United States Environmental Protection Agency

An Alternatives Assessment for the Flame Retardant Decabromodiphenyl Ether (DecaBDE)

Executive Summary

FINAL REPORT

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An Alternatives Assessment for the Flame Retardant Decabromodiphenyl Ether (DecaBDE) Executive Summary

This report provides detailed hazard information for 29 substances and mixtures that have been identified as potentially viable alternatives to decabromodiphenyl ether (decaBDE) in a variety of polymers and applications. Chemicals were selected for evaluation based on their potential as substitutes to decaBDE, not because they are expected to be safer than decaBDE. The purpose of the report is to provide human health and ecological hazard information; a fully informed choice of alternatives will likely require consideration of other factors, such as cost and efficacy. Efficacy of the flame retardant alternatives was not tested. The U.S. Environmental Protection Agency (EPA) developed the report with input from a partnership of stakeholders from business, government, academia, and environmental organizations. This report:

1. Identifies potentially viable and non-viable flame retardant alternatives for decaBDE in a variety of applications and end-uses;
2. Provides a use, life-cycle, and exposure overview for decaBDE;
3. Supplies hazard profiles for decaBDE and 29 chemical alternatives; and
4. Presents a general discussion of factors relevant to substitution decisions.

The hazard profiles for decaBDE and its alternatives can be found in Chapter 4 of the report. DecaBDE and the 29 alternatives evaluated in this alternative assessment fall into five general chemical classes:

1. Discrete halogenated flame retardants;
2. Polymeric brominated flame retardants;
3. Discrete phosphorus flame retardants, nitrogen flame retardants, and phosphorus/nitrogen flame retardants;
4. Polymeric phosphorus flame retardants and nitrogen flame retardants; and
5. Inorganic flame retardants.

Some of the alternatives have been in use for decades and others are relatively new to the market. The hazard profiles show that some of the alternatives have similar hazard profiles to decaBDE; other alternatives have trade-offs in hazard endpoints; some alternatives have preferable profiles compared to decaBDE. Flame retardants with similar profiles are persistent, potentially bioaccumulative, and tend to have hazards for carcinogenicity, developmental neurotoxicity and repeated dose toxicity. Other alternatives are associated with the concern for hazard based on different endpoints, for example aquatic toxicity, and present hazard trade-offs when compared to decaBDE. The large polymers are anticipated to be safer because their large size limits bioavailability. Unfortunately, their long-term fate in the environment is not known and some stakeholders point out that halogenated polymers can generate halogenated dioxins and furans during combustion; combustion by-products are not assessed in the report.

Some of the hazard profiles in this report are based largely on empirical data and others rely heavily on estimated values. Uncertainty is associated with estimated concern for hazards. Chemicals with limited empirical data that are currently or likely to be used at high volumes should be priority for further testing.

Background

In December 2009, EPA released the Polybrominated Diphenyl Ethers (PBDEs) Action Plan. The PBDE Action Plan summarizes hazard, exposure, and use information for three commercial PBDE mixtures, including decaBDE. DecaBDE is a flame retardant used in a variety of applications, including textiles, plastics, wiring insulation, and building and construction materials. Debromination (the physical or metabolic removal of bromine atoms) can convert decaBDE to lower brominated PBDE congeners, contributing further to the potential risk from exposure to these congeners. In March 2012, EPA initiated rulemaking and proposed a simultaneous significant new use rule (SNUR) and test rule for PBDEs under the Toxic Substances Control Act (TSCA). The proposed SNUR designates any use of decaBDE in manufacturing, importation, or processing that is not ongoing as of December 31, 2013 as a significant new use. Additionally, the manufacture (including import) or processing of any article to which PBDEs have been added will also be considered a significant new use. The proposed PBDE test rule requires testing of the health and environmental effects of PBDEs by manufacturers and processors of decaBDE and/or articles containing decaBDE for any use after December 31, 2013. In December 2009, the largest producers and suppliers of decaBDE in the U.S. committed to end its production, importation, and sales for all uses by the end of 2013.
As part of the Agency's efforts to manage chemical risks, the Action Plan called upon the DfE Program to conduct an alternatives assessment for decaBDE. A DfE Alternatives Assessment is a process for identifying and comparing potential chemical alternatives that can be used as substitutes to replace chemicals that the Agency has designated for action. DfE alternatives assessments provide information on functional class, intrinsic hazard, exposure properties, and environmental fate for chemical alternatives. It is expected that the information in DfE Alternatives Assessments will influence the selection of safer, more sustainable alternatives when combined with other information not highlighted in DfE Alternatives Assessments such as performance, cost, and efficacy of the alternatives. Alternative materials and barrier technologies could also be approaches for flame retardancy but were not a focus of this report.

Goal of the Partnership and Report

DfE convened a multi-stakeholder partnership to assess the potential human health and environmental hazards of decaBDE and its alternatives. The information presented in this report is based on the partnership's knowledge and the DfE Program's research. Chapter 1 of the report provides background information on decaBDE and defines the report's purpose and scope. Chapter 2 describes the materials and products in which decaBDE is used and briefly discusses flammability standards relevant to products that contain decaBDE. Chapter 3 provides background information on flame retardants and outlines which flame retardants are and are not included in the alternatives assessment. Chapter 3 provides details on two flame-retardant technologies not assessed in the report (inherently flame retardant materials and nanosilicates) and describes flame retardant modes of action. Chapter 4 is the largest part of the report and explains the hazard evaluation methodology and the hazard profiles for decaBDE and the 29 identified alternatives. Chapter 5 provides information on exposure and life-cycle considerations for decaBDE and its alternatives. Chapter 6 discusses considerations for selecting flame retardants and provides relevant resources for moving towards a substitution decision.

Results

With the assistance of the partnership, EPA identified 29 potentially functional, viable alternatives to decaBDE for use in select polyolefins, styrenics, engineering thermoplastics, thermosets, elastomers, or waterborne emulsions and coatings. The scope of this assessment was focused on the human health and environmental hazards of potential flame retardant substitutes. The human health endpoints evaluated in DfE alternatives assessments include acute toxicity, carcinogenicity, genotoxicity, reproductive toxicity, developmental toxicity, neurotoxicity, repeated dose toxicity, skin sensitization, respiratory sensitization, eye irritation, and dermal irritation. Large polymers were generally designated as Low concern for human health endpoints compared to discrete chemicals because the large polymers generally cannot be absorbed or easily metabolized. Although irritation can occur without absorption, it was not identified as a hazard for any of the large polymers and therefore was not a distinguishing characteristic in this assessment. Acute mammalian toxicity was Low for decaBDE and all but two of the alternatives: tris(tribromoneopentyl) phosphate and the substituted amine phosphate mixture. Carcinogenicity and genotoxicity hazards varied among the alternatives, with many Low or Moderate results. None of the chemicals had High concerns for carcinogenicity and only zinc borate had a High concern for genotoxicity. DecaBDE was Low for genotoxicity and Moderate for carcinogenicity. Reproductive, developmental, neurological, and repeated dose toxicity varied from Low to High across discrete chemicals. DecaBDE has High developmental toxicity, Moderate repeated dose toxicity, and an estimated Low neurological hazard in adults. Irritation and sensitization endpoints were generally not distinguishing, but five chemicals had at least one designation of Moderate, High, or Very High for one or more irritation or sensitization endpoints, whereas decaBDE has Low designations for these endpoints.

The aquatic toxicity endpoints evaluated in DfE alternatives assessments include acute and chronic aquatic toxicity. Aquatic toxicity hazards varied significantly due to the diverse chemistries of the alternatives. Large discrete chemicals and large polymers (both halogenated and non-halogenated) had generally Low aquatic toxicity hazards. The larger chemicals and compounds with high K_{ow} values are not expected to be bioavailable in the water column. For inorganic compounds, aquatic toxicity varied from Low to High. The metal species influences toxicity, as does the type of anion with which it is associated (e.g., a metal hydroxide). Metal compounds will have different solubilities depending on the anion involved, which will contribute to the level of toxicity of the metal compound. The aluminum, antimony and zinc compounds have Moderate to High aquatic toxicity. For ammonium polyphosphate, magnesium hydroxide and red phosphorus, aquatic toxicity was Low. In addition to some of the inorganic compounds, some of the phosphorus and/or nitrogen-containing compounds had High or Very High measured or predicted aquatic toxicity.

Chemical flame retardants must be stable by design in order to maintain their flame retardant properties throughout the lifetime of the product and most are designated as High or Very High for persistence. Additionally, the High persistence associated with the large polymers in this assessment is due to the limited bioavailability and lack of assimilation by microorganisms. The alternatives without High persistence were triphenyl phosphate, which is readily biodegradable (low persistence), as well as resorcinol bis-diphenyl phosphate, an inherently biodegradable chemical that degrades slowly (Moderate persistence), however these substances have aquatic toxicity hazards and bioaccumulation potential.

The ability of a chemical to accumulate in living organisms is described by the bioconcentration, bioaccumulation, biomagnification, and/or trophic magnification factors. DecaBDE has High potential for bioaccumulation, as do its breakdown products (lower brominated diphenyl ether congeners). Some of the alternatives assessed in this report also have a High potential for bioaccumulation, including the discrete brominated chemicals and, based on presence of oligomers below 1,000 daltons, some of the phenyl phosphates. The potential for a molecule to be absorbed by an organism tends to be lower when the molecule is greater than 1,000 daltons in size. This is reflected in the Low hazard designations for bioaccumulation for the polymeric flame retardants without low molecular weight components below 1,000 daltons. The inorganic flame retardants assessed in this report do not have High potential to bioaccumulate, nor do the discrete nitrogen-based flame retardants.

How to Use This Report

Audiences for this report include stakeholders interested in chemical hazards and safer alternatives, including but not limited to chemical manufacturers, component manufacturers, product manufacturers, retailers, consumers, non-governmental organizations, consultants, and state and federal regulators. Three potential uses of this report include:

Identification of potential substitutes. This report allows stakeholders interested in chemical substitution to identify functional substitutes for decaBDE in certain plastics. The list of potential alternatives introduced in Chapter 3 includes chemicals identified by stakeholders as viable, functional alternatives as well as chemicals that are not considered functional alternatives and information on inherently flame retardant polymers. The inclusion of a chemical in this assessment does not indicate environmental- or health-based preferability. By identifying potential functional alternatives, this report assists manufacturers in selecting chemicals for additional performance testing.

Selection of alternative chemicals based on comparative chemical hazard assessment. This report helps decision-makers understand and compare the hazards associated with potential alternatives and supplement information on performance and cost. Some alternatives may be associated with hazard concerns similar to those of decaBDE; others may be associated with different hazard concerns. Use of the hazard information in Chapter 4 may help businesses avoid the cost of repeated substitution. The information in Chapter 4 is a robust human health and environmental profile for each chemical that is based on empirical data and enhanced with modeling and expert judgment to fill data gaps. The profiles can help decision-makers understand which potential alternatives may come under scrutiny in the future and choose the safest possible alternative now in order to reduce future costs. In addition to reading the hazard summary tables (Table 4-4, Table 4-5, and Table 4-6), decision-makers should review the full hazard assessments for each chemical available in Section 4.8. The hazard assessments provide more information on hazard criteria, data interpretation and information used to assign hazard values in each category. Decision-makers should consider this information to ensure a complete understanding of the hazard profiles of each alternative.

Use of hazard information for further analysis and decision-making. The information in this report can be used to inform further analyses on preferred alternative chemicals, such as risk

assessments or life-cycle assessments. For example, a decision-maker could identify several functional alternatives with preferable hazard profiles, and conduct product-specific risk assessments based on exposure expectations along the product's life-cycle. This type of supplementary information may be helpful in guiding product-specific decision-making. Information in this report also can be used to identify the Very Persistent Very Bioaccumulative chemicals targeted under European REACH policy. This report does not evaluate the relative hazards of alternatives, but GreenScreen™ (www.cleanproduction.org/Greenscreen.php) is one tool that can be used for this purpose. The criteria used to develop the hazard assessments in this report can also be used to inform Green Chemistry design if availability of safer alternatives is limited.

Hazard Summary Table

Table ES-1 Screening Level Hazard Summary for DecaBDE and Halogenated Flame Retardant Alternatives

This table only contains information regarding the inherent hazards of flame retardant chemicals. Evaluation of risk considers both the hazard and exposure associated with the substance including combustion and degradation by-products. The caveats listed in the legend and footnote sections must be taken into account when interpreting the hazard information in the table.

VL = Very Low hazard L = Low hazard M = Moderate hazard H = High hazard VH = Very High hazard — Endpoints in colored text (VL, L, M, H, and VH) were assigned based on empirical data. Endpoints in black italics *(VL, L, M, H,* and *VH*) were assigned using values from predictive models and/or professional judgment.

§ Based on analogy to experimental data for a structurally similar compound.

¤ This alternative may contain impurities. These impurities have hazard designations that differ from the flame retardant alternative, Brominated poly(phenylether), as follows, based on experimental data: HIGH for human health, HIGH for aquatic toxicity, and VERY HIGH for bioaccumulation.

T This chemical is subject to testing in an EPA consent order for this endpoint.

Chemical (for full chemical name and relevant trade names see the individual profiles in Section 4.8)	CASRN	Human Health Effects											Aquatic Toxicity**		Environmental Fate	
		Acute Toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation
DecaBDE and Halogenated Flame Retardant Alternatives																
DecaBDE and Discrete Halogenated FR Alternatives																
Bis(hexachlorocyclopentadieno) Cyclooctane	13560-89-9	L	*M*§	*M*§	VL	VL	L	M	L		VL	*L*	*L*	*L*	VH	*H*
Brominated Poly(phenylether)	Confidential	L	*L*¤	L	VL¤	*M*¤	*L*¤	L¤	L		L	VL	L	*L*¤	VH*T*	*H*T¤
Decabromodiphenyl Ethane	84852-53-9	L	*M*§	L	L	*H*§	*L*	L	L		VL	VL	L	*L*	VH	*H*
Decabromodiphenyl Ether	1163-19-5	L	M	L	L	H	*L*	M	L		L	L	*L*	*L*	VH	*H*
Ethylene Bis-Tetrabromophthalimide	32588-76-4	L	*M*	L	*L*	*M*§	*L*	L	*L*		VL	VL	*L*	*L*	VH	*H*
Tetrabromobisphenol A Bis (2,3-dibromopropyl) Ether	21850-44-2	L	*M*	M	*M*	*M*	*L*	*M*	L		L	L	L	*L*	VH	*H*
Tris(tribromoneopentyl) Phosphate	19186-97-1	*M*	*M*	L	*M*	*M*	*H*	L	L		*L*	*L*	*L*	*L*	*H*	*M*
Tris(tribromophenoxy) Triazine	25713-60-4	L	*L*	L	*L*	*L*	*L*	L	L		L	VL	*L*	*L*	VH	*H*

**Aquatic toxicity: EPA/DfE criteria are based in large part upon water column exposures which may not be adequate for poorly soluble substances such as many flame retardants that may partition to sediment and particulates.

Table ES-1 Continued

VL = Very Low hazard L = Low hazard M = Moderate hazard H = High hazard VH = Very High hazard — Endpoints in colored text (VL, L, M, H, and VH) were assigned based on empirical data. Endpoints in black italics *(VL, L, M, H,* and *VH*) were assigned using values from predictive models and/or professional judgment.

[d] This hazard designation would be assigned MODERATE if >5% of the particles are in the respirable range as a result of dust forming operations.

♦ Different formulations of the commercial product are available. One of these many formulations has an average MW of ~1,600 and contains significant amounts of lower MW components. These lower MW components have hazard designations different than the polymeric flame retardant, as follows: HIGH (estimated) for bioaccumulation; HIGH (experimental) for acute aquatic toxicity; HIGH estimated for chronic aquatic toxicity; MODERATE (experimental) for developmental; and MODERATE (estimated) for carcinogenicity, genotoxicity, repeated dose, reproductive, and skin and respiratory sensitization toxicity.

Chemical (for full chemical name and relevant trade names see the individual profiles in Section 4.8)	CASRN	Human Health Effects											Aquatic Toxicity[**]		Environmental Fate	
		Acute Toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation
Halogenated Flame Retardant Alternatives Continued																
Polymeric Halogenated FR Alternatives[P]																
Brominated Epoxy Polymers	68928-70-1	*L*	*L*♦	L	*L*♦	*L*♦	*L*	*L*♦[d]	L	♦	*L*	*L*	*L*♦	*L*♦	*VH*	*L*♦
Brominated Epoxy Polymer(s)	Confidential	*L*	*L*♦	*L*♦	*L*♦	*L*♦	*L*	*L*♦[d]	*L*♦	♦	*L*	*L*	*L*♦	*L*♦	*VH*	*L*♦
Mixture of brominated epoxy polymer(s) and bromobenzyl acrylate	Confidential	*L*	*L*♦	*L*♦	*L*♦	*L*♦	*L*	*L*♦[d]	*L*♦	♦	*L*	*L*	*L*♦	*L*♦	*VH*	*L*♦
Brominated Epoxy Resin End-Capped with Tribromophenol	135229-48-0	*L*	*L*	*L*	*L*	*L*	*L*	*L*[d]	L		L	VL	*L*	*L*	*VH*	*L*
Brominated Polyacrylate	59447-57-3	*L*	*L*	*L*	*L*	*L*	*L*	*L*[d]	*L*		*L*	*L*	*L*	*L*	*VH*	*L*
Brominated Polystyrene	88497-56-7	L	*L*	*L*	*L*	*L*	*L*	*L*[d]	*L*		L	*L*	*L*	*L*	*VH*	*L*

[**] Aquatic toxicity: EPA/DfE criteria are based in large part upon water column exposures which may not be adequate for poorly soluble substances such as many flame retardants that may partition to sediment and particulates.

[P] The range of polymer molecular weight can be broad. The polymers listed here have low toxicity for human health and aquatic endpoints. Not all polymers will have this low toxicity; hazards will vary with physical-chemical properties.

Table ES-2 Screening Level Hazard Summary for Organic Phosphorus or Nitrogen Flame Retardant Alternatives

This table only contains information regarding the inherent hazards of flame retardant chemicals. Evaluation of risk considers both the hazard and exposure associated with the substance including combustion and degradation by-products. The caveats listed in the legend and footnote sections must be taken into account when interpreting the hazard information in the table.

VL = Very Low hazard L = Low hazard M = Moderate hazard H = High hazard VH = Very High hazard — Endpoints in colored text (VL, L, M, H, and VH) were assigned based on empirical data. Endpoints in black italics *(VL, L, M, H,* and *VH*) were assigned using values from predictive models and/or professional judgment.

§ Based on analogy to experimental data for a structurally similar compound.

‡ The highest hazard designation of any of the oligomers with MW <1,000.

◊ The highest hazard designation of a representative component of the oligomeric mixture with MWs <1,000.

Chemical (for full chemical name and relevant trade names see the individual profiles in Section 4.8)	CASRN	Human Health Effects											Aquatic Toxicity**		Environmental Fate	
		Acute Toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation
Organic Phosphorus or Nitrogen Flame Retardant (PFR or NFR) Alternatives																
Discrete PFR, NFR and P/NFR Alternatives																
Substituted Amine Phosphate Mixture [1]	Confidential	*H*	*M*	*M*	*M*	*M*	*L*	*M*	L	*M*§	M	VL	*M*	*L*	*H*	*L*
Triphenyl Phosphate	115-86-6	L	*M*	L	L	L	L	H	L		L	VL	VH	VH	L	M
Polymeric PFR and NFR Alternatives																
Bisphenol A bis-(diphenyl phosphate); BAPP	181028-79-5	L	*M*	L	*L*	*L*§	*L*§	L	L		L	L	L	L	H	*H*◊
Melamine Cyanurate[1]	37640-57-6	*L*	*M*	*M*	*M*§	*M*§	*L*	H	*L*		*L*	*L*	*L*	*L*	VH	*L*
Melamine Polyphosphate[1]	15541-60-3	L	*M*	*M*	*L*§	*L*	*L*§	*M*	*L*		L	VL	L	L	*H*	*L*
N-alkoxy Hindered Amine Reaction Products	191680-81-6	L	*M*	L	*H*	*H*	*L*	*H*	L		L	VL	*H*	*H*	H	*H*‡

** Aquatic toxicity: EPA/DfE criteria are based in large part upon water column exposures which may not be adequate for poorly soluble substances such as many flame retardants that may partition to sediment and particulates.

[1] Hazard designations are based upon the component of the salt with the highest hazard designation, including the corresponding free acid or base.

Table ES-2 Continued

VL = Very Low hazard L = Low hazard M = Moderate hazard H = High hazard VH = Very High hazard — Endpoints in colored text (VL, L, M, H, and VH) were assigned based on empirical data. Endpoints in black italics *(VL, L, M, H,* and *VH*) were assigned using values from predictive models and/or professional judgment.

[d] This hazard designation would be assigned MODERATE if >5% of the particles are in the respirable range as a result of dust forming operations

[§] Based on analogy to experimental data for a structurally similar compound.

[‡] The highest hazard designation of any of the oligomers with MW <1,000.

[¥] Phosphonate Oligomer, with a MW range of 1,000 to 5,000, may contain significant amounts of an impurity, depending on the final product preparation. This impurity has hazard designations that differ from the polymeric flame retardant, as follows: MODERATE (experimental) for carcinogenicity, reproductive and repeated dose toxicity, skin sensitization, eye and dermal irritation; and HIGH (experimental) for developmental toxicity and acute and chronic aquatic toxicity.

Chemical (for full chemical name and relevant trade names see the individual profiles in Section 4.8)	CASRN	Human Health Effects											Aquatic Toxicity[**]		Environmental Fate	
		Acute Toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation
Organic Phosphorus or Nitrogen Flame Retardant (PFR or NFR) Alternatives Continued																
Polymeric PFR and NFR Alternatives																
Phosphonate Oligomer[¥]	68664-06-2	L	*M*	*L*[§]	*L*[¥]	*L*[¥]	*M*[‡]	*L*[§¥]	*L*[§¥]		*M*[‡¥]	*M*[‡]	L[¥]	*H*[‡]	*VH*	*H*[‡]
Polyphosphonate	68664-06-2	L	*L*	*L*	*L*	*L*	*L*	*L*[d]	*L*		*L*	*L*	*L*	*L*	*VH*	*L*
Phosphoric acid, mixed esters with [1,1'-bisphenyl-4,4'-diol] and phenol; BPBP	1003300-73-9	L	*M*	L	*L*[§]	*L*[§]	L	L	L		VL	VL	*H*[§]	*H*[§]	H	*M*[‡]
Poly[phosphonate-co-carbonate]	77226-90-5	L	*L*	*L*	*L*	*L*	*L*	*L*[d]	*L*		*L*	*L*	*L*	*L*	*VH*	*L*
Resorcinol Bis-Diphenylphosphate; RDP	125997-21-9	L	*M*[§]	L	L	M	M	M	*L*		L	VL	VH	VH	M	*H*[‡]

[**] Aquatic toxicity: EPA/DfE criteria are based in large part upon water column exposures which may not be adequate for poorly soluble substances such as many flame retardants that may partition to sediment and particulates.

Table ES-3 Screening Level Hazard Summary for Inorganic Flame Retardant Alternatives

This table only contains information regarding the inherent hazards of flame retardant chemicals. Evaluation of risk considers both the hazard and exposure associated with the substance including combustion and degradation by-products. The caveats listed in the legend and footnote sections must be taken into account when interpreting the hazard information in the table.

VL = Very Low hazard L = Low hazard M = Moderate hazard H = High hazard VH = Very High hazard — Endpoints in colored text (VL, L, M, H, and VH) were assigned based on empirical data. Endpoints in black italics *(VL, L, M, H,* and *VH*) were assigned using values from predictive models and/or professional judgment.

[d] This hazard designation would be assigned MODERATE if >5% of the particles are in the respirable range as a result of dust forming operations.

[R] Recalcitrant: Substance is comprised of metallic species that will not degrade, but may change oxidation state or undergo complexation processes under environmental conditions.

[*] Ongoing studies may result in a change in this endpoint.

Chemical (for full chemical name and relevant trade names see the individual profiles in Section 4.8)	CASRN	Human Health Effects											Aquatic Toxicity**		Environmental Fate	
		Acute Toxicity	Carcinogenicity	Genotoxicity	Reproductive	Developmental	Neurological	Repeated Dose	Skin Sensitization	Respiratory Sensitization	Eye Irritation	Dermal Irritation	Acute	Chronic	Persistence	Bioaccumulation
Inorganic Flame Retardant Alternatives																
Aluminum Diethylphosphinate	225789-38-8	L	*L*	L	VL	*M*	*M*	*M*	L		L	VL	M	M	*H*[R]	*L*
Aluminum Hydroxide	21645-51-2	L	*L*	L	*L*	L	M	*M*	L		VL	VL	*M*	*M*	*H*[R]	*L*
Ammonium Polyphosphate	68333-79-9	L	*L*	*L*	*L*	*L*	*L*	*L*[d]	L		VL	L	*L*	*L*	*VH*	*L*
Antimony Trioxide[1]	1309-64-4	L	M[*]	M	*M*	*L*	*L*	H	L		L	M	H	M	*H*[R]	*L*
Magnesium Hydroxide	1309-42-8	L	L	L	L	*L*	*L*	L	*L*		M	L	*L*	*L*	*H*[R]	*L*
Red Phosphorus	7723-14-0	L	*L*	*M*	*L*	*L*	*L*	*L*	L		M	M	L	L	H	*L*
Zinc Borate	1332-07-6	L	*L*	*H*	*M*	*M*	*H*	*L*	L		L	L	*H*	*H*	H[R]	*L*

**Aquatic toxicity: EPA/DfE criteria are based in large part upon water column exposures which may not be adequate for poorly soluble substances such as many flame retardants that may partition to sediment and particulates.

[1] This compound is included in the ongoing EPA Work Plan evaluation for Antimony Trioxide.