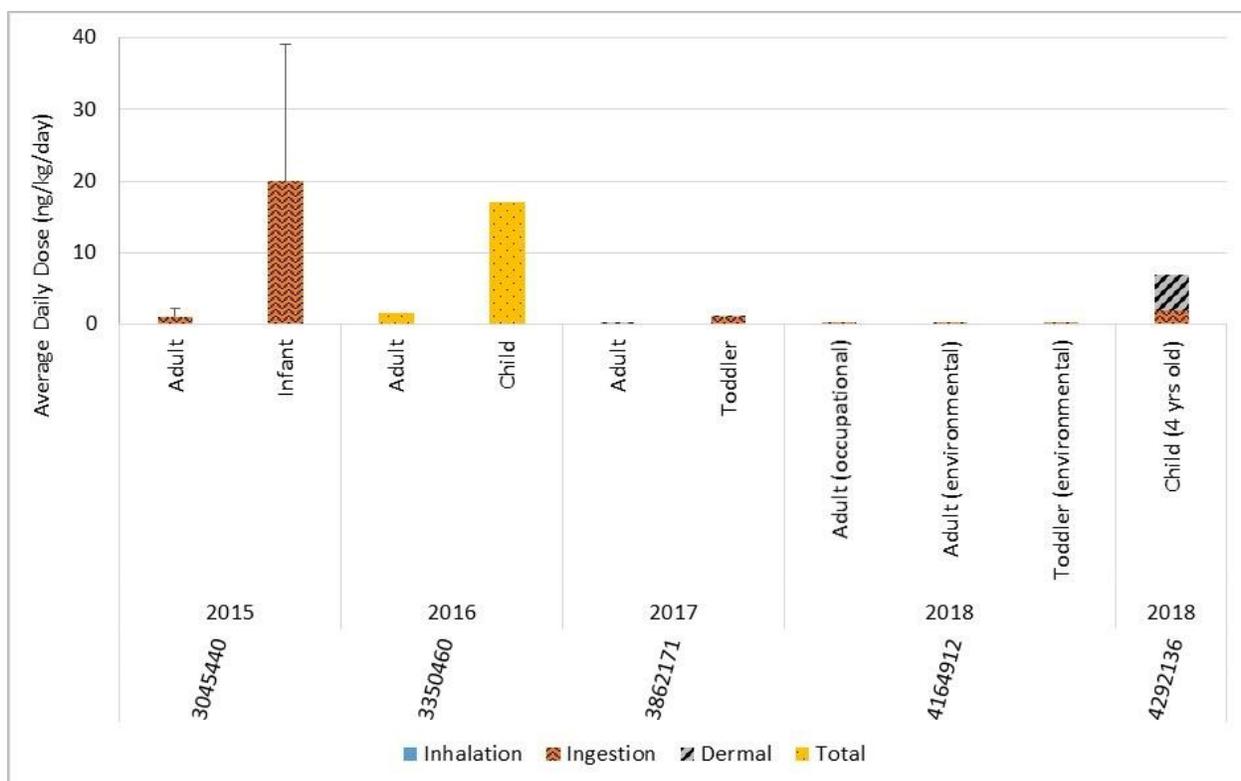


Figure 6-14. Estimated average daily dose (ng/kg/day) of TPP, a closely related chemical to PIP (3:1), for inhalation (blue), ingestion (orange), dermal (grey), and total (gold) exposure. Data are presented for infants, toddlers, children, and adults. If available, information on the age range and location of exposure are provided in the x axis description. The study year and HERO ID (diagonal text below the year) are also provided. Error bars represent the average daily dose estimated using maximum concentrations in dust samples.

In addition to modeled doses, one study estimated intake of TPP, a closely related chemical to PIP (3:1) ([Björnsdotter et al., 2017](#)). An additional scenario described as a worst case scenario was not plotted in the figure below. The worst case scenario assumed high dust ingestion and maximum concentration in dust and resulted in estimated doses of 157, 428, 191, and 3100 ng/day for workers, drivers, non-workers, and stay-at-home toddlers, respectively.

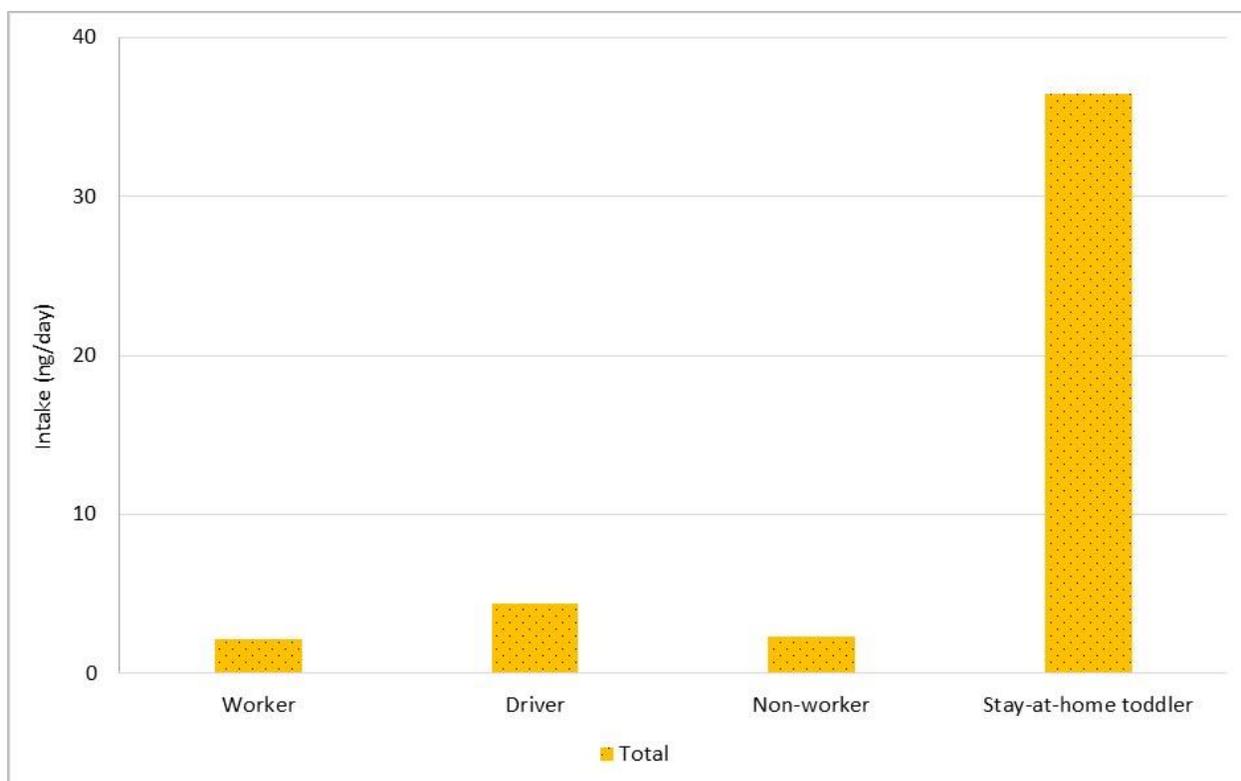


Figure 6-15. Estimated average intake (ng/day) of TPP, a closely related chemical to PIP (3:1), for total exposure. Data are presented for workers, drivers, non-workers, and stay-at-home toddlers.

6.9. Overview of Existing Exposure Assessments

A human health and environmental risk evaluation of PIP (3:1) was sponsored by the Environment Agency of the United Kingdom and Wales (and referred to as isopropylated triphenyl phosphate) ([European Environment Agency, 2009](#)). This assessment calculated predicted concentrations in air, soil, drinking water, food (fish, root crops, leaf crops, meat, and milk) and reported total daily human intake from regional sources and 22 production or application scenarios. These scenarios were based on OECD emission scenario methods for plastic additives (i.e., polyvinyl chloride additive), lubricants, and scenarios developed under the UK Existing Substances Regulation for other substances with similar uses, e.g., thermoplastics and polyurethane, textile coating, pigment dispersions, paints, and adhesives. The scenarios predicted to have the highest total daily intakes were two polyvinyl chloride-related scenarios—compounding and combined compounding and conversion (1.1×10^5 and 1.2×10^5 ng/kg bw/day, respectively) and textile/fabric coating—combined compounding and application of coating (1.0×10^5 ng/kg bw/day). This assessment predicted total intake from regional sources to be much lower than these industrial scenarios (3.0×10^2 ng/kg bw/day).

6.10. Representative Exposure Scenarios

PIP (3:1) has a wide variety of uses with potential for release and exposure. However, there is limited data for PIP (3:1) itself to document these exposures. Human exposure to PIP (3:1) has limited documentation from one completed assessment, and read-across monitoring data from TPP and other aryl phosphates. Based on its physical-chemical properties, ingestion is likely the primary exposure route. Inhalation would likely be comprised of particles which could be swallowed, and dermal absorption is likely low. There is also limited documentation for exposure to ecological receptors from one completed assessment, and read-across monitoring data from TPP and other aryl phosphates.

Representative Exposure Scenarios:

Occupational: Manufacturing of PIP (3:1) results in fugitive emissions from reaction, drying, and transfer operations. Workers can inhale these emissions and incidental dermal contact during unloading and transfer operations can occur. Inhalation and dermal exposure to workers in manufacturing facilities is possible.

Occupational: Processing of PIP (3:1) into articles such as plastic resins, foam, and synthetic rubber results in generation of fugitive vapors from liquid formulations containing PIP (3:1) and from curing steps. Fugitive dust from cutting and finishing operations can also be generated. Workers can inhale these vapors and dusts, and particles can settle on exposed skin. Workers can also be exposed to liquid formulations when small quantities of the liquid are spilled during transfer operations. Both inhalation and dermal exposures are possible.

Occupational: Processing of PIP (3:1) into hydraulic fluids, lubricating oils, and grease results in incidental dermal contact during unloading and transfer operations. Dermal exposure to workers in these processing facilities is possible.

Occupational: Use of PIP (3:1) in hydraulic fluids, lubricating oils, and grease results in full hand immersion, splashing, or spraying during handling. Dermal exposure to workers who use these products is possible. Inhalation and dermal exposure to mist from spray application of these products is also possible.

Occupational: Use of PIP (3:1) in industrial coatings. Application methods that include spray or roll coating result in generation of mist. Inhalation of mists for workers in these facilities performing these tasks is possible. Dermal exposure is also possible.

Ecological: Fugitive releases from manufacturing result in releases to air, which deposit to nearby waterbodies and catchments, leading to increased concentrations in sediment and soil and potential uptake into organisms who ingest or reside within sediment and soil.

General Population: As reported in the UK assessment, releases to air and water from processing and use facilities leads to presence in air, soil, drinking water, and dietary sources which contribute to intake to the general population.

Consumer: Residential homes may contain several articles with PIP (3:1). These articles can emit PIP (3:1) into indoor air and indoor dust through direct transfer, abrasion, and diffusion. Indoor air is inhaled and indoor dust is ingested by children and may lead to increased internal dose of PIP (3:1).

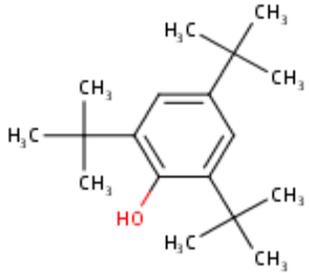
6.11. Summary of Review Articles

No review articles were identified that presented exposure estimates or doses for PIP (3:1) other than the authoritative sources presented in Section 6.9. For PIP (3:1), the United Kingdom Environmental Agency conducted a human health and environmental risk assessment for PIP (3:1) and predicted occupational exposures on the order of 0.1 mg/kg/day and general population exposures on the order of 3×10^{-4} mg/kg/day driven by consumption of contaminated fish ([European Environment Agency, 2009](#)).

From Section 6.6, human biomonitoring studies report TPP serum levels in the range of 2 ng/g.

7. 2, 4, 6-Tris(tert-butyl) Phenol (2, 4, 6-TTBP)

7.1. Chemistry and Physical-Chemical Properties

Chemical Name	2,4,6-Tris(-tert-butyl)phenol
CASRN	732-26-3
Synonyms	2,4,6 TTBP, 2,4,6-TRIS, 2,4,6-tritert-butylphenol; 2,4,6-Tri(tert-butyl)phenol; Phenol, 2,4,6-tris(1,1-dimethylethyl); 2,4,6-Tris(tert-butyl)phenol; 2,4,6-Tri(Tert-Butyl)Phenol; 2,4,6-Tri-t-butylphenol; 2,4,6-Tri-tert-butylphenol; 2,4,6-Tris(1,1-dimethylethyl)phenol; Phenol, 2,4,6-tri-tert-butyl-; Polyolefin alkyl
Molecular Formula	C ₁₈ H ₃₀ O
Structure	
MW	262.43
Density (g/cm³)	0.864 at 27°C (Haynes et al., 2014)
Molar Volume (cm³/mol)	304 [Calculated based on the molar mass and density]
Log K_{ow}	6.06 (Chemicals Inspection and Testing Institute, 1992)
Log K_{oA}	9.5 [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Log K_{oc}	4.4 [K _{ow} method, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Vapor Pressure (mm Hg)	6.6×10^{-4} [Extrapolated from (Liley, 1984)]

Henry's Law (atm·m ³ /mole)	6.5x10 ⁻⁶ [Calculated based on VP/WS, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Water Solubility (mg/L)	35 (Chemicals Inspection and Testing Institute, 1992)
Water Solubility (mol/L) ^c	1.3 × 10 ⁻⁴ [Calculated based on water solubility and molecular weight]

7.2. Uses

Use of 2,4,6 TTBP is prohibited by engineering standards of some large businesses in the U.S. For example, Toyota's North America construction site management handbook prohibits 2,4,6 TTBP due to its ban in Japan ([Toyota Motor Engineering & Manufacturing, 2007](#)). GE's Design Requirements for Regulated Materials and Chemicals lists 2,4,6-Tris(-tert-butyl)phenol as prohibited from use in parts, products, or other chemical substances ([General Electric Company, 1995](#)). In addition, IBM's Engineering Specification 46G3772 environmental requirements prohibits lubricants containing the chemical ([IBM, 2018](#)).

Since the publication of the Use Document in August 2017 for 2,4,6 Tris(tert-butyl)phenol, EPA received 12 public comments and communicated with several companies, industry groups, chemical users, and other stakeholders to aid in identifying and verifying conditions of use of 2,4,6 TTBP ([U.S. EPA, 2017a](#)). These interactions and comments further informed EPA's understanding of the uses for 2,4,6 TTBP. The information and input received from the public comments and stakeholder engagement has been incorporated into this document to the extent appropriate. Non-confidential public comments and stakeholder meeting summaries can be found in EPA's docket at [EPA-HQ-OPPT-2016-0734](#).

The primary use of 2,4,6 TTBP in the U.S. is as an intermediate and reactant in chemical processing ([U.S. EPA, 2014b](#)). It is also used as a component of both industrial and commercial fuel additives and lubricant additives. 2,4,6 TTBP is found in a variety of end-use products as an antioxidant in the automotive sector including fuel and lubricant additives ([U.S. EPA, 2014b](#)). However, it has also been identified for possible use industrially as a reactant in the production of other organic chemicals, plastics, and resins ([U.S. EPA, 2014b](#)).

The EU's OSPAR Commission identified five potential uses of 2,4,6 TTBP in Europe: a chemical intermediate in the production of antioxidants used in rubber and plastic; a lubricating agent in the transportation sector; a by-product in production of 4-tert-butylphenol, an additive for gasoline and fuel oil distillate; and use in the offshore sector ([OSPAR, 2006](#)). The OSPAR commission also indicated that 2,4,6 TTBP is listed as an impurity in 2,6 di-tert-butylphenol at concentration of 0.003%. However, the only use reported by industry in the EU was as a chemical intermediate used in the production of antioxidants used in rubber and plastic; the other potential uses were not confirmed ([OSPAR, 2006](#)). The chemical's only use in Canada is as a fuel additive ([Environment Canada and Health Canada, 2008](#)), but it has also been used as a lubricant additive in Canada in the past, as well as in the Netherlands ([SKF, 2017](#); [Environment Canada and Health Canada, 2008](#)). Industrial use of 2,4,6 TTBP is prohibited in Japan under the Chemical Substances Control Law ([NICNAS, 2017](#)).

Use of 2,4,6 TTBP is prohibited by engineering standards of some large businesses in the US. For example, Toyota's North America construction site management handbook prohibits 2,4,6 TTBP due to its ban in Japan ([Toyota Motor Engineering & Manufacturing, 2007](#)). GE's Design Requirements for Regulated Materials and Chemicals lists 2,4,6 TTBP as prohibited from use in parts, products, or other chemical substances ([General Electric Company, 1995](#)). In addition, IBM's Engineering Specification 46G3772 environmental requirements prohibit lubricants containing the chemical ([IBM, 2018](#)).

In the 2012 Chemical Data Reporting, 2,4,6 TTBP was reported to be used industrially as an intermediate and reactant for processing in plastics and resin manufacturing and other organic chemical manufacturing, and as a fuel additive in petroleum and coal products manufacturing ([U.S. EPA, 2014b](#)). 2,4,6 TTBP also had reported uses in the fuels and related products category. The chemical is an ingredient in automobile fuel injector cleaners, as well as in lubricant additives and fuel additives (as an antioxidant) in gasoline and jet fuel.

A variety of commercial fuel additives were also found to contain 2,4,6 TTBP, all at levels below 3 percent by weight ([U.S. EPA, 2017a](#)). Champion Brands' Fuel Stabilizer is marketed for use in 2-cycle, 4-cycle, gas, and diesel engine fuel systems to deter development of residue during periods of non-use ([Champion Brands, 2014](#)). Cyclo Industries' Fuel Stabilizer is similarly marketed for 2- and 4-cycle engines to prevent gum and varnish build-up ([Cyclo Industries, 2018](#)). Champion Brands' Engine Oil Additive (also sold as Engine Oil Treatment and Engine Protectant Oil Treatment) is marketed for engine wear protection in cars or light trucks during extreme cold or heat to maintain engine performance ([Champion Brands, 2014](#)).

At least two fuel injector cleaners sold in the US also contain 2,4,6 TTBP. The fuel injectors in a vehicle supply a fixed amount of gasoline to the engine ([Ryan, 2011](#)). Over time, components of fuel may oxidize and form residue that builds up on fuel injectors, negatively impacting engine performance and fuel efficiency ([Cole, 2011](#)). Products for fuel injector cleaning that contain 2,4,6 TTBP include Arctic Cat's Fuel Injector Cleaner (also sold as Fuel Injector and Carburetor Cleaner), which is recommended for use in stored sleds, Rislone's Fuel Injector Cleaner, which is recommended as an all-around fuel additive for gasoline and diesel engines, and Hy-Per Lube Corporation's Total Fuel System Cleaner, which is recommended for use in all cars, trucks, and marine engines ([Arctic Cat, 2018](#); [Hy-per Lube, 2018](#); [Rislone, 2018](#)).

A 2008 Environment Canada Screening Assessment of 2,4,6 TTBP identified that the substance is not naturally produced in the environment, has historically been used as a lubricant additive, and currently used in Canada as a fuel, oil, and gasoline additive ([U.S. EPA, 2017a](#)). Although use as a fuel additive is the only known use for 2,4,6 TTBP in Canada, several additional use pattern codes and corresponding applications were noted in the 2001 and 2007 survey, including: feedstock fuels, chemical intermediates, pesticides, fertilizers, salt for deicing, solvents, cutting fluids, aerosol propellants, hydraulic fluids, lubricants and additives, cleaning/washing agents and additives, plant protection products, agricultural products, explosives, antioxidants, corrosion inhibitors, tarnish inhibitors, scavengers, and anti-scaling agents ([U.S. EPA, 2017a](#)).

The categories of use that are considered within the scope of the use and exposure assessment during various life cycle stages including manufacturing, processing, use (industrial, commercial and consumer), distribution and disposal are depicted in Table 7-1 and the life cycle diagram (Figure 7-1). The information is grouped according to Chemical Data Reporting (CDR) processing codes and internationally harmonized functional, product and article use categories from the Organization for Economic Co-operation and Development (OECD) in combination with other data sources (e.g., published literature and consultation with stakeholders), to provide an overview of the uses.

Use categories are drawn from Instructions for Reporting for the 2016 CDR. “Industrial use” means use at a site at which one or more chemical substances or mixtures are manufactured (including imported) or processed. “Commercial use” means the use of a chemical or a mixture containing a chemical (including as part of an article) in a commercial enterprise providing saleable goods or services. “Consumer use” means the use of a chemical or a mixture containing a chemical (including as part of an article, such as furniture or clothing) when sold to or made available to consumers for their use ([U.S. EPA, 2016c](#)).

Table 7-1. Use Categories and Subcategories for 2,4,6 TTBP

Life Cycle Stage	Category ^a	Subcategory ^b	References
Manufacture	Domestic manufacture	Domestic manufacture	(U.S. EPA, 2016a) ; U.S. EPA (2017a) ; EPA-HQ-OPPT-2016-0734
Processing	Processing – reactant/chemical intermediate	Intermediate	(U.S. EPA, 2016a) ; U.S. EPA (2017a) ; EPA-HQ-OPPT-2016-0734
	Processing – incorporation into formulation, mixture or reaction product	Fuels and fuel additives/Antioxidant	U.S. EPA (2016a) ; U.S. EPA (2017a) ; EPA-HQ-OPPT-2016-0734
	Repackaging	Fuels and fuel additives/Antioxidant	U.S. EPA (2017a) ; EPA-HQ-OPPT-2016-0734
Industrial, Commercial, Consumer Uses	Fuels and related products	Fuel additive/fuel injector cleaner/Antioxidant	U.S. EPA (2017a) ; EPA-HQ-OPPT-2016-0734
	Maintenance, manufacture, and repair of motor vehicles/machinery	Wholesale and retail trade and repair of motor vehicles	U.S. EPA (2017a)
	Lubricating agent/additive in the transportation sector	Liquid lubricants and grease [additive/antioxidant]	U.S. EPA (2017a)
	Other uses	Fuel oil	EPA-HQ-OPPT-2016-0734
	Emissions to air		

Life Cycle Stage	Category ^a	Subcategory ^b	References
Releases and Waste Disposal	Wastewater		
	Liquid wastes		
	Solid wastes		

^aThese categories appear in the Life Cycle Diagram and broadly represent the uses of 2,4,6 TTBP in commercial and/or consumer settings.

^bThese subcategories reflect CDR and OECD codes and more specific uses of 2,4,6 TTBP based on stakeholder outreach, and comments received on EPA’s Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal published in August 2017.

Descriptions of the commercial or consumer use subcategories identified from the 2017 OECD Harmonized Use Codes are summarized below ([OECD, 2017b](#)):

The “antioxidant” functional use category includes chemical substances that retard oxidation, rancidity, deterioration, and gum formation. Used to maintain the quality, integrity, and safety of finished products by inhibiting the oxidative degradation of the ingredients in the formulation.

The “fuel additives” product use subcategory covers products added to fuels to improve properties such as stability, corrosion, oxygenation, and octane rating.

The “Liquid lubricants and greases” product use subcategory is defined as liquids that reduce friction, heat generation and wear between surfaces.

7.3. Characterization of Expected Environmental Partitioning

If released to air, the vapor pressure and Henry’s law constant of 2, 4, 6 TTBP indicate that some fraction of 2, 4, 6 TTBP will partition out of the air to water, airborne particulates, or soil, while some remains in the vapor phase. Particulate-bound 2, 4, 6 TTBP may be removed from the air through dry or wet deposition.

If released to water, 2, 4, 6 TTBP is expected to adsorb to suspended and settled sediments. It would be expected to accumulate in sediments via partitioning and settling, but also undergo transport downstream in both the aqueous phase and as part of suspended solids based on its partitioning parameters and water solubility. Volatilization to the air may occur based on its Henry’s law constant, but would likely be negligible in most environments due to adsorption to sediments.

Releases to waste water treatment plants should result in significant partitioning to biosolids along with some release of particulate bound 2, 4, 6 TTBP to surface water due to release of particulates in the effluent. The portion of the chemical bound to biosolids could then be either landfilled or applied to soil.

If released to soil, 2,4,6-Tris(tert-butyl) phenol is unlikely to undergo volatilization from dry soil based on its organic carbon partitioning and volatility. In moist soil, its Henry’s law constant

indicates that volatilization from the aqueous phase in soils may occur but will be limited by adsorption to soil organic matter. 2,4,6-Tris(tert-butyl) phenol will largely be associated with soil organic matter due to its log K_{oc} but may have some mobility in soil due to its relatively high water solubility.

If released to landfill, 2,4,6-Tris(tert-butyl) phenol should migrate slowly into leachate and will only migrate slowly to other environments. Volatilization is likely to be small based on its partitioning parameters.

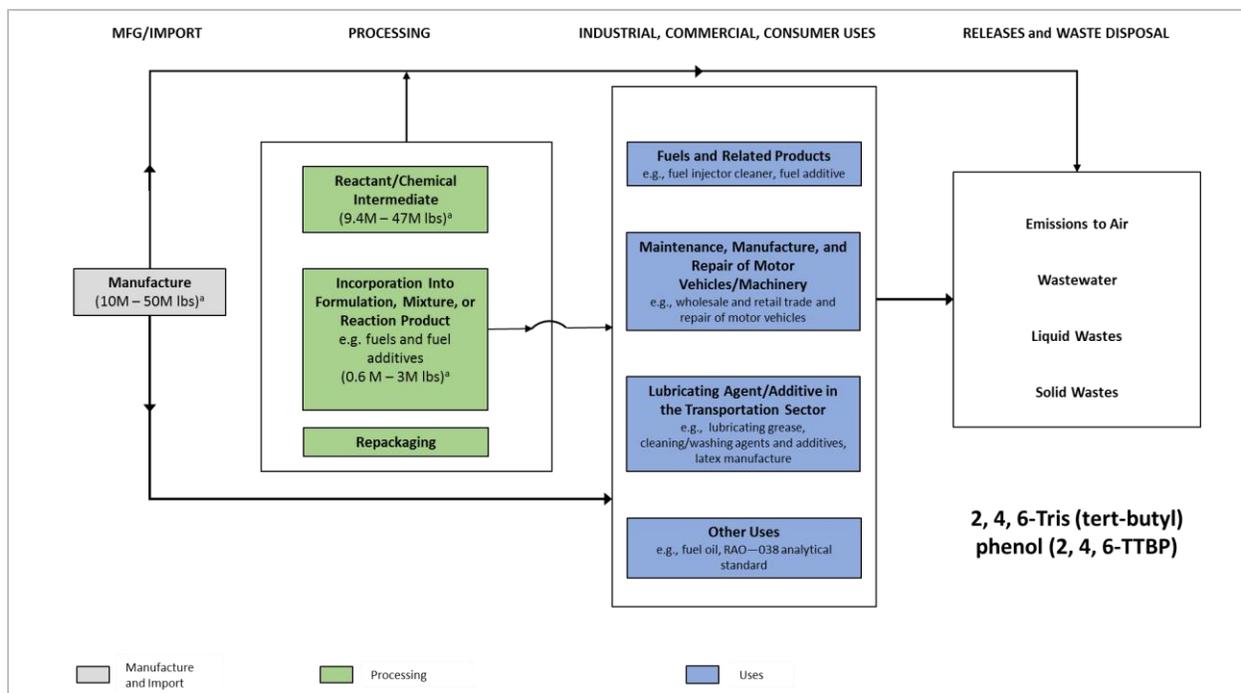
2,4,6-Tris(tert-butyl) phenol also may partition to the tissues of organisms that live in water, soil and sediment via dermal or gill exposure and ingestion. Exposure to water column organisms is also possible via resuspension of the chemical from the sediment to water either sorbed to particulates or part of the dissolved phase. The above characterization is meant to describe the primary behavior or movement of the chemical through a generic environment, not the complete exclusion of the chemical from a given media (e.g., water) or elimination of the possibility for more complex behavior in a particular location.

If released to the indoor environment, 2,4,6-Tris(tert-butyl) phenol will tend to partition to particulates and dust in the indoor environment based on its affinity for organic carbon relative to air. If the chemical enters the home via tap water, volatilization will not be a significant removal process in most cases. If released down the drain, it is likely it would arrive at nearby wastewater treatment plants due to relative mobility in water due to high water solubility and low K_{oc} .

7.4. Overview of Lifecycle and Potential Sources of Exposure

7.4.1. Background and Brief Description of Lifecycle.

2,4,6 TTBP is domestically manufactured at one known U.S. facility and is not imported by any facilities above the CDR reporting threshold. It is a yellow solid that dissolves in many organic solvents, but not in aqueous or alcoholic alkaline solutions ([Environment Canada and Health Canada, 2008](#)). 2,4,6 TTBP is primarily used as a site-limited intermediate that is destroyed in the production of other chemicals that are used as fuel additives. The majority of the remaining production volume is formulated and sold to customers who also use it as a fuel additive (containing unreacted 2,4,6 TTBP). A secondary use is in various formulations used in motor vehicle maintenance operations. Minor uses include: as a laboratory agent (analytical standard); as lubricating grease, cleaning/washing agents and additives for automobile servicing. Other miscellaneous uses include a component of fuel oil ([U.S. EPA, 2017a](#)).



ªFor the 2016 CDR, one company reported the manufacture and/or import of 2, 4, 6-TTBP in the U.S. above the reporting threshold. The production volume of was claimed as confidential business information. The CDR production was also CBI in 2012. PubChem and EPA have reported historical production ranges (e.g., in 2006 production ranged between 10 and 50 million pounds). 94% of the production volume is reported to be used as a reactant/intermediate, destroyed in the manufacture of other chemicals. The remaining portion of the production volume is incorporated into formulations or mixtures.

Figure 7-1. Lifecycle Diagram for 2, 4, 6 TTBP

7.4.2. Manufacturing and Processing as a Reactant/Chemical Intermediate

2,4,6 TTBP is manufactured as a solid powder at ambient temperature ([Environment Canada and Health Canada, 2008](#)) that is transferred to temporary storage vessels for use as a site-limited intermediate for the manufacture of other products ([U.S. EPA, 2017a](#)). Releases to air, water, and land are possible from the associated unit operations and transfer and on-site storage steps prior to the chemical being consumed in reaction. The primary sources of release include fugitive dust emissions, disposal and release of transfer-container cleaning solutions and disposal of empty containers, process equipment cleaning, and off-spec product. Fugitive and stack air (dust) emissions are expected from transfer of 2,4,6 TTBP into temporary storage and subsequent unloading and transfer into process equipment for final production of the final product. Release to water may result from equipment and general area cleaning with if aqueous cleaning materials are used. However, due to the low water solubility, cleaning with organic solvents is more likely and would be expected to be collected for incineration. Land releases may occur from disposal of empty storage containers and floor sweepings. Inhalation exposure to fugitive dust may occur during unloading, transfer, and processing steps. Dermal exposure is possible from contact during unloading and transfer operations.

7.4.3. Processing: Incorporation into Formulation, Mixture, or Reaction Products

2,4,6 TTBP is manufactured as a solid powder ([Environment Canada and Health Canada, 2008](#)) and formulated into products such as fuels and fuel additives at the U.S. manufacturing facility for sale to domestic customers ([U.S. EPA, 2017a](#)). Releases to air, land, and water are expected from 2,4,6 TTBP and 2,4,6 TTBP formulations (solids and liquids). Air releases (fugitive dust and dust collected and channeled to a stack) are expected from transfer operations. Releases to land may occur during disposal of transfer containers containing residual material, collection and disposal of floor sweepings, and disposal of off-spec product. Equipment and general area cleaning with liquid cleaning materials may result in releases to water, although waste cleaning solutions from cleaning with organic solvents are more likely to be collected for incineration. Occupational exposures from inhalation of fugitive dust and dermal exposure to dust may occur during transfer and packaging operations and from fugitive dust emissions from process operations. Dermal exposure to liquids is possible from incidental contact of liquid 2,4,6 TTBP formulations during transfer, loading, and mixing operations ([OECD, 2017a](#)).

7.4.4. Industrial, Commercial, and Consumer Use: Fuel and Related Products (fuel additives)

Fuel additive formulations containing 2,4,6 TTBP in solution may be shipped to end users in a variety of container types. Fugitive air releases of 2,4,6 TTBP are expected to be minimal due to the low vapor pressure, but are possible from unloading and transfer operations. It is expected that the majority of 2,4,6 TTBP is destroyed (burned) as the fuel is consumed/used. Land releases may occur from disposal of empty transport containers and waste absorbents used to clean regular spills and leaks from loading operations. Waste from equipment cleaning with organic cleaning solutions is anticipated to be collected for incineration. Water releases are possible from equipment and general area cleaning with aqueous cleaning solutions. Dermal exposure to 2,4,6 TTBP may occur from transfer and fuel loading operations. Inhalation exposure to fugitive air releases are expected to be minimal due to the low vapor pressure, but are possible.

7.4.5. Industrial, Commercial, and Consumer Use: Motor Vehicle Repair, Lubricating Agents and Additives in the Transportation Sector (lubricating grease, cleaning/washing agents and other additives)

Automobile lubricants, greases, and other additives containing 2,4,6 TTBP are expected to be shipped to end users as liquids in a variety of packaging container types. Fugitive air releases of 2,4,6 TTBP are expected to be minimal due to the low vapor pressure and they are expected to be in liquid formulation. Water releases are not expected from waste lubricants because waste material is usually incinerated ([OECD, 2017a](#)). However, land releases may occur from disposal of empty transport containers and other waste that is not incinerated ([OECD, 2017a](#); [Environment Canada and Health Canada, 2008](#)). Dermal exposure to 2,4,6 TTBP (full hand immersion, splashing, or spraying) is expected from handling lubricants. Inhalation exposure to

fugitive vapors is not likely, but is possible; however, inhalation exposure to mist may occur if spray application processes are used ([OECD, 2017a](#)).

7.4.6. Industrial/Commercial Use: Other Uses (e.g., laboratory research)

Small quantities of 2,4,6 TTBP are used in laboratories as an analytical standard. Potential releases to all media are possible from use and disposal of unused experimental reagents and laboratory equipment that may contain residual 2,4,6 TTBP. However, releases directly to the environment are expected to be minimal due to handling and disposal requirements in laboratory settings. Similarly, inhalation and dermal exposure to laboratory personnel is possible from the handling of laboratory reagents; however, it is expected to be minimal due to the use of engineering controls such as fume hoods and personal protective equipment.

7.4.7. Qualitative Trends Over Time for Releases for Releases and Occupational Exposures

2,4,6 TTBP is not reported to the Toxics Release Inventory and no release data over time were identified.

7.5. Environmental Monitoring

2,4,6 TTBP was detected in relatively few environmental monitoring studies. A supplemental search was conducted for 2,4,6 TTBP to determine if any studies co-reported information on aromatic phenol chemicals. The chemical most reported in environmental media from the supplemental search is Butyl Hydroxytoluene (BHT). BHT and 2,4,6 TTBP are structurally similar, have similar physical-chemical properties, but different uses. BHT is an antioxidant and food additive, whereas the uses of 2,4,6 TTBP are narrower. It may be possible that BHT could degrade to 2,4,6 TTBP in the environment. Table 7-2 provides a summary of the monitoring data for 2,4,6 TTBP and BHT identified in the peer-reviewed literature across all media considered. Also included in the count are available monitoring database sources. Only studies or databases that reported measurements of the chemical of interest above the limit of detection were extracted and included in the “# of studies” count. The frequency of detection is provided as a measure, across all samples in all extracted studies, of the frequency that the chemical was measured above the limit of detection. Note, the frequency of detection is reported only for peer-reviewed sources, unless the only data sources available were database sources.

This is generally consistent with the fate summary and reported physical-chemical properties for in that 2,4,6 TTBP was detected in surface water, influent/effluent, air, and dust. It is also notable that releases are primarily expected to air and water.

Table 7-2. Summary of 2,4,6 TTBP and BHT Monitoring Data from Peer-Reviewed Literature

Media	Presence	No. of Datasets	Frequency of Detection
Indoor dust	Yes	1	100%
Indoor air	Yes	1	100%
Ambient air	Yes	1	3%
Surface/Ground water	Yes	2	97%
Drinking water	No	0	n/a
Soil	No	0	n/a
Sediment	Yes	3	4%
Biosolids	No	0	n/a
Wastewater (influent, effluent)	Yes	1	17%
Landfill leachate	No	0	n/a
Vegetation/Diet	No	0	n/a
Other	No	0	n/a

The following chart provides the number of studies that reported 2,4,6 TTBP monitoring data over time. For this chart, the year the study is published rather than the sampling timeframe is used as a proxy, though for most studies, samples were collected a few years prior to publication. Note, EPA recognizes that the sampling dates, rather than the publication date, would be a better reflection of temporal trends.

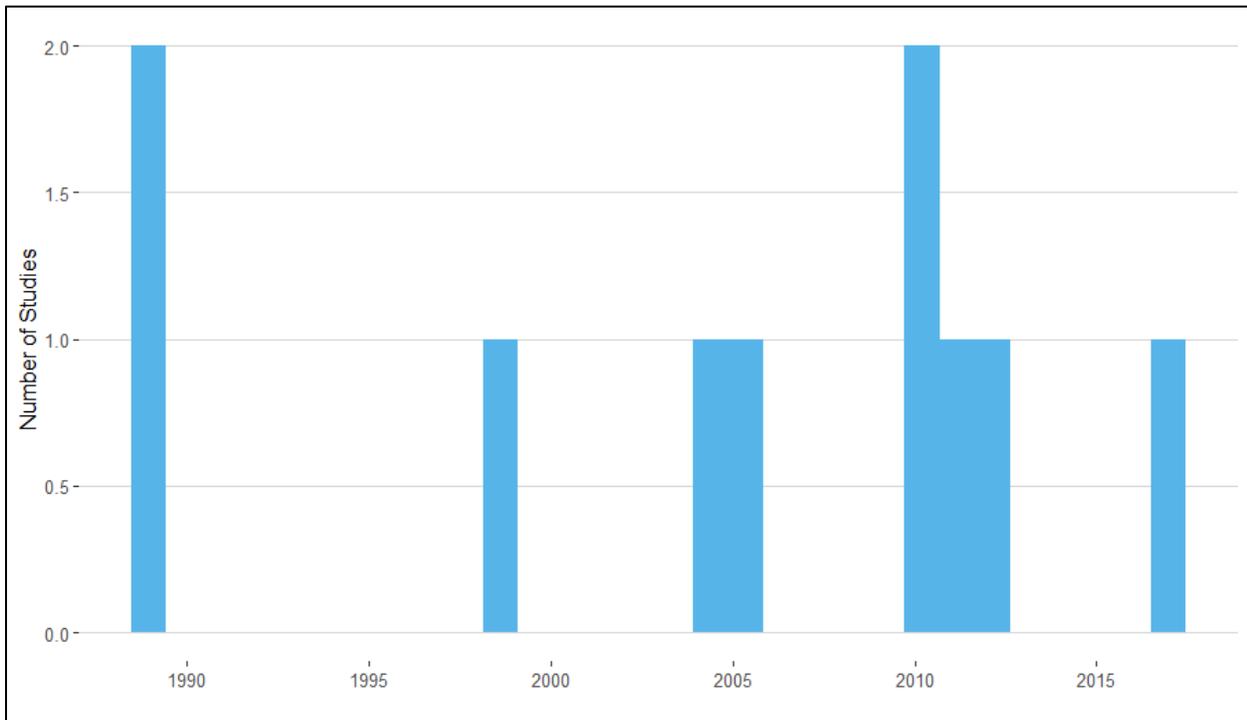


Figure 7-2. Frequency of peer-reviewed publications identified that contained 2,4,6 TTBP monitoring data.

All environmental monitoring data that passed EPA’s evaluation criteria are presented graphically in the plots below. These plots help visualize the data and are organized by study year and microenvironment, when reported. Note, some studies are discussed in Sections 7.7

and 7.11 as they pulled together information on monitoring data alongside supplemental contextualizing information on uses, sources, and trends.

7.5.1. Indoor Dust

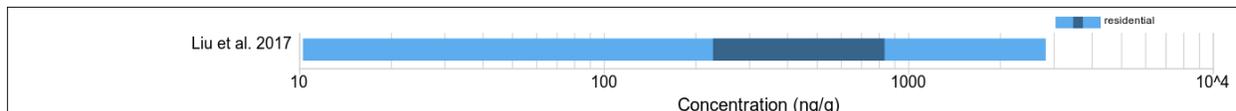


Figure 7-3. Concentration of 2,4,6 TTBP and BHT (ng/g) in indoor dust for residential locations in 2017. The range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This figure contains data for the following: ([Liu et al., 2017](#))

7.5.2. Indoor Air

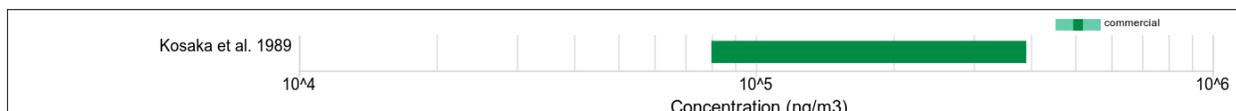


Figure 7-4. Concentration of 2,4,6 TTBP and BHT (ng/m³) in indoor air for commercial locations in 1989. The minimum and maximum of reported central tendency estimates are shown.

This figure contains data for the following: ([Kosaka et al., 1989](#))

7.5.3. Ambient Air

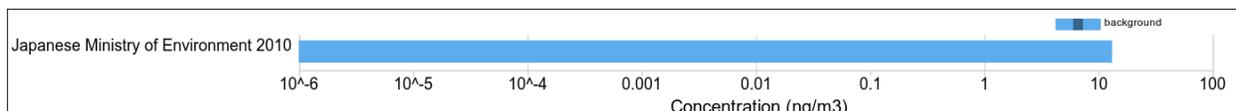


Figure 7-5. Concentration of 2,4,6 TTBP and BHT (ng/m³) in ambient air for background locations in 2010. The range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([Japanese Ministry of Environment, 2010](#))

7.5.4. Surface Water

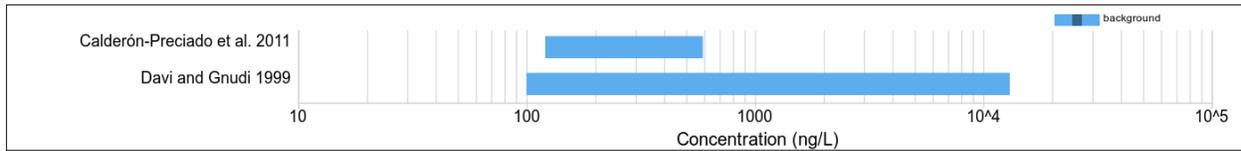


Figure 7-6. Concentration of 2,4,6 TTBP and BHT (ng/L) in surface water for background locations in 1999 and 2011. For each year, the range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([Calderón-Preciado et al., 2011](#); [Davi and Gnudi, 1999](#))

7.5.5. Sediment

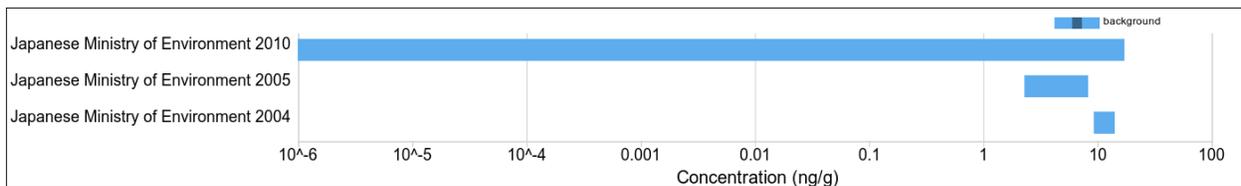


Figure 7-7. Concentration of 2,4,6 TTBP and BHT (ng/g) in sediment for background locations from 2004 to 2010. For each year, the range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([Japanese Ministry of Environment, 2010, 2005, 2004](#))

7.5.6. Influent/Effluent

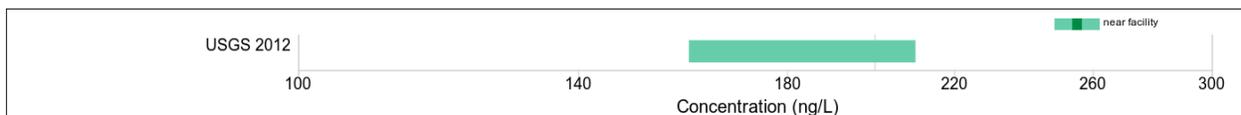


Figure 7-8. Concentration of 2,4,6 TTBP and BHT (ng/L) in influent/effluent for near facility locations in 2012. The range of values reported is presented by the entire length of the bar.

This figure contains data for the following: ([USGS, 2012](#))

7.5.7. Other

EPA did not identify any studies with extractable 2,4,6 TTBP nor BHT data in drinking water or landfill leachate. 2,4,6 TTBP is not expected to be present in these media due to the following:

- For drinking water, 2,4,6 TTBP is expected to adsorb to suspended and settled sediments.
- For landfill leachate, 2,4,6 TTBP should migrate slowly into leachate.

EPA did not identify any studies with detectable levels of 2,4,6 TTBP nor BHT in soil, sludge/biosolids, or vegetation/diet.

7.6. Biomonitoring

2,4,6 TTBP has a handful of reports of biomonitoring data. There are only a small handful of studies that show 2,4,6 TTBP detected in any biological matrix. A supplemental search was also performed on BHT, a surrogate for 2,4,6 TTBP; however no studies were identified with extractable biomonitoring data. Table 7-3 provides a summary of the biomonitoring data for 2,4,6 TTBP identified in the peer reviewed literature across all matrices considered. Also included in the count are available monitoring database sources. Only studies or databases that reported measurements of the chemical of interest above the limit of detection were extracted and included in the “# of studies” count. The frequency of detection is provided as a measure, across all samples in all extracted studies, of the frequency that the chemical was measured above the limit of detection. Note, the frequency of detection is reported only for peer-reviewed sources, unless the only data sources available were database sources.

This is generally consistent with the fate summary in that 2,4,6 TTBP was detected in matrices where it was expected due to physical-chemical properties; however, for many matrices, 2,4,6 TTBP data have not been collected.

Table 7-3. Summary of 2,4,6 TTBP Biomonitoring Data from the Peer-Reviewed Literature and Monitoring Databases

Matrix	Presence	No. of Datasets	Frequency of Detection
Human blood (serum)	No	0	n/a
Human (other)	No	0	n/a
Fish	Yes	1	n/a
Birds	No	0	n/a
Terrestrial invertebrates	No	0	n/a
Aquatic invertebrates	No	0	n/a
Terrestrial mammals	No	0	n/a
Aquatic mammals	No	0	n/a
Other	No	0	n/a

The following chart provides the number of studies that reported 2,4,6 TTBP biomonitoring data over time. For this chart, the year the study is published rather than the sampling timeframe is used as a proxy, though for most studies, samples were collected a few years prior

to publication. Note, EPA recognizes that the sampling dates, rather than the publication date, would be a better reflection of temporal trends.

7.6.1. Fish



Figure 7-9. Concentration of 2,4,6-tris(tert-butyl) phenol (ng/g) in fish from one monitoring database (USGS). The minimum and maximum of reported central tendency estimates are shown.

This figure contains data for the following HERO IDs: ([USGS, 1991](#))

7.6.2. Other

EPA did not identify any studies with detectable levels of 2,4,6 TTBP in human blood (serum), human (other), aquatic invertebrates, aquatic mammals, terrestrial invertebrates, birds, or terrestrial mammals.

7.7. Trends in Monitoring Data

EPA identified one study ([Davi and Gnudi, 1999](#)) that reported trends for 2,4,6 TTBP in surface water. No studies were identified that reported trends for closely-related chemicals. Only one monitoring database (USGS) reported data for concentrations of 2,4,6 TTBP in fish ([USGS, 1991](#)).

7.7.1. Surface Water

One study reported in surface water from 1994 to 1996 ([Davi and Gnudi, 1999](#)). A steady decrease in 2,4,6, TTBP was observed with time.

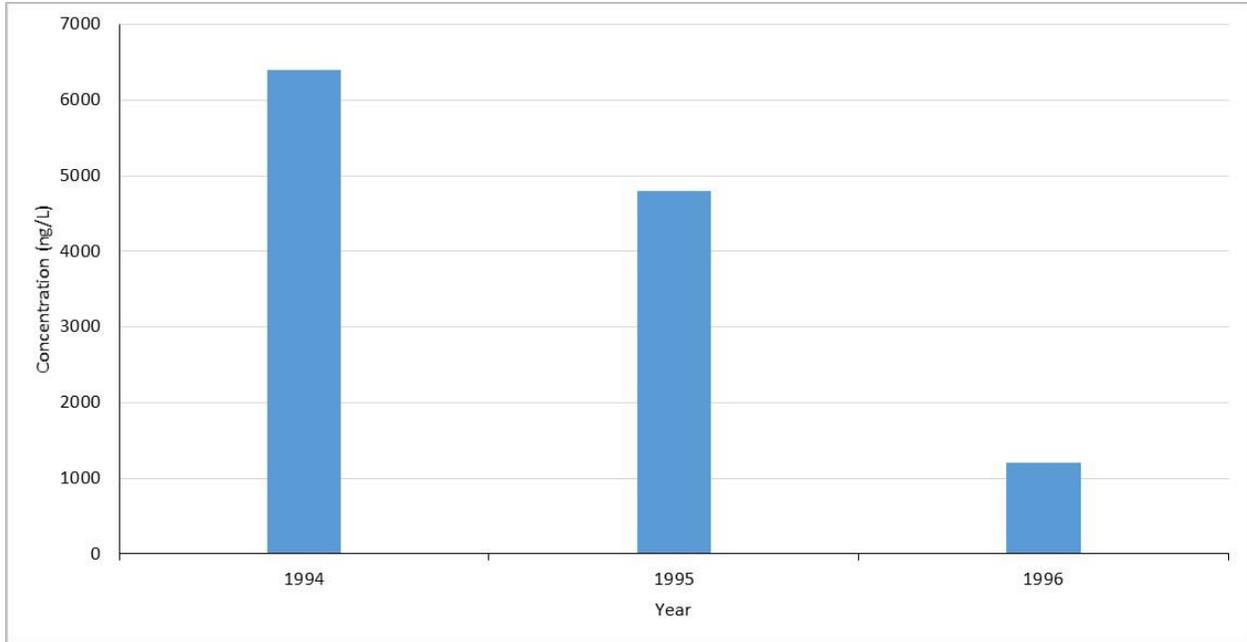


Figure 7-10. Concentration of 2,4,6 TTBP (ng/L) in surface water from 1994 to 1996.

7.7.2. Fish

One monitoring database (USGS) reported 2,4,6 TTBP concentrations in fish from 1999 through 2003 and showed no change in concentration during that period ([USGS, 1991](#)).

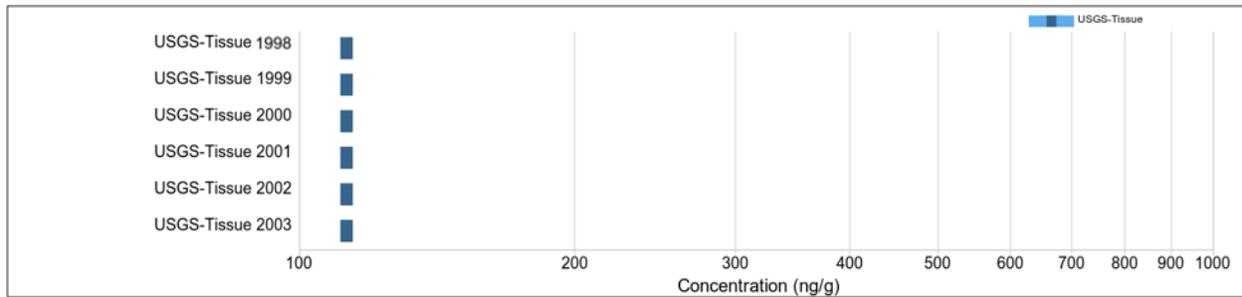


Figure 7-11. Concentration of 2,4,6 TTBP (ng/g) in fish from 1998 through 2003. Only central tendencies (dark blue) were reported.

7.8. Modeled Intake and Dose Data

One study ([Liu et al., 2017](#)) was identified that modeled the average daily dose for the sum of seven synthetic phenolic antioxidant analogues and was used as a surrogate for 2,4,6 TTBP. Urban environments resulted in higher dose estimates than rural environments, and children also had higher dose estimates than adults.

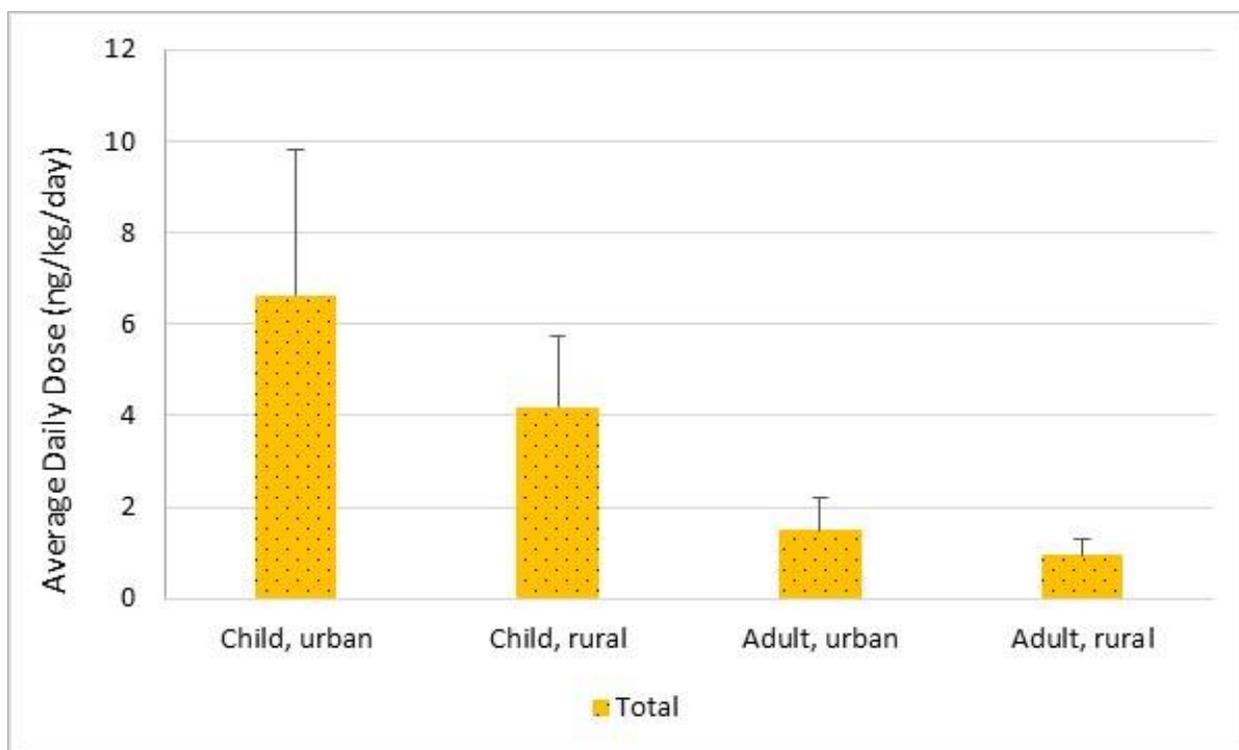


Figure 7-12. Estimated average daily dose (ng/kg/day) of the sum of seven synthetic phenolic antioxidant analogues, which are used as a surrogate for 2,4,6 TTBP, for total exposure. Data are presented for children and adults, separated by urban and rural regions.

7.9. Overview of Existing Exposure Assessments

[Environment Canada and Health Canada \(2008\)](#) prepared a screening assessment of 2,4,6 TTBP for ecological concerns related to persistence, bioaccumulation, and toxicity criteria. It stated that 2,4,6 TTBP is expected to adsorb strongly to soil and sediment, partition to lipids, and persist in water, soil, and sediments, and potentially biomagnify in food chains. The assessment also noted that the known use of 2,4,6 TTBP in Canada is as a fuel additive based on a 2007 survey, and most of the 2,4,6 TTBP is destroyed during combustion of the fuel. The European Union ([European Chemicals Agency \(ECHA\), 2008](#)) assessed risks of p-tert-butylphenol and stated that formation of 2,4,6 TTBP during the production of p-tert-butylphenol was theoretically possible but the material is not detected in the final product (detection limit of 2 ppm).

The Australian Government Department of Health ([NICNAS, 2013](#)) also evaluated persistence, bioaccumulation, and toxicity of 2,4,6 TTBP. It similarly concluded that the chemical would be expected to be combusted in the fuels to which it was added. This assessment expected that 2,4,6 TTBP releases to water would partition mainly to sediment, and releases to sewage treatment would partition to biosolids, which might be applied to agriculture soils.

No reported estimated exposure intake or dose estimates were presented in the authoritative sources for 2,4,6 TTBP.

7.10. Representative Exposure Scenarios

2,4,6 TTBP has a narrow set of uses. Each of these uses has potential for release and exposure. However, there is limited monitoring data for 2,4,6 TTBP itself to document these exposures. Based on its physical-chemical properties, ingestion is likely the primary exposure route. Inhalation would likely be comprised of particles which could be swallowed, and dermal absorption is likely low.

Occupational: Manufacturing of 2,4,6 TTBP as a solid powder results in particulates that are transferred to workplace air during transfer and packaging operations. Workers at manufacturing facilities can inhale these particulates and the particles can settle on exposed skin. Both inhalation and dermal exposures are possible.

Occupational: 2,4,6 TTBP that is manufactured as a solid powder and subsequently formulated into products such as fuels and fuel additives results in particulates in workplace air during transfer operations. Inhalation and dermal exposures to workers from particulates in facilities formulating 2,4,6 TTBP are possible.

Occupational: Use of 2,4,6 TTBP in fuel additives may result in dermal exposure from incidental contact during transfer and fuel loading operations.

Occupational: Use of 2,4,6 TTBP in lubricants results in full hand immersion, splashing, or spraying during handling. Dermal exposure to workers who use these products is possible. Inhalation and dermal exposure to mist from spray application of these products is also possible.

Occupational: Industrial and commercial use of 2,4,6 TTBP as an analytical standard may result in generation of particulates in workplace air. Laboratory workers may inhale these particulates and incidental contact with exposed skin may occur from accidental spills during use of the standards. However, the use of engineering controls such as fume hoods and personal protective equipment is expected to reduce these exposures.

General Population: Manufacturing of 2,4,6 TTBP results in fugitive air releases of particulates which may lead to elevated air concentrations for residents living near these facilities.

Ecological: Cleaning of equipment during use of industrial, commercial, and consumer use of fuels leads to releases to water and elevated concentrations in surface water where aquatic organisms may be exposed.

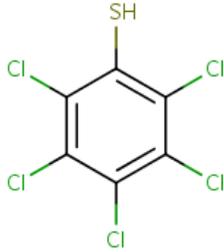
Consumer: Use of 2,4,6 TTBP in lubricants results in full hand immersion, splashing, or spraying during handling. Dermal exposure to consumers who use these products is possible. Inhalation and dermal exposure to mist from spray application of these products is also possible.

7.11. Summary of Review Articles

No review articles were identified that presented exposure estimates or doses for 2,4,6 TTBP, other than the authoritative sources presented in Section 7.9. For 2,4,6 TTBP, Environment Canada and Health Canada conducted an ecological screening assessment in 2008, and determined the potential for 2,4,6 TTBP contamination of soils and sediments after incomplete combustion as a fuel additive, but reported that 2,4,6 TTBP was not measured above 2 ppm in fuel additives. Minimal exposure data were reported in 2008 for this assessment.

8. Pentachlorothiophenol (PCTP)

8.1. Chemistry and Physical-Chemical Properties

Chemical Name	Pentachlorothiophenol
CASRN	133-49-3
Synonyms	PCTP; Benzenethiol, 2,3,4,5,6-pentachloro-; Benzenethiol, pentachloro-; Benzenethiol, pentachloro-; Pentachlorobenzenethiol; Pentachloro-benzenethiol; Pentachlorothiophenol; Pentachlorothio-phenol I; Pentachlorothiophenol; Pentachlorobenzene thiol
Molecular Formula	C ₆ HCl ₅ O
Structure	
Source: (NLM, 2018)	
MW	282.40
Density (g/cm³)	1.745 (Estimated by ACD/Labs in Chemistry Dashboard, 2017)
Molar Volume (cm³/mol)	162 [Calculated based on the molar mass and density]
Log K_{ow}	5.91 [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Log K_{oa}	8.2 [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Log K_{oc}	4.3 [Kow method, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Vapor Pressure (mm Hg)	5.1 × 10 ⁻⁶ [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Henry's Law (atm-m³/mole)	1.5 × 10 ⁻⁴ [Group Method, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Water Solubility (mg/L)	0.0048 [Estimated using EPISuite v 4.11 (U.S. EPA, 2012)]
Water Solubility (mol/L)	1.7 × 10 ⁻⁸ [Calculated based on water solubility and molecular weight, estimated using EPISuite v 4.11 (U.S. EPA, 2012)]

8.2. Uses

Since the publication of the Use Document in August 2017 for PCTP, EPA received 9 public comments and communicated with several companies, industry groups, chemical users, and

other stakeholders to aid in identifying and verifying conditions of use of PCTP ([U.S. EPA, 2017d](#)). These interactions and comments further informed EPA's understanding of the uses for PCTP. The information and input received from the public comments and stakeholder engagement has been incorporated into this document to the extent appropriate. Non-confidential public comments and stakeholder meeting summaries can be found in EPA's docket at [EPA-HQ-OPPT-2016-0739](#).

PCTP is obtained from hexachlorobenzene (a fungicide not used in the U.S. since 1984) (by treatment with sodium sulfide and sulfur in methanol, or with sodium hydrogensulfide ([U.S. EPA, 2017d](#))). Additionally, PCTP may be obtained with a "reaction of hydrogen sulfide with pentachlorophenol in the presence of an acidic catalyst, e.g., aluminum chloride or boron trifluoride" ([U.S. EPA, 2017d](#)).

No company has reported manufacture and/or import of PCTP (PCTP) in the U.S. above the reporting threshold of the Chemical Data Reporting (CDR) Rule for 2016 ([U.S. EPA, 2016c](#)). Only one company reported manufacture and/or import of PCTP in the U.S. in 2012 ([U.S. EPA, 2017d](#)).

Historically, PCTP (or its zinc salt) was used as the preferred peptizer for natural rubber. However the National Institutes of Health (NIH) reports that PCTP is banned in most parts of the world because it forms several teratogenic decomposition products ([HSDB, 2015](#)). According to Ullmann's Encyclopedia of Industrial Chemistry, PCTP has been replaced by 2,2'-dibenzamidodiphenyldisulfide (DBD), which reacts similarly, but is less toxic ([HSDB, 2015](#)).

PCTP is primarily used in the rubber manufacturing industry. According to Ullmann's Encyclopedia of Industrial Chemistry, PCTP is used as a mastication agent in the rubber industry and more specifically, a peptizing agent for natural rubber viscosity reduction in the early stages of rubber manufacturing ([HSDB, 2015](#)). Mastication and peptization are processing stages during which the viscosity of rubber is reduced to a level facilitating further processing ([Struktol, 2018](#)). It is possible to reduce the viscosity of natural and synthetic rubbers through solely mechanical efforts, but peptizers allow this process to be less sensitive to varying time and temperature, which improves the uniformity between batches ([HSDB, 2015](#)).

Although PCTP is reportedly largely replaced by 2,2'-dibenzamidodiphenyldisulfide (DBD) as the preferred peptizing agent for natural rubber, the predominant use of PCTP remains as a peptizer ([HSDB, 2015](#)). PCTP is primarily used in the peptization process of natural rubber. There is little data, however, on the types of end-use products that contain PCTP. A search of several product data bases including EPA's Chemical and Product Categories (CPCat) database, the National Library of Medicine's Household Products Database, and the Consumer Product Information Data Base (CPID), returned no product Safety Data Sheets (SDS). A Google search of PCTP returned no SDS' containing that chemical. A search of the website of the chemical processor, Struktol, returned five general technical data sheets for rubber peptizers, however none of them mention specific chemicals.

The Swedish Chemicals Agency KEMI Commodity Guide suggests that PCTP may be found in butadiene rubber, isoprene rubber, natural rubber, and other rubber materials ([U.S. EPA, 2017d](#)). It is possible that imported products containing these materials could contain PCTP. However, a letter to EPA from the Rubber Manufacturers Association, dated Feb. 22, 2017, indicates that its members “do not currently use ... PCTP to manufacture tires produced in the U.S. or imported into the U.S.” ([EPA-HQ-OPPT-2016-0739](#)).

Material	Content in Material,%
Butadiene rubber (BR)	15–20
Isoprene rubber (IR)	15–20
Natural rubber (NR)	15–20
Other rubber materials	15–20

Source: ([Kemi, 2007](#))

Research has shown PCTP to be a breakdown product of pentachloronitrobenzene, a fungicide, and hexachlorobenzene (HCB), a fungicide that has not been used in the U.S. since 1984 ([U.S. EPA, 2017d](#)). HCB is listed as POP under the Stockholm Convention ([UNEP, 2008](#)). However, no program that monitors PCTP across various media has been identified.

Table 8-1. Use Categories and Subcategories for PCTP

Life Cycle Stage	Category ^a	Subcategory ^b	References
Manufacture	Manufacture	Manufacture	U.S. EPA (2017d)
Processing	Incorporation into rubber	Cross-linking agent used in rubber manufacturing	U.S. EPA (2017d)
Industrial, Commercial, Consumer Uses	Incorporation into articles	Golf ball manufacturing	U.S. EPA (2017d)
	Other uses	Laboratory research	U.S. EPA (2017d)
Releases and Waste Disposal	Emissions to air		
	Wastewater		
	Liquid wastes		
	Solid wastes		

^aThese categories of conditions of use appear in the Life Cycle Diagram, broadly represent conditions of use of PCTP in commercial and/or consumer settings.

^bThese subcategories reflect more specific uses of PCTP based on stakeholder outreach, and comments received on EPA’s Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal published in August 2017.

8.3. Characterization of Expected Environmental Partitioning

If released to air, PCTP in the atmosphere is expected to remain in part in the vapor phase, while some fraction will partition from air into water due to its Henry’s law constant (1.5×10^{-4} atm m³/mole), or from air into soil and airborne particulates due to its vapor pressure (5.1×10^{-6} mm Hg) and log K_{OA} (8.2). Particulate-bound PCTP may be removed from the atmosphere through wet or dry deposition.

If released to water, based on its log K_{OW} (5.91) and log K_{OC} (4.3), PCTP in surface water is expected to adsorb to sediments and particulates suspended in the water column. PCTP may

volatilize from water due to its Henry's law constant, although volatilization is expected to be limited by adsorption to particulates.

PCTP is likely to be removed from wastewater in treatment plants via adsorption to biosolids, which may then be landfilled, applied to soil, or incinerated, based on its log K_{OC} and log K_{OW} . Volatilization of PCTP from wastewater is expected to be limited due to its Henry's law constant. Release of free PCTP with wastewater treatment plant effluent is expected to be limited, although PCTP adsorbed to small particles may be released with effluent.

If released to soil, due to its log K_{OC} and water solubility (4.8×10^{-3} mg/L), PCTP released to soil is expected to adsorb to organic matter. PCTP is not likely to volatilize from dry soil based on its vapor pressure. Based on its Henry's law constant, PCTP may volatilize from moist soil, but volatilization will be limited by adsorption to soil organic matter. Mobility of PCTP in soil pore water and groundwater is expected to be limited due to its log K_{OC} and water solubility, although PCTP may adsorb to colloids or other small particulates which are mobile in subsurface environments.

If released to landfill, migration of PCTP to landfill leachate is expected to be slow and limited due to its log K_{OC} and water solubility, although PCTP bound to small particulates may migrate into landfill leachate more rapidly. PCTP is not likely to volatilize from solid waste due to its vapor pressure and log K_{OA} .

PCTP also may partition to the tissues of organisms that live in water, soil and sediment via dermal or gill exposure and ingestion. Exposure to water column organisms is also possible via resuspension of the chemical from the sediment to water either sorbed to particulates or part of the dissolved phase. The above characterization is meant to describe the primary behavior or movement of the chemical through a generic environment, not the complete exclusion of the chemical from a given media (e.g., water) or elimination of the possibility for more complex behavior in a particular location.

If released to the indoor environment, based on its log K_{OA} , vapor pressure, and Henry's law constant, PCTP is not likely to volatilize from consumer products or articles, contaminated water, or other solutions. PCTP is more likely to be emitted from consumer products via abrasion or direct partitioning to dust. If it is present in the indoor air, PCTP is likely to deposit in dust or other organic matter due to its log K_{OA} .

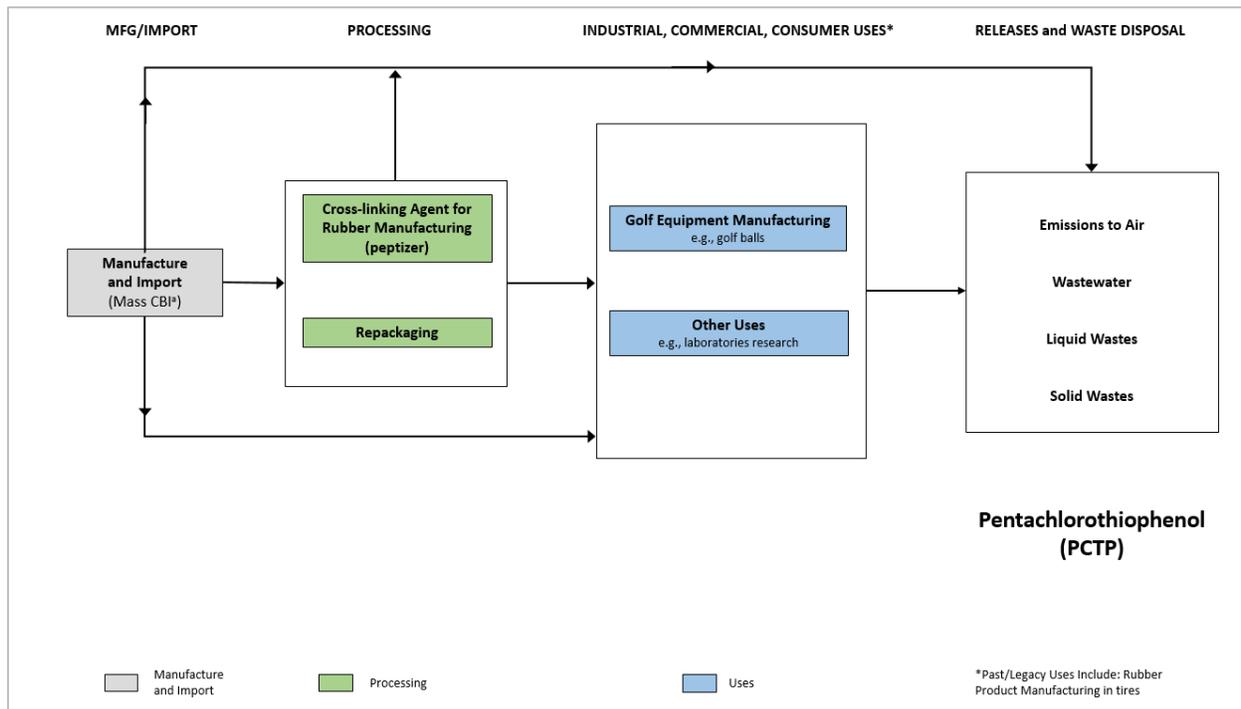
PCTP released down-the-drain to wastewater is expected to adsorb to organic matter in the wastewater due to its log K_{OC} and log K_{OW} .

8.4. Overview of Lifecycle and Potential Sources of Exposure

8.4.1. Background and Brief Description of Lifecycle

No U.S. companies currently domestically manufacture or import PCTP above the CDR reporting threshold. However, two domestic uses of PCTP have been identified. In the primary use, PCTP

is processed as a cross-linking agent and used in the commercial manufacture of golf balls. It is also used in small quantities in laboratory research ([U.S. EPA, 2017d](#), [2016e](#)).



^aNo company has reported manufacture and/or import of pentachlorothiophenol (PCTP) in the U.S. above the reporting threshold of the CDR Rule for 2016. Only one company reported manufacture and/or import of PCTP in the U.S. in 2012. The production volume of PCTP was claimed as confidential business information (CBI).

^bPCTP is mentioned in over 2,100 patents.

^{*}A letter to EPA from the Rubber Manufacturers Association, dated Feb. 22, 2017, indicates that its members “do not currently use PCTP to manufacture tires produced in the U.S. or imported into the U.S.”

Figure 8-1. Lifecycle Diagram for PCTP

8.4.2. Manufacturing and Import

Small quantities of PCTP, a dry powder, may be domestically manufactured and imported ([U.S. EPA, 2017d](#)). It can be manufactured by treatment of hexachlorobenzene (a fungicide not used in the U.S. since 1984) with sodium sulfide and sulfur in methanol, or with sodium hydrogensulfide. Additionally, PCTP may be created with a “reaction of hydrogen sulfide with pentachlorophenol in the presence of an acidic catalyst, e.g., aluminum chloride or boron trifluoride” ([U.S. EPA, 2017d](#)).

Because the product is a dry powder, the most likely sources of releases and occupational exposures from manufacturing processes are associated with fugitive dust. These include air releases from transfer and packaging operations (fugitive dust to ambient air as well as dust that is collected and channeled through a dedicated point as a stack release) and solid waste from floor sweepings, disposal of used transfer containers containing residual PCTP, and liquid waste from equipment cleaning. Fugitive vapor air releases are not expected due to the low vapor pressure. Releases to land are possible when floor sweepings and other solid waste are

collected and disposed in landfills. Similarly, the collection and disposal of liquid equipment cleaning solutions has the potential of generating liquid waste containing PCTP (aqueous waste to surface waters and sent to publicly owned treatment works, and organic waste collected and sent for other disposal or waste treatment such as incineration). Occupational exposures from inhalation of fugitive dust and dermal exposure to dust from transfer and packaging operations and from fugitive dust emissions from process operations is possible. However, dermal exposure to liquids is not anticipated. Similarly, inhalation exposure to fugitive vapors is not expected due to PCTP's low vapor pressure.

8.4.3. Processing: Cross-linking Agent for Rubber Manufacturing

PCTP is used as an additive in the rubber manufacturing industry, specifically as a peptizer to make rubber more pliable ([U.S. EPA, 2017d](#)). Although releases of PCTP after cross-linking occurs are expected to be minimal, releases of additives such as cross-linking agents from rubber manufacturing are possible to water, air, and land (predominantly prior to reaction processes are complete). Water releases are expected to be most prevalent. Sources include process wastewater from cooling or heating medium and vulcanization, where water has direct contact with the rubber mixture. Releases to water can also occur from equipment and general area cleaning ([OECD, 2004](#)). Land releases are possible from the disposal of off-spec product and empty transfer containers. Air releases are expected to be minimal due to the low vapor pressure of PCTP. Occupational inhalation and dermal exposure to dust is possible from unloading and transfer operations when the PCTP mixture is added to process equipment. Once incorporated into the rubber formulation, the potential for worker exposure is not expected.

8.4.4. Industrial/Commercial Use: Golf Equipment Manufacturing (golf balls)

PCTP is used as an additive in the manufacture of golf balls ([EPA-HQ-OPPT-2016-0739](#)). Releases to all media are possible. Land releases may occur from the disposal of off-spec product and empty transfer containers. Water releases may occur from process wastewater or from equipment and general area cleaning with aqueous cleaning solutions. Air releases are expected to be minimal due to the low vapor pressure of PCTP. Occupational inhalation and dermal exposure to dust may occur from unloading and transfer operations when the PCTP mixture is added to process equipment. Once incorporated into the product, the potential for worker exposure is not expected.

8.4.5. Industrial/Commercial Use: Other Uses (e.g. laboratory research)

Small quantities of PCTP are used as a laboratory reagent. Potential releases to all media are possible from use and disposal of unused experimental reagents and laboratory equipment that may contain residual PCTP. However, releases directly to the environment are expected to be minimal due to handling and disposal requirements at laboratories. Similarly, inhalation and dermal exposure to laboratory personnel is possible from the handling of laboratory reagents;

however, it is expected to be minimized by the use of engineering controls such as fume hoods and personal protective equipment.

8.5. Environmental Monitoring

No studies were identified that reported extractable PCTP data in environmental media. Therefore, no summary charts or graphs are presented here.

8.6. Biomonitoring

Very few detections of PCTP in biomonitoring matrices are reported. This is potentially caused by a lack of monitoring data for PCTP, rather than an absence of PCTP in biomonitoring media.

Table 8-2 summarizes the biomonitoring data for PCTP identified in the peer-reviewed literature across all matrices considered. Also included in the count are available monitoring database sources. Only studies or databases that reported measurements of the chemical of interest above the limit of detection were extracted and included in the “# of studies” count. The frequency of detection is provided as a measure, across all samples in all extracted studies, of the frequency that the chemical was measured above the limit of detection. Note, the frequency of detection is reported only for peer-reviewed sources, unless the only data sources available were database sources.

Table 8-2. Summary of PCTP Biomonitoring Data from the Peer-Reviewed Literature

Matrix	Presence	No. of Datasets	Frequency of Detection
Human blood (serum)	No	0	n/a
Human (other)	Yes	2	100%
Fish	No	0	n/a
Birds	No	0	n/a
Terrestrial invertebrates	No	0	n/a
Aquatic invertebrates	No	0	n/a
Terrestrial mammals	No	0	n/a
Aquatic mammals	No	0	n/a
Other	No	0	n/a

The following chart provides the number of studies that reported PCTP biomonitoring data over time. For this chart, the year the study is published rather than the sampling timeframe is used as a proxy, though for most studies, samples were collected a few years prior to publication. Note, EPA recognizes that the sampling dates, rather than the publication date, would be a better reflection of temporal trends.

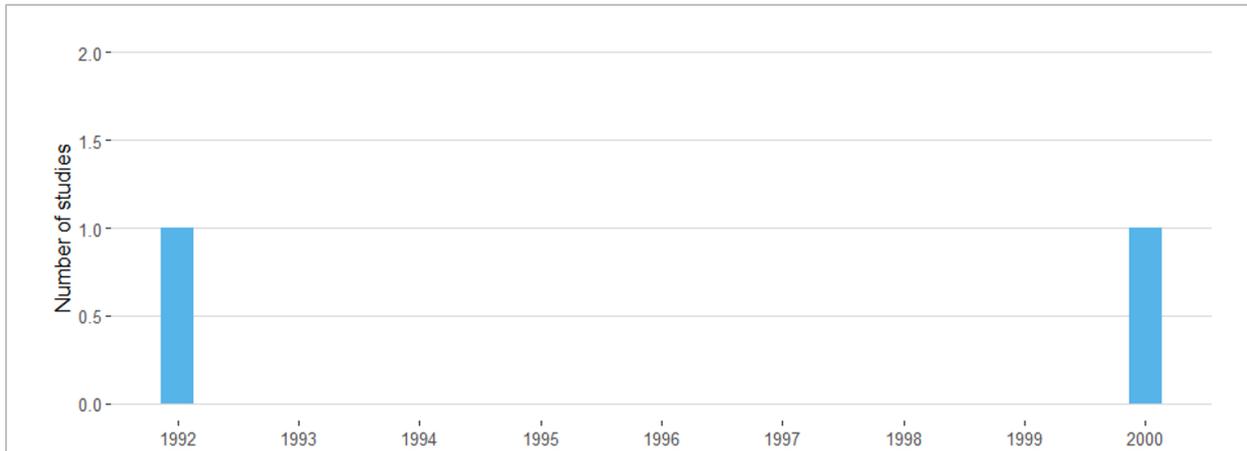


Figure 8-2. Frequency of peer-reviewed publications identified that contained PCTP biomonitoring data.

8.6.1. Human (other)

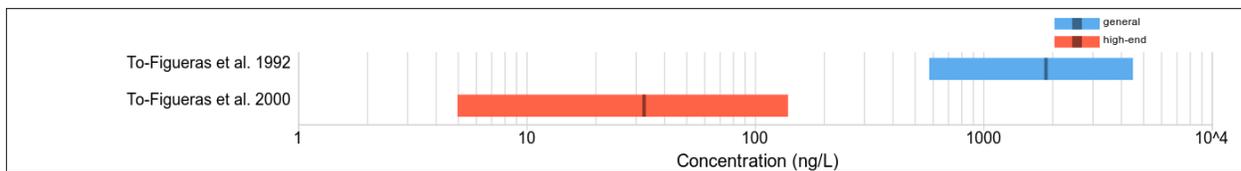


Figure 8-3. Concentration of PCTP (ng/L) in human (other) for the general (1992) and high-end (2000) populations. For each year, the range of values reported is presented by the entire length of the bar. The minimum and maximum of reported central tendency estimates are shown as a separate dark color within.

This chart contains data for the following: ([To-Figueras et al., 2000](#); [To-Figueras et al., 1992](#))

8.6.2. Other

Of the studies searched, EPA did not identify any studies with detectable levels of PCTP in human blood (serum), aquatic invertebrates, fish, aquatic mammals, terrestrial invertebrates, birds, or terrestrial mammals.

8.7. Trends in Monitoring Data

Of the studies searched, EPA did not identify any studies that reported trends for PCTP nor closely-related chemicals. Of the monitoring databases searched, no monitoring data was available for PCTP.

8.8. Modeled Intake and Dose Data

Of the studies searched, EPA did not identify any studies that reported modeled dose or intake data for PCTP.

8.9. Overview of Existing Exposure Assessments

EPA did not identify existing assessments of PCTP.

8.10. Representative Exposure Scenarios

PCTP has narrowly defined uses. Each of these uses has some potential for release and exposure. However, there is limited monitoring data for PCTP to document these exposures. Based on its physical-chemical properties, ingestion is likely the primary exposure route. Inhalation would likely be comprised of particles which could be swallowed, and dermal absorption is likely low.

Occupational: Manufacture of PCTP as a dry powder results in particulates in workplace air during transfer and packaging operations. Inhalation and dermal exposures to workers in these manufacturing facilities are possible.

Occupational: Processing of PCTP into rubber results in particulates in workplace air during unloading and transfer operations when PCTP mixture is added to processing equipment. Inhalation and dermal exposures to workers in these processing facilities are possible.

Occupational: Use of PCTP in the manufacture of golf balls results in particulates in workplace air during unloading and transfer operations. Inhalation and dermal exposures to workers in these facilities are possible

Occupational: Industrial and commercial use of PCTP as laboratory reagent may result in generation of particulates in workplace air. Laboratory workers may inhale these particulates and incidental contact with exposed skin may occur from accidental spills during use of the reagent. However, the use of engineering controls such as fume hoods and personal protective equipment is expected to reduce these exposures.

General Population: Rubber manufacturing is expected to result in water releases which could result in bioaccumulation to fish and subsequent ingestion by recreational fisherman.

Ecological: Rubber manufacturing and golf equipment manufacture are expected to result in releases to water which could result in exposures to aquatic organisms.

8.11. Summary of Review Articles

No review articles were identified that presented exposure estimates or doses for PCTP

Serum data are not available for PCTP and minimal exposure data are available.

9. References

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