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Replacement substances for the brominated flame retardants PBDE, HBCDD, and TBBPA

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Sammanfattning
En litteratur- och databasstudie genomfördes med syfte att identifiera nya flamskyddsmedel, dvs. ämnen som används som ersättningskemikalier för polybromerade difenyletrar (PBDEs), hexabromocyklododekan (HBCDD) samt tetrabromobisfenol-A (TBBPA). Först studerades utvalda patent från den amerikanska patentdatabasen, där ett antal nya flamskyddsmedel kunde identifieras, bl.a. pentaerytritol, melamin och bis-(t-butylfenyl)fenylfosfat. Därefter granskades den öppna litteraturen (inklusive internationellt publicerade vetenskapliga artiklar och rapporter från olika miljömyndigheter) för att finna tidigare rapporterade koncentrationer av nya flamskyddsmedel i inomhusdamm, inom- och utomhusluft, vatten, sediment, slam, jord, atmosfärisk deposition, växter, djur samt människor. Genom denna granskning identifierades 66 nya flamskyddsmedel som detekterats i minst en av de studerade matriserna. Vidare identifierades sex listor över prioriterade ämnen i den genomsökta litteraturen. Dessa listor innehöll ca 50 nya flamskyddsmedel som anses ha hög miljömässig relevans. Information om förbrukningsmängder av olika flamskyddsmedel i Sverige och Europeiska unionen (EU) hämtades från två olika databaser (*Registered substances* from the European Chemicals Agency (ECHA) and the Swedish product register from the Swedish Chemicals Agency (KemI)). I Sverige är pentaerytritol det flamskyddsmedel som används i störst mängd, följt av bl.a. kortkedjade klorerade paraffiner (SCCPs), 2-etylhexyldifenylfosfat (EHDPP), 1,2-bis(2,4,6-tribromofenoxy)- etan (BTBPE) och tetrabromobisfenol-A-bis(2,3-dibromopropyl)eter (TBBPA-BDBPE). I EU används pentaerytritol samt melamin i högst kvantiteter, följt av bl.a. kort- och mediumkedjade klorerade paraffiner, 1,2-bis(2,3,4,5,6-pentabromofenyl)etan (DBDPE) och trietylfosfat (TEP). Från den svenska databasen erhölls också exponeringsindex som ger en uppskattning av risken för exponering (för ytvatten, luft, jord, avloppsreningsverk, konsument, samt vid yrkesmässig hantering) för de olika flamskyddsmedlen. De flamskyddsmedel som generellt utgör den högsta exponeringsrisken konstaterades vara pentaerytritol, tributylfosfat (TNBP), trifenylfosfat (TPHP), SCCPs och tritolylfosfat (TMPP). Från den svenska databasen var det dessutom möjligt att få fram information om tidstrender i risken för exponering. Ökande risk identifierades för TBBPA-BDBPE, tris(tribromoneopentyl)fosfat (TTBNPP), DBDPE, resorcinolbis-(difenylfosfat) (PBDPP), TMPP och cresyldifenylfosfat (CDP). Slutligen, för att kunna prioritera mellan de identifierade flamskyddsmedlen, utvecklades en multikriterimodell baserad på (i) användningsdata, (ii) tidstrender i risken för exponering. (iii) detekterbarhet i miljön och (iv) publicerade prioriteringslistor. De tio högst rankade flamskyddsmedlen från denna modell var TBBPA-BDBPE, DBDPE, BTBPE, TTBNPP, bis(2-etyl-1-hexyl)tetrabromoftalat (BEH-TEBP), etylenbis-tetrabromoftalimid (EBTEBPI), PBDPP, *para*-TMPP, TPHP, and tri(1-kloro-2-propyl)fosfat (TCIPP). Dessa flamskyddsmedel föreslås bli prioriterade i framtida miljöövervakningar.

Replacement substances for the brominated flame retardants PBDE, HBCDD, and TBBPA

Ersättningsämnen för de bromerade flamskyddsmedlen PBDE, HBCDD och TBBPA

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Rapport till Naturvårdsverket

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Preface

As an assignment from the Swedish Environmental Protection Agency (Naturvårdsverket), a literature- and database-review focusing on emerging organic flame retardants (FRs) was conducted. The study aimed at identifying new alternative flame retardants used as replacement chemicals for the legacy FRs PBDEs and HBCDD, and also for TBBPA. To gather relevant information, (i) selected patents of the US patent database were explored, (ii) usage data from the EU and Sweden were extracted from databases, and (iii) environmental concentrations from published research articles and reports were collected. To finally prioritize between the identified FRs, a multicriteria model was developed based on the collected data. As the study focuses on emerging FRs, information about legacy FRs such as PBDEs and HBCDD is not part of this report. Furthermore, the review focuses entirely on organic FRs, and thus information on inorganic FRs is not included.

Förord

På uppdrag av Naturvårdsverket genomfördes en litteratur- och databasstudie med fokus på nya organiska flamskyddsmedel. Syftet med studien var att identifiera flamskyddsmedel som används som ersättningsämnen för traditionellt använda flamskyddsmedel såsom PBDEer och HBCDD och även TBBPA. Relevant information inhämtades genom att (i) utforska utvalda patent ur den amerikanska patentdatabasen, (ii) sammanställa användardata från två olika databaser (EU och Sverige), och (iii) sammanställa rapporterade koncentrationer från publicerade forskningsartiklar och rapporter. För att kunna prioritera mellan de identifierade flamskyddsmedlen utvecklades en multikriterimodell baserad på insamlade fakta. Eftersom studien fokuserar på nya flamskyddsmedel så inkluderas inte information om PBDEer och HBCDD. Vidare fokuserar studien enbart på organiska flamskyddsmedel, vilket innebär att information om oorganiska flamskyddsmedel inte heller inkluderas i rapporten.

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Summary

A literature and database review was conducted with the aim of identifying new alternative flame retardants (FRs) used as replacement chemicals for the traditionally used polybrominated diphenylethers (PBDEs) and hexabromocyclododecane (HBCDD), and also for tetrabromobisphenol-A (TBBPA). Firstly, selected patents from the US patent database were studied and a number of alternative FRs could be identified, including, e.g., pentaerythritol, melamine, and bis-(t-butylphenyl) phenyl phosphate. Secondly, two databases, containing quantity information on usage from Sweden and the EU, were searched to obtain usage data. In Sweden, the FR that is used in the highest quantities is pentaerythritol, followed by e.g., short-chained chlorinated paraffins (SCCPs), 2-ethylhexyl diphenyl phosphate (EHDPP), 1,2-bis(2,4,6-tribromophenoxy) ethane (BTBPE), and tetrabromobisphenol-A-bis(2,3-dibromopropyl) ether (TBBPA-BDBPE). In the EU, pentaerythritol and melamine are used in the highest quantities, followed by e.g., SCCPs, MCCPs, 1,2-bis(2,3,4,5,6-pentabromophenyl)ethane (DBDPE), and triethyl phosphate (TEP). From the Swedish database, exposure indices were obtained, indicating the potential of exposure for different environmental compartments to different FRs. The highest average potential of exposure was found for pentaerythritol, tributyl phosphate (TNBP), triphenyl phosphate (TPHP), SCCPs, and tritolyl phosphate (TMPP). In addition, time trends in the potential of exposure were obtained from the database and showed increasing trends for TBBPA-BDBPE, tris(tribromoneopentyl) phosphate (TTBNPP), DBDPE, Resorcinol bis(diphenyl phosphate) (PBDPP), TMPP, and cresyl diphenyl phosphate (CDP). Thirdly, the open literature (including international peer-reviewed articles and reports from environmental authorities), was reviewed in search for previously reported environmental concentrations of emerging FRs in indoor dust, indoor and outdoor air, water, sediment, sludge, soil, atmospheric deposition, plants and animals including humans. In total, 66 different FRs were detected in at least one of the studied matrices. In addition, six prioritization lists were identified, which included about 50 different FRs that were suggested to be of high environmental relevance. Finally, to be able to prioritize between the identified FRs for future screenings, a multicriteria model was developed based on (i) usage, (ii) time trends in the potential of exposure, (iii) environmental detection, and (iv) previous publication lists. From this multicriteria model, the top ten FRs were: TBBPA-BDBPE, DBDPE, BTBPE, TTBNPP, bis(2-ethyl-1-hexyl)tetrabromophthalate (BEH-TEBP), ethylene bis-tetrabromo phtalimide (EBTEBPI), PBDPP, *para*-TMPP, TPHP, and tri(1-chloro-2-propyl) phosphate (TCIPP). These FRs are suggested to be prioritized in future screenings.

Sammanfattning

En litteratur- och databasstudie genomfördes med syfte att identifiera nya flamskyddsmedel, dvs. ämnen som används som ersättningskemikalier för polybromerade difenyletrar (PBDEs), hexabromocyklododekan (HBCDD) samt tetrabromobisfenol-A (TBBPA). Först studerades utvalda patent från den amerikanska patentdatabasen, där ett antal nya flamskyddsmedel kunde identifieras, bl.a. pentaerytritol, melamin och bis-(t-butylfenyl)fenylfosfat. Därefter granskades den öppna litteraturen (inklusive internationellt publicerade vetenskapliga artiklar och rapporter från olika miljömyndigheter) för att finna tidigare rapporterade koncentrationer av nya flamskyddsmedel i inomhusdamm, inom- och utomhusluft, vatten, sediment, slam, jord, atmosfärisk deposition, växter, djur samt människor. Genom denna granskning identifierades 66 nya flamskyddsmedel som detekterats i minst en av de studerade matriserna. Vi identifierade sex listor över prioriterade ämnen i den genomsökta litteraturen. Dessa listor innehöll ca 50 nya flamskyddsmedel som anses ha hög miljömässig relevans. Information om förbrukningsmängder av olika flamskyddsmedel i Sverige och Europeiska unionen (EU) hämtades från två olika databaser (Registered substances from the European Chemicals Agency (ECHA) and the Swedish product register from the Swedish Chemicals Agency (KemI)). I Sverige är pentaerytritol det flamskyddsmedel som används i störst mängd, följt av bl.a. kortkedjade klorerade paraffiner (SCCPs), 2-etylhexyldifenylfosfat (EHDPP), 1,2-bis(2,4,6-tribromofenoxy)- etan (BTBPE) och tetrabromobisfenol-A-bis(2,3-dibromopropyl)eter (TBBPA-BDBPE). I EU används pentaerytritol samt melamin i högst kvantiteter, följt av bl.a. kort- och mediumkedjade klorerade paraffiner, 1,2-bis(2,3,4,5,6-pentabromofenyl)etan (DBDPE) och trietylfosfat (TEP). Från den svenska databasen erhölls också exponeringsindex som ger en indikation av risken för exponering (för ytvatten, luft, jord, avloppsreningsverk, konsument, samt vid yrkesmässig hantering) för de olika flamskyddsmedlen. De flamskyddsmedel som generellt utgör den högsta exponeringsrisken konstaterades vara pentaerytritol, tributylfosfat (TNBP), trifenylfosfat (TPHP), SCCPs och tritolylfosfat (TMPP). Från den svenska databasen var det dessutom möjligt att få fram information om tidstrender i risken för exponering. Ökande risk identifierades för TBBPA-BDBPE, tris(tribromoneopentyl)fosfat (TTBNPP), DBDPE, resorcinolbis-(difenylfosfat) (PBDPP), TMPP och cresyldifenylfosfat (CDP). Slutligen, för att kunna prioritera mellan de identifierade flamskyddsmedlen, utvecklades en multikriterimodell baserad på (i) användningsdata, (ii) tidstrender i risken för exponering. (iii) detekterbarhet i miljön och (iv) publicerade prioriteringslistor. De tio högst rankade flamskyddsmedlen från denna modell var TBBPA-BDBPE, DBDPE, BTBPE, TTBNPP, bis(2-etyl-1-hexyl)tetrabromoftalat (BEH-TEBP), etylenbis-tetrabromoftalimid (EBTEBPI), PBDPP, para-TMPP, TPHP, and tri(1-kloro-2-propyl)fosfat (TCIPP). Dessa flamskyddsmedel föreslås bli prioriterade i framtida miljöövervakningar.

1. Introduction

Flame retardants (FRs) are substances used in different materials to provide fire protection. The FRs are designed to interrupt chemical reactions of combustion through different mechanisms (e.g., by halogens reacting with H and OH radicals formed in the flame), and thereby slowing down the fire development or ultimately quench the fire. FRs are widely used in many different materials, including e.g., textiles and plastics, which are part of everyday-life products such as furniture, electronics and building insulation [1, 2].

During the 1970's, the production and usage of plastics and synthetic fibers increased and partly replaced more traditional materials like wood and metals [3]. As a result of plastics being more flammable than traditional materials, the incorporation of FRs into these materials was desired, which led to an increased use of FRs. Following this, many nations introduced legislation towards high fire safety standards by requiring producers of e.g., furniture and electronics to add FRs into their products [4]. FRs are emitted during production, usage and disposal of the products, and as a result, many FRs are nowadays ubiquitously spread in the environment. The traditionally heavily used polybrominated diphenyl ethers (PBDEs) have e.g., been detected in numerous abiotic (e.g. soil, freshwater and sediment) and biotic (e.g. seabirds and mammals) matrices in the Arctic [4]. Also several alternative FRs (e.g., BTBPE and DBE-DBCH) have been detected in remote sites such as the Arctic [5]. Detection of FRs at far distances from emission sources demonstrate that these substances are persistent and undergo long range transport (LRT) without being transformed.

As a consequence of persistency, bioaccumulation potential, and toxicicity (PBT), tetra- through hepta-PBDEs have been included in the Stockholm Convention. The use of two out of three technical PBDE products (pentaBDE and octaBDE) is forbidden in new materials in the European Union (EU) since 2009, while the third technical PBDE product (DecaBDE) has been suggested to be listed in the Stockholm Convention [6]. DecaBDE is, however, already banned from use in electrical and electronic appliances within the EU [7]. Two more FRs are listed in the Stockholm convention, namely hexabromocyclododecane (HBCDD) and hexabromobiphenyl [6]. Hexabromobiphenyl was one of the main components in the polybrominated biphenyl (PBB) mixture that was accidentally mixed into cattle feed in Michigan in 1973 [8], causing the widespread contamination of animal feed, animals and human food products.

The restriction of the previously heavily used PBDEs has increased the need of alternative FRs to be developed and used. For example, the use of TDCIPP in American couches has increased since the ban of PentaBDE [9]. The recent development and use of of alternative FRs has created a need of an up-to-date overview of the current situation. The aim of this literature study was to identify (i) what FRs are used as replacement chemicals for PBDEs, HBCDD, and also TBBPA, (ii) what FRs that have been detected in indoor air and dust, and (iii) what FRs that have been detected in the environment, and finally (iv) what FRs that should be included in future environmental screening studies.

2. Exploration of available databases

A number of available databases were utilized in the search for relevant information on alternative FRs of interest. The used databases were: i) the US patent database [10], ii) *Registered substances* from the European Chemicals Agency (ECHA) [11], and iii) the Swedish product register from the Swedish Chemicals Agency (KemI) [12]. Before a product is being introduced on a market (such as the EU or the US), it is often registered in a patent database. Thus, patent databases can be useful information sources when trying to predict future use of chemicals such as FRs. A search of US patents (US patent database, www.uspto.gov) was done to identify altrnative FRs using classification numbers given within the Cooperative Patent Classification (CPC)-system for polymers and beds, two types of products that often are treated to provide fire safety. Note that the results from the patent database search presented here are not comprehensive, but should rather be considered as an attempt of exploring the possibility of identifying trends in FRs usage through patent searches.

The database *Registered substances* from ECHA provides information on amounts of chemicals that is manufactured in and/or imported into the EU on an annual basis [11]. This database was used to obtain annual production/import data for the emerging FRs identified in this literature review. Furthermore, data on the use of emerging FRs in Sweden was obtained from the Swedish Chemicals Agency (Kemikalieinspektionen, KemI). EC/EINECS-numbers were used for the search if available and otherwise CAS-numbers (Table 1). Note that only non-confidential quantities are shown in these databases. Thus, the reported quantities may not necessarily reflect the real production/import, and additionally, intermediate substances used to produce other chemicals are not included in the databases.

All FRs (*n* = 125) identified in this literature review are listed with abbreviations, name, CAS- and EC-numbers (if available) in Table 1. Throughout this report, the FR abbreviations suggested by Bergman et al. (2012) [13] are used if available. Information on selected FRs are given in the Appendix, Table S1, and modelled physicochemical properties of selected FRs from a previous peer-reviewed publication [14] are given in the Appendix, Tables S16-S17.

Table 1 Identified FRs with abbreviation, name, CAS-, and EC-number (alphabetic order).

Abbreviation	Name	CAS#	EC#
2,4-DBP	2,4-Dibromophenol	615-58-7	210-436-5
2,6-DBP	2,6-Dibromophenol	608-33-3	210-161-0
2-BP	2-Bromophenol	95-56-7	251-200-1
3-BP	3-Bromophenol	591-20-8	209-706-5
4´-PeBPOBDE208	Pentabromophenoxy-nonabromodiphenyl ether	58965-66-5	261-526-6
4-BP	4-Bromophenol	106-41-2	203-394-4
TBP-AE/ATE	Allyl 2,4,6-tribromophenyl ether	221-913-2	221-913-2
BADP	Bisphenol A bis(diphenyl phosphate)	5945-33-5	425-220-8

BATE	2-Bromoallyl 2,4,6-tribromophenyl ether	-	-
bBDBP	Bis(2,3-Dibromopropyl) phoshate	5412-25-9	226-493-4
BCMP-BCEP/V6	Tetrakis(2-Chloroethyl)dichloroisopentyl diphosphate	38051-10-4	253-760-2
BdPhP	Butyldiphenyl phosphate	2752-95-6	220-398-1
BEH-TEBP	Bis(2-ethyl-1-hexyl)tetrabromophthalate	26040-51-7	247-426-5
BTBPE	1,2-Bis(2,4,6-tribromophenoxy) ethane	37853-59-1	253-692-3
CDP	Cresyl diphenyl phosphate	26444-49-5	247-693-8
Chlordene Plus	Chlordene Plus	-	-
CLP1	Tris(2-chloroethyl) phosphite	140-08-9	205-397-6
DBDPE	1,2-Bis(2,3,4,5,6-pentabromophenyl)ethane	84852-53-9	284-366-9
DBE-DBCH/TBECH	1,2-Dibromo-4-(1,2-dibromoethyl)cyclohexane	3322-93-8	222-036-8
DBHCTD	Hexachlorocyclopantadienyl-dibromocyclooctane	51936-55-1	257-526-0
DBNPG	Dibromoneopentyl alcohol	3296-90-0	221-967-7
DBPhP	Dibutyl phenyl phosphate	2528-36-1	219-772-7
DBS	Dibromostyrene	31780-26-4	-
DDC-Ant/Dec-603	Dechlorane 603	13560-92-4	-
DDC-CO/DP	Dechlorane Plus	13560-89-9	236-948-9
DDC-DBF/Dec-602	Dechlorane 602	31107-44-5	250-472-9
Dec-604A/HCTBPH	Dechlorane 604 component A	34571-16-9	-
Dec-604B	Dechlorane 604 component B	71245-27-7[a]	-
Dibutyl chlorendate	Dibutyl 1,4,5,6,7,7-hexachlorobicyclo[2.2.1]-hept-5-ene-2,3-dicarboxylate	1770-80-5	217-192-9
DMP	Dimethyl phosphate	813-78-5	212-389-6
DOPP	Dioctyl phenyl phosphate	6161-81-5	228-190-2
DPhBP	Diphenyl butyl phosphate	2752-95-6	220-398-1
EBTEBPI	Ethylene bis-tetrabromo phtalimide	32588-76-4	251-118-6
EHDPP	2-Ethylhexyl diphenyl phosphate	1241-94-7	214-987-2
EH-TBB	2-Ethylhexyl 2,3,4,5-tetrabromobenzoate	183658-27-7	-
HBB	Hexabromobenzene	87-82-1	201-773-9
HBCYD	Hexabromocyclodecane	25495-98-1	-
HEEHP-TEBP	2-(2-hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromophthalate	20566-35-2	243-885-0
IDP	Isodecyl diphenyl phosphate	29761-21-5	249-828-6
MCCP	Chlorinated paraffins (medium-chained)	85535-84-8	-
mDEP/dDEP	Diethyl phosphate (mono/di)	598-02-7	209-912-5
OBTMPI	4,5,6,7-Tetrabromo-1,1,3-trimethyl-3-(2,3,4,5-tetrabromophenyl)-indane	1084889-51-9	-
PBB	Pentabromobenzene	608-90-2	-
PBB-Acr	Pentabromobenzyl acrylate	59447-55-1	261-767-7
PBBBr	Pentabromobenzyl bromide	38521-51-6	253-985-6
PBBC	Pentabromobenzyl chloride	58495-09-3	-
PBCH	Pentabromochlorocyclohexane	87-84-3	201-776-5
PBDPP/RDP	Resorcinol bis(diphenyl phosphate)	57583-54-7	260-830-6
PBDMPP	Tetrakis(2,6-dimethylphenyl) 1,3-phenylene bis(phosphate)	139189-30-3	432-770-2
PBEB	Pentabromoethylbenzene	85-22-3	201-593-0
PBP	Pentabromophenol	608-71-9	210-167-3

PBPAE	Pentabromophenyl allyl ether	3555-11-01	-
PBT	Pentabromotoluene	87-83-2	201-774-4
SCCP	Chlorinated paraffins (short-chained)	85535-85-9	-
T2CPP	Tris(2-Chloropropyl)phosphate	6145-73-9	228-150-4
T3CPP	Tris(3-Chloropropyl)phosphate	26248-87-3	-
TBBBS	Tetrabromobisphenol S	39635-79-5	254-551-9
TBBPA	Tetrabromobisphenol A	79-94-7	201-236-9
TBBPA-BAE	Tetrabromobisphenol A bis(allyl ether)	25327-89-3	246-850-8
TBBPA-BDBPE	Tetrabromobisphenol A bis(2,3-dibromopropyl ether)	21850-44-2	244-617-5
TBBPA-BME	Tetrabromobisphenol A bismethyl ether	108608-62-4	253-693-9
TBBPA-DHEE	Tetrabromobisphenol A dihydroxyethyl ether	4162-45-2	224-005-4
TBBPS-DBPE	Tetrabromo-bisphenol-S-bis(2,3-dibromopropyl) ether	42757-55-1	255-929-6
TBCO	(1R,2R,5S,6S)-1,2,5,6-Tetrabromocyclooctane	3194-57-8	-
TBOEP	Tri(2-butoxyethyl) phosphate	78-51-3	201-122-9
TBP	2,4,6-Tribromophenol	118-79-6	204-278-6
TBP-DBPE	2,3-Dibromopropyl 2,4,6-tribromophenyl ether	35109-60-5	252-372-0
TBPP	Tris(4-tert-butylphenyl) phosphate	78-33-1	201-106-1
TBX	2,3,5,6-tetrabromo-p-xylene	23488-38-2	245-688-5
TCBPA	Tetrachlorobisphenol A	27360-90-3	201-237-4
TCEP	Tris(2-chloroethyl) phosphate	115-96-8	204-118-5
TCIPP	Tri(1-chloro-2-propyl) phosphate	13674-84-5	237-158-7
TDBPP	Tris(2,3-dibromopropyl) phosphate	126-72-7	204-799-9
TDBP-TAZTO	1,3,5-tris(2,3-dibromopropyl)-1,3,5-triazine-2,4,6(1H,3H,5H)-trione	52434-90-9	257-913-4
TDCIPP	Tris(1,3-dichloroisopropyl) phosphate	13674-87-8	237-159-2
TDCPP	Trisdichloropropyl phosphate	26604-51-3	247-843-2
TEBP-Anh	3,4,5,6-Tetrabromophthalic anhydride	632-79-1	211-185-4
TEEdP	Tetraethyl(ethylene)diphosphonate	995-32-4	213-625-0
TEHP	Tris(2-ethylhexyl) phosphate	78-42-2	201-116-6
TEP	Triethyl phosphate	78-40-0	201-114-5
THP	Trihexyl phosphate	2528-39-4	219-774-8
TIBP	Triisobutyl phosphate	126-71-6	204-798-3
TiPP	Triisopropyl phosphate	513-02-0	208-150-0
TiPPP	Tris(2-isopropyl) phosphate	64532-95-2	248-147-1
TMP	Trimethyl phosphate	512-56-1	208-144-8
TMPP (*m*-)	Tritolyl phosphate	563-04-2	209-241-8
TMPP (*o*-)	Tritolyl phosphate	78-30-8	201-103-5
TMPP (*p*-)	Tritolyl phosphate	1330-78-5	215-548-8
TNBP	Tributyl phosphate	126-73-8	204-800-2
TPeP	Tripentyl phosphate	2528-38-3	219-773-2
TPHP	Triphenyl phosphate	115-86-6	204-112-2
TPP	Tripropyl phosphate	513-08-6	208-151-6
TTBNPP	Tris(tribromoneopentyl) phosphate	19186-97-1	606-254-4
TTBP-TAZ	2,4,6-tris(2,4,6-tribromophenoxy)-1,3,5-triazine	25713-60-4	-
TXP	Trixylenyl phosphate	25155-23-1	246-677-8

-	1,3-hexylene dimelamine	-	-
-	1,3-phenylene-bis(dixylenyl phosphate)	-	-
-	Acetoguanamine	542-02-9	208-796-3
-	Ammeline/Cyanurodiamide	645-92-1	211-455-1
-	Benzoguanamine	91-76-9	202-095-6
-	Bis-(isopropylphenyl) phenyl phosphate	101299-37-0	248-849-8
-	Bis-(t-butylphenyl) phenyl phosphate	65652-41-7	265-859-8
-	Brominated paraffins	-	-
-	Butylene diguanamine	-	-
-	Chlordene Plus	-	-
-	Dibutyl chlorendate	1770-80-5	217-192-9
-	Ethylene dimelamine	-	-
-	Hexamethylene dimelamine	-	-
-	Isopropylphenyl diphenyl phosphate	28108-99-8	248-848-2
-	Melamine/Cyanurotriamide	108-78-1	203-615-4
-	Melamine (poly)phosphate	163183-93-5	243-601-5
-	Melamine cyanurate	37640-57-6	253-575-7
-	Melamine pyrophosphate	15541-60-3	239-590-1
-	Methylene diguanamine	-	-
-	Norbornene diguanamine	-	-
-	Octyl diphenyl phosphate	115-88-8	204-113-8
-	Pentaerythritol/Tetra(hydroxymethyl)methane	115-77-5	204-104-9
-	Phthalodiguanamine	5118-79-6[b]	-
-	Piperazine (poly)phosphate	1951-97-9	217-775-8
-	Piperazine pyrophosphate	66034-17-1	457-330-7
-	t-Butylphenyl diphenyl phosphate	83242-23-3	260-391-0
-	Tetramethylene dimelamine	-	-
-	Trimethylene dimelamine	-	-
-	Tris-(isopropylphenyl) phosphate	26967-76-0	248-147-1
-	Xylenyl diphenyl phosphate	25155-24-2	-

[a]CAS-number for Dechlorane 604; [b]uncertain CAS-number.

2.1 Patent database search

Within the CPC-system, flame retarded polymers and beds are given the classifications, C08L2201/02 and Y10S5/954, respectively. These CPC-codes were used to conduct the database search. When using the CPC-code for fireproof beds, two patents were retrieved, *Flame resistant filler cloth and mattresses incorporating same* (US patent 9,006,118) published in April, 2015, and *Fire resistant flange for removable top panels for use in mattress assemblies* (US patent 8,893,337) published in November, 2014. FRs mentioned in the patents can be utilized in accordance with embodiments of the invention, but the patents are not restricted to those FRs. In the patent published in 2015, several inorganic FRs (e.g., mono- and diammonium phosphate, boric acid, and ammonium sulfomate) are mentioned together with several organic FRs (including organic phosphate esters in general, BDE-209, chlorinated and brominated paraffin, and chlorinated and brominated binders), indicating a current or future use of those FRs in these type of products. In the second patent (published in 2014), in addition to inorganic FRs, several organic FRs are mentioned, including organic phosphorus compounds in general, BDE-209, and chlorinated paraffin, again, indicating a current or future use of those FRs in these type of products.

The CPC-code C08L 2201/02 refers to polymers with FR properties. Conducting a search using this CPC-code resulted in 100 found patents, of which the two newest were selected for further evaluation. The first patent refers to an insulated electrical wire for automobile (US patent 9,583,234) and was published in February, 2017. This patent allows the usage of two inorganic FRs and one organic FR, which is sold under the tradename SAYTEX 8010, produced by Albemarle corporation and contains the BFR DBDPE [15]. The second patent (published in February 2017) refers to a cellulose ester-based resin composition (US patent 9,580,580). In this patent, a large number of FRs are mentioned. The organic FRs include triazine ring-containing FRs (i.e. melamine, ammeline, benzoguanamine, acetoguanamine, phthalodiguanamine, melamine cyanurate, melamine pyrophosphate, butylene diguanamine, norbornene diguanamine, methylene diguanamine, ethylene dimelamine, trimethylene dimelamine, tetramethylene dimelamine, hexamethylene dimelamine and 1,3-hexylene dimelamine), organophosphorus compounds (i.e. TMP, TEP, TNBP, TBOEP, TCEP, TDCPP, TPHP, TMPP, CDP, trixylenyl phosphate (TXP), octyl diphenyl phosphate, xylenyl diphenyl phosphate, TiPPP, EHDPP, t-butylphenyl diphenyl phosphate, bis-(t-butylphenyl) phenyl phosphate, TBPP, isopropylphenyl diphenyl phosphate, bis-(isopropylphenyl) phenyl phosphate, and tris-(isopropylphenyl) phosphate, PBDPP, 1,3-phenylene-bis(dixylenyl phosphate), and BADP, and the non-halogenated FR pentaerythritol. Furthermore, a number of organic polyphosphate-based FRs are mentioned, including melamine polyphosphate, piperazine polyphosphate, and piperazine pyrophosphate. Surprisingly, the forbidden legacy FR BDE209 was mentioned in two of the patents. Even though only four different patents were investigated, it was still possible to identify a large number of realatively unknown FRs, including brominated paraffins, melamine, ammeline, benzoguanamine, acetoguanamine, phthalodiguanamine, melamine cyanurate, melamine pyrophosphate, butylene diguanamine, norbornene diguanamine, methylene diguanamine, ethylene dimelamine, trimethylene dimelamine, tetramethylene dimelamine, hexamethylene dimelamine, 1,3-hexylene dimelamine, TXP, octyl diphenyl phosphate, xylenyl diphenyl phosphate, t-butylphenyl diphenyl phosphate, bis-(t-butylphenyl) phenyl phosphate, isopropylphenyl diphenyl phosphate, bis-(isopropylphenyl) phenyl phosphate, and tris-(isopropylphenyl) phosphate, 1,3-phenylene-bis(dixylenyl phosphate), pentaerythritol, melamine polyphosphate, piperazine polyphosphate, and piperazine pyrophosphate. To determine the environmental relevance of these chemicals (and thus the need for screening), production and use data would be needed in combination with risk assessment. Other more known FRs were also identified within the patents, of which the majority are OPFRs, indicating a future interest for this class of FRs. Based only on this type of data it is not possible to determine which FRs to include in future screening as the environmental relevance is difficult to estimate due to lacking information for many compounds.

2.2 Use in the European Union

According to the ECHA database *Registered substances*, 10 000 to 100 000 tons are used in the EU annually of chlorinated paraffins, DBDPE, and TEP (Table 2). Other FRs, including EHDPP, PBDPP, TBBPA, TBBPA-BDBPE, TBOEP, TDCIPP, TEHP, TIBP, TNBP, and TPHP, are used in lower amounts (1000 to 10 000 tons per year), while BADP usage is reported as >1000 tons per year. BEH-TEBP, DBNPG, EBTEBPI, HEEHP-TEBP, IDP, PBB-Acr, TTBNPP, and BCMP-BCEP are all used between 100 to 1000 tons annually. TEBP-Anh and PBDMPP are used between 10 to 100 tons per year, while 3-BP is only used as an intermediate and therefore no quantities are available. TCEP, TCIPP, and TBP have not been registered within the REACH-regulation (Registration, Evaluation, Authorisation and restriction of Chemicals) of the EU. However, as discussed below, these three substances have frequently been detected in e.g., the Nordic countries. For 17 FRs (e.g., BATE, Chlordene plus, and Dec 604B), neither CAS- nor EC-number were available, and as a result no search could be made for these compounds. Finally, for the remaining FRs, no data was available in the database, suggesting that they are either not used within the EU or that the use information is confidential. However, due to limitations in the REACH legislation, finished products, such as electronics, that are imported into the EU may still contain FRs not registered within REACH.

For many of the FRs identified through the patent search, CAS- or EC-numbers were not found and thus no search in the ECHA database could be done for these chemicals. Melamine and pentaerythritol were found to be used in very high quantities, 100 000-1000 000 tons per year, while benzoguanamine and melamine cyanurate are used at 10 000-100 000 tons per year, trixylenyl phosphate at 100-1000 tons per year, and piperazine (poly)phosphate at 10-100 tonnes per year. However, several of these chemicals are likely to have other commercial use than as FRs, e.g., as intermediates in the production of other chemicals. One example is melamine, which is used in cooking utensils, paper, and as a fertilizer [16]. Another example is TBBPA of which >25% of the annual amount is transformed into other substances during use (e.g., through synthesis or burning of fuels) according to the Swedish product register (Table S2 in Appendix) [12]. Acetoguanamine is not registered in REACH and can thus be assumed not to be used during production within the EU but can still be present in imported goods. No data was available for ammeline, melamine pyrophosphate, octyl diphenyl phosphate, xylenyl diphenyl phosphate, t-butylphenyl diphenyl phosphate, bis-(t-butylphenyl) phenyl phosphate, isopropylphenyl diphenyl phosphate, bis-(isopropylphenyl) phenyl phosphate, tris-(isopropylphenyl) phosphate, and melamine (poly)phosphate, indicating that they are either not used during manufacture within the EU or that the information is confidential.

Table 2 Amounts of FRs produced/imported into the EU annually (tons) [11].

Compound	Annual amount (tons)
Melamine	100 000-1 000 000
Pentaerythritol	100 000-1 000 000
Benzoguanamine	10 000-100 000
SCCP/MCCP	10 000-100 000
DBDPE	10 000-100 000
Melamine cyanurate	10 000-100 000
TEP	10 000-100 000
EHDPP	1000-10 000
PBDPP	1000-10 000
TBBPA	1000-10 000
TBBPA-BDBPE	1000-10 000
TBOEP	1000-10 000
TDCIPP	1000-10 000
TEHP	1000-10 000
TIBP	1000-10 000
TNBP	1000-10 000
TPHP	1000-10 000
BADP	1000+
BEH-TEBP	100-1 000
DBNPG	100-1 000
EBTEBPI	100-1 000
HEEHP-TEBP	100-1 000
IDP	100-1 000
PBB-Acr	100-1 000
Trixylenyl phosphate (TXP)	100-1 000
TTBNPP	100-1 000
BCMP-BCEP	100-1 000
PBDMPP	10-100
TEBP-Anh	10-100
Piperazine (poly)phosphate	10-100
Piperazine pyrophosphate	10-100
1,3-hexylene dimelamine	-[a]
1,3-phenylene-bis(dixylenyl phosphate)	-[a]
TBP	Not registered in REACH
2,4-DBP	No data available
2,6-DBP	No data available
2-BP	No data available
3-BP	Used only as an intermediate
4´-PeBPOBDE208	No data available
4-BP	No data available
Acetoguanamine	Not registered in REACH
Cyanurodiamide	No data available
ATE	No data available
BATE	-[a]

bBDBP	No data available
Bis-(isopropylphenyl) phenyl phosphate	No data available
Bis-(t-butylphenyl) phenyl phosphate	No data available
Brominated paraffins	- [a]
BTBPE	No data available
Butylene diguanamine	- [a]
CDP	No data available
Chlordene Plus	- [a]
CLP1	No data available
DBE-DBCH	No data available
DBHCTD	No data available
DBPhP	No data available
DDC-DBF	No data available
DDC-Ant	No data available
Dec-604A/HCTBPH	No data available
Dec-604B	No data available
Dibutyl chlorendate	No data available
DMP	No data available
DOPP	No data available
DDC-CO	No data available
DPhBP	No data available
EH-TBB	No data available
Ethylene dimelamine	- [a]
HBB	No data available
HBCYD	No data available
Hexamethylene dimelamine	- [a]
Isopropylphenyl diphenyl phosphate	No data available
mDEP/dDEP	No data available
Melamine (poly)phosphate	No data available
Melamine pyrophosphate	No data available
Methylene diguanamine	- [a]
Norbornene diguanamine	- [a]
OBTMPI	No data available
Octyl diphenyl phosphate	No data available
PBB	No data available
PBBC	No data available
PBCH	No data available
PBEB	No data available
PBP	No data available
PBT	No data available
Phthalodiguanamine	No data available
T2CPP	No data available
T3CPP	No data available
TBBBS	No data available
TBBPA-BAE	No data available
TBBPA-BME	No data available

TBBPA-DHEE	No data available
TBBPS-DBPE	No data available
TBCO	No data available
TBP-DBPE	No data available
TBPP	No data available
t-Butylphenyl diphenyl phosphate	No data available
TBX	No data available
TCBPA	No data available
TCEP	Not registered in REACH
TCIPP	Not registered in REACH
TMPP (*m*-)	No data available
TMPP (*o*-)	No data available
TMPP (*p*-)	No data available
TDBP-TAZTO	No data available
TDCPP	No data available
TEEdP	No data available
Tetramethylene dimelamine	- [a]
THP	No data available
TiPP	No data available
TMP	No data available
TPeP	No data available
TPP	No data available
Trimethylene dimelamine	- [a]
Tris-(isopropylphenyl) phosphate	No data available
TTBP-TAZ	No data available
Xylenyl diphenyl phosphate	No data available

[a]Database search not possible due to lacking CAS- and EC-numbers.

2.3 Flame retardant use in Sweden

Quantitative FR data archived at KemI are mostly confidential and thus not publically available. To circumvent the confidentiality, the data was transformed into quantity indices (QI) ranging from 1 to 7, where 7 represents a high usage and 1 represents a low usage. Table 3 shows quantity indices (for FRs with available data, *n* = 46) obtained from KemI, while the whole dataset is given in the Appendix, Table S2. For most FRs, the compiled data represent the early 1990's to 2015.

Based on the data obtained from KemI, no FR was indexed into quantity Group 7. Pentaerythritol was indexed 6, showing an extensive use of this specific compound (Table 3). Furthermore, 18 FRs were indexed into quantity Group 5, meaning that they are used in fairly high volumes in Sweden. These FRs include BADP, CDP, SCCP, DBDPE, EHDPP, IDP, melamine, melamine cyanurate, PBDPP, TBBPA-BDBPE, TBOEP, TCIPP, *p*-TMPP, TEHP, TEP, TIBP, TNBP, and TPHP. Quantity Group 4 includes BEH-TEBP, BTBPE, DBPhP, DPhBP, EBTEBPI, HEEHP-TEBP, melamine pyrophosphate, T2CPP, TCEP, and

TXP. Smaller volumes are used of bis-(t-butylphenyl) phenyl phosphate, TBPP, *o*-TMPP, and TTBNPP, which are all indexed 3. No FR was indexed 2 but four compounds, including ammeline, DBNPG, DDC-CO, and TBBPA were indexed 1, indicating only a small usage in Sweden. Nine FRs (4´-PeBPOBDE208, Acetoguanamine, CLP1, MCCP, DMP, TDCIPP, TMP, and BCMP-BCEP) were indexed 0 meaning that they are not used in Sweden or that the information is confidential. For the remaining FRs listed in Table 2 but not in Table 3, no Swedish quantity data is available.

Table 3 Quantity Index (QI) of FRs in Sweden [12]. Indices were calculated from the Swedish Product Register based on registered use patterns in year 2015.

Abbreviation	Quantity index[a]
Pentaerythritol	6
BADP	5
CDP	5
SCCP	5
DBDPE	5
EHDPP	5
IDP	5
Melamine	5
Melamine cyanurate	5
PBDPP	5
TBBPA-BDBPE	5
TBOEP	5
TCIPP	5
TMPP (*p*-)	5
TEHP	5
TEP	5
TIBP	5
TNBP	5
TPHP	5
BEH-TEBP	4
BTBPE	4
DBPhP	4
DPhBP	4
EBTEBPI	4
HEEHP-TEBP	4
Melamine pyrophosphate	4
T2CPP	4
TCEP	4
TXP	4
bis-(t-butylphenyl) phenyl phosphate	3
TBPP	3
TMPP (*o*-)	3
TTBNPP	3
Ammeline	1
DBNPG	1

DDC-CO	1
TBBPA	1
4´-PeBPOBDE208	0
Acetoguanamine	0
Benzoguanamine	0
CLP1	0
MCCP	0
DMP	0
TDCIPP	0
TMP	0
BCMP-BCEP	0

[a]Indices range from 1-7 where 7 represents the highest quantity.

3. Flame Retardants in the environment

This chapter is based on the literature review and summarizes efforts made to detect FRs in various environmental matrices such as indoor dust, indoor and outdoor air, water, sediment, sludge, soil, atmospheric deposition, plants and animals including humans. It includes a broad range of FRs; however, legacy FRs PBDEs and HBCDD are excluded from the compilation. In total, about 60 references were reviewed, and in those, 66 different FRs were screened for in one or more matrices. The cited literature encompasses international peer-reviewed literature and reports from environmental authorities within the Nordic countries (e.g., the Swedish Environmental Protection Agency and the Norwegian Pollution Control Authority). A special emphasis was paid to studies conducted within the Nordic countries.

3.1 Indoor air and dust

In total, 50 different altrnative FRs were analysed in indoor air in the cited literature [17-25]. In public areas, 25 FRs were detected, in homes 22 FRs and in offices 20 FRs (Appendix, Table S3). Six brominated FRs (DBDPE, DBE-DBCH, HBB, PBEB, PBT and TBX), ten non-halogenated OPFRs (DOPP, EHDPP, TBOEP, TMPP, TEP, TEHP, TIBP, TNBP, TPHP, and TPP), and three halogenated OPFRs (TCEP, TCIPP, and TDCIPP) were detected above 1 ng m^{-3}. Cequier et al. (2014) [18] and Schlabach et al. (2011) [20] detected DBDPE in air of Norwegian living rooms, school classrooms, and offices at concentrations up to 1 ng m^{-3}, while it was not detected by Møskeland et al. (2009) [23] in an electronics store. DBE-DBCH have been detected up to 4.1 ng m^{-3} in living rooms and school classrooms in Norway, with a detection frequency of 100% [18]. In the same study, TBX was detected at concentrations up to 2.8 ng m^{-3} with a detection frequency of 38% and 17% in living rooms and classrooms, respectively. No other study targeted TBX in indoor air. Remberger et al. (2014) analysed indoor air in a recycling hall for electronics in Sweden and found concentrations of 220-530 ng m^{-3}, 6.7-8.3 ng m^{-3}, 1 400-1 600 ng m^{-3}, not detected (n.d.)-12 ng m^{-3}, and 14-25 ng m^{-3} for DBDPE, DBE-DBCH, HBB, PBEB, and PBT, respectively [25].

Non-halogenated OPFRs have frequently been analysed and detected in indoor air. Two exceptions are DOPP (analysed in one study, concentrations up to 4.8 ng m^{-3} [21]) and TPP (the same study, concentrations up to 8.4 ng m^{-3}). EHDPP has been detected in a number of studies (e.g., [17-19]) at concentrations up to 14 ng m^{-3}. Also, TBOEP has been frequently detected in indoor air (e.g., [17, 18, 24]) at concentration up to 1 300 ng m^{-3}. Interestingly, both Cequier et al. (2009) [18] and Green et al. (2007) [22] reported detection frequencies of 100% in air samples from Norwegian homes and public places. On the other hand, Luongo et al. (2015) detected TBOEP in only 5% of their sampled Swedish homes [19]. When interpreting the results, it should be kept in mind that detection frequencies are dependent on the detection limits. TEP and TIBP have been detected at concentrations up to 300 ng m^{-3} and 66 ng m^{-3}, respectively, with detection frequencies up to 100% in several different indoor air environments in Sweden and Norway [17, 19]. For TNBP, three different studies in Sweden and Norway reported detection frequencies of 100% with concentrations up to

320 ng m^{-3} [17-19, 22]. The by far highest reported concentration of any FR in the reviewed literature is 47 000 ng m^{-3}, which was determined for TPHP in a Norwegian shopping center [22]. Concentrations of TPHP were generally high in this study of public places in Norway, ranging between 2 300 ng m^{-3} and 47 000 ng m^{-3}, with 100% detection frequency. In Sweden, the highest reported concentration of TPHP is 25 ng m^{-3} (in a home) [19]. The detection frequency in this study was 15%. The three halogenated OPFRs with levels above 1 ng m^{-3} have all been frequently detected in both Sweden and Norway at rather high concentrations and detection frequencies. The highest reported concentrations are 730 ng m^{-3}, 1 200 ng m^{-3}, and 150 ng m^{-3} of TCEP, TCIPP, and TDCIPP, respectively [19, 21]. FRs that have been detected at lower concentrations (<1 ng m^{-3}) in indoor air in Sweden and Norway but with high detection frequencies (≥50%) in at least one study include TBP-AE, HBB, PBB, PBT, TBP-DBPE, and TMPP. BEH-TEBP, BTBPE, CLP1, syn-DDC-CO, anti-DDC-CO, and EH-TBB have also been detected but at lower detection frequencies.

In dust, 44 different altrnative FRs have been targeted for in the cited literature (Table S4) [17-19, 24-33]. A high number of FRs were detected in homes (*n* = 30) and public places (*n* = 39), but a variety of FRs were also detected in offices (*n* = 12) and special point sources, such as inside cars and recycling halls for electronics (*n* = 22). OPFRs and BFRs are frequently found in dust. Detection frequencies of >50% have been reported in at least one study for the BFRs BEH-TEBP, BTBPE, DBDPE, DBE-DBCH, syn-DDC-CO, anti-DDC-CO, EH-TBB, HBB, PBB, PBT, and TBP-DBE with concentrations up to 0.81, 0.23, 23, 0.17, 0.59, 0.31, 0.25, 8.2, 0.00068, 0.064, and 0.021 µg g^{-1}, respectively. For OPFRs, detection frequencies >50% were reported in at least one study for EHDPP, TBOEP, TCEP, TCIPP, TMPP, TDCIPP, TEP, TiBP, TNBP, and TPHP with maximum concentrations of 540, 11 000, 1 800, 370, 36, 860, 4.7, 47, 160, and 390 µg g^{-1}, respectively. In general, OPFRs showed higher concentrations than the BFRs. Other less frequently detected (<50%, but still detected in at least one study) FRs in dust include CLP1, DOPP, PBEB, TBX, and THP. Also TEEdP have been detected in indoor dust, but detection frequencies were not reported.

3.2 Outdoor air

In total, 38 FRs were analysed in outdoor air samples, out of which 34 were detected in at least one study (Appendix, Table S5) [20, 22, 23, 25, 33-38]. TPHP is the FR that has been detected at the highest concentration (12 000 pg m^{-3}) [34]. Surprisingly, this sample, which was collected at a background location in northern Finland, showed about twelve times higher concentration of TPHP than samples collected in urban areas in Norway (which were up to 1 000 pg m^{-3}) [22]. The detection of TPHP in a remote area indicates a potential of long-range transport by this FR. However, TPHP was not detected at background locations in Norway [22]. Other FRs detected in the same area as the high levels of TPHP include TCEP, TCIPP, TDCIPP, TMP (only tentatively identified), and TNBP, found at concentrations of 1.6, 810, 20, 24, and 280 pg m^{-3} [34], respectively. These concentrations are considerably lower than concentrations measured in Norwegian urban areas, which have been found to be up to 3700, 3700, 72, and 3700 pg m^{-3} of TCEP, TCIPP, TDCIPP and TNBP, respectively [22]. In addition, several other FRs have been detected at relatively high concentration in urban areas in Norway, including EHDPP, TBOEP, TIBP, and BCMP-BCEP at concentrations up to 1 100, 340, 4 400, and 5 200 pg m^{-3}, respectively. EHDPP, TBOEP and TIBP have also been detected in remote areas, but at lower concentrations, namely up to 260, 150 and 230 pg m^{-3}, respectively [22]. Not surprisingly, the detection frequencies were generally higher in the urban areas, e.g., 100% for TCEP, TCIPP, and TIBP, compared to in the remote areas (14% for TCEP and TCIPP, and 86% for TIBP) [22]. Regarding BFRs, some FRs have been found at relatively high concentrations in outdoor air in China. BTBPE, DBDPE, and TBBPA-BDBPE have been detected at concentrations of 3.8-67 pg m^{-3}, 402-3578 pg m^{-3}, and 130-1 200 pg m^{-3}, respectively, in the Pearl River delta [33]. In Sweden, Norway and Finland, outdoor air concentrations found for these FRs are considerably lower, with DBDPE ranging from n.d. to 44 pg m^{-3} [20, 23, 25, 38], while concentrations of BTBPE have been detected from n.d. to 2.2 pg m^{-3} [20]. TBBPA-BDBPE has, to our knowledge, never been detected in outdoor air in the Nordic countries. However, other BFRs have been detected at similar or higher concentrations in Sweden, Norway and Denmark, including anti-DDC-CO, detected up to 120 pg m^{-3}, syn-DDC-CO (up to 42 pg m^{-3}, and TBBPA, up to 280 pg m^{-3} [20]. Also TBP, 2,4-DP, and DBE-DBCH (individual isomers) have been detected at concentrations up to 27 pg m^{-3}, 21 pg $m^{-3}$and 18 pg m^{-3}, respectively [20]. However, bromophenols, such as TBP and 2,4-DBP, also occur naturally [23]. Other BFRs that have been detected in Nordic outdoor air (at concentrations ≤ 10 pg m^{-3}) include 2/3-BP, 2,6-DBP, 4-BP, TBP-AE, BATE, BEH-TEBP, EH-TBB, HBB, PBEB, PBP, PBT, and TBP-DBPE [20, 38]. In a study by Haglund et al. (2015), with samples collected at background sites in Sweden and Finland, TBP, BTBPE, DBE-DBCH, anti-DDC-CO, syn-DDC-CO, EH-TBB, HBB, PBEB, and PBT were detected in all samples, while BEH-TEBP and DBDPE were detected in 92% and 83% of the samples, respectively [38]. Even though concentrations were all <1 pg m^{-3}, the high detection frequency in background areas shows the wide spread of these type of FRs.

3.3 Atmospheric deposition

A few studies have analysed emerging FRs in atmospheric deposition. In total, 19 FRs have been targeted, and 14 were detected in at least one study (Appendix, Table S6) [25, 34, 39, 40]. Newton et al. (2013) detected DBE-DBCH and DDC-CO in wet and dry deposition at 3.1 ± 3.6 ng m^{-2} $month^{-1}$ and 22 ± 21 ng m^{-2} $month^{-1}$, respectively, in a boreal catchment in Sweden (Krycklan Catchment Study area) and 3.5 ± 2.8 ng m^{-2} $month^{-1}$ and 1.1 ± 0.52 ng m^{-2} $month^{-1}$, respectively, in Abisko [40]. Both locations are rather remote, thus indicating potential of long-range air transport of these FRs. In another study, DBDPE, DBE-DBCH, HBB, PBEB, and PBT were analysed in deposition samples from the Swedish west coast, but no FRs were detected [25]. Several OPFRs have been detected in wet and dry deposition in background areas in Finland. TCEP, TCIPP, TMP (tentatively identified), and TNBP where found at levels of 16 500, 15 300, 33, and 6 900 ng m^{-2} $month^{-1}$, respectively, while TBOEP, TMPP, TDCIPP, TEHP, TPHP, and TPP were not detected [34]. TBOEP, TCEP, TCIPP, p-TMPP, TDCIPP, TEHP, TMP (tentatively quantified), TNBP, and TPHP have been found at higher concentrations in snow close to a road (concentration ranges in ng L^{-1}: 4-12, 7-12, 110-170, n.d., 8-230, n.d.-130, n.d.-10, 11-20, and 4-68, respectively) and an airport (7-94, 29-39, 100-210, 260-9 900, 4-15, 1-95, 11-28, 2 100-23 000, and 120-830 ng L^{-1}, respectively) compared to a background location in Sweden (2, 7, 68, n.d., 29, n.d., n.d., 19, and 4 ng L^{-1}, respectively), showing that traffic may act as a point source of these FRs [34]. Similarly, urban rain was found to contain similar or higher levels of some OPFRs (i.e. TBOEP, TCEP, TCIPP, TIBP, and TNBP) than background rain and snow in Germany [39].

3.4 Water

In total, 35 out of 39 targeted emerging FRs have been detected in water, including freshwaters, marine waters and effluents from point sources such as WWTPs (Appendix, Table S7) [22, 23, 25, 35-37, 41-52]. A number of studies have investigated FR concentrations in water from point sources. The highest reported concentration was from a Swedish WWTP, where levels up to 52 000 ng L^{-1} were reported for TNBP [42]. Also other OPFRs showed high concentrations in this study, DOPP showed concentrations of n.d.-2 000 ng L^{-1}, TBOEP 3 100-35 000 ng L^{-1}, TCEP 90-450 ng L^{-1}, TCIPP 1 100-24 000 ng L^{-1}, TDCIPP 130-450 ng L^{-1}, TEHP n.d.-130 ng L^{-1}, TMP n.d.-584 ng L^{-1}, and TPHP 41-290 ng L^{-1}. Generally, slightly lower concentrations have been found for TBOEP (500-9 200 ng L^{-1}), TCIPP (400-2 900 ng L^{-1}), TDCIPP (86-820 ng L^{-1}), and TNBP (160-2 800 ng L^{-1}) in WWTPs in Germany and Norway, while reported concentrations of TCEP (130-2 500 ng L^{-1}) and TPHP (1 700-14 000 ng L^{-1}) were higher [22, 41]. In Norway, concentrations of EHDPP in WWTPs ranged from 250-710 ng L^{-1} [22]. For BFRs, reported concentrations in water from WWTPs are generally lower than for OPFRs. The highest concentration of a BFR has been reported for DBDPE (250-1 500 ng L^{-1}) and PBEB (up to 91 ng L^{-1}) in stormwater in Gothenburg and of DBDPE (330-1800 ng L^{-1}) and HBB (11-1 200 ng L^{-1}) in extinguishing water from a fire [25]. DBDPE has also, together with BTBPE and TBBPA-BDBPE, been found at relatively high concentrations close to point sources in Norway (up to 185.7, 107.0, and 159.6 ng L^{-1}, respectively) [23] while DBDPE concentration in a WWTP in Sweden ranged up to 420 ng L^{-1} [25]. In Norwegian WWTPs, TBBPA-BDBPE has showed concentrations up to 18 ng L^{-1} [47]. In conclusion, WWTP do act as point sources for the emission of OPFRs and BFRs.

Several studies have investigated the presence of emerging FRs in European rivers [41, 43, 46, 48-52]. Again, OPFRs dominate the FR content with e.g., EHDPP concentrations up to 46 ng L^{-1} [51], TBOEP up to 4600 ng L^{-1} [51], TCEP up to 330 ng L^{-1} [51], TCIPP up to 26000 ng L^{-1} [52], TDCIPP up to 200 ng L^{-1} [51], and TIBP up to 1200 ng L^{-1} [51]. The four BFRs detected at the highest concentration in any European river are TEBP-Anh, TBBPA, TCBPA, and EHTBB with maximum concentrations of 67, 62, 56, and 24 ng L^{-1}, respectively [49]. All the highest BFR concentrations were detected in the same study [49]. Few other studies have, to our knowledge, included these FRs. Other FRs detected in the Swedish rivers in the same study include TBP (n.d.-20 ng L^{-1}) , BTBPE (n.d.-4.7 ng L^{-1}), syn-DDC-CO (n.d.-12 ng L^{-1}), EHDPP (n.d.-9.2 ng L^{-1}), HBB (n.d.-0.13 ng L^{-1}), PBB-Acr (n.d.-2.6 ng L^{-1}), PBT (n.d.-2.5 ng L^{-1}), TBX (n.d.-0.022 ng L^{-1}), TCEP (n.d.-14 ng L^{-1}), TCIPP (n.d.-30 ng L^{-1}), *o*-TMPP (n.d.-1.4 ng L^{-1}), *p*-TMPP (n.d.-11 ng L^{-1}), ΣTDCIPP+TEHP (n.d.-48 ng L^{-1}), TNBP (n.d.-24 ng L^{-1}), TPHP (n.d.-66 ng L^{-1}), and TTBNPP (n.d.-3.6 ng L^{-1}). Finally, TEP and TPP have, to our knowledge, only been analysed in one study each and were found at concentrations of 13-51 ng L^{-1} and 40 ng L^{-1}, respectively [41, 43].

Five OPFRs have been detected in rural/remote surface waters, which indicate potential of long-range transport [44]. These OPFRs include TBOEP found at mean concentrations up to 31 ng L^{-1}, TCEP up to 33 ng L^{-1}, TCIPP up to 312 ng L^{-1}, TIBP up to 11 ng L^{-1}, and TNBP up to 7 ng L^{-1} [44]. Four BFRs (i.e. anti-DDC-CO, syn-DDC-CO, HBB, and TBP-DBPE) have been detected in marine water at very low concentrations (<0.02 ng L^{-1}) [36, 37].

3.5 Sediment and sludge

In total, 44 FRs have been targeted in sediment and sewage sludge [20, 22, 23, 25, 33, 35, 42, 43, 47, 48, 51, 53-60]. Out of these, 34 and 32 compounds have been detected in sediment and sludge, respectively (Appendix, Table S8 and S9). Concentrations are generally higher in sewage sludge than in sediment. Marklund et al. (2005) analysed OPFRs in Swedish sewage sludge and found comparably high concentrations [42]. EHDPP was found at concentrations ranging from 320-4 600 ng g^{-1} dw, TBOEP from nd-1900 ng g^{-1} dw, TCEP from 6.6-110 ng g^{-1} dw, TCIPP from 61-1 900 ng g^{-1} dw, TDCIPP from 3.3-260 ng g^{-1} dw, TIBP from 27-2 700 ng g^{-1} dw, TNBP from 39-850 ng g^{-1} dw, and TPHP from 52-320 ng g^{-1} dw. Other studies have reported concentrations of BFRs in sludge from the Nordic countries, with concentrations of TBP up to 100 ng g^{-1} dw, 2,4-DBP up to 40 ng g^{-1} dw, TBP-AE up to 27 ng g^{-1} dw, BATE up to 4.1 ng g^{-1} dw, BEH-TEBP up to 42 ng g^{-1} dw, BTBPE up to 3.9 ng g^{-1} dw, DBDPE up to 190 ng g^{-1} dw, α-DBE-DBCH up to 4.7 ng g^{-1} dw, β-DBE-DBCH up to 2.6 ng g^{-1} dw, Σγ+δ-DBE-DBCH up to 1.7 ng g^{-1} dw, anti-DDC-CO up to 25 ng g^{-1} dw, syn-DDC-CO up to 14 ng g^{-1} dw, EH-TBB up to 2.6 ng g^{-1} dw, HBB up to 1.6 ng g^{-1} dw, PBP up to 3.5 ng g^{-1} dw, PBT up to 5.2 ng g^{-1} dw, TBBPA up to 59 ng g^{-1} dw, and TBP-DBPE up to 120 ng g^{-1} dw [20, 23, 25, 35, 47]. Similar concentrations of DBDPE, anti-DDC-CO, and syn-DDC-CO have been reported from Spain [59]. In the Spanish study, low concentrations (< 1 ng g^{-1} dw) of DDC-DBF and DDC-Ant were also reported. Furthermore, low concentrations have been reported for TCBPA in sludge from Canada, while TBBPA concentrations were higher (2.1-28 ng g^{-1} dw) [60]. Elevated concentrations of some FRs have been detected in the Pearl River delta, China, with high concentrations of DBDPE and TBBPA-BDBPE up to 2 000 and 9 000 ng g^{-1} dw, respectively, while BTBPE concentration (up to 1.66 ng g^{-1} dw) were more similar to concentrations detected on other locations [33].

Also in sediment from Pearl River delta, high concentrations of some FRs have been found, including BTBPE (0.05-22 ng g^{-1} dw), DBDPE (39-360 ng g^{-1} dw), and TBBPA-BDBPE (n.d.-2 300 ng g^{-1} dw) [33]. Even higher levels of DBDPE (up to 440 ng g^{-1} dw) have been detected in sediment from Spain [51]. However, in two other Spanish studies, concentrations of DBDPE were lower (up to 32 ng g^{-1} dw and 24 ng g^{-1} dw) [55, 59]. In the Nordic countries, reported DBDPE concentrations are lower, up to 2.4 ng g^{-1} dw

[20]. BTBPE has been detected up to 4.5 ng g^{-1} dw in sediment in Norway, while TBBPA-BDBPE has not been detected [23, 47]. Other BFRs detected in sediment from the Nordic countries include TBP (up to 7.8 ng g^{-1} dw), 2,4-DBP (up to 2.9 ng g^{-1} dw), BEH-TEBP (up to 3.3 ng g^{-1} dw), DBE-DBCH (< 1 ng g^{-1} dw), anti-DDC-CO (up to 2.5 ng g^{-1} dw), syn-DDC-CO (up to 0.99 ng g^{-1} dw), EH-TBB (up to 0.21 ng g^{-1} dw), HBB (up to 1.8 ng g^{-1} dw), PBEB (up to 0.1 ng g^{-1} dw), PBT (up to 2.7 ng g^{-1} dw), TBBPA (up to 16 ng g^{-1} dw), and TBBPA-BAE (up to 2.4 ng g^{-1} dw) [20, 23]. In North America, BTBPE concentrations up to 1.6 ng g^{-1} dw, anti-DDC-CO concentrations up to 120 ng g^{-1} dw, syn-DDC-CO concentrations up to 34 ng g^{-1} dw, and PBEB concentration up to 0.1 ng g^{-1} dw have been reported [54, 57]. Four studies identified in this literature review have analysed OPFRs in sediments from Austria, Norway, and Spain. The highest concentration of any OPFR was found of TCIPP in Austrian sediments, with concentrations up to 1300 ng g^{-1} dw [43]. In Norway and Spain, concentrations of TCIPP were lower, up to 54 and 370 ng g^{-1} dw, respectively [51, 56]. Other detected OPFRs in the four studies include EHDPP (up to 63 ng g^{-1} dw), TBOEP (up to 130 ng g^{-1} dw), TCEP (160 ng g^{-1} dw), *o*-TMPP (up to 1.5 ng g^{-1} dw), *p*-TMPP (up to 290 ng g^{-1} dw), TDCIPP (up to 8.7 ng g^{-1} dw), TEHP (up to 290 ng g^{-1} dw), TEP (up to 81 ng g^{-1} dw), TIBP (up to 8.4 ng g^{-1} dw), TNBP (up to 50 ng g^{-1} dw), and TPHP (up to 160 ng g^{-1} dw) [43, 51, 56]. Out of the detected OPFRs, high detection frequencies (>50%) were reported for EHDPP, TBOEP, TCEP, TCIPP, *p*-TMPP, TEHP, TIBP, TNBP, and TPHP, indicating wide spread in sediments [56]. In addition to the previously mentioned studies, Green et al. (2008) reported concentrations of several OPFRs in sediment and sludge from Norway. Reported concentrations are in the unit of µg kg^{-1} loss-of-ignition weight [22]. Detected OPFRs in this study include EHDPP, TBOEP, TCEP, TCIPP, TDCIPP, TIBP, TNBP, TPHP, and BCMP-BCEP (for concentrations, see Appendix, Table S9).

3.6 Soil and plants

Studies of emerging FRs in soil are scarce. However, three BFRs have been detected in farmland soil in China, including soils from an e-waste processing area (Appendix, Table S10) [33]. BTBPE were detected up to 6.2 ng g^{-1} dw, DBDPE up to 36 ng g^{-1} dw, and TBBPA-BDBPE up to 60 ng g^{-1} dw [33]. In Norway, BEH-TEBP has been detected at 1.0 ng g^{-1} dw, with 100% detection frequency [58].

Three studies report concentrations of emerging FRs in mosses and tree needles collected nearby potential point sources in the Nordic countries (Appendix, Table S11) [20, 23, 35]. In total, 23 different FRs were targeted, out of which 14 were detected in at least one study. In needles, most of the targted FRs were not detected. Nevertheless, a few compounds including DBDPE (nd-0.1 ng g^{-1} ww), HBB (n.d.-0.05 ng g^{-1} ww), and TBBPA-BDBPE (n.d.-0.16 ng g^{-1} ww) were detected. [23, 35]. DBDPE and HBB have also been detected in mosses at concentrations up to 0.1 ng g^{-1} dw (note the different unit compared to needles) [23, 35]. On Faroe Islands TBP, 2,4-DBP, BEH-TEBP, BTBPE, DBDPE, DBE-DBCH, anti-DDC-CO, syn-DDC-CO, HBB, PBEB, PBT, and TBP-DBPE have been detected in mosses close to an incineration plant (concentrations shown in Table S12) [20].

3.7 Wildlife

A wide variety of different wildlife animal species have been analysed for emerging FRs, including e.g., arctic fox, polar bear, moose, seal, cod, salmon, mussels, crab, common eider and herring gull [22, 23, 25, 33, 35, 47, 53, 56, 57, 61-67]. Starting with the mammals, no OPFRs have to our knowledge been targeted in mammals (except humans), while BFRs have been analysed in a number of studies (e.g., [57, 61]). The highest concentration of an emerging FR was detected for TBP in harbour seal (160 ± 84 ng g^{-1} ww) with a detection frequency of 100% [58] (Appendix, Table S12). However, TBP is not only a FR but also a naturally occurring compound [23]. TBP has also been detected in moose (81 ± 45 ng g^{-1} ww), mouse (54 ± 43 ng g^{-1} ww), and shrew liver (27.1 ±6.9 ng g^{-1} ww) in Norway, all with detection frequencies ≥88% [58]. Sagerup et al. (2010) detected TBP in ringed seal liver (0.050 ±0.023 ng g^{-1} ww) in the Norwegian Arctic but not in arctic fox liver or polar bear plasma [63]. On the other, Harju et al. (2013) detected TBP in polar bear plasma at 26 ± 15 ng mL^{-1} (note the unit) with 100% detection frequency [61]. In the same study, BEH-TEBP was detected in polar bear plasma at 0.15 ± 0.16 ng mL^{-1} with 95% detection frequency. The same compound has also been detected in ringed seal liver (0.57 ± 0.20 ng g^{-1} ww) from the Arctic with 60% detection frequency [63], showing the ubiquitous spread. Another ubiquitously spread FR is DBDPE. It has, for example, been detected in moose, mouse, shrew and Arctic harbor seal livers at concentrations up to 26 ± 9 ng g^{-1} ww, with 100% detection frequency [61]. It has also been detected in polar bear adipose in Canada [62] and in polar bear and ringed seal plasma in the Norwegian arctic [61]. Chlorinated paraffins (CCPs) have to our knowledge only recently been addressed as FRs that may pollute the environment. Both SCCPs and MCCPs have been detected in polar bear and ringed seal plasma in the Arctic [61]. Concentrations of SCCPs were determined to 4-5 ng mL^{-1} in both polar bear and seal plasma, while the MCCPs showed slightly lower concentrations of 2-3 ng mL^{-1}. Detection frequencies were high (≥ 90%) in both species. Two other other chlorinated FRs, anti-DDC-CO and syn-DDC-CO, have been detected at similar concentrations (up to approx. 3.5 ng g^{-1} lw, note the unit) in harbor seal blubber in the US [57]. Detection frequencies of both DDC-COs in adult seals were 100%, and concentrations were higher in adult seals than in cubs. Finally, another three FRs have been detected in mammal tissues; EH-TBB has been detected in arctic fox liver, polar bear plasma, and ringed seal liver at concentrations up to 3.5 ± 2.5 ng g^{-1} ww with detection frequencies ≥90% [63]. HBB has been detected in polar bear plasma up to 3.4 ng g^{-1} lw [62], and PBEB has been detected in polar bear plasma up to 1.7 ng g^{-1} lw [62] and in harbor seal blubber up to 0.5 ng g^{-1} lw [57]. In adult seals, the detection frequency was 100%, while it was slightly lower (83%) in the younger seals.

A number of Nordic studies have analysed emerging FRs in different types of water living organisms, such as e.g., fish and mussels (Appendix, Table S13) (e.g., [35, 53, 65]). In total, 37 different FRs have been detected in this type of biota. As previously mentioned, TBP is a naturally occurring compound but also produced and used as a FR [23]. It has been detected in aquatic biota in several studies up to 130 ng g^{-1} ww

[23] and up to 86 μg g^{-1} lw [20], and often with high detection frequency [61]. A rarely analysed FR is DPhBP, which has been detected in freshwater carp/perch in Sweden close to a potential point source at concentrations up to 2000 ng g^{-1} lw [64]. Concentrations in marine mussel were, however, much lower (up to 0.5 ng g^{-1} lw), and it was not detected in a Norwegian study [56]. BEH-TEBP has been detected at 0.72 ± 0.29 ng g^{-1} ww in whole capelin in the Norwegian Arctic with 90% detection frequency [63]. However, both lower concentrations [58] and detection frequencies have been observed in other studies [58, 65]. BTBPE was not detected in US [57] and Canada [65], but has been detected in fish both in the Nordic countries and China at concentrations up to 0.20 ng g^{-1} ww and 0.15 ng g^{-1} lw, respectively [20, 33]. Regarding chlorinated compounds, Chlordene plus (up to 8.7 ± 7.3 ng g^{-1} lw), DDC-DBF (up to 24 ± 20 ng g^{-1} lw), Dec 604B (up to 140 ± 130 ng g^{-1} lw), anti-DDC-CO (up to 2.8 ng g^{-1} lw), and syn-DDC-CO (up to 9.1 ng g^{-1} lw) have all been detected in northern pike and muskellunge in Canada at detection frequencies ranging from 36% up to 91% [65]. DDC-CO (anti- and syn-) has also been detected in fish and mussel in the Nordic countries at concentrations up to approx. 25 ng g^{-1} ww [20] while anti-DDC-CO also has been detected in fish from the US (up to 3.7 ng g^{-1} lw) with detection frequencies up to 83% [57]. Chlorinated paraffins (short- and medium-chained) have been detected in Atlantic and polar cod liver at concentrations up to 10 ±11 ng g^{-1} ww with detection frequencies up to 100% [61]. Another FR with high detection frequencies is DBDPE. It has, for example, been detected in brown trout liver and mussels in the Nordic countries at concentrations up to 11 ± 9 ng g^{-1} ww and also in cod in the Arctic with 100 % detection frequency [58]. DBDPE was, however, only rarely detected in fish from Canada [65] and not at all in other studies from Norway [23], Sweden [25] and China [33]. In a study by Sundkvist et al. (2010), several OPFRs were detected in aquatic biota [64]. DBPhP was found at concentrations up to 3 300 ng g^{-1} lw in freshwater perch/carp close to point sources, and EHDPP was detected up to 14 000 ng g^{-1} lw in marine eelpout (in other fish species it was <190 ng g^{-1} ww). EHDPP has also been detected in fish from Svalbard (up to 52 ng g^{-1} ww, note the different unit) [53] and in fish from Norway (up to 1.1 ng g^{-1} ww) with a detection frequency up to 33% [56]. Sundkvist et al. (2010) [64] also detected TBOEP at concentrations ranging between 240 and 1 000 ng g^{-1} lw in perch/carp caught close to point sources in Sweden but not in any other sampled fish. Nevertheless, TBOEP has been detected in Burbon liver (up to 410 ng g^{-1} ww, note the unit) in Norwegian [56] and Canadian fish (up to 9.8 ng g^{-1} ww) [66]. Sundkvist et al. (2010) [64] also detected TCEP (up to 160 ng g^{-1} lw), TCIPP (up to 1300 ng g^{-1} lw), *o*-TMPP (up to 2.5 ng g^{-1} lw), *p*-TMPP (up to 140 ng g^{-1} lw), TDCIPP (up to 140 ng g^{-1} lw), TNBP (up to 4 900 ng g^{-1} lw), and TPHP (up to 180 ng g^{-1} lw). TCEP, TCIPP, TDCIPP, TNBP, and TPHP have also been detected in other studies at concentrations up to 26, 17, <0.88, 17, and 44 ng g^{-1} ww, respectively [22, 53, 56, 66]. Other detected FRs in aquatic biota include 2,4-DBP (up to 6.4 ng g^{-1} ww) [20], BATE (up to 0.00072 ng g^{-1} ww) [20], DBE-DBCH (e.g., α+β-isomers, up to 0.14 ng g^{-1} ww) [25], HBB (up to 0.047 ng g^{-1} ww [20], 4.6 ng g^{-1} ww [25]), PBEB (up to 0.044 ng g^{-1} ww [20], 3.9 ng g^{-1} ww [25]), PBT (up to 0.021 ng g^{-1} ww) [20], T2CPP (up to 8.9 ng g^{-1} ww)

[53], TBP-DBPE (up to 0.049 ng g^{-1} ww) [20], TDCIPP (up to 8.1 ng g^{-1} ww) [53], TEHP (up to 4.6 ng g^{-1} ww)[53, 56], and TIBP (up to 4.9 ng g^{-1} ww) [53].

Seven studies within this literature review have reported on concentrations of emerging FRs in birds and/or bird eggs [20, 33, 53, 56, 57, 61, 63]. In total, 29 different FRs have been detected in birds/eggs (Appendix, Table S14). TBP has been detected in common eider liver (detection frequency 90%) and Kittiwake egg (83%) from the Arctic [63], and in common eider (90%) and herring gull eggs (80%) from the Nordic countries [61], at concentrations up to 66 ng g^{-1} ww. It has also been detected in glaucous gull plasma from the Arctic (31 ± 9 ng mL^{-1}) with 100% detection frequency [61] and in eggs from Sweden and Faroe islands (up to 1.4 ng g^{-1} ww) [20]. Also BEH-TEBP has been detected in a number of different bird species and eggs from both the Arctic and the Nordic countries. Reported concentrations of BEH-TEBP range between n.d. and 2.0 ± 2.6 ng g^{-1} ww with detection frequencies of 17-100% [61, 63]. This FR has also been detected up to 0.021 ng g^{-1} ww in eggs from different wild bird species from Sweden and Faroe Islands and at 0.026 ± 0.001 ng mL^{-1} in glaucous gull plasma in the Arctic [20, 61]. BTBPE has been detected in birds from an e-waste area in China at concentrations up to 2.4 ng g^{-1} lw, which is much lower than the concentrations found of DBDPE (up to 120 ng g^{-1} lw) in the same study [33]. In eggs from Faroe Islands and Sweden, BTBPE has been detected up to 0.042 ng g^{-1} ww [20], while it was not detected in cormorant eggs from the US [57]. DBDPE has been frequently detected, even in Arctic birds. Concentrations ranged up to 1.0 ± 1.6 ng g^{-1} ww in eggs, and 6.4 ±2.62 ng mL^{-1} in gull plasma, most often with 100% detection frequency [61, 63]. Other BFRs that has been detected in birds include DBE-DBCH (e.g., up to 0.33 ng g^{-1} ww of the α-isomer) [20], EHDPP (up to 1.2 ± 0.98 ng g^{-1} ww [63], and 0.18 ng g^{-1} ww [20]), HBB (up to 0.03 ng g^{-1} ww), PBEB (up to 0.0014 ng g^{-1} ww), PBP (up to 0.43 ng g^{-1} ww), and PBT (up to 0.0063 ng g^{-1} ww [20]. Regarding chlorinated FRs, Chlordene Plus has been detected in guillemot eggs in the Arctic (0.66 ± 0.37 ng g^{-1} ww, df 40%) but was not detected in common eider liver or Kittiwake liver [63]. SCCPs and MCCPs have been detected at high frequency (>67%) in eggs from the Arctic at concentrations up to 7.8 ± 8.3 and 4.9 ± 4.9 ng g^{-1} ww, respectively [61]. In the same study, S/MCCPs were also detected in glaucous gull plasma. Both anti-DDC-CO and syn-DDC-CO have been detected in eggs from different wild bird species from Sweden and Faroe Islands at concentrations up to 0.057 and 0.026 ng g^{-1} ww [20], while syn-DDC-CO also has been detected in cormorant eggs from the US at concentrations up to 1.1 ng g^{-1} lw with 100% detection frequency [57]. Only a few studies have analysed OPFRs in birds and bird's eggs, and in general the detection frequencies are lower (usually <31%) than for many brominated and chlorinated FRs. Evenset et al. (2009) detected DBPhP (up to 0.33 ng g^{-1} dw), EHDPP (up to 28 ng g^{-1} dw), T2CPP (up to 2.6 ng g^{-1} dw), TCEP (up to 4.7 ng g^{-1} dw), TEHP (up to 4.6 ng g^{-1} dw), TIBP (up to 2.6 ng g^{-1} dw), TNBP (up to 6.8 ng g^{-1} dw), and TPHP (up to 3.3 ng g^{-1} dw) in seabirds from Svalbard [53]. In another study, Leonards et al. (2010) analysed blood and eggs from Norwegian birds [56] and detected DBPhP (up to 5.6 ng g^{-1} ww), EHDPP (up to 3.1 ng g^{-1} ww), TBOEP (up to 57 ng g^{-1} ww), TCEP (up to 6.1 ng g^{-1} ww), TCIPP (up to 10 ng g^{-1} ww), TDCIPP (up to 1.9 ng g^{-1} ww), TEHP (up to 8.7 ng g^{-1} ww), and TPHP (up to 14 ng g^{-1} ww).

3.8 Humans

In Sweden, FRs have been analysed in human blood serum and breast milk [25, 38, 64]. Eight BFRs including 2/3-BP (up to 0.19 ng g^{-1}), TBP (up to 0.27 ng g^{-1}), 2,4-DBP (up to 0.076 ng g^{-1}), 2,6-DBP (up to 0.047 ng g^{-1}), 4-BP (up to 0.16 ng g^{-1}), BTBPE (up to 0.78 ng g^{-1}), EH-TBB (up to 0.0055 ng g^{-1}), and PBEB (up to 0.072 ng g^{-1}) have been detected in blood serum [25, 38] (Appendix, Table S15). Both TBP and BTBPE were detected in all samples. The detected OPFRs in human milk were EHDPP (up to 13 µg g^{-1} lw), TBOEP (up to 63 µg g^{-1} lw), TCEP (up to 8.2 µg g^{-1} lw), TCIPP (up to 82 µg g^{-1} lw), *p*-TMPP (up to 3.7 µg g^{-1} lw), TDCIPP (up to 5.3 µg g^{-1} lw), TNBP (up to 57 µg g^{-1} lw), and TPHP (up to 11 µg g^{-1} lw) [64].

4. Estimation of potential exposure in Sweden

In addition to Swedish quantity data, also data concerning the potential exposure to FRs for different environmental compartments was obtained from KemI [12]. Again, the data was transformed into indices to circumvent confidentiality. The exposure index (EI) was calculated based on registered use patterns from the Swedish Product Register and gives an estimate of the potential "worst case" exposure to FRs for different environmental compartments, such as e.g., surface water, air, and waste water treatment plant (WWTP) water. Indices 1 to 7 are used, where 7 represents a high potential of exposure and 1 represent a low potential of exposure. Since no physicochemical properties are included in the calculations, the exposure is only valid close to the release source. Table 4 shows the obtained exposure indices together with the average exposure index for each FR for which data is available. Darker cell color indicates a higher potential of exposure. In addition, Table 4 contains indices for trends in exposure for humans and the environment. These indices range between -2 and 2, where a negative value indicates a decreasing time trend in the potential exposure while a positive value indicates an increasing trend.

Pentaerythritol (EI = 6.7), TNBP (6.5), TPHP (6.3), SCCPs (6.2), and TMPP (6.0) all had average EIs ≥6, indicating a high potential of exposure for many environmental compartments. In fact, all compartments (except air for a few FRs) had an EI of 6 or 7 for these compounds. Seven FRs (i.e. CDP (5.7), TBOEP (5.7), TIBP (5.7), DBPhP (5.5), TXP (5.5), TEHP (5.3), DPhBP (5.2), and melamine (5.0)) had average EIs between 5 and 6, also indicating a generally high potential of exposure to these FRs. Both bis-(t-butylphenyl) phenyl phosphate and TCIPP had average EIs of 4.8, while TEP, EHDPP, IDP, melamine cyanurate, and BEH-TEBP had EIs of 3.7, 3.3, 3.3, 3.3, and 3.0, respectively. The remaining FRs all had average EIs <3 with generally higher EIs for WWTP and occupational than for the other categories.

Regarding time trends in exposure, two FRs were indiced with a 2 (TBBPA-BDBPE in humans and environment, and TTBNPP in humans), indicating a strong increasing trend in the potential of exposure. Furthermore, in humans, an increasing potential (index 1) can be observed for DBDPE, PBDPP, and *o*-TMPP. In the environment, an increasing potential of exposure (1) can be associated with TMPP, CDP, DBDPE, PBDPP, and TTBNPP. One FR, SCCP, showed a decreasing potential of exposure (-1) for the environment.

Table 4 Exposure Indices (EI) of FRs in Sweden [12]. Indices were calculated based on registered use patterns in year 2015 from the Swedish Product Register, considering only diffuse emissions, mainly during end product use. The FRs are sorted based on the average EI, from high to low.

Abbreviation/ name	**EI Surface water**	**EI Air**	**EI Soil**	**EI WWTP**	**EI Consumer**	**EI Occupational**	**Average EI**	**EI Human trend**	**EI Environmental trend**
Pentaerythritol	7	6	7	6	7	7	6.7	0	0
TNBP	6	6	7	6	7	7	6.5	0	0
TPHP	6	5	7	6	7	7	6.3	0	0
SCCP	6	3	7	7	7	7	6.2	0	-1
TMP (o-, m-, p-)	7	2	7	6	7	7	6.0	0	1
TMPP (p-)	7	2	7	6	7	7	6.0	0	1
CDP	6	3	6	6	6	7	5.7	0	1
TBOEP	5	3	7	6	6	7	5.7	0	0
TIBP	6	2	7	6	6	7	5.7	0	0
DBPhP	5	2	7	5	7	7	5.5	0	0
TXP	5	2	7	5	7	7	5.5	0	0
TEHP	5	5	5	5	5	7	5.3	0	0
DPhBP	5	1	7	5	6	7	5.2	0	0
Melamine	3	3	4	6	7	7	5.0	0	0
Bis-(t-butylphenyl) phenyl phosphate	6	1	6	3	6	7	4.8	0	0
TCIPP	4	3	4	6	5	7	4.8	0	0
TEP	2	2	2	4	5	7	3.7	0	0
EHDPP	1	1	3	5	3	7	3.3	0	0
IDP	1	1	1	4	6	7	3.3	0	0
Melamine cyanurate	2	1	2	6	2	7	3.3	0	0
BEH-TEBP	2	2	2	1	4	7	3.0	0	0
BADP	1	1	1	5	1	7	2.7	0	0
DBDPE	1	1	1	5	1	7	2.7	1	1
TCEP	2	1	1	4	1	7	2.7	0	0
PBDPP	1	1	1	4	1	7	2.5	1	1
TBBPA-BDBPE	1	1	1	4	1	7	2.5	2	2
BTBPE	1	1	1	3	1	7	2.3	0	0
EBTEBPI	1	1	1	3	1	7	2.3	0	0
HEEHP-TEBP	1	1	1	3	1	7	2.3	0	0
TBPP	1	1	4	1	2	4	2.2	0	0
TTBNPP	1	1	1	2	1	7	2.2	2	1
Melamine pyrophosphate	1	1	1	2	1	6	2.0	0	0
TMPP (o-)	1	1	1	1	1	6	1.8	1	1
TBBPA	1	1	1	1	1	5	1.7	0	0
Ammeline	1	1	1	1	1	1	1.0	0	0
DBNPG	1	1	1	1	1	1	1.0	0	0
DDC-CO	1	1	1	1	1	1	1.0	0	0
T2CPP	1	1	1	1	1	1	1.0	0	0
4´-PeBPO-BDE208	0	0	0	0	0	0	0.0	0	0
Acetoguanamine	0	0	0	0	0	0	0.0	0	0
Benzoguanamine	0	0	0	0	0	0	0.0	0	0

CLP1	0	0	0	0	0	0	0.0	0	0
MCCP	0	0	0	0	0	0	0.0	0	0
DMP	0	0	0	0	0	0	0.0	0	0
HBCDD	0	0	0	0	0	0	0.0	0	0
TDCIPP	0	0	0	0	0	0	0.0	0	0
TMP	0	0	0	0	0	0	0.0	0	0
BCMP-BCEP	0	0	0	0	0	0	0.0	0	0

5. Prioritization lists in the open literature

Several prioritization lists for FRs have been published [58, 68-72]. Harju et al. (2009) recommended a number of BFRs to be included in future monitoring in the Norwegian environment [58]. The list is based upon production volumes, product usage, potential of long range atmospheric transport (LRAT), potential of bioaccumulation, persistence, levels in the environment and environmental transport processes. In total, 14 BFRs were recommended for future studies, including TBP, TBP-AE, BEH-TEBP, BTBPE, DBDPE, EBTEBPI, EH-TBB, HBB, PBEB, PBT, TBBPA-BAE, TBBPA-BDBPE, TBP-DBPE, and TEBP-Anh. Furthermore, a step-by-step approach for prioritizing chemicals to include in long-term air monitoring programs have been suggested and applied to 138 organic chemicals, including several FRs [68]. This prioritization generated a list of 15 high-priority substances, out of which three are FRs, specifically short-chain paraffins, HBCDD, and PBP. In another study, Howard and Muir (2010) identified 610 organic chemicals with persistent and bioaccumulative properties that had not been included in measurement programs before. They determined top ten priority compounds within brominated, chlorinated, fluorinated, siloxanes and other chemical classes. Among the top ten priority chemicals in the different classes, TBBPA, PBCH, HBCDD, TBECH, BEH-TEBP, EBTEBPI, BTBPE, DBDPE, OBTMPI, Dibutyl chlorendate, and DDC-CO were included [69]. Covaci et al. (2011) have reported TBBPA-BDBPE, HCDBCO, TBP, DBDPE, BTBPE, HBB, EH-TBB, BEH-TEBP, PBEB, DBE-DBCH, TBP-AE, PBT, TTBP-TAZ, EBTEBPI, and TBBPA-BAE as the most important alternative BFRs [70].

The European Food Safety Authority (EFSA, 2012) have evaluated 27 emerging FRs in terms of potential persistence in the environment, potential of bioaccumulation and toxicity [71]. A modeling exercise was conducted based on chemical properties. Fifteen (15) out of the 27 compounds was determined to have a high overall persistence, while a high potential of bioaccumulation was determined for 14 compounds. Both high potential for bioaccumulation and a high overall persistence was found for 10 FRs, including BTBPE, DBHCTD, EBTEBPI, HBB, HBCYD, HCTBPH, PBB-Acr, PBEB, PBT, and TBX. As a result, these FRs were recommended for further studies. In fact, experimental data have shown that HBB and BTBPE have high bioaccumulation factors in several aquatic species. Furthermore, experimental studies have shown that both DBNPG and TDBPP are genotoxic and carcinogenic [71], which can motivate inclusion in future studies. In another modeling study, 37 BFRs and 24 OPFRs were evaluated in terms of persistence and ability of LRT by comparing physicochemical properties to previously known persistent organic pollutants [72]. Out of the tested BFRs, eight or 13 (depending on the chosen parameters) were predicted to be of low concern, typically having low molecular weight, low degree of bromination, and containing OH-Groups, while the remaining compounds (i.e. TBBPA, HBCDD, DBDPE, BTBPE, BEH-TEBP, EH-TBB, TBBPA-BDBPE, PBT, PBEB, 2,4-DBP, TBX, PBP, pentabromobenzyl chloride (PBBC), PBPAE, TBP-DBPE, HBB, PBBBr, TBBBS (Tetrabromobisphenol-S), TBBPA-DHEE, Tetrabromobisphenol A bismethyl ether (TBBPA-BME), TBBPA-BAE, DBDPE, TDBP-TAZTO, PBB-Acr, DBHCTD, HCTBPH, EBTEBPI, HBCYD, and TTBP-TAZ) were suggested to be as persistent as the legacy PBDEs. Three of those (PBT, HBB, and TBX) may also travel extremely long distances in the atmosphere and were therefore suggested to be of extra concern. For OPFRs, the applied model suggested potentially lower hazard for the environment in terms of persistence and LRT compared to for BFRs and PBDEs. All OPFRs except PBDMPP, PBDPP, BADP, TIPPP, and TTBNPP are likely compounds of lower concern. However, authors stress that the atmospheric half-lives of particle-bound FRs can be much higher than for FRs in the gas-phase, which may increase their persistence and LRT compared to the model predictions. Furthermore, neither toxicity nor potential of bioaccumulation were considered in the model, which might be important to consider. TCEP, TCIPP, TPHP, CDP, TMPP, DBNPG, DBS, and TBECH have toxic or bioaccumulative properties making them less suitable as replacement chemicals for the legacy FRs.

6. Discussion on prioritization among the identified flame retardants

The following discussion on prioritization among the identified flame retardants is based on usage, exposure time trend, environmental detection, and previous prioritization lists. It would have also been relevant to include environmental risk, e.g. as the ratio between measured environmental concntrations (MECs) and predicted no effect concntrations (PNEC). However, it was out of the scope of the current study to also include toxicity assessments in the ranking among FRs. Thus, the toxicity aspect has not been given priority. Neither in the previously published prioritization lists [58, 68-72] was toxicity considered, explained by e.g., the need of vast toxicity data for the estimation of toxicity tresholds which is often lacking for newer substances [68].

6.1 Usage and time trends in exposure

Combining the results from the databases of the EU and Sweden, in total 45 different chemicals have been identified as being used as FRs. Pentaerythritol and melamine appear to be used in the highest quantities with indicies of 0.92 and 0.83, respectively (calculated as summed indices of Swedish and EU usage, normalized against the highest possible score (12)). However, it is likely that these chemicals also have other usages than as FRs. Other highly used FRs include SCCPs (0.75), DBDPE (0.75), TEP (0.75), melamine cyanurate (0.75), TBBPA-BDBPE (0.67), TPHP (0.67), EHDPP (0.67), PBDPP (0.67), TIBP (0.67), TEHP (0.67), BADP (0.67), IDP (0.58), BEH-TEBP (0.50), EBTEBPI (0.50), HEEHP-TEBP (0.50), and TXP (0.50). Interestingly, there are twelve FRs that are reported to be used in Sweden, but for which there is no information available in the ECHA database. Similarly, two FRs (TCEP and TCIPP) are among the most extensively used FRs in Sweden, but according to the EU database, they have not been registered within REACH. This mismatch may be explained by differences in the reporting limits of the two databases where the ECHA database has a higher threshold for when a chemical needs to be registered. If prioritization of FRs for environmental montoring was entirely based on use data, the list could include up to 45 FRs depending on the quantity threshold.

Increasing time trends in exposure indices were observed for TMPP (environment, human), CDP (environment), DBDPE (environment, human), PBDPP (environment, human), TBBPA-BDBPE (environment and human), and TTBNPP (environment, human). A decreasing trend in the potential of exposure was observed for SCCPs (environment). Based on the increasing trend in exposure to some FRs, it can be argued that these FRs should be included in future studies. Depending on the type of samples (i.e. water, soil, air etc.) collected, some FRs may be more important to include than other.

6.2 Environmental detection

In indoor air, 19 different FRs have been detected at concentrations higher than 1 ng m^{-3}, including DBDPE, DBE-DBCH, HBB, PBEB, PBT, TBX, DOPP, EHDPP, TBOEP, TMPP, TEP, TEHP, TIBP, TNBP, TPHP, TPP, TCEP, TCIPP, and TDCIPP (Appendix, Table S3). Detection frequencies up to 100% have been reported in at least one study for DBE-DBCH, TBOEP, TEP, TIBP, TNBP, and TPHP [18, 19, 22]. Other FRs (HBB, PBB, PBT, TBP-AE, TBP-DBPE, and TMPP) have been detected in Sweden and Norway at lower concentrations but still with high detection frequencies (≥50%) [18]. Other detected FRs in indoor air, but with lower detection frequencies, are BEH-TEBP, BTBPE, CLP1, syn-DDC-CO, anti-DDC-CO, and EH-TBB [18, 20, 21]. In dust, detection frequencies >50% (often >90%) have been reported in at least one study for BEH-TEBP, BTBPE, DBDPE, DBE-DBCH, syn-DDC-CO, anti-DDC-CO, EH-TBB, HBB, PBB, PBT, TBP-DBPE, EHDPP, TBOEP, TCEP, TCIPP, TMPP, TDCIPP, TEP, TiBP, TNBP, and TPHP [18, 19, 22, 26, 27, 29] (Appendix, Table S4). Other FRs detected in dust include CLP1, DOPP, PBEB, TBX, THP, and TEEdP [18-21, 25, 32]. In general, concentrations in dust of OPFRs were higher than for BFRs, which may indicate a more frequent use of OPFRs than of BFRs or possibly a higher ability of OPFRs of leaking from the materials. As a result, in a prioritization process, it could be argued that including the OPFRs in future indoor screenings is more important than the BFRs; however, some BFRs such as e.g., DBE-DBCH, DBDPE, and HBB may also be important to include.

Many of the FRs that have been detected in indoor environments have also been detected in outdoor air, sometimes even in remote regions (Appendix, Table S5). TPHP, TCEP, TCIPP, TDCIPP, TMP (tentatively identified), TNBP, EHDPP, TBOEP, TIBP, TBP, BTBPE, DBE-DBCH, anti-DDC-CO, syn-DDC-CO EHTBB, HBB, PBEB, PBT, BEH-TEBP, and DBDPE have all been detected in remote areas within the Nordic countries [22, 25, 34, 38], showing that they all are likely to undergo LRT. With respect to this, these chemicals may be important to include in future screenings. It is, however, important to remember that bromophenols such as e.g., TBP are also naturally produced. Other FRs detected in outdoor air of urbanized areas in the Nordic countries include BCMP-BCEP, TBBPA, 2,4-DBP, 2/3-BP, 2,6-DBP, 4-BP, TBP-AE, BATE, PBP, and TBP-DBPE [20, 22, 37, 38]. In China, also TBBPA-BDBPE has been detected [33].

In Sweden and Finland, DBE-DBCH, DDC-CO, TCEP, TCIPP, TMP (tentatively identified), and TNBP have been detected in atmospheric deposition in remote areas [34, 39, 40] (Appendix, Table S6). Again, this is showing LRT potential. A number of OPFRs (TBOEP, TCEP, TCIPP, *p*-TMPP, TDCIPP, TEHP, TMP (tentatively quantified), TNBP, and TPHP) have been detected in snow close to a road and an airport, indicating these as being emitted from point sources [34]. TBOEP, TCEP, TCIPP, TIBP, and TNBP have also been detected in urban rain in Germany [39]. Possibly, all FRs mentioned in this section may be important to include in future screenings, and especially the ones found in remote areas.

Five OPFRs have been detected in rural/remote surface waters, including TBOEP, TCEP, TCIPP, TIBP, and TNBP [44], which makes them important to include in future screenings (Appendix, Table S7). In general, concentrations of OPFRs appear to be higher than for BFRs in European rivers. Detected OPFRs in European rivers include EHDPP, TBOEP, TCEP, TDCIPP, TIBP and TCIPP [41, 43, 46, 51, 52]. In the screening study of FRs in Swedish rivers, TEBP-Anh, TBBPA, TCBPA, and EHTBB were detected at the highest concentrations, but also TBP, BTBPE, syn-DDC-CO, EHDPP, HBB, PBB-Acr, PBT, TBX, TCEP, TCIPP, *o*-TMPP, *p*-TMPP, ΣTDCIPP+TEHP, TNBP, TPHP, and TTBNPP [49]. Even though concentrations were relatively low (<67 ng L^{-1}), it could be argued that these FRs are important to include in future studies since they are in fact polluting the Swedish environment. Finally, also TEP and TPP have been detected in European rivers [41, 43]. In addition to many of the FRs detected in surface waters, several other FRs have been detected in European WWTP, including DOPP, TEHP, TMP, DBDPE, PBEB, and TBBPA-BDBPE [23, 35, 42, 47]. As these are likely to also reach surface waters, including them in future screenings may be important.

The OPFRs EHDPP, TBOEP, TCEP, TCIPP, TDCIPP, TIBP, TNBP, and TPHP have all been detected in sewage sludge from Sweden [42], while the BFRs TBP, 2,4-DBP, TBP-AE, BATE, BEH-TEBP, BTBPE, DBDPE, DBE-DBCH, anti-DDC-CO, syn-DDC-CO, EH-TBB, HBB, PBEB, PBP, PBT, TBBPA, and TBP-DBPE have been detected in sewage sludge from the Nordic countries [20] (Appendix, Table S9). Other detected FRs in sewage sludge include DDC-DBF and DDC-Ant in Spain [59], TCBPA in Canada [60], and TBBPA-BDBPE in China [33]. Also in sediment, many FRs have been detected (Appendix, Table S8). In the Nordic countries, detected FRs in sediment include TBP, 2,4-DBP, BEH-TEBP, DBE-DBCH, anti-DDC-CO, syn-DDC-CO, EH-TBB, HBB, PBEB, PBT, TBBPA, and TBBPA-BAE [20, 23, 61]. Within Europe, the OPFRs EHDPP, TBOEP, TCEP, *o*-TMPP, *p*-TMPP, TDCIPP, TEHP, TEP, TIBP, TNBP, TPHP and BCMP-BCEP have been detected in sediment, some with high detection frequencies [22, 43, 51, 56]. In North America, China and Norway, BTBPE has been detected, while TBBPA-BDBPE has, to our knowledge, only been detected in China [20, 23, 33, 47, 54, 57]. Based on this, it could be argued that all FRs that have been detected in sludge and/or sediment in the Nordic countries should be included in future studies. Perhaps is also BTBPE a compound of interest, as it is frequently detected in other environmental compartments. Furthermore, FRs such as DDC-DBF, DDC-Ant, TCBPA, and TBBPA-BDBPE may also be interesting to include, even though they have not (yet) been detected in Nordic sediment or sludge.

Not many alternative FRs have been analysed or detected in soil (Appendix, Table S10). However, BTBPE, DBDPE, and TBBPA-BDBPE have been detected in soil in China and BEH-TEBP in Norway [33, 61]. In plants, DBDPE, HBB, TBBPA-BDBPE, TBP, 2,4-DBP, BEH-TEBP, BTBPE, DBDPE, DBE-DBCH, anti-DDC-CO, syn-DDC-CO, HBB, PBEB, PBT, and TBP-DBPE have been detected in mosses/tree needles close to point sources in the Nordic countries [20, 23, 35] (Appendix, Table S11).

A wide variety of different animal species have been analysed for emerging FRs, including e.g., arctic fox, polar bear, moose, seal, cod, salmon, mussels, crab, common eider and herring gull (Appendix, Tables S12 and S13). Several BFRs, including BEH-TEBP, DBDPE, CCPs, anti- and syn-DDC-CO, EH-TBB, HBB, PBEB, and TBP have been detected in Arctic species such as e.g., polar bear [61-63], indicating potential of LRT and possibly also bioaccumulation. Thus, these FRs may be important to include in upcoming studies.

However, as previously mentioned TBP is also a naturally occurring compound. In this literature review, no studies concerning OPFRs in mammals (except in humans) were found. The number of detected FRs in aquatic animals (37) is higher compared to detected FRs in mammals (8). BEH-TEBP, S/MCCPs, DBDPE, and EHDPP have all been detected in fish from the Arctic [53, 61, 63], indicating potential of LRT and possibly also bioaccumulation. These may therefore be important to include in future studies. In the Nordic countries, the following FRs have been detected in fishes and mussels etc.: TBP, BEH-TEBP, BTBPE, anti-DDC-CO, syn-DDC-CO, DBDPE, DBPhP, EHDPP, TBOEP, TCEP, TCIPP, o-TMPP, p-TMPP, TDCIPP, TNBP, TPHP, 2,4-DBP, BATE, DBE-DBCH, HBB, PBEB, PBT, T2CPP, TBP-DBPE, TEHP, and TIBP [20, 22, 23, 25, 35, 56, 61, 64]. Also these FRs may be important to include in future studies, as they are polluting the Nordic environment with possible bioaccumulation. In Canada, the chlorinated FRs Chlordene plus, DDC-DBF, Dec 604B, anti-, and syn-DDC-CO have been detected in fish [65]. To our knowledge, chlordene Plus, DDC-DBF and Dec-604 component B have never been analysed in any of the Nordic countries before (except in the Norwegian Arctic), which could motivate to include also them in future studies. In birds and/or bird eggs, a total of 29 FRs have been detected (Appendix, Table S14). FRs that has been detected in Arctic birds/eggs include TBP, BEH-TEBP, DBDPE, Chlordene Plus, S/MCCPs, DBPhP, EHDPP, T2CPP, TCEP, TEHP, TIBP, TNBP, and TPHP [53, 61, 63]. Other FRs that have been detected in birds/eggs from other areas include BTBPE, DBE-DBCH, EHDPP, HBB, PBEB, PBP, PBT, anti-DDC-CO and syn-DDC-CO, TBOEP, TCIPP, and TDCIPP [20, 33, 56, 57, 61]. In general, detection frequencies of OPFRs were lower than for BFRs and CFRs.

Finally, eight BFRs have been detected in human blood serum from Sweden, including 2/3-BP, TBP, 2,4-DBP, 2,6-DBP, 4-BP, BTBPE, EH-TBB, and PBEB [25, 38] (Appendix, Table S15). Both TBP and BTBPE were detected in 100% of the analysed samples, showing the wide-spread contamination of these FRs. In human breast milk, also from Sweden, EHDPP, TBOEP, TCEP, TCIPP, *p*-TMPP, TDCIPP, TNBP, and TPHP were detected [64].

6.3 Prioritization lists

In total, 51 different FRs have been suggested as priority substances in literature. These include TBP, TBP-AE, BEH-TEBP, BTBPE, DBDPE, EBTEBPI, EH-TBB, HBB, PBEB, PBT, TBBPA-BAE, TBBPA-BDBPE, TBP-DBPE, TEBP-Anh, S/MCCPs, PBP, TBBPA, PBCH, OBTMPI, Dibutyl chlorendate, DDC-CO, DBE-DBCH, TTBP-TAZ, DBHCTD, HBB, HBCYD, HCTBPH, PBB-Acr, TBX, DBNPG, TDBPP, 2,4-DBP, PBBC, PBPAE, PBBBr, TBBBS, TBBPA-DHEE, TBBPA-BME, TDBP-TAZTO, HBCYD, PBDMPP, PBDPP, BADP, TiPPP, TTBNPP, TCEP, TCIPP, TPHP, CDP, TMPP, and DBS. As all FRs addressed in published prioritization lists have for different reasons, such as e.g., potential of bioaccumulation, persistence and toxicity, been thought of as posing a special hazard to the environment and humans, all of them may be important to include in future screenings.

6.4 Summary

In total, approximately 120 alternative FRs have been identified within this literature review through the search in patents, databases of chemical use, literature from previous studies and available prioritization lists. Additionally, five FRs (bBDBP, mDEP/dDEP, T3CPP, TBBPS-DBPE, and TPeP) are being sold as FR reference standards by two chemical suppliers (Accustandard and BOC sciences), despite no other information about these compounds seems to be available.

7. Multicriteria model for prioritization among flame retardants

A simple (but novel) multicriteria model was created to aid in prioritization of FRs to be included in future screening studies. The model takes four different types of data into account, namely (i) usage, (ii) time trend data of exposure for humans and the environment, (iii) environmental detection (for those that have been screened for in the environment), and (iv) previously published prioritization lists. Each FR was ranked individually between 0 (low importance) and 1 (high importance) in each data category, resulting in a maximum possible score of 3 or 4 (3 for those that were never screen for). It should be noted that the model is not compartment specific. If a specific environmental media should be screened (e.g., surface water), the model needs to be refined to also include exposure media specific indicies. Toxicity was not included since such toxicity data often is lacking, especially for newer compounds.

For the category of usage, Swedish usage data was used if available [12], otherwise the EU usage data was used [11]. If no usage data was available a score of 0 was given indicating little or no use. The Swedish usage data was indiced from 0 to 7, and the data was normalized to 0 to 1 by dividing each index by 7, which was the highest possible score. The EU usage data was transformed into indices by assigning the FRs with the highest usage amount (i.e. 100 000 to 1 000 000 tonnes per year) with an index of 5, FRs with the second highest usage amount (i.e. 10 000 to 100 000 tonnes per year) with an index of 4 and so on. If no data was available, the index was put to 0. Then the the data were normalized to 0 to 1 by dividing each index by 5 which was the highest possible score.

For environmental detection, 11 different environmental compartments (including indoor air, indoor dust, outdoor air, atmospheric deposition, water, sewage sludge, sediment, soil, plants, animals and humans) were reviewed within this literature study (see Section 3). To create a score based on environmental detection of FRs, one point was given per detected compartment, followed by normalization against the highest possible score, which was 11. As an example, if a FR has been detected in 5 out of the 11 environmental compartments, this resulted in a score of 5/11 = 0.45. As rarely monitored FRs (≤1 study) would be discriminated in this category, these FRs (*n* = 40) were considered to have a maximum score of 3, and they were consequently normalized to 3. The rarely monitored FRs include TTBNPP, EBTEBPI, PBDPP, CDP, BADP, bBDBP, pentaerythritol, IDP, melamine, melamine cyanurate, melamine pyrophosphate, DPhBP, HEEHP-TEBP, TXP, DBNPG, TBPP, PBDMPP, HCTBPH, HBCYD, mDEP/dDEP, TBBPS-DBPE, TPeP, TTBP-TAZ, piperazine polyphosphate, piperazine pyrophosphate, DBS, dibutyl chlorendate, PBBBr, PBBC, PBCH, PBPAE, T3CPP, TBBPA-BME, TBBPA-DHEE, TBBPS, TDBPP, TDBP-TAZTO, TiPPP, and cyanurodiamide.

For the prioritization lists, six prioritization lists were identified [58, 68-72] within this literature review. For each list where a FR was included, the FR was given one point. By dividing the obtained score with the highest possible score in this category (6), scores between 0 and 1 were obtained.

The last category, time trends in exposure calculated from the Swedish product database, was already indiced with values between -2 and 2 [12]. To normalize this category, the assigned indices in the two exposure categories (human and ecosystem) were summed and divided by the highest possible score. As each exposure category could have an index up to 2, the highest possible score was 4. The actual score for each FR was thus normialized by dividing by 4.

Finally, the score from each data category were summed together into one final total score for each FR. This total score was converted into total scores (0 to 100) to obtain an easily understandable and interpretable value (Table 5). The calculation of the total scores was performed by dividing the total score by the highest possible score of 3 or 4 and multiplying with 100.

Based on the score, ranging between 0 and 100, the FRs can be ranked and prioritized for future studies (Table 5). The highest total score was obtained for TBBPA-BDBPE (69), DBDPE (65), BTBPE (58), TTBNPP (48) BEH-TEBP (47), EBTEBPI (47), PBDPP (46) *p*-TMPP (44), TPHP (42), and TCIPP (40). When interpreting the results, it should be kept in mind that there are some limitations of this simplistic model. For example, the levels of the FRs are not considered, only the occurence. As a result, the score in the category of environmental detection is highly dependent on the detection limits in each specific study. Furthermore, although ~60 peer-reviewed papers were included for the category of environmental detection, the literature review may not be completely comprehensive. Moreover, the total scores is influenced by whether there is data available or not (e.g., for usage and time trend); if no data are available (or if EC/CAS numbers are lacking and no database search is possible), the score will be low. Another limitation is that the model is not compartment specific. If a specific environmental media should be screened (e.g., surface water), the model needs to be refined to also include exposure media specific indicies. FRs that are used but only have been targeted in maximum one study are marked with an asterisk (*) in Table 5. These FRs may be interesting to include in future studies despite a comparably low ranking. Nevertheless, the developed multicriteria model provide a simple and effective way of prioritizing FRs, and can readily be used to obtain priorities of FRs that are important to include in future monitoring studies.

Table 5 Multicriteria model results for prioritization of alternative FRs.

	Usage	Environmental detection	Prioritization lists	Trends	∑score	Total score
TBBPA-BDBPE	0.71	0.55	0.50	1.00	2.76	**69**[a]
DBDPE	0.71	0.73	0.67	0.50	2.61	**65**[a]
BTBPE	0.57	0.91	0.83	0	2.31	**58**[a]
TTBNPP*	0.43	0.09	0.17	0.75	1.44	**48**[b]
BEH-TEBP	0.57	0.64	0.67	0	1.87	**47**[a]
EBTEBPI*	0.57	0	0.83	0	1.40	**47**[b]
PBDPP*	0.71	0	0.17	0.50	1.38	**46**[b]
TMPP (*p*-)	0.71	0.64	0.17	0.25	1.77	**44**[a]
TPHP	0.71	0.82	0.17	0	1.70	**42**[a]
TCIPP	0.71	0.73	0.17	0	1.61	**40**[a]
TCEP	0.57	0.82	0.17	0	1.56	**39**[a]
TMPP (*o*-)	0.43	0.45	0.17	0.50	1.55	**39**[a]
TBOEP	0.71	0.82	0	0	1.53	**38**[a]
TNBP	0.71	0.82	0	0	1.53	**38**[a]
CDP*	0.71	0	0.17	0.25	1.13	**38**[b]
EHDPP	0.71	0.73	0	0	1.44	**36**[a]
HBB	na	0.73	0.67	0	1.40	**35**[a]
PBEB	na	0.73	0.67	0	1.40	**35**[a]
PBT	na	0.73	0.67	0	1.40	**35**[a]
TIBP	0.71	0.64	0	0	1.35	**34**[a]
DBE-DBCH	na	0.73	0.50	0	1.23	**31**[a]
BADP*	0.71	0	0.17	0	0.88	**29**[b]
TEHP	0.71	0.45	0	0	1.17	**29**[a]
Pentaerythritol*	0.86	0	0	0	0.86	**29**[b]
EH-TBB	na	0.64	0.50	0	1.14	**28**[a]
DDC-CO	0.14	0.82	0.17	0	1.13	**28**[a]
TEP	0.71	0.36	0	0	1.08	**27**[a]
MCCP	0.80	0.09	0.17	0	1.06	**26**[a]
SCCP	0.80	0.09	0.17	0	1.06	**26**[a]
TBP	0.00	0.64	0.33	0	0.97	**24**[a]
IDP*	0.71	0	0	0	0.71	**24**[b]
Melamine*	0.71	0	0	0	0.71	**24**[b]
Melamine cyanurate*	0.71	0	0	0	0.71	**24**[b]
PBB-Acr	0.40	0.18	0.33	0	0.92	**23**[a]
TBP-DBPE	na	0.55	0.33	0	0.88	**22**[a]
TBBPA	0.14	0.36	0.33	0	0.84	**21**[a]
TDCIPP	0	0.82	0	0	0.82	**20**[a]
DPhBP*	0.57	0	0	0	0.57	**19**[b]
HEEHP-TEBP*	0.57	0	0	0	0.57	**19**[b]
Melamine pyrophosphate*	0.57	0	0	0	0.57	**19**[b]
TXP*	0.57	0	0	0	0.57	**19**[b]
2,4-DBP	na	0.55	0.17	0	0.71	**18**[a]
DBPhP	0.57	0.09	0	0	0.66	**17**[a]

T2CPP	0.57	0.09	0	0	0.66	**17**[a]
DBNPG*	0.14	0	0.33	0	0.48	**16**[b]
ATE	na	0.27	0.33	0	0.61	**15**[a]
PBP	na	0.27	0.33	0	0.61	**15**[a]
TBX	na	0.27	0.33	0	0.61	**15**[a]
TBBPA-BAE	na	0.09	0.50	0	0.59	**15**[a]
bis-(t-butylphenyl) phenyl phosphate*	0.43	0	0	0	0.43	**14**[a]
TBPP*	0.43	0	0	0	0.43	**14**[b]
DBHCTD	na	0	0.50	0	0.50	**13**[a]
PBDMPP*	0.2	0	0.17	0	0.37	**12**[b]
TEBP-Anh	0.2	0.09	0.17	0	0.46	**11**[a]
Dec-604A/ HCTBPH	na	0	0.33	0	0.33	**11**[b]
HBCYD	na	0	0.33	0	0.33	**11**[b]
TTBP-TAZ	na	0	0.33	0	0.33	**11**[b]
TMPP (*m*-)	0	0.27	0.17	0	0.44	**11**[a]
BATE	na	0.27	0	0	0.27	**7**[a]
DOPP	na	0.27	0	0	0.27	**7**[a]
TMP	0	0.27	0	0	0.27	**7**[a]
TPP	na	0.27	0	0	0.27	**7**[a]
Piperazine (poly)phosphate*	0.20	0.00	0	0	0.20	**7**[b]
DBS	na	0	0.17	0	0.17	**6**[b]
Dibutyl chlorendate	na	0	0.17	0	0.17	**6**[b]
PBBBr	na	0	0.17	0	0.17	**6**[b]
PBBC	na	0	0.17	0	0.17	**6**[b]
PBCH	na	0	0.17	0	0.17	**6**[b]
PBPAE	na	0	0.17	0	0.17	**6**[b]
TBBPA-BME	na	0	0.17	0	0.17	**6**[b]
TBBPA-DHEE	na	0	0.17	0	0.17	**6**[b]
TBBPS	na	0	0.17	0	0.17	**6**[b]
TDBPP	na	0	0.17	0	0.17	**6**[b]
TDBP-TAZTO	na	0	0.17	0	0.17	**6**[b]
TiPPP	na	0	0.17	0	0.17	**6**[b]
Ammeline*	0.14	0	0	0	0.14	**5**[b]
Piperazine pyrophosphate	0.14	0	0	0	0	**5**[b]
2,6-DBP	na	0.18	0	0	0.18	**5**[a]
2-BP	na	0.18	0	0	0.18	**5**[a]
3-BP	na	0.18	0	0	0.18	**5**[a]
4-BP	na	0.18	0	0	0.18	**5**[a]
CLP1	na	0.18	0	0	0.18	**5**[a]
DDC-DBF	na	0.18	0	0	0.18	**5**[a]
PBB	na	0.18	0	0	0.18	**5**[a]
TCBPA	na	0.18	0	0	0.18	**5**[a]
BCMP-BCEP	0	0.18	0	0	0.18	**5**[a]
OBTMPI	na	0	0.17	0	0.17	**4**[a]
BdPhP	na	0.09	0	0	0.09	**2**[a]

Chlordene Plus	na	0.09	0	0	0.09	**2**[a]
Dec 604B	na	0.09	0	0	0.09	**2**[a]
DDC-Ant	na	0.09	0	0	0.09	**2**[a]
TEEdP	na	0.09	0	0	0.09	**2**[a]
THP	na	0.09	0	0	0.09	**2**[a]
TiPP	na	0.09	0	0	0.09	**2**[a]
1,3-hexylene dimelamine	na	0	0	0	0	**0**[b]
1,3-phenylene-bis(dixylenyl phosphate)	na	0	0	0	0	**0**[b]
4´-PeBPOBDE208	0	0	0	0	0	**0**[b]
Acetoguanamine	0	0	0	0	0	**0**[b]
bBDBP	na[c]	0	0	0	0	**0**[b]
Benzoguanamine*	0	0	0	0	0	**0**[b]
bis-(isopropylphenyl) phenyl phosphate	na	0	0	0	0	**0**[b]
Brominated paraffins	na	0	0	0	0	**0**[b]
Butylene diguanamine	na	0	0	0	0	**0**[b]
DMP	0	0	0	0	0	**0**[b]
Ethylene dimelamine	na	0	0	0	0	**0**[b]
Hexamethylene dimelamine	na	0	0	0	0	**0**[b]
Isopropylphenyl diphenyl phosphate	na	0	0	0	0	**0**[b]
mDEP/dDEP	na[c]	0	0	0	0	**0**[b]
Melamine (poly)phosphate	na	0	0	0	0	**0**[b]
Methylene diguanamine	na	0	0	0	0	**0**[b]
Norbornene diguanamine	na	0	0	0	0	**0**[b]
Octyl diphenyl phosphate	na	0	0	0	0	**0**[b]
Phthalodiguanamine	na	0	0	0	0	**0**[b]
T3CPP	na[c]	0	0	0	0	**0**[b]
TBBPS-DBPE	na[c]	0	0	0	0	**0**[b]
TBCO	na	0	0	0	0	**0**[b]
t-butylphenyl diphenyl phosphate	na	0	0	0	0	**0**[b]
TDCPP	na	0	0	0	0	**0**[b]
Tetramethylene dimelamine	na	0	0	0	0	**0**[b]
TPeP	na[c]	0	0	0	0	**0**[b]
Trimethylene dimelamine	na	0	0	0	0	**0**[b]
Tris-(isopropylphenyl) phosphate	na	0	0	0	0	**0**[b]
Xylenyl diphenyl phosphate	na	0	0	0	0	**0**[b]

*Used but rarely monitored; [a]A highest possible score of 4 was used in the calculation of total scores; [b]A highest possible score of 3 used in the calculation of total scores; [c]No search was done in the Swedish database as the FR was identified after the database search was finished.

8. Conclusions

In total, ~125 chemical substances used as alternative FRs were studied within this literature review. The majority of these have previously been targeted in environmental monitoring; however, through the search of US patents, some altrnative FRs were identified, although only a limited number of patents were investigated. This indicates a high potential of using patents in the search for new chemicals on developing markets. Searching new chemicals through patent documentation studies is, however, not straight-forward, as generally no CAS- or EC-numbers are provided in the patents. Several FRs were reported in the Swedish database as being used in Sweden, although there was no usage information in the European database (ECHA). Furthermore, two FRs (i.e. TCEP and TCIPP) are extensively used in Sweden, but according to the ECHA database, they have not been registrered within REACH. This mismatch may be explained by differences in the reporting limits of the two databases where the ECHA database has a higher threshold for when a chemical needs to be registered. Thus, the Swedish database may contain information on chemicals produced in lower amounts which are excluded by the ECHA database. However, the mismatch could also indicate that the two databases may not be completely up-to-date or that they simply contain erroneous information. Another explanation might be that information could be excluded due to confidentiality. Through the application of a multicriteria model, the FRs were ranked for future studies based on their (i) usage, (ii) time trends in exposure, (iii) environmental detection, and (iv) published prioritization lists. Out of the top 20 ranked FRs, eight were BFRs and twelve were OPFRs. This signals the importance of including both BFRs and OPFRs in future screening studies.

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Appendix

Table S1 Brief information about FRs identified in a previous internal literature study.[a]

Brominated flame retardants (BFRs)			
DBNPG	Dibromoneopentyl glucol	DBNPG is a reactive FR incorporated in rigid polyurethane foams and unsaturated polyester resins for molded products. It is genotoxic and carcinogenic.	[71]
TBNPA	Tribromoneopentyl alcohol	TBNPA is considered potentially persistent and may cause aquatic environmental damage.	[71]
4-BP	4-bromophenol	No information found.	
2,4-DBP	2,4-dibromophenol	Produced as an industrial BFR but also naturally occurring in the marine environment.	[20]
2,6-DBP	2,6-dibromophenol	No information found.	
2,4,6-tribromo-phenol	TBP	TBP is used as a reactive FR, but also as an antifungal agent and a chemical intermediate. It is considered to be a high production volume (HPV) chemical in the EU. TBP is not only anthropogenically produced; it is also produced naturally by for example marine algae. Furthermore, it can also be formed as a biotransformation product of PBDEs and is often found as a by-product in commercial BTBPE products.	[70]
PBP	Pentabromophenol	No information found.	
HBB	Hexabromobenzene	HBB can be used as an additive FR in products like paper, woods, textiles and electronics. It is not registered as a compound that is produced within EU, but HBB is produced in China. It may undergo debromination under environmental conditions.	[70, 71]
PBT	Pentabromotoluene	PBT is listed as a low production volume (LPV) chemical in the EU. It is used in for example plastics such as polystyrene, polyethylene and polypropylene. PBT is thought to be a stable compound that might undergo debromination in the environment.	[70, 71]
PBBBr	Pentabromobenzyl-bromide	No information found.	
DBS	Dibromostyrene	DBS is not completely defined but is likely to consist of a mixture of isomers. It is used as a FR in styrenic polymers, probably incorporated in the polymeric chain (reactive FR).	[71]
TBCO	1,2,5,6-tetrabromo-cyclooctane	TBCO consists of two diastereomers which are easily transformed into one another upon heating. TBCO has the potential of being an aquatic hazardous, very persistent and	[70]

		bioaccumulative substance.	
DBE-DBCH	4-(1,2-dibromo-ethyl)-1,2dibromo-cyclohexane	DBE-DBCH consists of four isomers (α, β, δ and γ) of which α and β are the main compounds in technical mixtures. However, at high temperature α- and β-isomers rearrange to δ- and γ-isomers. These high temperatures can be expected during production of the materials. DBE-DBCH is used as an additive FR in polystyrene and polyurethane materials. DBE-DBCH has been predicted to have a high bioconcentration potential, slow biodegradation and high potential of long-range atmospheric transport (LRAT).	[70, 71]
TBX	2,3,5,6-tetrabromo-p-xylene	TBX is considered to be a stable compound in the environment but with possibility to undergo debromination.	[71]
PBEB	Pentabromoethyl-benzene	PBEB is no longer in use. Earlier, it was incorporated as an additive in polyester materials like circuit boards and textiles. PBEB is considered to be a persistent and toxic compound that is likely to bioaccumulate.	[58, 70, 71]
TEBP-Anh	3,4,5,6-Tetrabromophthalic anhydride	TEBP-Anh is used both as an additive and reactive FR in materials such as unsaturated polyesters, rigid polyurethane foams and paper. It is proposed as a LPV chemical in the EU. It has also been proposed as a compound with similar properties as those undergoing LRAT, which means that it might undergo LRAT. On the other hand, TEBP-Anh is also considered to be easily hydrolyzed and thus not persistent or bioaccumulative to any extent at all.	[70, 71]
TBP-AE	2,4,6-tribromophenyl allyl ether	ATE is used as an additive FR in expandable styrene and polystyrene foam, but can also be used as a reactive FR. TBP-AE is listed as a LPV chemical in the EU but when TBP-DBPE is degraded or biotransformed, TBP-AE can be formed. TBP-AE might be able to undergo LRAT since its structure and partitioning properties are similar to many of those compounds found in the Arctic.	[70]
BATE	2-Bromoallyl 2,4,6-tribromophenyl ether	No information found.	
PBPAE	Pentabromophenyl allyl ether	No information found.	
TBP-DBPE	2,3-Dibromopropyl-2,4,6-tribromophenyl ether	TBP-DBPE is not a commercial product anymore. Can degrade into TBP-AE.	[70]
HBCYD	Hexabromo-cyclodecane	No information found.	
PBB-Acr	Pentabromobenzyl-acrylate	PBB-Acr is a reactive FR used in polybutylene terephthalate and polyethylene	[70, 71]

		terephthalate. It is classified as a LPV chemical in the EU. Very little is known about this FR.	
HBCDD	Hexabromocyclo-dodecane	During 1999-2004, the use of HBCDD in Sweden fluctuated between 0 and 70 tonnes/year. No data is available after 2004.	[73]
TDBP-TAZTO	Tris(2,3-dibromopropyl)-isocyanurate	TDBP-TAZTO is an additive FR used in many different materials, e.g. polyurethane, polyolefin, polyvinyl chloride (PVC) and synthetic rubber. It is classified as a LPV chemical in the EU and is used in a mixture with DBP-TAZTO and BDBP-TAZTO. According to the Danish Environmental Protection Agency (2000), TDBP-TAZTO can be classified as a toxic, persistent and very bioaccumulative compound.	[70, 71]
DBP-TAZTO	1-(2,3-dibromopropyl)-3,5-diallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione	DBP-TAZTO has been found in plastic consumer products in Switzerland. It is used in a mixture with TDBP-TAZTO and BDBP-TAZTO.	[71]
BDBP-TAZTO	1,3-bis(2,3-dibromopropyl-5-(2-propen-1-yl)-1,3,5-triazine-2,4,6(1H,3H,5H)-trione	BDBP-TAZTO has been found in plastic consumer products in Switzerland. It is used in a mixture with TDBP-TAZTO and DBP-TAZTO.	[71]
DBDPE	Decabromo-diphenylethane	DBDPE was introduced to the market in the mid-1980's as a replacement for BDE-209. It is used in materials like plastics, rubber and polymers used in electronic equipment. DBDPE is listed as a LPV chemical in the European chemical substances Information System (ESIS). In Sweden, 39 tonnes of DBDPE were used in 2008 but only about 7 tonnes in 2012. However, in China, DBDPE is the second most used BFR. The hatching success of some fish has been found to be suppressed by DBDPE.	[71], [73]
BTBPE	1,2-Bis(2,4,6-tribromophenoxy)-ethane	BTBPE has been produced since the 1970's and is used as an additive FR in e.g. thermoplastics and polycarbonate. In the EU, it is listed as a LPV chemical. BTBPE has shown potential biomagnification in aquatic food webs, and it is considered to be highly persistent in the environment even though it might be debrominated.	[70, 71]
BEH-TEBP	Bis(2-ethyl-1-hexyl)tetrabromo phthalate	BEH-TEBP is used in e.g., PVC, neoprene, wire insulation and wall coverings. It is often used in a mixture with EH-TBB in polyurethane foam. Both compounds undergo debromination in photo-degradation experiments. For BEH-TEBP, this can result	[70]

EH-TBB	2-Ethylhexyl- 2,3,4,5-tetrabromo-benzoate	in formation of the plasticizer bis(2-ethylhexyl)-phtalate which is restricted or banned in many countries.	
HEEHP-TEBP	2-(2-hydroxyethoxy)-ethyl 2-hydroxy-propyl- 3,4,5,6-tetrabromo-phthalate	HEEHP-TEBP is classified as a LPV chemical in the EU. It consists of a pair of enantiomers. It has been reported to be used during production of foam for insulation.	[71]
OBTMPI	Octobromo-1,3,3-trimethyl-1-phenylindane	Very little is known about OBTMPI. It consists of one enantiomeric pair and can be expected to undergo debromination in the environment.	[71]
EBTEBPI	Ethylene bis-tetrabromo-phtalimide	EBTEBPI is used in polyethylene, polypropylene, thermoplastics, rubber, textiles and other plastic materials. EBTEBPI has been reported as bioaccumulative, but conflicting results have been reported in literature.	[70]
4´-PeBPOBDE208	Pentabromo-phenoxy-nonabromo-diphenyl ether	4´-PeBPOBDE-208 is classified as a LPV in the EU. It is used in high performance polyamide and linear polyester engineering resins and alloys. Its bioavailability is likely to be restricted by its high molecular mass, and it is expected to undergo photolysis in the environment.	[71]
TBBPA	Tetrabromo-bisphenol-A	TBBPA is the most used BFR worldwide. It can be used as both an additive and reactive component and is used in printed circuit boards, plastics and resins. The content of TBBPA in printed circuit boards can be as high as 34 % (by weight). TBBPA has been shown to be a potential disruptor of the thyroid hormone system. In Sweden, the usage of TBBPA peaked at 438 tonnes/year in 2000. After that, the usage has decreased and was 24 tonnes/year in 2010.	[20], [60], [73]
TBBPA-DHEE	Tetrabromo-bisphenol-A dihydroxyethyl ether	TBBPA-DHEE is an additive FR used in engineering polymers and coatings. It is listed as a LPV chemical in the EU and is likely to be stable at normal environmental pH.	[70]
TBBPA-BDBPE	Tetrabromo-bisphenol A bis(2,3-dibromopropyl ether)	TBBPA-BDBPE is an additive FR found in pipes, water barriers, kitchen hoods and electronics. In the EU it is listed as a LPV chemical. The compound can be hydrolyzed to form TBBPA bis-(bromopropenyl ether) which might be more prevalent in sediment than the original compound.	[70]
TBBPA-BAE	Tetrabromo-bisphenol-A bis(allyl ether)	TBBPA-BAE is used both as an additive and reactive FR. It is used in polystyrene foam and expanded polystyrene. TBBPA-BAE is considered to be a LPV chemical in the EU. Laboratory experiments show that it might be resistant to degradation in the environment.	[70]
TBBPS-DBPE	Tetrabromo-	No information found.	

	bisphenol-S-bis(2,3-dibromopropyl)ether		
TTBP-TAZ	2,4,6-tris(2,4,6-tribromophenoxy)-1,3,5-triazine	TTBP-TAZ is used in high-impact polystyrene polymers and in acrylonitrile butadiene styrene polymers.	[71]
Chlorinated and brominated flame retardants (CBFRs)			
DDC-CO	Dechlorane Plus	DDC-CO is used in e.g., coatings for electrical wires and in plastic roofing materials. DDC-CO can be assumed to no longer exist on the Nordic chemical product market but can still be present in imported goods.	[20]
PBCH	Pentabromo-chlorocyclohexane	No information found.	
HCTBPH	1,2,3,4,7,7-hexachloro-5-(2,3,4,5-tetrabromophenyl)-bicyclo[2.2.1]hept-2-ene	HCTBPH belongs to the group of chemicals called Dechloranes. It has been used since the mid1960's as an additive FR in plastics, rubber, paint and electrical equipment. It is expected to undergo dehalogenation in the environment.	[71]
DBHCTD	Hexachloro-cyclopentadienyl-dibromo-cyclooctane	This FR is used in styrenic polymers such as polystyrene and styrene butadiene rubber. The first time DBHCTD was reported as a FR was in an US patent in 1975. DBHCTD consists of two enantiomers. The stability of DBHCTD in abiotic matrices is mainly unknown, but it is likely to be a stable compound.	[70, 71, 73]
TBCT	1,2,3,4-Tetrabromo-5-chloro-6-methylbenzene	No information found.	
TCBPA	Tetrachloro-bisphenol A	TCBPA is less used than TBBPA but chlorination of bisphenol-A in aqueous media can lead to its formation. Like TBBPA, TCBPA has been shown to have potential of disrupting the thyroid hormone.	[60]
Phosphorous flame retardants (PFRs)			
TEP	Triethyl phosphate	TEP is used in e.g. PVC, polyester resins and polyurethane foam. In total the usage of TEP in the Nordic countries was 78 tonnes in 2010.	[73, 74].
TCEP	Tris(2-chloroethyl) phosphate	TCEP is an additive FR used in e.g. PVC, textile and polyurethane foam. It is considered dangerous to the environment and carcinogenic to animals. Reduced fertility for humans has been reported as a result of exposure to TCEP. Due to its toxicity, the worldwide use and production of TCEP is believed to have been phased out. Nevertheless, there are still plenty of TCEP	[73, 74]

		built into houses and buildings that may continue to pose a threat to human health and the environment. According to the Swedish Chemicals Agency, the use of TCEP in the Nordic countries has decreased since 2000. In 2010, Sweden and Denmark used less than 10 tonnes each, while Finland and Norway used 147 and 65 tonnes, respectively.	
TPP	Tripropyl phosphate	No information found.	
TCIPP	Tris(chloropropyl) phosphate	TCIPP was in 2000 the most important PFR in Europe (by volume). It is used in resins, latexes and foams present in e.g. furniture. TCIPP have shown low degradability in experiments and it is assumed that it might bioaccumulate.	[74]
TDCIPP	Tris(1,3-dichloro-2-propyl) phosphate	TDCIPP is an additive FR used for the same kind of applications as TCIPP. It is more expensive than TCIPP but also more effective. It is therefore only used when extra fire safety is needed. However, contrasting facts exist. In one study, TDCIPP was detected in 52% of the sampled couches purchased in the US after 2005 indicating a much larger use. In the Nordic countries, about 1400 tonnes were used in 2010. TDCIPP is classified as dangerous for the environment and is not easily degraded. Nevertheless, it is rapidly biotransformed in fish and is not considered to bioconcentrate to any large extent. TDCIPP has been reported to be carcinogenic.	[74], [9], [73]
TDBPP	Tris(2,3-dibromopropyl) phosphate	The production of TDBPP is estimated to have started about 60 years ago. It has been used as a FR on cellulose, polyester fabrics and carpets among others. In the 1970's, TDBPP was removed from the market due to its mutagenic and carcinogenic properties. There are, however, indications that TDBPP might still be in use today.	[71]
TNBP	Tributyl phosphate	TNBP is used in hydraulic fluids, lacquers and plastic. In total, 168 tonnes of TNBP was used in the Nordic countries in 2010.	[74], [73]
TTBNPP	Tris(tribromo-neopentyl) phosphate	TTBNPP is often used in polypropylene products, such as carpets and stadium seats. It is considered to be stable in the environment but can be degraded biologically.	[71]
TPHP	Triphenyl phosphate	TPHP is used in plastics and hydraulic fluids. When leached into water, it is rapidly adsorbed to sediment, and it is not considered persistent or bioaccumulative. TPHP have shown toxicity to water-living organisms. Among the Nordic countries, Sweden used the most TPHP in 2010, about 100 tonnes.	[74], [73]

TBOEP	Tris(2-butoxyethyl) phosphate	TBOEP is used in floor polish, lacquers, plastic and rubber. In Sweden, 18 tonnes were used in 2010.	[74], [73]
EHDPP	2-Ethylhexyl-diphenyl phosphate	EHDPP is used in e.g. hydraulic fluids. EHDPP is also used in PVC as a plasticizer. The usage in Sweden, Norway and Denmark were all below 37 tonnes/year in 2010. In Finland, however, the usage was 282 tonnes in 2010.	[74], [73]
TMPP	Tritolyl phosphate	TMPP is used in e.g. hydraulic fluids. TMPP is also used in PVC as a plasticizer. Less than two tons were used in each of the Nordic countries in the year 2010.	[74], [73]
TEHP	Tris(2-ethylhexyl) phosphate	TEHP is used in for instance PVC, paints, rubber and polyurethane foam. The main user of TEHP among the Nordic countries is Finland. In 2010, Finland used 263 tons to be compared with Sweden which used 25 tons.	[74], [73]
TBPP	Tris(4-tert-butylphenyl phosphate	TBPP has been detected in 13% of the sampled couches purchased in the US year 2005 or later. It is not used in Sweden.	[9], [73]
BCMP-BCEP	2,2-Bis(chloromethyl)-1,3-propanediyl-tetrakis(2-chloroethyl) bis(phosphate)	BCMP-BCEP main usage is in polyurethane foams in cars. It is considered not readily biodegradable. Less than 5000 tons were produced within EU in 2000.	[75]

[a]The information presented in this table was collected in year 2013. More updated information may have been presented in other parts of this report.

Table S2 Data for FRs in Sweden obtained from the Swedish Chemical Agency (KemI).

	Range of Use (1-7)	Prod grp (1-7)	Consumer grp (0-7)	Article prod grp (1-7)	Quantity grp (1-7)	Quant reduction>25%	EI_Surface water	EI_Air	EI_Soil	EI_WWTP	EI_Consumer	EI_Occupational	EI_HumTrend	EI_EnvTrend	First_Year	Latest_Year	Swedish monitoring (number of analyses above detection limits, Swedish EPA screening database)
4´-PeBPOBDE208	0	0	1	7	0		0	0	0	0	0	0	0	0	1994	2010	
Acetoguanamine	0	0	1	1	0		0	0	0	0	0	0	0	0	1994	2000	
Ammeline	1	1	1	1	1		1	1	1	1	1	1	0	0	2010	2015	
BADP	1	1	1	7	5		1	1	1	5	1	7	0	0	2004	2015	
BEH-TEBP	1	1	7	6	4		2	2	2	1	4	7	0	0	2001	2015	
Benzoguanamine	0	0	1	1	0		0	0	0	0	0	0	0	0	1992	2007	
Bis-(t-butylphenyl) phenyl phosphate	1	1	7	4	3		6	1	6	3	6	7	0	0	1995	2015	
BTBPE	1	1	1	7	4		1	1	1	3	1	7	0	0	1993	2015	
CDP	4	3	1	3	5		6	3	6	6	6	7	0	1	1992	2015	
CLP1	0	0	7	6	0		0	0	0	0	0	0	0	0	2003	2011	10
SCCP	5	4	6	6	5		6	3	7	7	7	7	0	-1	1992	2015	85
MCCP	2	0	1	6	0		0	0	0	0	0	0	0	0	1992	2014	133
DBDPE	2	3	1	7	5		1	1	1	5	1	7	1	1	1995	2015	39
DBNPG	1	1	1	7	1		1	1	1	1	1	1	0	0	1999	2015	
DBPhP	1	1	1	1	4		5	2	7	5	7	7	0	0	1997	2015	2
DMP	0	0	1	1	0		0	0	0	0	0	0	0	0	1992	2012	1
DDC-CO	1	1	1	6	1		1	1	1	1	1	1	0	0	1992	2015	30
DPhBP	1	1	1	1	4		5	1	7	5	6	7	0	0	1997	2015	2
EBTEBPI	2	2	1	7	4		1	1	1	3	1	7	0	0	1992	2015	
EHDPP	3	3	1	7	5		1	1	3	5	3	7	0	0	1992	2015	173

HBCDD	1	0	1	7	0		0	0	0	0	0	0	0	0	1993	2014	297
HEEHP-TEBP	1	1	1	7	4		1	1	1	3	1	7	0	0	1993	2015	
IDP	3	2	1	7	5		1	1	1	4	6	7	0	0	1992	2015	
Melamine	4	4	1	99	5	x	3	3	4	6	7	7	0	0	1992	2015	
Melamine cyanurate	3	4	1	7	5		2	1	2	6	2	7	0	0	1992	2015	
Melamine pyrophosphate	1	1	1	7	4		1	1	1	2	1	6	0	0	2003	2015	
Pentaerythritol	5	5	1	5	6		7	6	7	6	7	7	0	0	1992	2015	
PBDPP	2	2	1	7	5		1	1	1	4	1	7	1	1	1993	2015	
T2CPP	1	1	7	1	4		1	1	1	1	1	1	0	0	1992	2015	
TBBPA	1	3	1	99	1	x	1	1	1	1	1	5	0	0	1992	2015	61
TBBPA-BDBPE	1	1	1	7	5		1	1	1	4	1	7	2	2	1998	2015	
TBOEP	5	5	3	3	5		5	3	7	6	6	7	0	0	1992	2015	214
TBPP	1	1	1	7	3		1	1	4	1	2	4	0	0	1995	2015	
TCEP	2	1	1	6	4		2	1	1	4	1	7	0	0	1992	2015	425
TCIPP	4	5	4	7	5		4	3	4	6	5	7	0	0	1992	2015	289
TMPP (o-)	2	2	1	4	3		1	1	1	1	1	6	1	1	2002	2015	1
TMPP (o-, m-, p-)	4	4	1	5	5		7	2	7	6	7	7	0	1	1992	2015	111
TMPP (p-)	4	4	1	5	5		7	2	7	6	7	7	0	1	1992	2015	111
TDCIPP	0	0	1	7	0		0	0	0	0	0	0	0	0	1992	2010	237
TEHP	3	3	1	1	5		5	5	5	5	5	7	0	0	1992	2015	38
TEP	4	4	2	4	5		2	2	2	4	5	7	0	0	1992	2015	
TIBP	5	4	1	4	5		6	2	7	6	6	7	0	0	1992	2015	37
TMP	0	0	1	1	0		0	0	0	0	0	0	0	0	1993	1993	5
TNBP	5	4	1	1	5		6	6	7	6	7	7	0	0	1992	2015	349
TPHP	5	4	1	6	5		6	5	7	6	7	7	0	0	1992	2015	288
TTBNPP	1	1	1	7	3		1	1	1	2	1	7	2	1	2005	2015	
TTBNPP	1	1	1	7	3		1	1	1	2	1	7	2	1	2005	2015	
TXP	2	1	1	2	4		5	2	7	5	7	7	0	0	1992	2015	
BCMP-BCEP	0	0	1	6	0		0	0	0	0	0	0	0	0	1992	2001	[i]

Table S3 Concentrations of detected FRs in indoor air (ng m^{-3}). Detection frequency in brackets.

Home	Type of environment, country	TBP	2,4-DBP	TBP-AE	BATE	BEH-TEBP	BTBPE	CLP1
Bergh 2011	Home, Sweden							
Cequier 2014[a]	Living room, Norway			0.0693 (70%)	nd	0.0242 (19%)	nd	
Luongo 2015	House air, Stockholm, Sweden							
Office	**Type of environment, country**	**TBP**	**2,4-DBP**	**TBP-AE**	**BATE**	**BEH-TEBP**	**BTBPE**	**CLP1**
Bergh 2011	Offices and workshop, Sweden							
Schlabach, 2011	Office building, Oslo, Norway	nd	nd	nd	nd	0.0067-0.0074	0.0088-0.019	
Public place	**Type of environment, country**	**TBP**	**2,4-DBP**	**TBP-AE**	**BATE**	**BEH-TEBP**	**BTBPE**	**CLP1**
Marklund 2005	Different indoor compartments, Sweden							nd-0.8
Green 2008	Shopping centre, Norway							
Moskeland 2009	Electronics store, Norway	nd				nd	nd	
Bergh 2011	Day care, Sweden							
Cequier 2014[a]	School classroom, Norway			0.00288 (0%)		0.00632 (33%)		
Fromme 2014	Daycare centers, Germany							
Point source	**Type of environment, country**	**TBP**	**2,4-DBP**	**TBP-AE**	**BATE**	**BEH-TEBP**	**BTBPE**	**CLP1**
Remberger 2014	Point source, recycling hall, electronics							

[a]Maximum value

Home	**DBDPE**	**DBE-DBCH (α-)**	**DBE-DBCH (β-)**	**DBE-DBCH (γ-)**	**DBE-DBCH (δ-)**	**DBHCTD**	**DDC-DBF**	**DDC-Ant**	**DOPP**	**DDC-CO (anti-)**	**DDC-CO (syn-)**
Bergh 2011											
Cequier 2014[a]	0.963 (47%)	4.120 (100%)				nd	nd	nd		0.00761 (4%)	0.00739 (2%)
Luongo 2015											
Office	**DBDPE**	**DBE-DBCH (α-)**	**DBE-DBCH (β-)**	**DBE-DBCH (γ-)**	**DBE-DBCH (δ-)**	**DBHCTD**	**DDC-DBF**	**DDC-Ant**	**DOPP**	**DDC-CO (anti-)**	**DDC-CO (syn-)**
Bergh 2011											
Schlabach, 2011	nd-0.056	nd-0.0023	nd-0.00079	nd						nd	nd
Public place	**DBDPE**	**DBE-DBCH (α-)**	**DBE-DBCH (β-)**	**DBE-DBCH (γ-)**	**DBE-DBCH (δ-)**	**DBHCTD**	**DDC-DBF**	**DDC-Ant**	**DOPP**	**DDC-CO (anti-)**	**DDC-CO (syn-)**
Marklund 2005									nd-4.8		
Green 2008											
Moskeland 2009	nd										
Bergh 2011											
Cequier 2014[a]	0.0206 (50%)	0.399 (100%)				nd	nd	nd		nd	nd
Fromme 2014											
Point source	**DBDPE**	**DBE-DBCH (α-)**	**DBE-DBCH (β-)**	**DBE-DBCH (γ-)**	**DBE-DBCH (δ-)**	**DBHCTD**	**DDC-DBF**	**DDC-Ant**	**DOPP**	**DDC-CO (anti-)**	**DDC-CO (syn-)**
Remberger 2014	220-530	6.7-8.3									

[a]Maximum value

Home	**EBTEBPI**	**EHDPP**	**EH-TBB**	**HBB**	**OBTMPI**	**PBB**	**PBB-Acr**	**PBEB**	**PBP**	**PBT**	**TBBPA**	**TBBPA-BAE**
Bergh 2011		nd-<LOQ										
Cequier 2014[a]		0.00351 (62%)		0.297 (70%)	nd	0.0508 (100%)	nd	0.0306 (45%)		0.213 (100%)		
Luongo 2015		nd-3.9 (3%)										
Office	**EBTEBPI**	**EHDPP**	**EH-TBB**	**HBB**	**OBTMPI**	**PBB**	**PBB-Acr**	**PBEB**	**PBP**	**PBT**	**TBBPA**	**TBBPA-BAE**
Bergh 2011		nd-14										
Schlabach, 2011			nd-0.0067	0.012-0.015				nd-0.00021	nd	0.0025-0.0028	nd	
Public place	**EBTEBPI**	**EHDPP**	**EH-TBB**	**HBB**	**OBTMPI**	**PBB**	**PBB-Acr**	**PBEB**	**PBP**	**PBT**	**TBBPA**	**TBBPA-BAE**
Marklund 2005												
Green 2008		nd-0.42 (28%)										
Moskeland 2009	nd		nd	nd				nd		nd		nd
Bergh 2011		nd-2.2										
Cequier 2014[a]		0.00503 (67%)		0.00652 (83%)	nd	0.00735 (83%)		nd		0.00414 (100%)		
Fromme 2014												
Point source	**EBTEBPI**	**EHDPP**	**EH-TBB**	**HBB**	**OBTMPI**	**PBB**	**PBB-Acr**	**PBEB**	**PBP**	**PBT**	**TBBPA**	**TBBPA-BAE**
Remberger 2014				1400-1600				nd-12		14-25		

[a]Maximum values

Home	TBBPA-BDBPE	TBCO	TBOEP	TBP-DBPE	TBX	TCEP	TCIPP	TMPP (*o*-)	TMPP (*m*-)	TMPP (*p*-)
Bergh 2011			nd-4.5			nd-28	2.4-64			nd-<LOQ
Cequier 2014[a]		nd	0.0182 (100%)	0.132 (40%)	2.830 (38%)	0.0101 (98%)	0.462 (100%)		0.000644 (57%)	
Luongo 2015			nd-10 (5%)			nd-233 (65%)	1.3-1179 (100%)			
Office	**TBBPA-BDBPE**	**TBCO**	**TBOEP**	**TBP-DBPE**	**TBX**	**TCEP**	**TCIPP**	**TMPP (*o*-)**	**TMPP (*m*-)**	**TMPP (*p*-)**
Bergh 2011			nd-73			nd-140	16-240			nd-1.0
Schlabach 2011				nd-0.0017						
Public place	**TBBPA-BDBPE**	**TBCO**	**TBOEP**	**TBP-DBPE**	**TBX**	**TCEP**	**TCIPP**	**TMPP (*o*-)**	**TMPP (*m*-)**	**TMPP (*p*-)**
Marklund 2005			nd-55			0.4-730	10-570			
Green 2008			8-55 (100%)			2.7-23 (100%)	10-49 (100%)			
Moskeland 2009	nd			nd						
Bergh 2011			nd-380			7.8-230	1.3-72			nd-<LOQ
Cequier 2014[a]		nd	0.0201 (100%)	0.0106 (50%)	0.00292 (17%)	0.0213 (100%)	0.0251 (100%)		nd	
Fromme 2014			nd-1279			nd-33	nd-45			
Point source	**TBBPA-BDBPE**	**TBCO**	**TBOEP**	**TBP-DBPE**	**TBX**	**TCEP**	**TCIPP**	**TMPP (*o*-)**	**TMPP (*m*-)**	**TMPP (*p*-)**
Remberger 2014										

[a]Maximum values

Home	TDCIPP	TEBP-Anh	TEEdP	TEHP	TEP	TIBP	TNBP	TPHP	TPP	BCMP-BCEP
Bergh 2011	nd-17			nd	3.2-16	3.0-66	3.5-45	nd-0.8		
Cequier 2014[a]	0.0106 (98%)						0.124 (100%)	0.00165 (89%)		
Luongo 2015					0.84-297 (100%)	2.4-53 (100%)	2.5-94 (100%)	nd-25 (15%)		
Office	**TDCIPP**	**TEBP-Anh**	**TEEdP**	**TEHP**	**TEP**	**TIBP**	**TNBP**	**TPHP**	**TPP**	**BCMP-BCEP**
Bergh 2011	nd-73			nd	0.7-91	4.4-13	nd-100	nd-2.7		
Schlabach 2011										
Public place	**TDCIPP**	**TEBP-Anh**	**TEEdP**	**TEHP**	**TEP**	**TIBP**	**TNBP**	**TPHP**	**TPP**	**BCMP-BCEP**
Marklund 2005	nd-150		Excluded	nd-14			nd-120	nd-23	nd-8.4	
Green 2008	nd-18 (50%)					nd-7.9 (75%)	8.2-16 (100%)	2300-47000 (100%)		nd
Moskeland 2009		nd								
Bergh 2011	nd-30			nd	0.8-20	nd-63	3.7-320	nd-0.9		
Cequier 2014[a]	0.000140 (100%)						0.00457 (100%)	0.000234 (100%)		
Fromme 2014							nd-80			
Point source	**TDCIPP**	**TEBP-Anh**	**TEEdP**	**TEHP**	**TEP**	**TIBP**	**TNBP**	**TPHP**	**TPP**	**BCMP-BCEP**
Remberger 2014										

[a]Maximum values

Table S4 Concentrations of detected FRs in indoor dust. Detection frequency in brackets.

Home	Year	Unit	Type of environment, country	TBP-AE	BATE	BEH-TEBP	BTBPE
Van den Eede 2011	2011	ug/g	House dust, Belgium				
Bergh 2011	2011	ug/g	Home, Sweden				
Abdallah 2014	2014	ug/g	Houses				
Cequier 2014[a]	2014	ug/g	Living room, Norway	nd	nd	0.809 (100%)	0.0419 (92%)
He 2015	2015	ug/g	Rural home, China				
He 2015	2015	ug/g	Urban home, China				
Hoffman 2015	2015	ug/g	Homes, US				
Luongo 2015	2015	ug/g	House dust (2008), Stockholm, Sweden				
Brommer 2015	2015	ug/g	Living room, UK				
Langer 2016	2016	ug/g	Homes, Denmark				
Office	**Year**	**Unit**	**Type of environment, country**	**TBP-AE**	**BATE**	**BEH-TEBP**	**BTBPE**
Bergh 2011	2011	ug/g	Offices and workshop, Sweden				
Abdallah 2014	2014	ug/g	Office, Egypt				
Brommer 2015	2015	ug/g	Office, UK				
Public place	**Year**	**Unit**	**Type of environment, country**	**TBP-AE**	**BATE**	**BEH-TEBP**	**BTBPE**
Marklund 2003	2003	ug/g	Different indoor compartments,such as e.g., home, hospital, prison, Sweden				
Bergh 2011	2011	ug/g	Day care, Sweden				
Van den Eede 2011	2011	ug/g	Dust from different types of stores, Belgium				
Abdallah 2014	2014	ug/g	Public places, such as e.g., restaurants, Egypt				
Cequier 2014[a]	2014	ug/g	School classroom, Norway	nd	nd	0.151 (100%)	0.0530 (100%)
Fromme 2014	2014	ug/g	Daycare centers, Germany				
Remberger 2014	2014	ug/g	Public places and homes, Sweden				
He 2015	2015	ug/g	Urban college dormitory, China				
Brommer 2015	2015	ug/g	Classroom, UK				
Langer 2016	2016	ug/g	Daycare centers, Denmark				
Point source	**Year**	**Unit**	**Type of environment, country**	**TBP-AE**	**BATE**	**BEH-TEBP**	**BTBPE**
Marklund 2003	2003	ng/m^2	Dust from computer, Sweden				
Mai 2009	2009	ug/g dw	Dust from e-waste processing area, China				0.0146-0.232
Remberger 2014	2014	ug/g	Dust in new car (2012)				
Remberger 2014	2014	ug/g	Dust, recycling hall, electronics				
Abdallah 2014	2014	ug/g	Cars, Egypt				
Brommer 2015	2015	ug/g	Car, UK				
He 2015	2015	ug/g	E-waste workshop, China				

Homes	**Unit**	**CLP1**	**DBDPE**	**DBE-DBCH**	**DBHCTD**	**DDC-DBF**	**DDC-Ant**	**DOPP**	**DDC-CO (anti-)**	**DDC-CO (syn-)**	**EHDPP**
Van den Eede 2011	ug/g										
Bergh 2011	ug/g										nd-1.8
Abdallah 2014	ug/g										0.052 ±0.032 (55%)
Cequier 2014[a]	ug/g		4.460 (96%)	0.172 (96%)	nd	nd	nd		0.590 (92%)	0.311 (92%)	5.900 (100%)
He 2015	ug/g										0.06-1.28
He 2015	ug/g										0.03-3.47
Hoffman 2015	ug/g										
Luongo 2015	ug/g										nd-20 (84%)
Brommer 2015	ug/g										0.18-130
Langer 2016	ug/g										nd-11
Office	**Unit**	**CLP1**	**DBDPE**	**DBE-DBCH**	**DBHCTD**	**DDC-DBF**	**DDC-Ant**	**DOPP**	**DDC-CO (anti-)**	**DDC-CO (syn-)**	**EHDPP**
Bergh 2011	ug/g										nd-73
Abdallah 2014	ug/g										0.043 ±0.021 (60%)
Brommer 2015	ug/g										0.15-81
Public places	**Unit**	**CLP1**	**DBDPE**	**DBE-DBCH**	**DBHCTD**	**DDC-DBF**	**DDC-Ant**	**DOPP**	**DDC-CO (anti-)**	**DDC-CO (syn-)**	**EHDPP**
Marklund 2003	ug/g	nd-0.11						nd-5.1			
Bergh 2011	ug/g										0.2-160
Van den Eede 2011	ug/g										
Abdallah 2014	ug/g										0.049 ±0.019 (36%)
Cequier 2014[a]	ug/g		0.360 (83%)	0.010 (100%)	nd	nd	nd		0.00925 (100%)	0.00313 (83%)	79.000 (100%)
Fromme 2014	ug/g										0.30-95.6
Remberger 2014	ug/g		0.140-8.100	nd-0.0013							
He 2015	ug/g										nd-0.57
Brommer 2015	ug/g										0.30-470
Langer 2016	ug/g										nd-540
Point sources	**Unit**	**CLP1**	**DBDPE**	**DBE-DBCH**	**DBHCTD**	**DDC-DBF**	**DDC-Ant**	**DOPP**	**DDC-CO (anti-)**	**DDC-CO (syn-)**	**EHDPP**
Marklund 2003	ng/m^2	nd						130-450			
Mai 2009	ug/g dw		nd-0.139								
Remberger 2014	ug/g		92	nd							
Remberger 2014	ug/g		20.000-23.000	0.0013-0.0028							
Abdallah 2014	ug/g										0.066 ±0.053 (50%)
Brommer 2015	ug/g										0.29-11
He 2015	ug/g										0.15-2.39

[a]Maximum values

Homes	Unit	EH-TBB	HBB	OBTMPI	PBB	PBB-Acr	PBEB	PBP	PBT	TBBPA	TBBPA-BDBPE
Van den Eede 2011	ug/g										
Bergh 2011	ug/g										
Abdallah 2014	ug/g										
Cequier 2014[a]	ug/g	0.245 (58%)	0.00894 (50%)	nd	0.00464 (40%)	0.0113 (13%)	0.00800 (33%)		0.0161 (94%)		
He 2015	ug/g										
He 2015	ug/g										
Hoffman 2015	ug/g										
Luongo 2015	ug/g										
Brommer 2015	ug/g										
Langer 2016	ug/g										
Office	**Unit**	**EH-TBB**	**HBB**	**OBTMPI**	**PBB**	**PBB-Acr**	**PBEB**	**PBP**	**PBT**	**TBBPA**	**TBBPA-BDBPE**
Bergh 2011	ug/g										
Abdallah 2014	ug/g										
Brommer 2015	ug/g										
Public places	**Unit**	**EH-TBB**	**HBB**	**OBTMPI**	**PBB**	**PBB-Acr**	**PBEB**	**PBP**	**PBT**	**TBBPA**	**TBBPA-BDBPE**
Marklund 2003	ug/g										
Bergh 2011	ug/g										
Van den Eede 2011	ug/g										
Abdallah 2014	ug/g										
Cequier 2014[a]	ug/g	0.00572 (67%)	0.00527 (67%)	nd	0.000682 (50%)	nd	0.000103 (0%)		0.00106 (67%)		
Fromme 2014	ug/g										
Remberger 2014	ug/g		nd-0.020				nd		0.00072-0.002		
He 2015	ug/g										
Brommer 2015	ug/g										
Langer 2016	ug/g										
Point sources	**Unit**	**EH-TBB**	**HBB**	**OBTMPI**	**PBB**	**PBB-Acr**	**PBEB**	**PBP**	**PBT**	**TBBPA**	**TBBPA-BDBPE**
Marklund 2003	ng/m^2										
Mai 2009	ug/g dw										nd
Remberger 2014	ug/g		0.08				nd		0.042		
Remberger 2014	ug/g		1.200-8.200				0.0091-0.016		0.0054-0.064		
Abdallah 2014	ug/g										
Brommer 2015	ug/g										
He 2015	ug/g										

[a]Maximum values

Homes	Unit	TBCO	TBOEP	TBP-DBPE	TBX	TCEP	TCIPP	TMPP (*o*-)	TMPP (*m*-)	TMPP (*p*-)
Van den Eede 2011	ug/g		0.36-67.6 (100%)			nd-2.65 (86%)	0.19-73.7 (100%)	nd-5.07 (97%)		
Bergh 2011	ug/g		0.6-30			nd-33	0.7-11			nd-3.0
Abdallah 2014	ug/g		0.086 ±0.125 (25%)			0.049 ±0.049 (55%)	0.053 ±0.045 (45%)			
Cequier 2014[a]	ug/g	nd	128.000 (100%)	0.0214 (69%)	0.0888 (6%)	4.630 (98%)	40.100 (100%)	16.200 (92%)		
He 2015	ug/g		0.03-1.76			0.05-9.36	0.24-10.7	nd-3.65		
He 2015	ug/g		nd-3.05			1.55-9.70	0.16-2.93	nd-7.74		
Hoffman 2015	ug/g									
Luongo 2015	ug/g		nd-107 (98%)			nd-808 (97%)	1.21-98 (100%)	nd-31 (85%)		
Brommer 2015	ug/g					nd-28	3.7-100	nd-14 b		
Langer 2016	ug/g		nd-1300			nd-230	nd-100			nd-18
Office	**Unit**	**TBCO**	**TBOEP**	**TBP-DBPE**	**TBX**	**TCEP**	**TCIPP**	**TMPP (*o*-)**	**TMPP (*m*-)**	**TMPP (*p*-)**
Bergh 2011	ug/g		4.5-960			1.3-260	3.4-120			nd-2.9
Abdallah 2014	ug/g		0.263 ±0.515 (30%)			0.061 ±0.042 (55%)	0.119 ±0.196 (55%)			
Brommer 2015	ug/g					nd-160	3.6-230	nd-5.3 b		
Public places	**Unit**	**TBCO**	**TBOEP**	**TBP-DBPE**	**TBX**	**TCEP**	**TCIPP**	**TMPP (*o*-)**	**TMPP (*m*-)**	**TMPP (*p*-)**
Marklund 2003	ug/g		14-5300			0.19-94	0.47-73			
Bergh 2011	ug/g		31-4100			2.5-150	0.8-12			nd-13
Van den Eede 2011	ug/g		0.20-55.7 (100%)			nd-5.46 (93%)	0.58-24.4 (100%)	nd-12.5 (93%)		
Abdallah 2014	ug/g		0.311 ±0.425 (64%)			0.277 ±0.189 (64%)	0.232 ±0.178 (73%)			
Cequier 2014[a]	ug/g	nd	163.000 (100%)	0.000707 (50%)	nd	6.160 (100%)	2.740 (100%)	0.333 (50%)		
Fromme 2014	ug/g		1.61-4711			0.10-8.3	0.71-47.0			
Remberger 2014	ug/g									
He 2015	ug/g		0.04-0.77			2.78-20.8	0.06-2.30	nd		
Brommer 2015	ug/g					nd-8.3	1.7-210	nd-5.8 b		
Langer 2016	ug/g		nd-11000			nd-1800	nd-350			nd-36
Point sources	**Unit**	**TBCO**	**TBOEP**	**TBP-DBPE**	**TBX**	**TCEP**	**TCIPP**	**TMPP (*o*-)**	**TMPP (*m*-)**	**TMPP (*p*-)**
Marklund 2003	ng/m^2		170-940			210-220	220-370			
Mai 2009	ug/g dw									
Remberger 2014	ug/g									
Remberger 2014	ug/g									
Abdallah 2014	ug/g		0.284 ±0.274 (30%)			0.198 ±0.195 (50%)	0.513 ±0.475 (55%)			
Brommer 2015	ug/g					nd-8.7	2.4-370	nd-5.6 b		
He 2015	ug/g		0.04-0.81			0.18-1.56	0.11-22.3	0.52-46.6		

[a]Maximum values

Homes	Unit	TDCIPP	TEEdP	TEHP	TEP	THP
Van den Eede 2011	ug/g	nd-6.64 (97%)			nd	
Bergh 2011	ug/g	2.2-27		nd-0.2	nd	
Abdallah 2014	ug/g	0.147 ±0.164 (65%)				
Cequier 2014[a]	ug/g	6.920 (100%)				
He 2015	ug/g	nd-2.77		0.08-1.85	0.03-0.41	
He 2015	ug/g	nd-9.63		0.03-1.37	0.02-0.24	
Hoffman 2015	ug/g	0.197-39.530 (100%)				
Luongo 2015	ug/g	nd-12 (81%)		nd-46 (2%)	nd-4.3 (84%)	nd-5.8 (6%)
Brommer 2015	ug/g	0.06-14				
Langer 2016	ug/g	nd-860		nd-11		
Office	**Unit**	**TDCIPP**	**TEEdP**	**TEHP**	**TEP**	**THP**
Bergh 2011	ug/g	3.3-91		nd-0.3	nd-0.3	
Abdallah 2014	ug/g	0.099 ±0.137 (70%)				
Brommer 2015	ug/g	nd-51				
Public places	**Unit**	**TDCIPP**	**TEEdP**	**TEHP**	**TEP**	**THP**
Marklund 2003	ug/g	0.20-67	0.16-12	0.06-13		
Bergh 2011	ug/g	3.9-150		nd-0.7	nd-4.7	
Van den Eede 2011	ug/g	nd-56.2 (93%)			nd-0.37 (53%)	
Abdallah 2014	ug/g	0.601 ±0.572 (91%)				
Cequier 2014[a]	ug/g	6.140 (100%)				
Fromme 2014	ug/g			nd-4.85		
Remberger 2014	ug/g					
He 2015	ug/g	0.06-3.71		nd-0.32	0.03-0.94	
Brommer 2015	ug/g	0.04-10				
Langer 2016	ug/g	nd-320		nd-3.8		
Point sources	**Unit**	**TDCIPP**	**TEEdP**	**TEHP**	**TEP**	**THP**
Marklund 2003	ng/m^2	170-290	290-560	nd		
Mai 2009	ug/g dw					
Remberger 2014	ug/g					
Remberger 2014	ug/g					
Abdallah 2014	ug/g	0.087 ±0.076 (50%)				
Brommer 2015	ug/g	0.11-740				

[a]Maximum values

Table S5 Concentrations of detected FRs in outdoor air (pg m^{-3}). Detection frequency in brackets.

	Brief description, country	**2/3-BP**	**2,4,6-TBP**	**2,4-DBP**	**2,6-DBP**	**4-BP**
Marklund 2005	Background air, Finland					
Green 2008	Urban areas, Mainland Norway					
Green 2008	Remote area, Svalbard and mainland, Norway					
Moskeland 2009	Norway screening		nd			
Mai 2009	Pearl river delta, China					
Arp 2010	Atm. Particles, city, Norway					
Möller 2010	Sea air, Arctic to Antarctica					
Schlabach, 2011	Background and urban, Sweden/Norway/Denmark		nd-27	nd-21		
Xie 2011	Sea air from the Atlantic and Southern Ocean					
Remberger 2014	Background sites in Sweden and Finland					
Remberger 2014	Diffuse sources					
Haglund 2015	Background sites in Sweden and Finland	0.495-9.278	0.145-1.626 (100%)	0.209-13.315	0.031-0.271	0.210-7.908

	TBP-AE	**BATE**	**BEH-TEBP**	**BTBPE**	**DBDPE**	**DBE-DBCH (α-)**	**DBE-DBCH (β-)**
Marklund 2005							
Green 2008							
Green 2008							
Møskeland 2009			nd	nd	nd		
Mai 2009				3.83-67.4	402-3578		
Arp 2010							
Möller 2010							
Schlabach 2011	nd-0.27	nd-0.051	nd-1.7	nd-2.2	nd-44	0.039-13	nd-11
Xie 2011							
Remberger 2014					nd	nd	
Remberger 2014					nd	0.19-0.62	
Haglund 2015			nd-0.087 (92%)	0.011-0.395 (100%)	nd-0.470 (83%)	0.017-0.504 (100%)	0.010-0.141 (100%)

	DBE-DBCH (γ-)	DBE-DBCH (δ-)	DDC-CO (anti-)	DDC-CO (syn-)	EHDPP	EH-TBB	HBB
Marklund 2005							
Green 2008					nd-1100 (33%)		
Green 2008					nd-260 (29%)		
Moskeland 2009						nd	nd-10.2
Mai 2009							
Arp 2010							4.3
Möller 2010			nd-1.01	nd-4.1			
Schlabach 2011	nd-18		0.065-120	0.039-42		nd-1.4	nd-2.3
Xie 2011							0.92 (median)
Remberger 2014							nd-0.21
Remberger 2014							nd-0.25
Haglund 2015			0.0096-0.064 (100%)	0.0090-0.068 (100%)		0.0032-0.036 (100%)	0.017-0.091 (100%)

	PBEB	PBP	PBT	TBBPA	TBBPA-BAE	TBBPA-BDBPE	TBOEP	TBP-DBPE	TCEP
Marklund 2005							nd		1.6
Green 2008							nd-340 (50%)		510-3700 (100%)
Green 2008							nd-150 (14%)		nd-270 (14%)
Moskeland 2009			nd		nd	nd		nd	
Mai 2009						131-1240			
Arp 2010			nd						
Möller 2010									
Schlabach 2011		nd-1.5	nd-4.4	nd-284				nd-3.2	
Xie 2011			0.01 (median)					0.56 (median)	
Remberger 2014			nd						
Remberger 2014			nd-0.06						
Haglund 2015	0.0013-0.0080 (100%)		0.0019-0.0090 (100%)						

	TCIPP	TMPP (*p*-)	TDCIPP	TEHP	TIBP	TMP	TNBP	TPHP	TPP	BCMP-BCEP
Marklund 2005	810	nd	20	nd		24 a	280	12000	nd	
Green 2008	240-3700 (100%)		nd-72 (33%)		320-4400 (100%)		300-3700 (100%)	nd-1000 (33%)		nd-5200 (17%)
Green 2008	nd-330 (14%)		nd-250 (57%)		nd-230 (86%)		nd	nd		nd
Moskeland 2009										
Mai 2009										
Arp 2010										
Möller 2010										
Schlabach 2011										
Xie 2011										
Remberger 2014										
Remberger 2014										
Haglund 2015										

Table S6 Concentrations of detected FRs in atmospheric deposition.

	Brief information, country	Unit	DBDPE	DBE-DBCH (α-)	DBE-DBCH (β-)	DDC-CO (anti-)	DDC-CO (syn-)	HBB	PBEB	PBT
Marklund 2005	Wet and dry deposition, Background, Finland	ng m^{-2} month^{-1}								
Marklund 2005	Snow from ground, close to road	ng/L								
Marklund 2005	Snow from ground, close to airport	ng/L								
Marklund 2005	Snow from ground, background, Sweden	ng/L								
Regnery 2009	Urban rain, Germany	ng/L								
Regnery 2009	Background rain, Germany	ng/L								
Regnery 2009	Background snow, Germany	ng/L								
Newton 2013	Wet and dry deposition (2009-2010), Abisko, Sweden	ng m^{-2} month^{-1}		3.1 ±3.6		22 ±21				
Newton 2013	Wet and dry deposition (2009-2010), Krycklan, Sweden	ng m^{-2} month^{-1}		3.5 ±2.8		1.1 ±0.52				
Remberger 2014	Background, Swedish westcoast	ng m^{-2} day^{-1}	nd	nd				nd	nd	nd

	Unit	TBOEP	TCEP	TCIPP	TMPP (*p*-)	TDCIPP	TEHP	TIBP	TMP a	TNBP
Marklund 2005	ng/m^{2}month	nd	16500	15300	nd	nd	nd		33	6900
Marklund 2005	ng/L	4-12	7-12	110-170	nd	8-230	nd-130		nd-10 a	11-20
Marklund 2005	ng/L	7-94	29-39	100-210	260-9900	4-15	1-95		11-28 a	2100-23000
Marklund 2005	ng/L	2	7	68	nd	29	nd		nd a	19
Regnery 2009	ng/L	25 (median)	73 (median)	743 (median)		7 (median)		244 (median)		203 (median)
Regnery 2009	ng/L	3-39 (median)	3-39 (median)	30-387 (median)		2-24 (median)		42-123 (median)		37-133 (median)
Regnery 2009	ng/L	4-21 (median)	4-21 (median)	20-83 (median)		5-40 (median)		39-196 (median)		15-192 (median)
Newton 2013	ng/m^{2}month									
Newton 2013	ng/m^{2}month									
Remberger 2014	ng/m2day									

	Unit	TPHP	TPP
Marklund 2005	ng m^{-2} $month^{-1}$	nd	nd
Marklund 2005	ng/L	4-68	nd
Marklund 2005	ng/L	120-830	nd-2
Marklund 2005	ng/L	4	nd
Regnery 2009	ng/L		
Regnery 2009	ng/L		
Regnery 2009	ng/L		
Newton 2013	ng m^{-2} $month^{-1}$		
Newton 2013	ng m^{-2} $month^{-1}$		
Remberger 2014	ng m^{-2} day^{-1}		

Table S7 Concentrations of detected FRs in water (ng L^{-1}).

	Brief information, country	TBP	TBP-AE
Andresen 2004	Rivers, Germany		
Andresen 2004	WWTP effluent, Germany		
Marklund 2005	Influent/effluent WWTP, Sweden		
Martinez-Carballo 2007	River water, Austria		
Green 2008	Influent/effluent WWTP, Norway		
Moskeland 2009	Screening in Norway, including point sources	nd	nd
Möller 2010	Sea water, Arctic to Antarctica		
Arp 2010	Wastewater, seepage water, near suspected sources, Norway		
Regnery 2010	Urban surface waters, Germany		
Regnery 2010	Rural surface water, Germany		
Regnery 2010	Subalpine water, Germany		
Xie 2011	Seawater from the Atlantic and Southern Ocean		nd
Möller 2011	Seawater, European Arctic		
Lacorte 2012	River water, Spain		
Andersson 2013	WWTP, influent/effluent, Norway		
Cristale 2013a	River Aire, UK		
Cristale 2013b	Rivers, Spain		
Remberger 2014	Stormwater, diffuse sources, Gothenburg		
Remberger 2014	WWTP, influent/effluent, Gothenburg/Borås		
Remberger 2014	Point source, extinguishing water		
Gustavsson 2016	Swedish river screening for Naturvårdsverket	nd-20*	

	BEH-TEBP	BTBPE
Andresen 2004		
Andresen 2004		
Marklund 2005		
Martinez-Carballo 2007		
Green 2008		
Moskeland 2009	nd	nd-107.0
Möller 2010		
Arp 2010		
Regnery 2010		
Regnery 2010		
Regnery 2010		
Xie 2011		
Möller 2011	nd-0.0013 (dissolved, 25%), 0-0.00012 (particulate, 6%)	nd (dissolved), 0-0.000002 (particulate, 6%)
Cristale 2012		
Andersson 2013		nd
Cristale 2013a		
Cristale 2013b	nd	nd
Remberger 2014		
Remberger 2014		
Remberger 2014		
Gustavsson 2016		nd-4.7

	DBDPE	DBE-DBCH	DBHCTD	DOPP	DDC-CO (anti-)	DDC-CO (syn-)	EBTEBPI	EHDPP	EH-TBB
Andresen 2004									
Andresen 2004									
Marklund 2005				nd-2000					
Martinez-Carballo 2007									
Green 2008								250-710	
Moskeland 2009	nd-185.7						nd		nd
Möller 2010					nd-0.0004	nd-0.0009			
Arp 2010									
Regnery 2010									
Regnery 2010									
Regnery 2010									
Xie 2011			nd						nd
Möller 2011									
Cristale 2012									
Andersson 2013	nd-5.1 (average)	0.6-5.3 (average)							
Cristale 2013a									
Cristale 2013b	nd		nd					nd-46	nd
Remberger 2014	250-1500	nd							
Remberger 2014	nd-420	nd							
Remberger 2014	330-1800	nd							
Gustavsson 2016						nd-12		nd-9.2*	nd-24

	HBB	PBB-Acr	PBEB	PBT	TBBPA	TBBPA-BAE
Andresen 2004						
Andresen 2004						
Marklund 2005						
Martinez-Carballo 2007						
Green 2008						
Moskeland 2009	0.1-19.1		nd-1.3	nd-7.5		nd-2.0
Möller 2010						
Arp 2010	0.40-15.37		nd-0.94	nd-5.63		
Regnery 2010						
Regnery 2010						
Regnery 2010						
Xie 2011	nd-0.02			nd		
Möller 2011	nd-0.000003 (dissolved, 13%), 0-0.000002 (particulate, 19%)			nd		
Cristale 2012						
Andersson 2013						nd-0.46
Cristale 2013a	nd-0.76		nd-0.40			
Cristale 2013b	nd		nd	nd		
Remberger 2014	2.2-22		nd-91	nd-2.2		
Remberger 2014	nd		nd-9.9	nd-2.4		
Remberger 2014	11-1200		nd-16	nd-4.2		
Gustavsson 2016	nd-0.13	nd-2.6		nd-2.5	nd-62	

	TBBPA-BDBPE	TBOEP	TBP-DBPE	TBX	TCBPA	TCEP
Andresen 2004		10-200				13-130
Andresen 2004		500				130
Marklund 2005		3100-35000				90-450
Martinez-Carballo 2007		24-500	0			13-130
Green 2008		1600-9200				1600-2500
Moskeland 2009	nd-159.6		nd			
Möller 2010						
Arp 2010						
Regnery 2010		nd-53 (median)				23-61 (median)
Regnery 2010		nq				3 (median)
Regnery 2010		<LOQ-31 (mean)				6-33 (mean)
Xie 2011			nd-0.00005 (median)			
Möller 2011			nd-0.0003 (dissolved, 81%), nd (particulate)			
Cristale 2012						320
Andersson 2013	nd-18					
Cristale 2013a						119-316
Cristale 2013b		nd-4600	nd			nd-330
Remberger 2014						
Remberger 2014						
Remberger 2014						
Gustavsson 2016				nd-0.022*	nd-56*	nd-14

	TCIPP	TMPP (*o*-)	TMPP (p-)	TDCIPP	TEBP-Anh	TEHP	TEP	TIBP	TMP
Andresen 2004	20-200			13-50				30-100	
Andresen 2004	400			120					
Marklund 2005	1100-24000			130-450		nd-130			nd-584
Martinez-Carballo 2007	33-170	nd		nd-19		nd-<LOQ	13-51		
Green 2008	1700-2900			86-820				210-410	
Moskeland 2009					nd				
Möller 2010									
Arp 2010									
Regnery 2010	85-126 (median)							8-10 (median)	
Regnery 2010	7-18 (median)							nd-9 (median)	
Regnery 2010	31-312 (mean)							<LOQ-11 (mean)	
Xie 2011									
Möller 2011									
Cristale 2012	220			30					
Andersson 2013									
Cristale 2013a	113-26050			62-149					
Cristale 2013b	nd-1800	nd-9.2		nd-200		nd-4		nd-1200	
Remberger 2014									
Remberger 2014									
Remberger 2014									
Gustavsson 2016	nd-30	nd-1.4*	nd-11	nd-48 a	nd-67	nd-48 a			

	TNBP	TPHP	TPP	TTBNPP
Andresen 2004	30-120		40	
Andresen 2004				
Marklund 2005	360-52000	41-290		
Martinez-Carballo 2007	20-110	nd-10		
Green 2008	160-1800	1700-14000		
Moskeland 2009				
Möller 2010				
Arp 2010				
Regnery 2010	17-32 (median)			
Regnery 2010	nd-5 (median)			
Regnery 2010	<LOQ-7 (mean)			
Xie 2011				
Möller 2011				
Cristale 2012		20		
Andersson 2013				
Cristale 2013a		6.3-22		
Cristale 2013b	nd-370	nd-35		
Remberger 2014				
Remberger 2014				
Remberger 2014				
Gustavsson 2016	nd-24	nd-66*		nd-3.6*

Table S8 Concentrations of detected FRs in sediment (ng g^{-1} dw, unless other is stated).

		TBP	2,4-DBP	TBP-AE	BATE	BDPhP	BEH-TEBP
Martinez-Carballo 2007	River sediment, Austria						
Green 2008[a]	Sediment, point sources, Norway						
Green 2008 [a]	Recipient waters, Norway						
Mai 2009	Sediment from Pearl river delta, China						
Evenset 2009	Svalbard						
Kolic 2009	Lake Ontario, US/Canada						
Moskeland 2009	Screening in Norway, including point sources	nd-3.3		nd			nd
Guerra 2010	Llobregat river basin, Spain						
Arp 2010	Sediment and seepage sediment, near suspected sources Norway						
Leonards 2011	Sediment close to WWTP and remote areas, Norway					nd	
Schlabach 2011	Sediment, Nordic countries	nd-7.8	nd-2.9	nd	nd		nd-3.3
Klosterhaus 2012	San Fransisco bay, US						nd
Andersson 2013	Sediment near WWTP, Norway						
Cristale 2013b	Rivers, Spain						nd
Kaasa 2013	Terrestrial/freshwater	nd					0.11 ±0.03 (100%)
Kaasa 2013	Marine	2.47 ±0.51 (100%)					nd
Barón 2014	Sediment, Spain						
Remberger 2014	Background, Kosterfjorden, Strömstad						
Remberger 2014	Diffuse sources						

[a]Unit: μg/kg LOI weight

	BTBPE	DBPhP	DBDPE	DBE-DBCH (α-)	DBE-DBCH (β-)	DBE-DBCH (γ-)	DBE-DBCH (δ-)	DBHCTD	DDC-DBF
Martinez-Carballo 2007									
Green 2008 [a]									
Green 2008 [a]									
Mai 2009	0.05-21.9		38.8-364						
Evenset 2009									
Kolic 2009	1.6								
Moskeland 2009	nd-4.5		nd-1.8						
Guerra 2010			4.8-24						
Arp 2010									
Leonards 2011		nd							
Schlabach 2011	nd-0.25		nd-2.4	nd-0.3	nd-0.15	nd-0.63			
Klosterhaus 2012	nd-0.06 (50%)		nd						
Andersson 2013	nd-1.0 (average)		nd	nd					
Cristale 2013b	nd		nd-435					nd	
Kaasa 2013			2.08 ±0.76 (100%)						
Kaasa 2013			0.24 ±0.21 (100%)						
Barón 2014			nd-31.5 (85%)						nd-1.91 (21%)
Remberger 2014			nd	nd					
Remberger 2014			nd	nd					

[a]Unit: μg/kg LOI weight

	DDC-Ant	DDC-CO (anti-)	DDC-CO (syn-)	EBTEBPI	EHDPP	EH-TBB	HBB	PBEB	PBP	PBT	TBBPA
Martinez-Carballo 2007											
Green 2008 [a]					320-1500						
Green 2008 [a]					140-560						
Mai 2009											
Evenset 2009											nd
Kolic 2009		120	34								
Moskeland 2009				nd		nd	nd-1.8	nd-0.1		nd-0.3	
Guerra 2010							nd-2.4	nd-9.6			
Arp 2010							nd-1.33	nd-0.028		nd-0.22	
Leonards 2011					nd-15 (60%)						
Schlabach 2011		0.0049-2.5	0.0035-0.99			nd-0.21	nd-0.019	nd-0.046	nd	nd-2.7	nd-16
Klosterhaus 2012		0.06-0.6 (100%)	0.03-0.3 (100%)			nd	nd	nd-0.1 (50%)			
Andersson 2013											
Cristale 2013b					nd-63	nd	nd	nd		nd	
Kaasa 2013									nd		
Kaasa 2013									nd		
Barón 2014	nd-1.04 (52%)	nd-1.50 (97%)	nd-0.73 (94%)				nd	nd			
Remberger 2014							nd	nd		nd	
Remberger 2014							nd-0.52	nd-0.19		nd-0.02	

[a]Unit: μg/kg LOI weight

	TBBPA-BAE	TBBPA-BDBPE	TBOEP	TBP-DBPE	TCBPA	TCEP	TCIPP	TMPP (*o*-)	TMPP (*m*-)	TMPP (p-)
Martinez-Carballo 2007			2.4-130			nd-160	<LOQ-1300	nd-39		
Green 2008 [a]			540-2900			27-5500	490-24000			
Green 2008 [a]			nd-3100			nd-1600	63-16000			
Mai 2009		nd-2300								
Evenset 2009										
Kolic 2009										
Moskeland 2009	nd-2.4	nd		nd						
Guerra 2010										
Arp 2010										
Leonards 2011			0.69-100 (100%)			nd-8.5 (85%)	nd-54 (70%)	nd-1.5 (25%)		nd-288 (80%)
Schlabach 2011				nd						
Klosterhaus 2012										
Andersson 2013	nd-0.81 (average)	nd								
Cristale 2013b			nd	nd		nd-9.7	nd-365	nd-84		
Kaasa 2013										
Kaasa 2013										
Barón 2014										
Remberger 2014										
Remberger 2014										

[a]Unit: μg/kg LOI weight

	TDCIPP	TEBP-Anh	TEHP	TEP	TIBP	TNBP	TPHP	BCMP-BCEP
Martinez-Carballo 2007	nd-<LOQ		nd-140	<LOQ-81		<LOQ-50	nd-160	
Green 2008 [a]	nd-8800				nd-1100	210-4300	900-1500	nd-2800
Green 2008 [a]	63-870				62-470	67-480	nd-370	nd
Mai 2009								
Evenset 2009								
Kolic 2009								
Moskeland 2009		nd						
Guerra 2010								
Arp 2010								
Leonards 2011	nd-1.0 (40%)		nd-46 (60%)		nd-2.5 (80%)	nd-6.7 (65%)	nd-6.8 (75%)	nd
Schlabach 2011								
Klosterhaus 2012								
Andersson 2013								
Cristale 2013b	nd-8.7		nd-290		nd-8.4	nd-13	nd-23	
Kaasa 2013								
Kaasa 2013								
Barón 2014								
Remberger 2014								
Remberger 2014								

[a]Unit: μg/kg LOI weight

Table S9 Concentrations of detected FRs in sludge (ng g^{-1} dw, unless other is stated).

	Brief description, country	**TBP**	**2,4-DBP**	**TBP-AE**	**BATE**	**BDPhP**	**BEH-TEBP**
Marklund 2005	Sewage sludge, Sweden						
Chu 2005	WWTP sludge, Canada						
Green 2008 [a]	WWTP sludge, Norway						
Moskeland 2009	Screening in Norway, sewage sludge	nd		nd			nd
Mai 2009	Sewage sludge from Pearl river delta, China						
Arp 2010	Wastewater sludge, near suspected sources, Norway						
Schlabach 2011	Sludge, Nordic countries	nd-101	nd-40	nd-27	nd-4.1		nd-42
Andersson 2013	WWTP sludge, Norway						
Remberger 2014	WWTP sludge, Gothenburg/Borås						
Barón 2014	Sewage sludge, Spain						

[a]Unit: μg/kg LOI weight

	BTBPE	**DBPhP**	**DBDPE**	**DBE-DBCH (α-)**	**DBE-DBCH (β-)**	**DBE-DBCH (γ-)**	**DBE-DBCH (δ-)**	**DBHCTD**	**DDC-DBF**
Marklund 2005									
Chu 2005									
Green 2008 [a]									
Moskeland 2009	nd-2.08		nd-8.7						
Mai 2009	0.31-1.66		266-1995						
Arp 2010									
Schlabach 2011	nd-3.9		nd-160	nd-4.7	nd-2.6	nd-1.7			
Andersson 2013	0.7-1.7 (average)		1.9-6.3 (average)	0.6-1.4 (average)					
Remberger 2014			63-190	nd					
Barón 2014			<LOQ-124						nd-0.24

[a]Unit: μg/kg LOI weight

	DDC-Ant	**DDC-CO (anti-)**	**DDC-CO (syn-)**	**EBTEBPI**	**EHDPP**	**EH-TBB**	**HBB**	**PBEB**	**PBP**	**PBT**	**TBBPA**
Marklund 2005					320-4600						
Chu 2005											2.1-28.3
Green 2008 [a]					462-1200						
Moskeland 2009				nd		nd	0.12-0.6	nd		nd	
Mai 2009											
Arp 2010							0.34-0.39	nd		nd	
Schlabach 2011		0.05-25	nd-14			nd-2.6	nd-0.72	nd-0.13	nd-3.5	nd-5.2	nd-59
Andersson 2013											
Remberger 2014							0.49-1.6	0.43-0.64		0.14-0.6	
Barón 2014	nd-0.60	<LOQ-11.9	0.85-11.2								

[a]Unit: μg/kg LOI weight

	TBBPA-BAE	**TBBPA-BDBPE**	**TBOEP**	**TBP-DBPE**	**TCBPA**	**TCEP**	**TCIPP**	**TMPP (*o*-)**	**TMPP (*m*-)**	**TMPP (p-)**
Marklund 2005			nd-1900			6.6-110	61-1900			
Chu 2005					0.14-0.54					
Green 2008 [a]			1200-2200			nd	650-944			
Moskeland 2009	nd	nd		nd						
Mai 2009		238-8946								
Arp 2010										
Schlabach 2011				nd-120						
Andersson 2013	nd	nd								
Remberger 2014										
Barón 2014										

[a]Unit: μg/kg LOI weight

	TDCIPP	TEBP-Anh	TEHP	TEP	TIBP	TNBP	TPHP	BCMP-BCEP
Marklund 2005	3.3-260				27-2700	39-850	52-320	
Chu 2005								
Green 2008 [a]	110-330				52-81	69-270	13-1100	nd
Moskeland 2009		nd						
Mai 2009								
Arp 2010								
Schlabach 2011								
Andersson 2013								
Remberger 2014								
Barón 2014								

[a]Unit: μg/kg LOI weight

Table S10 Concentrations of detected FRs in soil (ng g^{-1} dw). Detection frequency in brackets.

	Brief information, country	TBP	BEH-TEBP	BTBPE	DBDPE	PBP	TBBPA-BDBPE
Mai 2009	Farmland soil, China			0.02-0.11	17.6-35.8		17.3-60.4
Mai 2009	Farmland soil from e-waste processing area, China			0.07-6.19	nd-4.56		nd
Kaasa 2013	Soil, Norway	nd	1.04 (100%)		nd	nd	

Table S11 Concentrations of detected FRs in plants.

	Brief description, country	Unit	TBP	2,4-DBP	TBP-AE	BATE	BEH-TEBP	BTBPE	DBDPE	DBE-DBCH (α-)
Moskeland 2009	Moss, Energy recycling, Norway	ng/g dw	nd		nd		nd	nd	nd-0.1	
Moskeland 2009	Needles, Energy recycling, Norway	ng/g ww	nd		nd		nd	nd	nd-0.1	
Arp 2010	Pine needles, near supected sources, Norway	ng/g ww								
Arp 2010	Moss, near supected sources, Norway	ng/g dw								
Schlabach 2011	Moss, near incineration, Faroe islands	ng/g ww	nd-0.46	nd-0.53	nd	nd	nd-0.039	0.056-0.15	0.14-0.34	0.0029-0.0046

	Unit	DBE-DBCH (γ-)	DBE-DBCH (δ-)	DDC-CO (anti-)	DDC-CO (syn-)	EBTEBPI	EH-TBB	HBB	PBEB	PBT	TBBPA
Moskeland 2009	ng/g dw					nd	nd	nd-0.1	nd	nd	
Moskeland 2009	ng/g ww					nd	nd	nd-0.05	nd	nd	
Arp 2010	ng/g ww							0.05	nd	nd	
Arp 2010	ng/g dw							< LOQ	nd	nd	
Schlabach 2011	ng/g ww	nd		0.04-0.12	0.02-0.05		nd	0.0076-0.011	0.0038-0.0059	0.0031-0.0032	nd

	Unit	TBBPA-BAE	TBBPA-BDBPE	TBP-DBPE	TEBP-Anh
Moskeland 2009	ng/g dw	nd	nd	nd	nd
Moskeland 2009	ng/g ww	nd	nd-0.16	nd	nd
Arp 2010	ng/g ww				
Arp 2010	ng/g dw				
Schlabach 2011	ng/g ww			nd-0.0039	

Table S12 Concentrations of detected FRs in mammals. Detection frequency in brackets.

	Brief description, country	Unit	TBP	2,4-DBP	TBP-AE	BATE
McKinney 2010	Adipose from polar bear, Western Hudson Bay, Canada	ng/g lw				
Sagerup 2010	Arctic fox liver, Norwegian Arctic	ng/g ww	nd		nd	
Sagerup 2010	Polar bear plasma, Norwegian Arctic	ng/g ww	nd		nd	
Kaasa 2013	Moose liver, Norway	ng/g ww	80.7 ±44.6 (89%)			
Kaasa 2013	Mouse liver, Norway	ng/g ww	53.6 ±43.4 (88%)			
Kaasa 2013	Shrew liver, Norway	ng/g ww	27.1 ±6.9 (100%)			
Kaasa 2013	Polar bear plasma, Norwegan Arctic	ng/mL	25.7 ±14.7 (100%)			
Sagerup 2010	Ringed seal liver, Norwegian Arctic	ng/g ww	0.050 ±0.023 (50%)		nd	
Klosterhaus 2012	Harbor seal blubber Adults, San Frasisco Bay, US	ng/g lw				
Klosterhaus 2012	Harbor seal blubber Pups, San Frasisco Bay, US	ng/g lw				
Kaasa 2013	Harbor seal liver	ng/g ww	164 ±84 (100%)			
Kaasa 2013	Ringed seal plasma, arctic	ng/mL	31.2 ±32.3 (100%)			

	Unit	BdPhP	BEH-TEBP	BTBPE	Chlordene Plus	SCCPs	MCCPs
McKinney 2010	ng/g lw						
Sagerup 2010	ng/g ww		nd		nd		
Sagerup 2010	ng/g ww		nd		nd		
Kaasa 2013	ng/g ww		nd				
Kaasa 2013	ng/g ww		nd				
Kaasa 2013	ng/g ww		nd				
Kaasa 2013	ng/mL		0.15 ±0.16 (95%)			3.99 ±2.91 (95%)	2.20 ±1.84 (95%)
Sagerup 2010	ng/g ww		0.573 ±0.198 (60%)		nd		
Klosterhaus 2012	ng/g lw			nd			
Klosterhaus 2012	ng/g lw			nd			
Kaasa 2013	ng/g ww		0.10 (10%)				
Kaasa 2013	ng/mL		0.04 (10%)			4.96 ±2.70 (100%)	2.91 ±2.39 (90%)

	Unit	DBDPE	DBE-DBCH (α-)	DBE-DBCH (β-)	DBE-DBCH (γ-)	DBE-DBCH (δ-)	DBPhP	DDC-DBF
McKinney 2010	ng/g lw	nd-2.0						
Sagerup 2010	ng/g ww	nd						
Sagerup 2010	ng/g ww	nd						
Kaasa 2013	ng/g ww	0.40 ±0.09 (100%)						
Kaasa 2013	ng/g ww	11.9 ±5.7 (100%)						
Kaasa 2013	ng/g ww	25.5 ±9.1 (100%)						
Kaasa 2013	ng/mL	6.98 ±9.11 (100%)						
Sagerup 2010	ng/g ww	nd						
Klosterhaus 2012	ng/g lw							
Klosterhaus 2012	ng/g lw							
Kaasa 2013	ng/g ww	12.9 ±6.8 (100%)						
Kaasa 2013	ng/mL	5.36 ±1.94 (100%)						

	Unit	Dec 604B	DDC-CO (anti-)	DDC-CO (syn-)	DPhBP	EBTEBPI	EHDPP
McKinney 2010	ng/g lw						
Sagerup 2010	ng/g ww						
Sagerup 2010	ng/g ww						
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/mL						
Sagerup 2010	ng/g ww						
Klosterhaus 2012	ng/g lw		0.06-3.3 (100%)	0.08-3.8 (100%)			
Klosterhaus 2012	ng/g lw		nd-0.06 (8%)	nd-0.07 (42%)			
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/mL						

	Unit	EH-TBB	HBB	OBTMPI	PBEB	PBP	PBT	T2CPP	TBBPA	TBBPA-BAE
McKinney 2010	ng/g lw		nd-3.4		nd-1.7					
Sagerup 2010	ng/g ww	0.975 ±0.608 (90%)	nd		nd		nd			
Sagerup 2010	ng/g ww	3.460 ±2.481 (90%)	nd		nd		nd			
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/mL					nd				
Sagerup 2010	ng/g ww	0.435 ±0.292 (100%)	nd		nd		nd			
Klosterhaus 2012	ng/g lw	nd	nd		0.07-0.5 (100%)					
Klosterhaus 2012	ng/g lw	nd	nd		nd-0.2 (83%)					
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/mL					nd				

	Unit	TBBPA-BDBPE	TBOEP	TBP-DBPE	TCEP	TCIPP	TMPP (*o*-)	TMPP (*p*-)	TDCIPP
McKinney 2010	ng/g lw								
Sagerup 2010	ng/g ww	nd		nd					
Sagerup 2010	ng/g ww	nd		nd					
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/mL								
Sagerup 2010	ng/g ww	nd		nd					
Klosterhaus 2012	ng/g lw								
Klosterhaus 2012	ng/g lw								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/mL								

	Unit	TEBP-Anh	TEHP	TEP	TIBP	TNBP	TPHP	BCMP-BCEP
McKinney 2010	ng/g lw							
Sagerup 2010	ng/g ww	nd						
Sagerup 2010	ng/g ww	nd						
Kaasa 2013	ng/g ww							
Kaasa 2013	ng/g ww							
Kaasa 2013	ng/g ww							
Kaasa 2013	ng/mL							
Sagerup 2010	ng/g ww	nd						
Klosterhaus 2012	ng/g lw							
Klosterhaus 2012	ng/g lw							
Kaasa 2013	ng/g ww							
Kaasa 2013	ng/mL							

Table S13 Concentrations of detected FRs in aquatic species. Detection frequency in brackets.

	Brief description, country	Unit	TBP	2,4-DBP	TBP-AE	BATE
Arp 2010	Fish liver, crab, mussel, near suspected sources, Norway	ng/g ww				
Green 2008	Mussels, Norway	ng/g ww				
Green 2008	Cod liver, Norway	ng/g ww				
Evenset 2009	Fish, Svalbard	ng/g ww				
Sundkvist 2009	Freshwater perch, background, Sweden	ng/g lw				
Sundkvist 2009	Freshwater perch/carp, close to sources, Sweden	ng/g lw				
Sundkvist 2009	Marine herring, Sweden	ng/g lw				
Sundkvist 2009	Marine perch, Sweden	ng/g lw				
Sundkvist 2009	Marine mussels, Sweden	ng/g lw				
Sundkvist 2009	Marine eelpout, Sweden	ng/g lw				
Sundkvist 2009	Marine salmon, Sweden	ng/g lw				
Mai 2009	Fish from e-waste processing area, China	ug/g lw				
Moskeland 2009	Fish liver, Norway	ng/g ww	nd-55.8		nd	
Moskeland 2009	Blue mussel, Norway	ng/g ww	nd-1.1		nd	
Moskeland 2009	Crab, Norway	ng/g ww	2.4-130.5		nd	
Leonards 2011	Cod liver, Norway	ng/g ww				
Leonards 2011	Trout, Norway	ng/g ww				
Leonards 2011	Beach crab, Norway	ng/g ww				
Leonards 2011	Blue mussel, Norway	ng/g ww				
Leonards 2011	Burbot liver, Norway	ng/g ww				
Sagerup 2010	Whole Capelin, Norwegian Arctic	ng/g ww	nd		nd	
Schlabach 2011	Fish and mussel, Nordic countries	ng/g ww	nd-86	nd-6.4	nd	nd-0.00072
Klosterhaus 2012	White croaker, San Frasisco Bay, US	ug/g lw				
Klosterhaus 2012	Shiner surfperch, San Frasisco Bay, US	ug/g lw				
Kaasa 2013	Perch liver	ng/g ww	42.4 ±16.1 (67%)			
Kaasa 2013	Brown trout liver	ng/g ww	66.2 ±39.6 (40%)			
Kaasa 2013	Atlantic cod liver	ng/g ww	68.8 ±35.8 (60%)			
Kaasa 2013	Mussels	ng/g ww	2.53 ±0.22 (100%)			
Kaasa 2013	Atlantic cod liver, arctic	ng/g ww	115 ±61 (70%)			
Kaasa 2013	Polar cod, arctic	ng/g ww	nd			
Houde 2014	Yellow perch, Canada	ug/g lw				
Houde 2014	Northern pike, Canada	ug/g lw				
Houde 2014	Muskellunge, Canada	ug/g lw				
McGoldrick 2014	Fish, Canada	ng/g ww				

Remberger 2014	Herring muscle, background Swedish westcoast	ng/g ww				
Remberger 2014	Netted dogwhelk, diffuse sources Swedish westcoast	ng/g ww				
Malarvannan 2015	Yellow eel, Belgium	ng/g lw				

	Unit	BdPhP	BEH-TEBP	BTBPE	Chlordene Plus	SCCPs	MCCPs
Arp 2010	ng/g ww						
Green 2008	ng/g ww						
Green 2008	ng/g ww						
Evenset 2009	ng/g ww						
Sundkvist 2009	ng/g lw	nd					
Sundkvist 2009	ng/g lw	nd-2000					
Sundkvist 2009	ng/g lw	nd					
Sundkvist 2009	ng/g lw	nd					
Sundkvist 2009	ng/g lw	nd-0.5					
Sundkvist 2009	ng/g lw	<LOQ					
Sundkvist 2009	ng/g lw	nd					
Mai 2009	ug/g lw			nd-0.00015			
Moskeland 2009	ng/g ww		nd	nd			
Moskeland 2009	ng/g ww		nd	nd			
Moskeland 2009	ng/g ww		nd	nd			
Leonards 2011	ng/g ww	nd					
Leonards 2011	ng/g ww	nd					
Leonards 2011	ng/g ww	nd					
Leonards 2011	ng/g ww	nd					
Leonards 2011	ng/g ww	nd					
Sagerup 2010	ng/g ww		0.719 ±0.292 (90%)		nd		
Schlabach 2011	ng/g ww		nd-0.46	nd-0.2			
Klosterhaus 2012	ug/g lw			nd			
Klosterhaus 2012	ug/g lw			nd			
Kaasa 2013	ng/g ww		nd				
Kaasa 2013	ng/g ww		0.04 ±0.01 (30%)				
Kaasa 2013	ng/g ww		0.14 ±0.02 (30%)				
Kaasa 2013	ng/g ww		nd				
Kaasa 2013	ng/g ww		0.07 (10%)			10.3 ±10.7 (100%)	0.94 (10%)
Kaasa 2013	ng/g ww		nd			2.28 (100%)	1.51 (100%)
Houde 2014	ug/g lw		nd	nd	nd		

Houde 2014	ug/g lw		0.0054 ±0.0017 (64%)	nd	0.0012 ±0.0002 (91%)		
Houde 2014	ug/g lw		nd-0.013 (40%)	nd	0.0087 ±0.0073 (80%)		
McGoldrick 2014	ng/g ww						
Remberger 2014	ng/g ww						
Remberger 2014	ng/g ww						
Malarvannan 2015	ng/g lw						

	Unit	DBDPE	DBE-DBCH (α-)	DBE-DBCH (β-)	DBE-DBCH (γ-)	DBE-DBCH (δ-)	DBPhP	DDC-DBF
Arp 2010	ng/g ww							
Green 2008	ng/g ww							
Green 2008	ng/g ww							
Evenset 2009	ng/g ww						nd	
Sundkvist 2009	ng/g lw						nd	
Sundkvist 2009	ng/g lw						nd-3300	
Sundkvist 2009	ng/g lw						nd	
Sundkvist 2009	ng/g lw						nd	
Sundkvist 2009	ng/g lw						nd-1.2	
Sundkvist 2009	ng/g lw						nd	
Sundkvist 2009	ng/g lw						nd	
Mai 2009	ug/g lw	nd						
Moskeland 2009	ng/g ww	nd						
Moskeland 2009	ng/g ww	nd						
Moskeland 2009	ng/g ww	nd						
Leonards 2011	ng/g ww						nd	
Leonards 2011	ng/g ww						nd	
Leonards 2011	ng/g ww						nd	
Leonards 2011	ng/g ww						nd	
Leonards 2011	ng/g ww						nd	
Sagerup 2010	ng/g ww	nd						
Schlabach 2011	ng/g ww	nd-0.092	nd-0.26	nd-0.25	nd-1.1			
Klosterhaus 2012	ug/g lw	nd						
Klosterhaus 2012	ug/g lw							
Kaasa 2013	ng/g ww	2.47 ±0.30 (100%)						
Kaasa 2013	ng/g ww	11.1 ±8.57 (100%)						
Kaasa 2013	ng/g ww	4.29 ±0.70 (100%)						
Kaasa 2013	ng/g ww	0.29 ±0.10 (100%)						

Kaasa 2013	ng/g ww	5.57 ±1.38 (90%)						
Kaasa 2013	ng/g ww	0.42 (100%)						
Houde 2014	ug/g lw	nd						nd
Houde 2014	ug/g lw	0.0267 (9%)						0.0026 ±0.0010 (55%)
Houde 2014	ug/g lw	nd						0.0237 ±0.0201 (50%)
McGoldrick 2014	ng/g ww							
Remberger 2014	ng/g ww	nd	nd-0.14					
Remberger 2014	ng/g ww	nd	nd					
Malarvannan 2015	ng/g lw							

	Unit	Dec 604B	DDC-CO (anti-)	DDC-CO (syn-)	DPhBP	EBTEBPI	EHDPP
Arp 2010	ng/g ww						
Green 2008	ng/g ww						nd
Green 2008	ng/g ww						nd
Evenset 2009	ng/g ww				nd		nd-52
Sundkvist 2009	ng/g lw						8.9-150
Sundkvist 2009	ng/g lw						160-190
Sundkvist 2009	ng/g lw						3.0-7.5
Sundkvist 2009	ng/g lw						37-78
Sundkvist 2009	ng/g lw						14-16
Sundkvist 2009	ng/g lw						14000
Sundkvist 2009	ng/g lw						1.5
Mai 2009	ug/g lw						
Moskeland 2009	ng/g ww					nd	
Moskeland 2009	ng/g ww					nd	
Moskeland 2009	ng/g ww					nd	
Leonards 2011	ng/g ww						nd
Leonards 2011	ng/g ww						nd-1.1 (13%)
Leonards 2011	ng/g ww						nd-0.41 (8%)
Leonards 2011	ng/g ww						nd-0.3 (33%)
Leonards 2011	ng/g ww						nd
Sagerup 2010	ng/g ww						
Schlabach 2011	ng/g ww		nd-0.026	nd-0.023			
Klosterhaus 2012	ug/g lw		nd-0.0018 (83%)	nd			
Klosterhaus 2012	ug/g lw		nd-0.0037 (75%)	nd			
Kaasa 2013	ng/g ww						

Kaasa 2013	ng/g ww						
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/g ww						
Houde 2014	ug/g lw	nd	nd	nd			
Houde 2014	ug/g lw	0.0059 ±0.0025 (82%)	nd-0.0028 (45%)	nd-0.0091 (36%)			
Houde 2014	ug/g lw	0.139 ±0.130 (80%)	0.0018 ±0.0011 (80%)	0.0044 ±0.0025 (90%)			
McGoldrick 2014	ng/g ww						
Remberger 2014	ng/g ww						
Remberger 2014	ng/g ww						
Malarvannan 2015	ng/g lw						

	Unit	EH-TBB	HBB	OBTMPI	PBEB	PBP	PBT	T2CPP	TBBPA	TBBPA-BAE
Arp 2010	ng/g ww		nd		nd		nd			
Green 2008	ng/g ww									
Green 2008	ng/g ww									
Evenset 2009	ng/g ww							nd-8.9	nd	
Sundkvist 2009	ng/g lw									
Sundkvist 2009	ng/g lw									
Sundkvist 2009	ng/g lw									
Sundkvist 2009	ng/g lw									
Sundkvist 2009	ng/g lw									
Sundkvist 2009	ng/g lw									
Sundkvist 2009	ng/g lw									
Mai 2009	ug/g lw									
Moskeland 2009	ng/g ww	nd	nd		nd		nd			nd
Moskeland 2009	ng/g ww	nd	nd		nd		nd			nd
Moskeland 2009	ng/g ww	nd	nd		nd		nd			nd
Leonards 2011	ng/g ww									
Leonards 2011	ng/g ww									
Leonards 2011	ng/g ww									
Leonards 2011	ng/g ww									
Leonards 2011	ng/g ww									
Sagerup 2010	ng/g ww	0.378 ±0.240 (100%)	nd		nd		nd			

Schlabach 2011	ng/g ww	nd-0.12	0.0058-0.047		nd-0.0044	nd	0.0015-0.021		nd	
Klosterhaus 2012	ug/g lw	nd	nd		nd					
Klosterhaus 2012	ug/g lw	nd	nd		nd					
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/g ww					nd				
Houde 2014	ug/g lw	nd	nd		nd					
Houde 2014	ug/g lw	nd	0.0032 (9%)							
Houde 2014	ug/g lw	nd	0.0014-0.0039	nd						
McGoldrick 2014	ng/g ww									
Remberger 2014	ng/g ww		0.15-0.56		0.38-0.67		nd			
Remberger 2014	ng/g ww		nd-4.6		0.65-3.9		nd			
Malarvannan 2015	ng/g lw									

	Unit	TBBPA-BDBPE	TBOEP	TBP-DBPE	TCEP	TCIPP	TMPP (*o*-)	TMPP (*p*-)	TDCIPP
Arp 2010	ng/g ww								
Green 2008	ng/g ww		nd		nd-23	nd			nd
Green 2008	ng/g ww		nd		nd	nd			nd
Evenset 2009	ng/g ww		nd		nd-26		nd	nd	nd-8.1
Sundkvist 2009	ng/g lw		nd		nd-83	220-750	nd	nd-43	nd
Sundkvist 2009	ng/g lw		240-1000		39-160	170-770	nd-2.5	22-137	49-140
Sundkvist 2009	ng/g lw		nd		2.0-3.4	42-150	nd	nd	nd
Sundkvist 2009	ng/g lw		nd		43-69	140-250	nd	20-23	nd
Sundkvist 2009	ng/g lw		nd		nd-55	130-1300	nd	11-110	nd
Sundkvist 2009	ng/g lw		nd		59	310	nd	19	nd
Sundkvist 2009	ng/g lw		nd		1.5	23	nd	1.8	nd
Mai 2009	ug/g lw	nd							
Moskeland 2009	ng/g ww	nd		nd					
Moskeland 2009	ng/g ww	nd		nd					
Moskeland 2009	ng/g ww	nd		nd					
Leonards 2011	ng/g ww		nd		nd	nd	nd	nd	nd

Leonards 2011	ng/g ww		nd		nd-0.21 (13%)	nd-2 (7%)	nd	nd	< 0.88 (13%)
Leonards 2011	ng/g ww		nd		nd-1.9 (25%)	nd-8.9 (17%)	nd	nd	nd
Leonards 2011	ng/g ww		nd		nd-0.11 (20%)	nd-0.81 (20%)	nd	nd	nd
Leonards 2011	ng/g ww		nd-411 (7%)		nd-8.6 (7%)	nd-17 (7%)	nd	nd	nd
Sagerup 2010	ng/g ww	nd		nd					
Schlabach 2011	ng/g ww			nd-0.049					
Klosterhaus 2012	ug/g lw								
Klosterhaus 2012	ug/g lw								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Houde 2014	ug/g lw								
Houde 2014	ug/g lw								
Houde 2014	ug/g lw								
McGoldrick 2014	ng/g ww		nd-9.8		nd-3.4	nd-<LOQ			nd-<LOQ
Remberger 2014	ng/g ww								
Remberger 2014	ng/g ww								
Malarvannan 2015	ng/g lw								

	Unit	TEBP-Anh	TEHP	TEP	TIBP	TNBP	TPHP	BCMP-BCEP	ΣPFR
Arp 2010	ng/g ww								
Green 2008	ng/g ww				nd	nd-17	nd	nd	
Green 2008	ng/g ww				nd	nd	nd	nd	
Evenset 2009	ng/g ww		nd-4.6		nd-4.9	nd-11.0	0.3-13		
Sundkvist 2009	ng/g lw					12-36	21-180		
Sundkvist 2009	ng/g lw					34-4900	100-170		
Sundkvist 2009	ng/g lw					3.1-7.9	7.1-34		
Sundkvist 2009	ng/g lw					16-23	64-81		
Sundkvist 2009	ng/g lw					14-20	18-93		
Sundkvist 2009	ng/g lw					120	400		
Sundkvist 2009	ng/g lw					1.6	4.2		

Mai 2009	ug/g lw								
Moskeland 2009	ng/g ww	nd							
Moskeland 2009	ng/g ww	nd							
Moskeland 2009	ng/g ww	nd							
Leonards 2011	ng/g ww		nd		nd	nd	nd-9.9 (3%)	nd	
Leonards 2011	ng/g ww		nd-0.02 (7%)		nd	nd	nd-44 (67%)	nd	
Leonards 2011	ng/g ww		nd-0.09 (17%)		nd	nd	nd-0.31 (8%)	nd	
Leonards 2011	ng/g ww		nd-0.25 (33%)		nd	nd	nd	nd	
Leonards 2011	ng/g ww		nd		nd	nd	nd	nd	
Sagerup 2010	ng/g ww	nd							
Schlabach 2011	ng/g ww								
Klosterhaus 2012	ug/g lw								
Klosterhaus 2012	ug/g lw								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Houde 2014	ug/g lw								
Houde 2014	ug/g lw								
Houde 2014	ug/g lw								
McGoldrick 2014	ng/g ww					nd-<LOQ	nd-<LOQ		
Remberger 2014	ng/g ww								
Remberger 2014	ng/g ww								
Malarvannan 2015	ng/g lw								0.0071-0.329

Table S14 Concentrations of detected FRs in birds and bird eggs. Detection frequency in brackets.

	Brief description, country	Unit	TBP	2,4-DBP	TBP-AE	BATE
Evenset 2009	Seabirds, Svalbard	ng/g dw				
Mai 2009	Bird from e-waste processing area, China	ng/g lw				
Leonards 2011	Bird blood/plasma, Norway	ng/g ww				
Leonards 2011	Bird egg, Norway	ng/g ww				
Sagerup 2010	Common Eider liver, Norwegian Arctic	ng/g ww	0.090 ±0.095 (90%)		nd	
Sagerup 2010	Brünnich's guillemot egg, Norwegian Arctic	ng/g ww	nd		nd	
Sagerup 2010	Kittiwake liver, Norwegian Arctic	ng/g ww	nd		nd	
Schlabach 2011	Eggs, Sweden/Faroe islands	ng/g ww	0.20-1.4	nd	nd	nd
Klosterhaus 2012	Double-crested cormorant egg, San Fransisco Bay, US	ng/g lw				
Kaasa 2013	Herring gull egg	ng/g ww	62.5 ±64.8 (80%)			
Kaasa 2013	Common Eider egg	ng/g ww	66.2 ±74.2 (90%)			
Kaasa 2013	Glaucous gull plasma, arctic	ng/mL	30.8 ±9.0 (100%)			
Kaasa 2013	Kittiwake egg, arctic	ng/g ww	52.6 ±18.8 (83%)			
Kaasa 2013	Common eider egg, arctic	ng/g ww	37.8 ±17.6 (58%)			

	Unit	BdPhP	BEH-TEBP	BTBPE	Chlordene Plus	SCCPs	MCCPs
Evenset 2009	ng/g dw						
Mai 2009	ng/g lw			0.07-2.41			
Leonards 2011	ng/g ww	nd					
Leonards 2011	ng/g ww	nd					
Sagerup 2010	ng/g ww		1.652 ±1.396 (60%)		nd		
Sagerup 2010	ng/g ww		1.799 ±1.358 (70%)		0.664 ±0.367 (40%)		
Sagerup 2010	ng/g ww		0.800 ±0.356 (50%)		nd		
Schlabach 2011	ng/g ww		nd-0.021	0.019-0.042			
Klosterhaus 2012	ng/g lw		nd	nd			
Kaasa 2013	ng/g ww		1.99 ±2.65 (20%)				
Kaasa 2013	ng/g ww		0.04 ±0.02 (100%)				
Kaasa 2013	ng/mL		0.026 ±0.001 (17%)			3.95 ±1.99 (75%)	8.87 ±9.88 (67%)
Kaasa 2013	ng/g ww		0.10 ±0.09 (100%)			7.83 ±8.26 (67%)	4.91 ±4.88 (100%)
Kaasa 2013	ng/g ww		0.06 ±0.07 (58%)			3.23 ±1.77 (83%)	4.24 ±4.07 (100%)

	Unit	DBDPE	DBE-DBCH (α-)	DBE-DBCH (β-)	DBE-DBCH (γ-)	DBE-DBCH (δ-)	DBPhP	DDC-DBF
Evenset 2009	ng/g dw						nd-0.33	
Mai 2009	ng/g lw	9.6-124						
Leonards 2011	ng/g ww						nd	
Leonards 2011	ng/g ww						nd-5.6 (4%)	
Sagerup 2010	ng/g ww	nd						
Sagerup 2010	ng/g ww	0.581 (10%)						
Sagerup 2010	ng/g ww	nd						
Schlabach 2011	ng/g ww	nd-0.12	nd-0.022	0.059-0.33	nd-0.31			
Klosterhaus 2012	ng/g lw							
Kaasa 2013	ng/g ww	0.44 ±0.20 (100%)						
Kaasa 2013	ng/g ww	0.33 ±0.11 (100%)						
Kaasa 2013	ng/mL	6.43 ±2.62 (100%)						
Kaasa 2013	ng/g ww	1.01 ±1.55 (100%)						
Kaasa 2013	ng/g ww	0.82 ±0.62 (100%)						

	Unit	Dec 604B	DDC-CO (anti-)	DDC-CO (syn-)	DPhBP	EBTEBPI	EHDPP
Evenset 2009	ng/g dw				nd		6.0-28
Mai 2009	ng/g lw						
Leonards 2011	ng/g ww						nd
Leonards 2011	ng/g ww						nd-3.1 (7%)
Sagerup 2010	ng/g ww						
Sagerup 2010	ng/g ww						
Sagerup 2010	ng/g ww						
Schlabach 2011	ng/g ww		0.012-0.057	nd-0.026			
Klosterhaus 2012	ng/g lw		nd	0.9-1.1 (100%)			
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/mL						
Kaasa 2013	ng/g ww						
Kaasa 2013	ng/g ww						

	Unit	EH-TBB	HBB	OBTMPI	PBEB	PBP	PBT	T2CPP	TBBPA	TBBPA-BAE
Evenset 2009	ng/g dw							nd-2.6		
Mai 2009	ng/g lw									
Leonards 2011	ng/g ww									
Leonards 2011	ng/g ww									
Sagerup 2010	ng/g ww	0.862 ±1.243 (100%)	nd		nd		nd			
Sagerup 2010	ng/g ww	1.213 ±0.984 (100%)	nd		nd		nd			
Sagerup 2010	ng/g ww	0.732 ±0.261 (90%)	nd		nd		nd			
Schlabach 2011	ng/g ww	nd-0.18	0.023-0.03		nd-0.0014	0.12-0.43	0.0054-0.0063		nd	
Klosterhaus 2012	ng/g lw	nd	nd		nd					
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/mL					nd				
Kaasa 2013	ng/g ww					nd				
Kaasa 2013	ng/g ww					nd				

	Unit	TBBPA-BDBPE	TBOEP	TBP-DBPE	TCEP	TCIPP	TMPP (*o*-)	TMPP (*p*-)	TDCIPP
Evenset 2009	ng/g dw		nd		nd-4.7		nd	nd	nd
Mai 2009	ng/g lw	nd							
Leonards 2011	ng/g ww		nd-57 (16%)		nd-6.1 (10%)	nd-10 (24%)	nd	nd	nd-1.9 (6%)
Leonards 2011	ng/g ww		nd		nd-6.0 (11%)	nd-5.0 (6%)	nd	nd	nd-0.16 (5%)
Sagerup 2010	ng/g ww	nd		nd					
Sagerup 2010	ng/g ww	nd		nd					
Sagerup 2010	ng/g ww	nd		nd					
Schlabach 2011	ng/g ww			nd					
Klosterhaus 2012	ng/g lw								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/mL								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								

	Unit	TEBP-Anh	TEHP	TEP	TIBP	TNBP	TPHP	BCMP-BCEP	ΣPFR
Evenset 2009	ng/g dw		nd-4.6		nd-2.6	nd-6.8	0.6-3.3		
Mai 2009	ng/g lw								
Leonards 2011	ng/g ww		nd		nd	nd	nd-2.2 (14%)	nd	
Leonards 2011	ng/g ww		nd-8.7 (9%)		nd	nd	nd-14 (31%)	nd	
Sagerup 2010	ng/g ww	nd							
Sagerup 2010	ng/g ww	nd							
Sagerup 2010	ng/g ww	nd							
Schlabach 2011	ng/g ww								
Klosterhaus 2012	ng/g lw								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/mL								
Kaasa 2013	ng/g ww								
Kaasa 2013	ng/g ww								

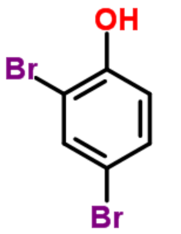
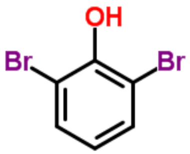
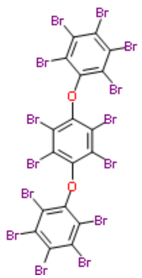
Table S15 Concentrations of detected FRs in humans. Detection frequency in brackets.

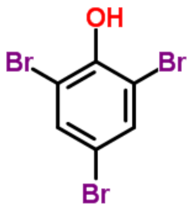
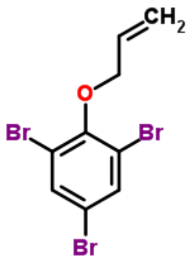
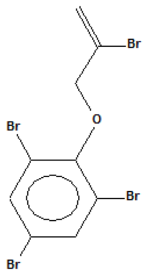
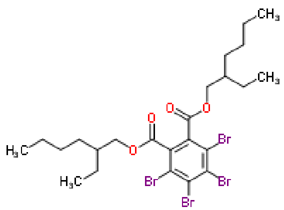
		Unit	2/3-BP	TBP	2,4-DBP	2,6-DBP	4-BP	BdPhP
Sundkvist 2009	Human milk, Sweden	ug/g lw						
Remberger 2014	Serum, Sweden	ng/g						
Haglund 2015	Serum, Sweden	ng/g	0.034-0.185	0.049-0.269 (100%)	0.016-0.076	0.020-0.047	0.031-0.155	nd

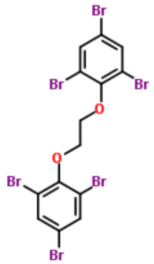
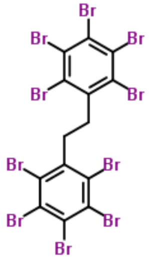
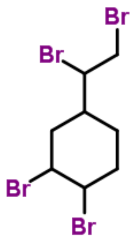
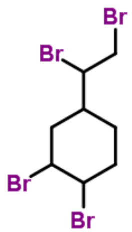
	Unit	BTBPE	DBE-DBCH (α-)	DBE-DBCH (β-)	DBPhP	EHDPP	EH-TBB	HBB	PBEB	PBT	TBOEP	TCEP
Sundkvist 2009	ug/g lw					3.5-13					nd-63	2.1-8.2
Remberger 2014	ng/g		nd		nd			nd	nd-0.072	nd		
Haglund 2015	ng/g	0.0034-0.779 (100%)					nd-0.0055 (35%)		nd-0.0014 (41%)			

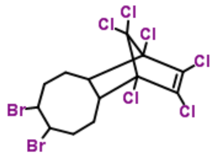
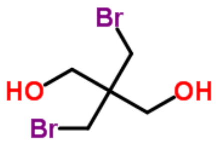
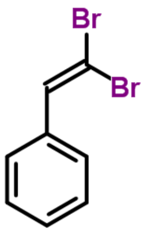
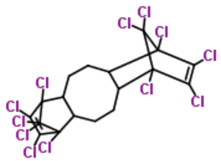
	Unit	TCIPP	TMPP (*o*-)	TMPP (*p*-)	TDCIPP	TNBP	TPHP
Sundkvist 2009	ug/g lw	22-82	nd	nd-3.7	1.6-5.3	11-57	3.2-11
Remberger 2014	ng/g						
Haglund 2015	ng/g						

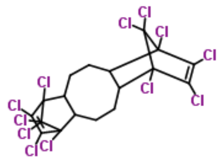
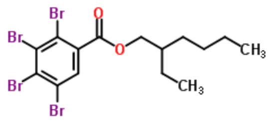
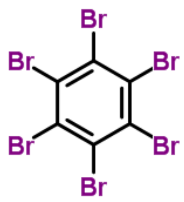
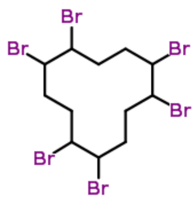
Table S16 Structure, molecular formula, CAS no., retention time and physico-chemical properties of all HFRs (n = 46) included in this study. Table is reused with some modifications from Gustavsson et al. (2017) [14].[a]

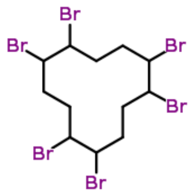
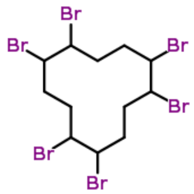
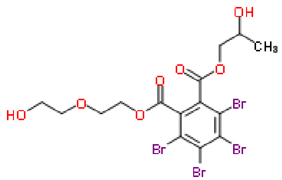
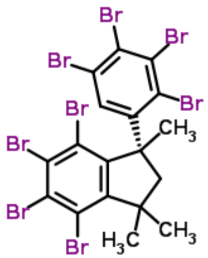
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
2,4-DBP	2,4-Dibromophenol		$C_6H_4Br_2O$	615-58-7	251.9	3.69	269.7	3536	3.29	2.87	8.66	2.1	8.9E-8	7.86
2,6-DBP	2,6-Dibromophenol		$C_6H_4Br_2O$	608-33-3	251.9	4.04	269.7	3536	3.29	2.95	8.80	0.57	8.9E-8	na
4-BP	4-Bromophenol		C_6H_5BrO	106-41-2	173.0	-	223.0	14308	2.40	2.53	7.80	1.2	1.5E-7	na
4´-PeBPOBDE208	Pentabromophenoxy-nonabromo-diphenyl ether		$C_{18}Br_{14}O_2$	58965-66-5	1367	-	808.7	1.4E-6	16.9	10.38	26.5	4.9E-18	6.5E-12	na

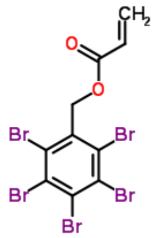
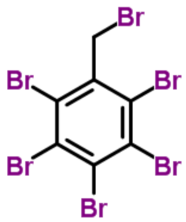
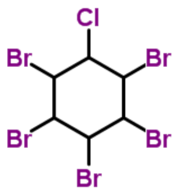
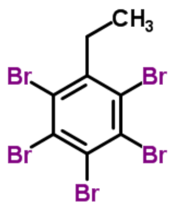
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
TBP	2,4,6-Tribromo phenol		$C_6H_3Br_3O$	118-79-6	330.8	6.18	310.1	788	4.13[1]	3.38	10.0	0.040	3.6E-8	6.32 ± 0.23
TBP-AE	Allyl 2,4,6-tribromophenyl ether		$C_9H_7Br_3O$	221-913-2	370.9	6.89	323.2	1.3	5.59	4.07	8.6	0.014	2.7E-5	na
BATE	2-Bromoallyl 2,4,6-tribromophenyl ether		$C_9H_6Br_4O$	na	449.8	8.35	359.1	0.59	5.98	4.29	9.7	9.8E-4	5.3E-6	na
BEH-TEBP	Bis(2-ethyl-1-hexyl)tetrabromo phthalate		$C_{24}H_{34}Br_4O_4$	26040-51-7	706.1	13.56	539.8	1.9E-6	11.95	7.40	16.9	2.3E-9	3.0E-7	na

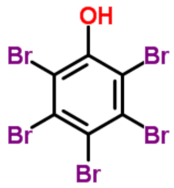
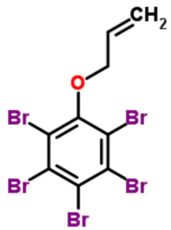
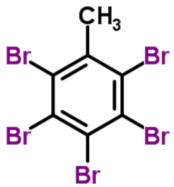
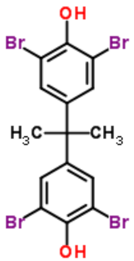
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
BTBPE	1,2-Bis(2,4,6-tribromophenoxy) ethane		$C_{14}H_8Br_6O_2$	37853-59-1	687.6	13.2	502.2	2.2E-4	9.15	6.10	15.7	3.2E-8	7.3E-9	na
DBDPE	1,2-Bis(2,3,4,5,6-pentabromophenyl) ethane		$C_{14}H_4Br_{10}$	84852-53-9	971.2	17.47	600.9	9.7E-7	13.64	11.84	19.2	2.5E-11	6.4E-8	na
α-DBE-DBCH (TBECH)	1,2-Dibromo-4-(1,2-dibromoethyl) cyclohexane		$C_8H_{12}Br_4$	3322-93-8	427.8	8.16	336.8	0.92	5.24	4.55	8.0	0.014	4.2E-5	na
β-DBE-DBCH (TBECH)	1,2-Dibromo-4-(1,2-dibromoethyl) cyclohexane		$C_8H_{12}Br_4$	3322-93-8	427.8	8.16	336.8	0.92	5.24	4.55	8.0	0.014	4.2E-5	na

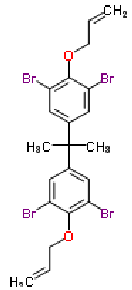
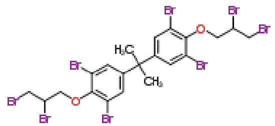
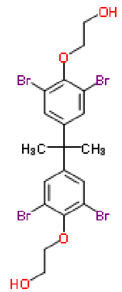
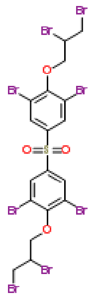
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	*Bp*[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	*H*[j]	pK_a[k]
DBHCTD	Hexachlorocyclo-pentadienyl dibromocyclooctane		$C_{13}H_{12}Br_2Cl_6$	51936-55-1	540.8	11.31	414.8	1.4E-4	7.91	6.87	11.1	1.4E-5	1.8E-5	na
DBNPG	Dibromoneopentyl alcohol		$C_5H_{10}Br_2O_2$	3296-90-0	261.9	5.58	307.0	10158	0.85	0.69	7.84	8.6E-4	4.1E-9	13.6
DBS	(2,2-Dibromovinyl) benzene		$C_8H_6Br_2$	31780-26-4	261.9	4.39	273.4	75.8	3.55	3.08	5.90	0.78	1.1E-4	na
anti-DDC-CO	Dechlorane Plus		$C_{18}H_{12}Cl_{12}$	13560-89-9	653.7	13.91	486.8	6.5E-7	11.27	9.78	14.8	9.4E-8	7.4E-6	na

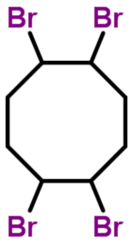
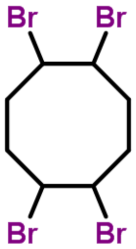
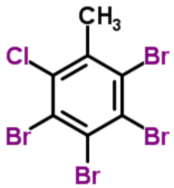
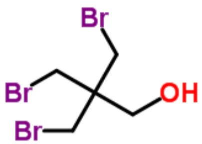
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
syn-DDC-CO	Dechlorane Plus		$C_{18}H_{12}Cl_{12}$	13560-89-9	653.7	13.67	486.6	6.5E-7	11.27	9.78	14.8	9.4E-8	7.4E-6	na
EH-TBB	2-Ethylhexyl 2,3,4,5-tetra-bromobenzoate		$C_{15}H_{18}Br_4O_2$	183658-27-7	549.9	11.33	432.9	3.4E-3	8.75	5.70	12.3	4.6E-6	6.4E-6	na
HBB	Hexabromo-benzene		C_6Br_6	87-82-1	551.5	10.02	370.7	0.23	6.07[1]	5.27	9.1	2.2E-6	2.2E-5	na
α-HBCDD	Hexabromo-cyclododecane		$C_{12}H_{18}Br_6$	3194-55-6	641.7	12.34	462.0	3.1E-3	7.74	6.72	10.5	2.3E-6	4.6E-5	na

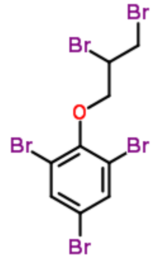
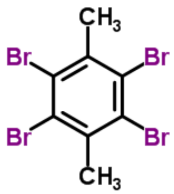
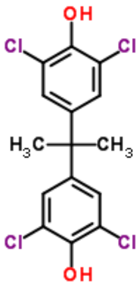
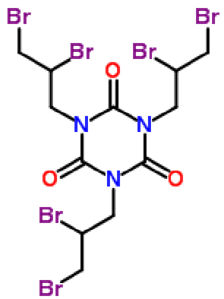
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
β-HBCDD	Hexabromo-cyclododecane		$C_{12}H_{18}Br_6$	3194-55-6	641.7	12.34	462.0	3.1E-3	7.74	6.72	10.5	2.3E-6	4.6E-5	na
γ-HBCDD	Hexabromo-cyclododecane		$C_{12}H_{18}Br_6$	3194-55-6	641.7	12.34	462.0	3.1E-3	7.74	6.72	10.5	2.3E-6	4.6E-5	na
HEEHP-TEBP	2-(2-hydroxyethoxy) ethyl-2-hydroxy-propyl-3,4,5,6-tetrabromophthalate		$C_{15}H_{16}Br_4O_7$	20566-35-2	627.9	11.43	537.5	769	3.83	2.00	17.8	3.2E-12	2.7E-16	na
OBTMPI	4,5,6,7-Tetrabromo-1,1,3-trimethyl-3-(2,3,4,5-tetrabromophenyl)-indane		$C_{18}H_{12}Br_8$	1084889-51-9	867.5	15.86	572.2	8.7E-7	13.03	11.31	17.8	2.1E-10	4.6E-7	na

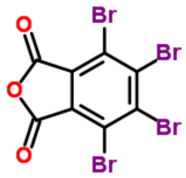
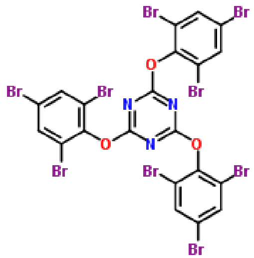
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	*Bp*[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	*H*[j]	pK_a[k]
PBB-Acr	Pentabromobenzyl acrylate		$C_{10}H_5Br_5O_2$	59447-55-1	556.7	10.91	411.7	0.13	6.89	4.67	12.4	1.8E-5	7.5E-8	na
PBBBr	Pentabromobenzyl-bromide		$C_7H_2Br_6$	38521-51-6	565.5	10.56	389.2	0.067	7.33	6.36	10.9	8.5E-5	6.9E-6	na
PBCH	Pentabromochloro-cyclohexane		$C_6H_6Br_5Cl$	87-84-3	513.1	8.90	373.2	0.45	4.72[1]	4.10	9.1	4.6E-4	9.6E-7	na
PBEB	Pentabromoethyl-benzene		$C_8H_5Br_5$	85-22-3	500.6	9.46	363.2	0.11	7.48	6.49	10.0	6.2E-4	7.9E-5	na

Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	*Bp*[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	*H*[j]	pK_a[k]
PBP	Pentabromo-phenol		C_6HBr_5O	608-71-9	488.6	9.57	374.8	34	5.96	4.39	12.6	6.8E-6	5.6E-9	4.4± 0.33
PBPAE	Pentabromo-phenyl allyl ether		$C_9H_5Br_5O$	3555-11-1	528.7	9.95	386.0	0.052	7.37	5.06	11.1	1.2E-4	4.2E-6	na
PBT	Pentabromo-toluene		$C_7H_3Br_5$	87-83-2	486.6	9.23	351.6	0.35	6.99	6.07	9.6	2.0E-5	6.0E-5	na
TBBPA	Tetrabromo-bisphenol A		$C_{15}H_{12}Br_4O_2$	79-94-7	543.9	12.14	454.6	4.3E-3	6.25	5.42	18.2	9.1E-7	2.3E-13	7.5/ 8.5 ± 0.1

Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
TBBPA-BAE	Tetrabromo-bisphenol A bis(allyl ether)		$C_{21}H_{20}Br_4O_2$	25327-89-3	624.0	-	508.7	3.4E-6	10.02	6.58	15.3	2.7E-7	1.3E-7	na
TBBPA-BDBPE	Tetrabromo-bisphenol A-bis(2,3-dibromo-propyl ether)		$C_{21}H_{20}Br_8O_2$	21850-44-2	943.6	14.03	646.9	9.4E-7	11.52	7.41	20.3	8.5E-13	4.1E-11	na
TBBPA-DHEE	Tetrabromo-bisphenol A dihydroxyethyl ether		$C_{19}H_{20}Br_4O_4$	4162-45-2	632.0	13.92	574.1	2.3E-2	6.78	3.96	17.9	5.3E-12	1.8E-13	13.8
TBBPS-DBPE	Tetrabromo-bisphenol-S-bis(2,3-dibromopropyl) ether		$C_{18}H_{14}Br_8O_4S$	42757-55-1	965.6	-	705.9	9.7E-7	9.52	6.33	21.8	1.0E-14	1.2E-14	na

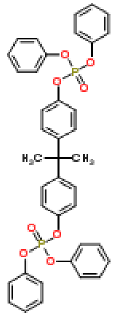
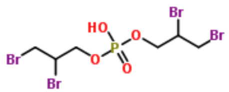
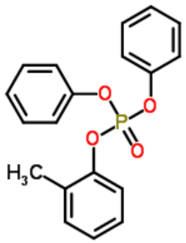
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
α-TBCO	1,2,5,6-Tetrabromo-cyclooctane		$C_8H_{12}Br_4$	3194-57-8	427.8	8.49	342.8	1.5	5.24	4.55	8.0	9.4E-3	4.2E-5	na
β-TBCO	1,2,5,6-Tetrabromo-cyclooctane		$C_8H_{12}Br_4$	3194-57-8	427.8	8.49	342.8	1.5	5.24	4.55	8.0	9.4E-3	4.2E-5	na
TBCT	1,2,3,4-Tetrabromo-5-chloro-6-methylbenzene		$C_7H_3Br_4Cl$	39569-21-6	442.2	8.70	339.4	0.38	6.74	5.85	9.1	3.7E-3	1.1E-4	na
TBNPA	Tribromoneopentyl alcohol		$C_5H_9Br_3O$	1522-92-5	324.8	5.84	299.7	852	2.25	1.76	8.5	5.6E-3	1.3E-8	13.7

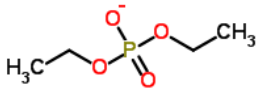
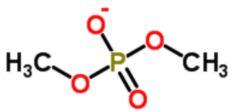
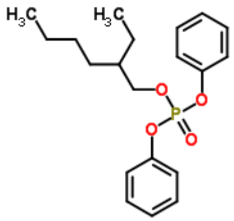
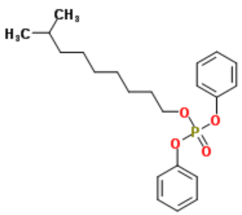
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	*Bp*[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	*H*[j]	pK_a[k]
TBP-DBPE	2,3-Dibromopropyl-2,4,6-tribromophenyl ether		$C_9H_7Br_5O$	35109-60-5	530.7	9.88	393.7	0.080	6.34	4.49	11.1	8.3E-5	4.7E-7	na
TBX	2,3,5,6-tetrabromo-p-xylene		$C_8H_6Br_4$	23488-38-2	421.8	8.35	331.9	0.53	6.65	5.77	8.8	5.5E-3	1.7E-4	na
TCBPA	Tetrachloro-bisphenol-A		$C_{15}H_{12}Cl_4O_2$	27360-90-3	366.1	10.81	438.3	0.40	6.22	4.84	16.2	3.8E-7	2.8E-12	na
TDBP-TAZTO	1,3,5-tris(2,3-dibromopropyl)-1,3,5-triazine-2,4,6(1H,3H,5H)-trione		$C_{12}H_{15}Br_6N_3O_3$	52434-90-9	728.7	13.54	669.5	1.4E-5	7.37	4.92	23.7	1.5E-10	1.2E-18	na

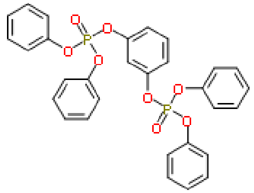
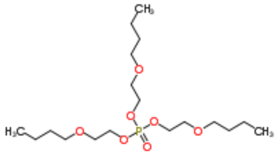
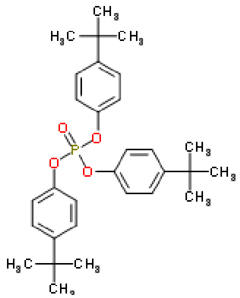
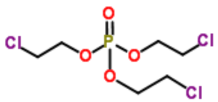
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
TEBP-Anh	3,4,5,6-Tetrabromophthalic anhydride		$C_8Br_4O_3$	632-79-1	463.7	10.03	394.1	65	5.63	3.58	10.8	2.7E-6	1.6E-7	na
TTBP-TAZ	2,4,6-tris(2,4,6-tribromophenoxy)-1,3,5-triazine		$C_{21}H_6Br_9N_3O_3$	25713-60-4	1067	18.00	767.7	1.1E-6	11.46	7.25	21.5	9.3E-17	2.4E-12	na

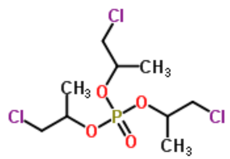
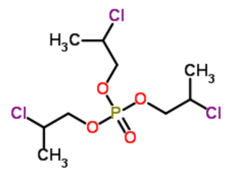
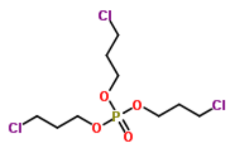
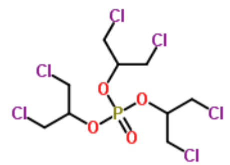
[a]Physico-chemical properties (except pK_a) were modeled using EPIsuite 4.1 (US EPA); na = not available; [b]MW = molecular weight; [c]t_R = retention time (min) using GC-conditions given in *Section 2.3*; [d]B_p = boiling point (°C); [e]S_W= water solubility (mg L^{-1}, 25°C); [f]K_{OW} = octanol-water partition coefficient; [g]K_{OC} = organic carbon-water partition coefficient; [h]K_{OA} = octanol-air partition coefficient; [i]V_p = vapour pressure; [j]H= Henry's law constant (atm m^3 $mole^{-1}$); [k]acid dissociation values (pK_a) from Bergman et al. (2012) [13]. [l]Experimental value from EPIsuite 4.1.

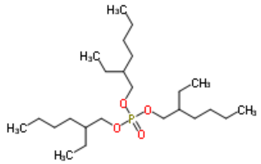
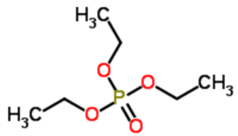
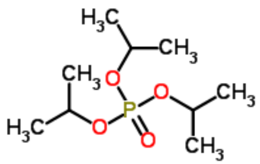
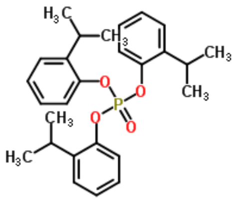
Table S17 Structure, molecular formula, CAS no., retention time and physico-chemical properties of selected OPFRs (*n* = 29). Table reused from Gustavsson et al. (2017) [14]. [a]

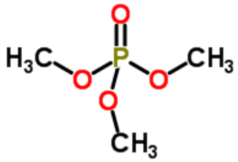
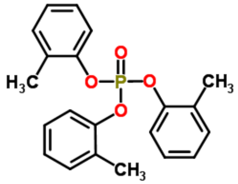
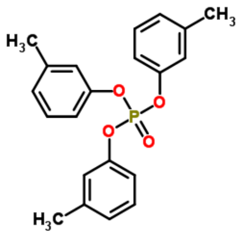
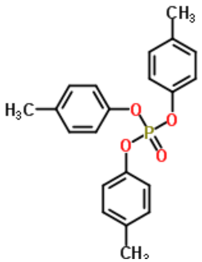
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	*Bp*[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	*H*[j]	pK_a[k]
BADP	Bisphenol A bis (diphenyl phosphate)		$C_{39}H_{34}O_8P_2$	5945-33-5	692.7	-	480.0	1.9E-6	10.0	6.24	21.7	2.7E-6	4.6E-14	na
bBDBP	bis(2,3-Dibromopropyl) phoshate		$C_6H_{11}Br_4O_4P$	5412-25-9	497.7	-	434.9	220	2.53	2.43	13.3	6.0E-7	4.3E-13	na
CDP	Cresyl diphenyl phosphate		$C_{19}H_{17}O_4P$	26444-49-5	340.3	-	452.9	1.5	5.25	3.19	10.3	1.4E-5	4.2E-8	na

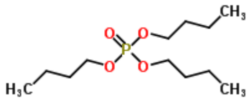
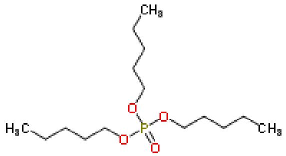
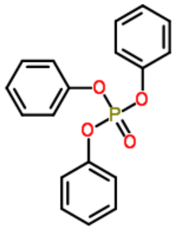
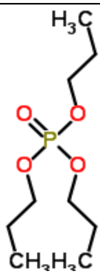
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
mDEP/dDEP	Diethyl phosphate (mono & di)		$C_4H_{11}O_4P$	598-02-7	154.1	-	258.8	4.0E5	0.32	1.21	7.57	1.8E-3	1.4E-9	na
DMP	Dimethyl phosphate		$C_2H_7O_4P$	813-78-5	126.1	-	222.9	1.0E6	-0.66	0.66	6.84	46	7.8E-10	na
EHDPP	2-Ethylhexyl diphenyl phosphate		$C_{20}H_{27}O_4P$	1241-94-7	362.4	10.00	443.0	0.18	5.73[1]	3.87	8.4	4.5E-3	2.5E-7	na
IDP	Isodecyl diphenyl phosphate		$C_{22}H_{31}O_4P$	29761-21-5	390.5	10.82	466.2	1.7E-2	7.28	3.71	10.2	6.3E-6	4.4E-7	na

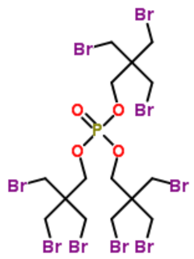
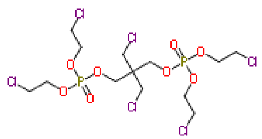
Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
PBDPP	Resorcinol bis (diphenyl phosphate)		$C_{30}H_{24}O_8P_2$	57583-54-7	574.5	15.43	480.0	6.9E-3	7.41	4.80	18.3	2.7E-6	2.9E-13	na
TBOEP	Tri(2-butoxyethyl) phosphate		$C_{18}H_{39}O_7P$	78-51-3	398.5	9.99	433.8	604	3.00	2.83	13.1	1.7E-4	1.2E-11	na
TBPP	Tris(4-tert-butylphenyl) phosphate		$C_{30}H_{39}O_4P$	78-33-1	494.6	13.25	480.0	4.1E-5	10.43	6.47	15.0	2.7E-6	6.9E-7	na
TCEP	Tris(2-chloroethyl) phosphate		$C_6H_{12}Cl_3O_4P$	115-96-8	285.5	7.00	351.7	5597	1.63	1.83	5.31	0.052	3.3E-6	na

Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	*Bp*[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	*H*[j]	pK_a[k]
TCIPP	Tri(1-chloro-2-propyl) phosphate		$C_9H_{18}Cl_3O_4P$	13674-84-5	327.6	7.14	365.5	740	2.59[1]	2.46	8.2	7.5E-3	6.0E-8	na
T2CPP	Tris(2-Chloropropyl) phosphate		$C_9H_{18}Cl_3O_4P$	6145-73-9	327.57	7.14	346.5	740	2.89	2.63	8.50	7.0E-3	6.0E-8	na
T3CPP	Tris(3-chloropropyl) phosphate		$C_9H_{18}Cl_3O_4P$	26248-87-3	327.57	7.14	386.5	157	3.11	2.75	8.72	6.4E-4	6.0E-8	na
TDCIPP	Tris(1,3-dichloroisopropyl) phosphate		$C_9H_{15}Cl_6O_4P$	13674-87-8	430.9	9.57	458.7	30	3.65[1]	3.05	10.6	3.8E-5	2.6E-9	na

Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
TEHP	Tris(2-ethylhexyl) phosphate		$C_{24}H_{51}O_4P$	78-42-2	434.7	9.57	446.3	2.8E-4	9.49	6.28	15.0	8.1E-5	7.9E-8	na
TEP	Triethyl phosphate		$C_6H_{15}O_4P$	78-40-0	182.2	-	233.3	11525	0.87	1.47	6.63	22	3.6E-8	na
TiPP	Triisopropyl phosphate		$C_9H_{21}O_4P$	513-02-0	224.2	-	254.5	16352	2.12	2.20	6.38	18	1.4E-6	na
TiPPP	Tri(2-Isopropylphenyl) phosphate		$C_{27}H_{33}O_4P$	64532-95-2	452.5	11.24	480.0	4.9E-4	9.07	5.72	14.0	2.7E-6	2.9E-7	na

Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	Bp[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	H[j]	pK_a[k]
TMP	Trimethyl phosphate		$C_3H_9O_4P$	512-56-1	140.1	-	174.2	1.0E6	-0.60	0.669	5.88	55	7.2E-9	na
o-TMPP	*ortho*-Tritolyl phosphate		$C_{21}H_{21}O_4P$	1330-78-5	368.4	10.58	476.1	0.14	6.34	4.21	12.0	4.7E-6	5.4E-8	na
m-TMPP	*meta*-Tritolyl phosphate		$C_{21}H_{21}O_4P$	1330-78-5	368.4	10.86	476.1	0.14	6.34	4.21	12.0	4.7E-6	5.4E-8	na
p-TMPP	*para*-Tritolyl phosphate		$C_{21}H_{21}O_4P$	1330-78-5	368.4	11.19	476.1	0.14	6.34	4.21	12.0	4.7E-6	5.4E-8	na

Abbreviation	Name	Structure	Molecular formula	CAS no.	MW[b]	t_R[c]	*Bp*[d]	S_W[e]	log K_{OW}[f]	log K_{OC}[g]	log K_{OA}[h]	V_P[i]	*H*[j]	pK_a[k]
TNBP	Tributyl phosphate		$C_{12}H_{27}O_4P$	126-73-8	266.3	6.35	327.0	101	4[1]	3.24	8.2	0.47	1.4E-6	na
TPeP	Tripentyl phosphate		$C_{15}H_{33}O_4P$	2528-38-3	308.4	7.86	362.9	2.9	5.29	3.96	8.8	2.2E-3	7.5E-6	na
TPHP	Triphenyl phosphate		$C_{18}H_{15}O_4P$	115-86-6	326.3	9.82	441.3	4.7	4.70	3.24	8.46	6.3E-5	3.3E-6	na
TPP	Tripropyl phosphate		$C_9H_{21}O_4P$	513-08-6	224.2	4.46	284.2	3474	1.87[1]	2.06	6.4	3.1	6.8E-7	na

Abbreviation	Name	Structure	Molecular formula	CAS no.	MW^b	t_R^c	*Bp*^d	S_W^e	log K_{OW}^f	log K_{OC}^g	log K_{OA}^h	V_P^i	*H*^j	pK_a^k
TTBNPP	Tris(tribromoneopentyl) phosphate		$C_{15}H_{24}Br_9O_4P$	19186-97-1	1020	5.91	480.0	1.2E-5	8.05	5.48	20.0	2.7E-6	2.7E-14	na
BCMP-BCEP	Tetrakis(2-Chloroethyl) dichloroisopentyl diphosphate		$C_{13}H_{24}Cl_6O_8P_2$	38051-10-4	583.0	12.91	480.0	33	3.31	2.86	15.5	2.7E-6	1.6E-14	na

[a]Physico-chemical properties (except pK_a) were modeled using EPIsuite 4.1 (US EPA); na = not available; [b]MW = molecular weight; [c]t_R = retention time (min) using GC-conditions given in *Section 2.3*; [d]B_p = boiling point (°C); [e]S_W= water solubility (mg L^{-1}, 25°C); [f]K_{OW} = octanol-water partition coefficient; [g]K_{OC} = organic carbon-water partition coefficient; [h]K_{OA} = octanol-air partition coefficient; [i]V_p = vapour pressure; [j]*H*= Henry's law constant (atm m^3 $mole^{-1}$); [k]acid dissociation values (pK_a) from Bergman et al. (2012) [13]. [l]Experimental value from EPIsuite 4.1.