

October 28, 2019

Comments from Academics, Scientists and Clinicians on the Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act

Submitted online via *Regulations.gov* to docket EPA-HQ-OPPT-2019-0080

These comments are submitted on behalf of the undersigned academics, scientists, and clinicians. We declare collectively that we have no direct or indirect financial or fiduciary interest in any chemical or product that is the subject of these comments. The co-signers' institutional affiliations are included for identification purposes only and do not imply institutional endorsement or support.

We appreciate the opportunity to provide written comments on the proposed rule for persistent, bioaccumulative and toxic (PBT) chemicals, issued under EPA's Toxic Substances Control Act (TSCA), as amended by the Frank R. Lautenberg Chemical Safety for the 21st Century Act ("amended TSCA").¹ EPA assessed five chemicals that meet TSCA's PBT definition:

- Decabromodiphenyl ethers (DecaBDE);
- Hexachlorobutadiene (HCBd);
- Pentachlorothiophenol (PCTP);
- Phenol, isopropylated, phosphate (3:1) (PIP (3:1)); and
- 2,4,6-Tris(tert-butyl) phenol (2,4,6-TTBP)

PBTs (also known as persistent organic pollutants, or POPs) are called the 'worst of the worst' chemicals because of their inherent nature- they have a high resistance to degradation, will build up in people and wildlife, and are toxic (harmful to life). In amended TSCA, Congress recognized that any production or use of PBT chemicals will present unreasonable risks to health and/or the environment and created a separate mandate for PBT chemicals, requiring expedited action by EPA with no risk evaluation. PBT chemicals are thus presumed to present unreasonable risks and EPA does not need to quantify specific risks per the law. Instead, the law states that once EPA determines exposure is likely, "the Administrator shall address the risks of injury to health or the environment that the Administrator determines are presented by the chemical substance and shall reduce exposure to the substance to the extent practicable."^{2,3}

EPA demonstrated that exposure to these PBTs is likely, and the proposed rule appropriately prohibits manufacturing, processing, and distribution for some uses of some of the PBTs. However, the proposed rule does not reduce exposures to these chemicals to the extent practicable as required by law. EPA's proposal falls short because it: contains numerous exemptions not allowed under TSCA with no phase out deadline; does not address disposal/recycling; and does not regulate HCBd in any way. EPA's approach is in marked contrast to the consensus achieved under the Stockholm Convention by science

¹ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

² US EPA (June 2018) Exposure and use assessment of five persistent, bioaccumulative and toxic chemicals.

³ 15 U.S.C. § 2605(h)(4)

and policy experts for global elimination of DecaBDE⁴ and HCB⁵ (Appendices A and B). EPA's proposal is not consistent with the best available science on these specific chemicals and on PBTs in general.

The law requires that EPA remove exposures to these harmful PBT chemicals to the extent practicable, including for potentially exposed and susceptible sub-populations. To do this EPA's rule must address all phases of the chemical life-cycle (manufacturing, processing, use, recycling and disposal of these chemicals and products containing them) and all pathways of exposure and release.

Our comments address the following main points:

- 1. EPA does not demonstrate how its proposal reduces exposures the PBTs to the extent practicable, including to potentially exposed or susceptible subpopulations.**
 - a. EPA finds that DecaBDE in toys exposes infants and children but takes no action to remove these exposures.**
 - b. EPA fails to reduce exposure to workers to the extent practicable and makes assumptions about the use personal protective equipment (PPE) that are unsupported by the science.**
- 2. By not prohibiting uses of 2,4,6-TTBP, PCTP and HCB⁵, EPA's approach allows ongoing exposures, including to potentially exposed and susceptible subpopulations, and potential expansion of uses for these PBTs.**
- 3. The proposal contains exemptions for PIP (3:1) uses with no time limit or phase-out period.**
- 4. The proposal fails to regulate recycling and disposal which, if left unchecked, will contribute to PBT exposures for generations.**
- 5. EPA must use a validated systematic review methodology for hazard identification and characterization to inform its proposal.**
 - a. The methods used in this proposed rule do not allow EPA to adequately "Address the risks of injury to health or the environment..."**
 - b. The methods used in this proposed rule do not allow EPA to adequately "...reduce exposure to the substance to the extent practicable."**

We appreciate the opportunity to provide public input. Please do not hesitate to contact us with any questions regarding these comments.

Sincerely,

Swati Rayasam, MSc
Science Associate, Program on Reproductive Health and the Environment
Department of Obstetrics, Gynecology and Reproductive Sciences
University of California, San Francisco

Veena Singla, PhD
Associate Director, Program on Reproductive Health and the Environment
Department of Obstetrics, Gynecology and Reproductive Sciences
University of California, San Francisco

⁴ UNEP (2015) Report of the Persistent Organic Pollutants Review Committee on the work of its eleventh meeting: Risk management evaluation on decabromodiphenyl ether (commercial mixture, c-decaBDE). Available: <http://chm.pops.int/TheConvention/POPsReviewCommittee/Reports/tabid/2301/Default.aspx>

⁵ UNEP (2015) Report of the Persistent Organic Pollutants Review Committee on the work of its ninth meeting: risk management evaluation on hexachlorobutadiene. Available: <http://chm.pops.int/TheConvention/POPsReviewCommittee/Reports/tabid/2301/Default.aspx>

Nicholas Chartres, PhD
Associate Research Scientist, Program on Reproductive Health and the Environment
Department of Obstetrics, Gynecology and Reproductive Sciences
University of California, San Francisco

Tracey Woodruff, PhD, MPH
Professor and Director, Program on Reproductive Health and the Environment
Department of Obstetrics, Gynecology and Reproductive Sciences
University of California, San Francisco

Dimitri Abrahamsson, PhD
Postdoctoral Scholar, Program on Reproductive Health and the Environment
Department of Obstetrics, Gynecology and Reproductive Sciences
University of California, San Francisco

Courtney Carignan, PhD
Assistant Professor
Michigan State University

Steven Gilbert, PhD, DABT
Director, Institute of Neurotoxicology and Neurological Disorders
School of Public Health
University of Washington

Rainer Lohmann, PhD
Professor of Oceanography, Graduate School of Oceanography
University of Rhode Island

Ted Schettler MD, MPH
Science Director
Science and Environmental Health Network

Patrice Sutton, MPH
Research Scientist, Program on Reproductive Health and the Environment
Department of Obstetrics, Gynecology and Reproductive Sciences
University of California, San Francisco

Marya Zlatnik, MD
Professor, Department of Obstetrics, Gynecology and Reproductive Sciences
University of California, San Francisco

DETAILED COMMENTS

1. EPA does not demonstrate how its proposal reduces exposures the PBTs to the extent practicable, including to potentially exposed or susceptible subpopulations.

The TSCA section 6(h)(4) regulatory standard requires that EPA reduce exposures to the extent practicable; EPA has failed to demonstrate how its proposed actions achieve this standard. EPA states that its proposal will achieve the following:

- DecaBDE: “This proposal would, over time, eliminate the introduction of new DecaBDE into the supply chain.”⁶
- PIP (3:1): “...EPA is not proposing regulatory controls on the manufacturing of PIP (3:1) beyond recordkeeping and downstream notification requirements.”⁷
- 2,4,6-TTBP: “The proposed approach allows for the processing and distribution for use in the industrial/ commercial fuel sector where prohibitions or restrictions on 2,4,6-TTBP mixtures would not be practicable due to its essential use in the nation’s fuel supply system.”⁸
- HCBd: “EPA is not proposing to regulate HCBd under TSCA section 6(h) because releases resulting in exposures have been nearly eliminated through actions under other statues[sic] such as the CAA and RCRA.”⁹
- PCTP: “The proposed reduction in the concentration of PCTP in mixtures would result in lower amounts of the chemical that may be manufactured and processed and subsequently available for release, resulting in a reduction in exposures.”¹⁰

These do not meet the regulatory standard because in no case does EPA present information demonstrating that its proposal will maximally reduce exposures. For example, the United Nations Environment Program Persistent Organic Pollutants Review Committee (UNEP POPRC) found that “Emissions of c-decaBDE to the environment occur at all its life cycle stages, but are assumed to be highest during service life and in the waste phase.”¹¹ Yet, EPA’s proposal addresses only manufacture and *excludes* service life and the waste phase for decaBDE- the exact places where the highest exposures occur.

EPA should eliminate PBTs if it is practicable, and for cases where it is not, the Agency should assess the residual exposure and employ the most effective control to manage exposure.¹² PBTs by their very definition “...build up in the environment over time...”¹³ and have a high resistance to degradation, thus any continued release of PBTs will lead to potential risks for exposed populations.

⁶ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36748 Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

⁷ Id. Pg. 36750

⁸ Id. Pg. 36752

⁹ Id. Pg. 36753

¹⁰ Id. Pg. 36754

¹¹ UNEP (2015) Report of the Persistent Organic Pollutants Review Committee on the work of its eleventh meeting: Risk management evaluation on decabromodiphenyl ether (commercial mixture, c-decaBDE). Pg 4. Available: <http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC11/POPRC11Documents/tabid/4573/>

¹² US OSHA. Recommended Practices for Safety and Health Programs, Hazard Prevention and Control. Available: <https://www.osha.gov/shpguidelines/hazard-prevention.html>

¹³ US EPA. Persistent, Bioaccumulative, and Toxic (PBT) Chemicals under TSCA Section 6(h). Available: <https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/persistent-bioaccumulative-and-toxic-pbt-chemicals-under>

We recently published a paper in PLOS Biology on population susceptibility, highlighting the ways that EPA's approach under TSCA is inconsistent with current science.¹⁴ Established science indicates that both biological and social factors can make people more susceptible to chemicals, but EPA has not been integrating this information to identify and protect vulnerable groups. For example, the hazard summary documents for DecaBDE, HCB, PIP 3:1, TBBP and PCPT all identify developmental toxicity as a key hazard endpoint, indicating that women of childbearing age, pregnant women, infants and children should be susceptible sub-populations for those chemicals. Fetuses, infants and children are especially susceptible to reproductive and developmental toxicants because of critical windows of vulnerability during important stages of development.¹⁵ Because these chemicals accumulate in fish, wildlife and in the Arctic, subsistence fishers and people in the Arctic should also be identified as potentially exposed sub-populations.

EPA fails to identify or present any data on the exposures of any potentially exposed or susceptible sub-populations for each PBT in the proposed rule, and information on these populations is not presented in the exposure or hazard documents.¹⁶

a. EPA finds that DecaBDE in toys exposes infants and children but takes no action to remove these exposures.

Fetuses, infants, and children are especially susceptible to reproductive and developmental toxicants because of critical windows of vulnerability during important stages of development.¹⁷ EPA finds that infants and children are likely exposed to DecaBDE from toys, but takes no action to remove these exposures, contrary to TSCA's mandate.

In the proposed rule, EPA cites a study from Ionas et al. that simulated PBDE leaching by mouthing from toys using artificial saliva to estimate possible exposure to infants, finding a risk of exposure of 67 ng/day for high exposures and 24 ng/day for low exposures for the sum of all studied PBDE congeners (not solely from DecaBDE).¹⁸ In the table provided in EPA's exploratory analysis, EPA identified that the Ionas paper demonstrated an ingested dose of 3.11E-6 mg/kg/day for a low exposure infant and 8.7E-6 mg/kg/day for a high exposure infant. How EPA arrived at its calculations for ingested dose from mouthing for solely decaBDE is not clear based on any of the data present in the source citation. If EPA is making "adjustments" to data from its source citations it must be clear about its process and how it arrived at its conclusions.

Regardless, both Ionas, et al. and EPA's exploratory analysis find that toys are a source of DecaBDE exposure to children. EPA's finding that "DecaBDE migration from articles like toys does not represent a risk concern due to the mouthing behaviors (e.g., teething), based on the available information (Ref 40)." ¹⁹ is firstly flawed because it does not account for aggregate DecaBDE exposures from other

¹⁴ Koman, P.D., Singla, V. I., Lam, J., & Woodruff, T. J. (2019). Population susceptibility: A vital consideration in chemical risk evaluation under the Lautenberg Toxic Substances Control Act. *PLoS Biology*. <https://doi.org/10.1371/journal.pbio.3000372>

¹⁵ US EPA and NIEHS (2017) NIEHS/EPA Children's Environmental Health and Disease Prevention Research Centers: Impact Report.

¹⁶ US EPA (2018) Exposure and use assessment of five persistent, bioaccumulative and toxic chemicals.

¹⁷ US EPA and NIEHS (2017) NIEHS/EPA Children's Environmental Health and Disease Prevention Research Centers: Impact Report.

¹⁸ Ionas, A. C., Ulevicus, J., Gómez, A. B., Brandsma, S. H., Leonards, P. E., van de Bor, M., & Covaci, A. (2016). Children's exposure to polybrominated diphenyl ethers (PBDEs) through mouthing toys. *Environment international*, 87, 101-107.

¹⁹ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36746. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

sources such as diet, and second is irrelevant because TSCA requires EPA to reduce exposure to the extent practicable, not calculate risk.

As EPA clearly found that toys expose children to DecaBDE, it must take action to reduce these exposures to the extent practicable.

b. EPA fails to reduce exposure by workers to the extent practicable and makes assumptions about the use personal protective equipment (PPE) that are unsupported by the science.

Workers typically experience many concurrent chemical exposures, which can increase susceptibility to chemical toxicity.²⁰ Workers have known or likely exposures to all of the PBTs. For example, biomonitoring studies found that workers including firefighters, rubber manufacturers and electronic waste (e-waste) handlers have significantly elevated exposures to PBTs like DecaBDE because they handle DecaBDE-containing materials or they are exposed to DecaBDE routinely on the job.^{21,22, 23,24} E-waste workers have the highest body burdens of DecaBDE ever measured.^{25, 26} As detailed below, failure to consider the entire lifecycle of PBTs such as DecaBDE also presents a health risk to workers, as the recycling and disposal processes are a source of exposure.

When discussing potential worker exposures, EPA “generally expects there is compliance with Federal and state laws...”²⁷ indicating an assumption that employers will comply with general OSHA regulations for PPE, as there are no OSHA standards for any of the five PBTs.

First, even if there was an OSHA standard for these PBTs, OSHA standards explicitly allow worker exposure to chemicals at levels considered unreasonable for any other person. TSCA requires EPA to reduce exposures to PBTs to the extent practicable, especially for susceptible subpopulations like workers, so the Agency’s reliance on OSHA standards does not meet the mandate of the law.

Second, EPA assumes, without adequate evidence, that workers will use PPE to mitigate these exposures of concern. But assumption of use of PPE in absence of a standard is scientifically

²⁰ National Research Council. *Science and Decisions: Advancing Risk Assessment*. Washington, D.C.: National Academies Press; 2009.

²¹ Park J-S, Voss RW, McNeel S, Wu N, Guo T, Wang Y, et al. High Exposure of California Firefighters to Polybrominated Diphenyl Ethers. *Environ Sci Technol*. 2015 Mar;49(5):2948–58.

²² Thuresson K, Bergman A, Jakobsson K. Occupational exposure to commercial decabromodiphenyl ether in workers manufacturing or handling flame-retarded rubber. *Environ Sci Technol*. 2005 Apr;39(7):1980–6.

²³ Eguchi A, Nomiya K, Devanathan G, Subramanian A, Bulbule K a, Parthasarathy P, et al. Different profiles of anthropogenic and naturally produced organohalogen compounds in serum from residents living near a coastal area and e-waste recycling workers in India. *Environ Int*. 2012 Oct;47:8–16.

²⁴ Bi X, Thomas GO, Jones KC, Qu W, Sheng G, Martin FL, et al. Exposure of electronics dismantling workers to polybrominated diphenyl ethers, polychlorinated biphenyls, and organochlorine pesticides in South China. *Environ Sci Technol*. 2007 Aug;41(16):5647–53.

²⁵ Qu W, Bi X, Sheng G, Lu S, Fu J, Yuan J, et al. Exposure to polybrominated diphenyl ethers among workers at an electronic waste dismantling region in Guangdong, China. *Environ Int*. 2007 Nov;33(8):1029–34.

²⁶ Zhao X-R, Qin Z-F, Yang Z-Z, Zhao Q, Zhao Y-X, Qin X-F, et al. Dual body burdens of polychlorinated biphenyls and polybrominated diphenyl ethers among local residents in an e-waste recycling region in Southeast China. *Chemosphere*. 2010 Feb;78(6):659–66.

²⁷ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36740. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

unsupported; even when an OSHA standard exists, it is not followed, as shown by the methylene chloride standard where failure to provide PPE was one of most common employer violations.²⁸

By law under TSCA 6(h), these documented and likely exposures compel EPA to take action and ensure enforceable protections to reduce the exposures of the susceptible sub-populations discussed above. EPA must amend its rule to ensure the maximal reduction of exposures for the potentially exposed or susceptible sub-populations identified for each PBT.

2. By not prohibiting uses of 2,4,6-TTBP, PCTP and HCBP, EPA's approach allows ongoing exposures, including to potentially exposed and susceptible subpopulations, and potential expansion of uses for these PBTs.

EPA's proposal prohibits only one use of 2,4,6-TTBP (as an oil and lubricant additive) and places no prohibitions on the uses of HCBP and PCTP. This means that current uses will continue and uses could expand in the future. To reduce exposures to the extent practicable, it is necessary for EPA to prohibit all uses of these chemicals.

2,4,6-TTBP: EPA has prohibited use as an oil and lubricant additive and required that all 2,4,6-TTBP be distributed in 55-gallon drums. EPA states that this will "effectively prevent the use of 2,4,6-TTBP as a fuel additive or fuel injector cleaner by consumers and small commercial operations (e.g., automotive repair shops, marinas)."²⁹ It is unclear how the container size will prevent these uses; EPA must make an explicit prohibition on fuel additive and fuel injector cleaner uses. EPA also states that its proposal does not address 2,4,6-TTBP in the fuel supply (refineries, bulk petroleum storage) because in those circumstances 2,4,6-TTBP "is managed through highly regulated engineered controls designed to mitigate environmental and human health exposures."³⁰ EPA does not provide evidence that this "mitigation" of exposures is equivalent to exposure reduction to the extent practicable. Both workers and nearby communities could be exposed. Finally, EPA has proposed to define 2,4,6-TTBP for this rule as any concentration above 0.01% by weight. EPA does not provide evidence that this lower concentration limit would reduce exposure to the extent practicable nor that a ban would be impracticable.

PCTP: EPA proposes to allow PCTP below 1% by weight as it would be "unreasonable, because of the low concentrations of PCTP in golf balls,...and, thus, impracticable to prohibit or otherwise restrict the continued commercial use of the products."³¹ First, EPA has not demonstrated that levels below 1% do not present risks. Second, EPA's allowance for PCTP is overly broad; while the proposed rule only details one use (rubber used in golf balls), the proposal allows PCTP below 1% by weight without any further prohibition on uses. This allows any use of this PBT, including uses which EPA has not evaluated and may not be aware of, which could present a greater risk to the general population than golf ball manufacture. We recommend that EPA amend this proposed rule to prohibit PCTP as it is practicable

²⁸ U.S. Department of Labor, Occupational Safety and Health Administration. (2010) "Regulatory Review of 29 CFR 1910.1052: Methylene Chloride." Available: <https://www.osha.gov/dea/lookback/MC-lookback-Feb-2010-final-for-publication-May-2010.pdf>

²⁹ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg 36730. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

³⁰ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36751 Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

³¹ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36745. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

per EPA's statement that "there are viable substitutes for PCTP in rubber manufacturing,"³² thus golf ball manufacturers can reformulate. Exemptions are only allowed for PBTs when one or more of the criteria specified in USC §2605 (g) is met, and PCTP use in golf balls does not meet these criteria.

HCBD: EPA states that it "is not proposing to regulate HCBD under TSCA section 6(h) because the potential for exposure from uses of this chemical is already addressed by actions taken under other statutes and further measures are not practicable."³³ Yet, EPA's exposure assessment found that HCBD is found in widespread media, including ambient air, surface water, soil, sediment, drinking water, indoor air, and sludge/ biosolids—all of which people breathe, eat and drink--so clearly the existing controls are not addressing these exposures. Further, the POPRC found that HCBD's "...high toxicity to the kidneys, genotoxicity and carcinogenicity is of special concern especially for lifelong dietary low level exposure conditions," and "Evidence of cancer in animals is sufficient to cause concern for populations that may be exposed to low levels of HCBD for long periods."³⁴ EPA has not demonstrated that its actions address these health effects. EPA reported only one use for HCBD (burning as a waste fuel) – it should prohibit this use and all other uses to preclude new uses of HCBD in the future. For unintentionally generated HCBD, EPA should require best available techniques and best environmental practices to control releases and emissions from sources and develop a plan to further eliminate HCBD sources to the extent practicable through use of alternatives to the chlorinated chemicals that generate HCBD in their manufacturing processes.

3. The proposal contains exemptions for PIP (3:1) uses with no time limit or phase-out period.

EPA appropriately proposes to prohibit processing and distribution in commerce of PIP (3:1) and products containing the chemical, but proposes multiple exemptions to the prohibition: aviation hydraulic fluid; lubricants and greases; and new and replacement parts for vehicles.³⁵

Exemptions are only allowed when one or more of the criteria specified in USC §2605 (g) is met, and it does not appear any of these exemptions meet the criteria. EPA should remove these exemptions from the proposal. If the USC §2605 (g) criteria were met, section 6(g) would require EPA to impose a time limit on of the exemption after which the specified uses would be phased out. Without a pre-specified time period for the exemption, there is no incentive to search for safer alternatives, and PIP (3:1) use will continue, resulting in accumulation in the environment and in people.

³² US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36754. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

³³ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 76753. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

³⁴ UNEP (2015) Report of the Persistent Organic Pollutants Review Committee on the work of its eleventh meeting: Risk management evaluation on decabromodiphenyl ether (commercial mixture, c-decaBDE). Available: <http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC11/POPRC11Documents/tabid/4573/>

³⁵ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36759. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

4. The proposal fails to regulate recycling and disposal which, if left unchecked, will contribute to PBT exposures for generations.

We previously commented on the need to address the full life cycle of PBT chemicals, including recycling and disposal, to effectively address health risks and limit exposures.^{36, 37,38,39,40,41} Yet, EPA's proposal does not address recycling or disposal for any of the PBTs. For DecaBDE, the POPRC found that:

"Emissions of c-decaBDE to the environment occur at all its life cycle stages but are assumed to be highest during service life and in the waste phase. The average service life for electric and electronic equipment is about 10 years hence c-decaBDE will continue to be released to the environment through articles in use for years to come. The most efficient control measure to reduce the releases of c-decaBDE and its main constituent BDE-209, would be to list BDE-209 (c-decaBDE) in Annex A of the Convention without specific exemptions. Furthermore, efficient control measures for the handling of waste containing c-decaBDE will also be essential. Due to the historical and present use of c-decaBDE as a flame retardant, a large number of products in use will become waste in the future."⁴²

And

"...emissions of c-decaBDE to the environment occur at all its life cycle stages; during production, formulation and other first- and second-line uses at industrial/professional sites, as well as during service life of articles, their disposal as waste and during recycling operations (UNEP/POPS/POPRC.10/10/Add.2 and references within). The release and distribution of c-decaBDE to the environment via these routes is confirmed by monitoring data (UNEP/POPS/POPRC.10/INF/5), and are likely to occur over a long time-frame. A number of emission assessments have been performed based on modelling (UK EA, 2009; RPA, 2014; ECHA, 2014a; Earnshaw et al., 2013). The assessments collectively indicate that emissions of c-decaBDE during service life and upon disposal of products (as waste) are the most important sources of release, and are in line with reported environmental monitoring data (UNEP/POPS/POPRC.10/10/Add.2)... Control measures should be considered for all the

³⁶ US EPA (2018). 2,4,6-Tris(tert-butyl)phenol; TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0734-0008>

³⁷ US EPA (2018). 2Decabromodiphenyl Ethers; TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0724-0007>

³⁸ US EPA (2018). Pentachlorothiophenol; TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0739-0007>

³⁹ US EPA (2018). Hexachlorobutadiene; TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0738-0008>

⁴⁰ US EPA (2018). Phenol, isopropylated, phosphate (3:1); TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0730-0011>

⁴¹ US EPA (2018). Letter Peer Reviews for Exposure and Use Assessment and Ecological and Human Health Summary for Five PBT chemicals, Comment submitted by V. Singla, et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2018-0314-0024>

⁴² UNEP (2015) Report of the Persistent Organic Pollutants Review Committee on the work of its eleventh meeting: Risk management evaluation on decabromodiphenyl ether (commercial mixture, c-decaBDE). Pg 4. Available: <http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC11/POPRC11Documents/tabid/4573/>

above described sources of exposure and releases including production, use and in the waste management phase.”⁴³

And

“POPRC recommendations on elimination of PBDEs from the waste stream note that the objective is to eliminate PBDEs from the recycling streams as swiftly as possible. Failure to do so will inevitably result in wider human and environmental contamination and the dispersal of PBDEs into matrices from which recovery is not technically or economically feasible and may result in loss of long-term credibility of recycling (Decision POPRC-6/2)...Although materials containing c-decaBDE can be recycled several times with only a small loss of the c-decaBDE content (Hamm et al., 2001; as cited in Earnshaw et al., 2013) this practice will continue to spread c-decaBDE to the environment as well as human exposure.”⁴⁴

These findings all indicate that it is critical for EPA to address recycling and disposal to effectively reduce human exposure to DecaBDE. Indeed, because the PBTs all share the characteristics of persistence and bioaccumulation, it is essential that EPA address disposal and recycling for all the PBTs to effectively address health risks and limit exposures. These public health protections are required by law.

5. EPA must use a validated systematic review methodology for hazard identification and characterization to inform its proposal.

Despite the law requiring EPA to use “best available science”⁴⁵ and the “weight of the scientific evidence”⁴⁶ defined as “...a systematic review method”⁴⁷ EPA states in the proposed rule that it “did not perform a systematic review or a weight of the scientific evidence assessment for the hazard characterization of these chemicals.”⁴⁸ EPA justified this decision by stating “EPA does not interpret TSCA section 6(h)(4), specifically the language directing EPA to ‘address the risks of injury to health or the environment that the Administrator determines are presented,’ to require EPA to determine, through a risk assessment or risk evaluation, whether risks are presented.” While we agree the law does not require a risk evaluation, we disagree that EPA cannot make a risk determination.

As discussed previously, due to their nature, exposures to PBTs are presumed to present unreasonable risk under TSCA and the law directs EPA to address these risks by removing exposures. We

⁴³ UNEP (2015) Report of the Persistent Organic Pollutants Review Committee on the work of its eleventh meeting: Risk management evaluation on decabromodiphenyl ether (commercial mixture, c-decaBDE). Pg 10-11. Available: <http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC11/POPRC11Documents/tabid/4573/>

⁴⁴ Id. Pg 13.

⁴⁵ 40 CFR 702.33 pg 33731

⁴⁶ 15 USC §2625 (h)-(i)

⁴⁷ 40 CFR 702.33 pg 33733

⁴⁸ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36733. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

have previously commented on the process leading up to this proposed rule,^{49, 50,51,52,53,54} outlining that EPA is unable to address risks and reduce exposure to PBTs to the extent practicable without using of a validated systematic review to generate a comprehensive hazard characterization.

a. The methods used in this proposed rule do not allow EPA to adequately “Address the risks of injury to health or the environment...”

The fundamental purpose of conducting a systematic review is to evaluate the entire body of evidence of all science relevant to the review question/s, which allows the formulation of conclusions from the body of evidence as a whole. By EPA’s own admission “The information in the Hazard Summary does not represent an exhaustive literature review nor is it an analysis of relative importance or comparative dose-response among hazards”⁵⁵ and goes on to state “Other information on these chemicals may exist in addition to the studies summarized in the Hazard Summary that could refine the characterization”⁵⁶ By acknowledging that these characterizations could be further refined, EPA is recognizing that not all risks posed to human health and the environment through exposure to these chemicals is known, and therefore there may be additional harms posed that have not been considered in EPA’s proposed rule for risk management. This is deeply concerning.

b. The methods used in this proposed rule do not allow EPA to adequately “...reduce exposure to the substance to the extent practicable.”

EPA supports its decision for not conducting a systematic review or a weight of the scientific evidence assessment for the hazard summary of these chemicals because “EPA does not believe that a systematic review would change our proposed risk management determinations as TSCA section 6(h)(4) requires EPA to reduce exposure to the substance to the extent practicable, regardless of risk.”⁵⁷ We agree that EPA must reduce exposures regardless of risk, however where elimination is not practicable, the law also requires that EPA “address the risks of injury to health or environment,” posed by the PBT.

⁴⁹ US EPA (2018). 2,4,6-Tris(tert-butyl)phenol; TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0734-0008>

⁵⁰ US EPA (2018). 2Decabromodiphenyl Ethers; TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0724-0007>

⁵¹ US EPA (2018). Pentachlorothiophenol; TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0739-0007>

⁵² US EPA (2018). Hexachlorobutadiene; TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0738-0008>

⁵³ US EPA (2018). Phenol, isopropylated, phosphate (3:1); TSCA Review, Comment submitted by Veena Singla, PhD, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco (UCSF) et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2016-0730-0011>

⁵⁴ US EPA (2018). Letter Peer Reviews for Exposure and Use Assessment and Ecological and Human Health Summary for Five PBT chemicals, Comment submitted by V. Singla, et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2018-0314-0024>

⁵⁵ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36733. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

⁵⁶ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36733. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

⁵⁷ US EPA (2019) Regulation of Persistent, Bioaccumulative, and Toxic Chemicals under Section 6(h) of the Toxic Substances Control Act. Pg. 36733. Available: <https://www.federalregister.gov/documents/2019/07/29/2019-14022/regulation-of-persistent-bioaccumulative-and-toxic-chemicals-under-tsca-section-6h>

For EPA to make an informed decision in this case, it must fully understand all the hazards posed by each PBT through a comprehensive systematic review. Where elimination is not practicable, a systematic review of hazards would help inform EPA's management actions to address risks of injury to health. We again strongly recommend that EPA adhere to the law and use the "best available science"⁵⁸ and the "weight of the scientific evidence"⁵⁹ defined as "...a systematic review method"⁶⁰ to address risks of injury and maximally reduce exposures to PBTs for both the general population and susceptible sub-populations.

Finally, we have previously detailed the scientific flaws in EPA's systematic review method developed under TSCA ("TSCA method") in August 2018 and published a peer-reviewed analysis in the *American Journal of Public Health*.^{61,62,63} We recommend that EPA use well-established, scientifically valid systematic review approaches already being used in environmental health assessments, including the Navigation Guide⁶⁴ and the Office of Health Assessment and Translation (OHAT),⁶⁵ for hazard identification, characterization and dose-response analysis. The use of such methods will allow EPA to ensure that where elimination is not practicable, its actions address health risks for both the general population and susceptible sub-populations.

⁵⁸ 40 CFR 702.33 pg 33731

⁵⁹ 15 USC §2625 (h)-(i)

⁶⁰ 40 CFR 702.33 pg 33733

⁶¹ EPA (2018) Application of Systematic Review in TSCA Risk Evaluations.

⁶² US EPA (2018) Problem Formulations for the Risk Evaluations to be Conducted for the First Ten Chemical Substances under the Toxic Substances Control Act, and Application of Systematic Review in TSCA Risk Evaluations; Notice of Availability, Comment submitted by Veena Singla, Associate Director, Science and Policy, Program on Reproductive Health and the Environment, University of California, San Francisco et al. Available: <https://www.regulations.gov/document?D=EPA-HQ-OPPT-2018-0210-0107>

⁶³ Singla, V. I., Sutton, P. M., & Woodruff, T. J. (2019). The Environmental Protection Agency Toxic Substances Control Act Systematic Review Method May Curtail Science Used to Inform Policies, With Profound Implications for Public Health. *American Journal of Public Health*, 109(7), 982–984. doi:10.2105/AJPH.2019.305068

⁶⁴ Woodruff TJ, Sutton P. The Navigation Guide systematic review methodology: a rigorous and transparent method for translating environmental health science into better health outcomes. *Environ Health Perspect*. 2014;122(10):1007-1014.

⁶⁵ National Toxicology Program (NTP). Handbook for Conducting a Literature-Based Health Assessment Using OHAT Approach for Systematic Review and Evidence Integration. Research Triangle Park, NC: National Toxicology Program; 2015.

Appendices:

Appendix A: Risk management evaluation on decabromodiphenyl ether
(commercial mixture, c-decaBDE)

Appendix B: Risk management evaluation on hexachlorobutadiene

Appendix A: Risk management evaluation on decabromodiphenyl ether
(commercial mixture, c-decaBDE)



**Stockholm Convention
on Persistent Organic
Pollutants**

Persistent Organic Pollutants Review Committee
Eleventh meeting
Rome, 19–23 October 2015

**Report of the Persistent Organic Pollutants Review Committee
on the work of its eleventh meeting**

Addendum

**Risk management evaluation on decabromodiphenyl ether (commercial
mixture, c-decaBDE)**

At its eleventh meeting, by its decision POPRC-11/1, the Persistent Organic Pollutants Review Committee adopted a risk management evaluation for decabromodiphenyl ether (commercial mixture, c-decaBDE) on the basis of the draft contained in the note by the secretariat (UNEP/POPS/POPRC.11/2). The text of the risk management evaluation, as amended, is set out in the annex to the present addendum. It has not been formally edited.

Annex

DECABROMODIPHENYL ETHER
(commercial mixture, c-decaBDE)
RISK MANAGEMENT EVALUATION

Prepared by the intersessional working group on decabromodiphenyl ether
Persistent Organic Pollutants Review Committee

October 2015

Table of Contents

Executive summary	4
1. Introduction.....	5
1.1 Chemical identity of the proposed substance.....	5
1.2 Conclusions of the Review Committee, Annex E information	6
1.3 Data sources.....	7
1.4 Status of the chemical under international conventions.....	7
1.5 Any national or regional control actions taken	7
2. Summary information relevant to the risk management evaluation.....	9
2.1 Identification of possible control measures	10
2.2 Efficacy and efficiency of possible control measures in meeting risk reduction goals...	11
2.3 Information on alternatives (products and processes) where relevant	15
2.3.1 Alternative substances	16
2.3.2 Plastics	18
2.3.3 Textiles	19
2.3.4 Other uses	21
2.3.5 Alternative techniques and inherent flame-resistant materials	21
2.3.6 Fire-safety standards, requirements and solutions	23
2.4 Summary of information on impacts on society of implementing possible control measures	25
2.4.1 Health, including public, environmental and occupational health	25
2.4.2 Agriculture, including aquaculture and forestry	27
2.4.3 Biota (biodiversity).....	27
2.4.4 Economic aspects and social costs	27
2.4.5 Movement towards sustainable development	30
2.5 Other considerations	30
3. Synthesis of information	31
3.1 Summary of risk profile information	31
3.2 Summary of risk management evaluation information	32
3.3 Suggested risk management measures	33
4. Concluding statement.....	33

Executive summary

1. In 2013, Norway submitted a proposal to list commercial decabromodiphenyl ether (c-decaBDE) as a persistent organic pollutant under the Stockholm Convention. In 2014, at the 10th meeting of the POPs Review Committee, it was decided that BDE-209, the main constituent of c-decaBDE is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects, such that global action is warranted. An ad hoc working group was established to prepare a risk management evaluation for c-decaBDE, in accordance with Annex F of the Convention, for consideration by POPs Review Committee at its 11th meeting in October 2015.
2. C-decaBDE is an intentionally produced chemical consisting of the fully brominated decaBDE congener or BDE-209 ($\geq 90-97\%$), with small amounts of nona- and octa-bromodiphenyl ether. C-decaBDE has been under investigation for its potential health and environmental impacts for more than a decade and has been subject to restrictions and voluntary risk management actions in some countries and regions, as well as by some companies. Production of c-decaBDE but is still ongoing in a few countries globally.
3. C-decaBDE is an additive flame retardant that has a variety of applications including in plastics, textiles, adhesives, sealants, coatings and inks. C-decaBDE containing plastics are used in electrical and electronic equipment, wires and cables, pipes and carpets. In textiles, c-decaBDE is mainly used in upholstery, window blinds, curtains and mattresses for public and domestic buildings, and in the transportation sector. The amount of c-decaBDE used in plastics and textiles globally varies but up to about 90% of c-decaBDE ends up in plastic and plastics used in electronics while the remainder is used in coated textiles, upholstered furniture and mattresses.
4. Emissions of c-decaBDE to the environment occur at all its life cycle stages, but are assumed to be highest during service life and in the waste phase. The average service life for electric and electronic equipment is about 10 years hence c-decaBDE will continue to be released to the environment through articles in use for years to come. The most efficient control measure to reduce the releases of c-decaBDE and its main constituent BDE-209, would be to list BDE-209 (c-decaBDE) in Annex A of the Convention without specific exemptions. Furthermore, efficient control measures for the handling of waste containing c-decaBDE will also be essential. Due to the historical- and present use of c-decaBDE as a flame retardant, a large number of products in use will become waste in the future. Controlled incineration of waste containing c-decaBDE at high temperatures is one way of destruction, with systems to remove possible brominated furan/dioxin compounds produced in the process, along with continuous monitoring and strict compliance with Convention BAT/BEP guidelines and environmentally sound treatment of fly ashes. Other means are described in document UNEP/POP/COP.7/INF/22 which also provides constraints in recycling.
5. According to Article 6 of the Convention, waste shall be disposed of in such a way that the POP content is destroyed or irreversibly transformed so that it does not exhibit the characteristics of POPs, or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the POP content is low. For this reason, recycling of material containing c-decaBDE above the low POP content limit value is not recommended and should be avoided. Recently, BDE-209 has been detected in a number of articles, made from recycled material, including articles in contact with food. This indicates that it is difficult to control the content of c-decaBDE in plastic material destined for recycling and that recycling may contribute to human exposure to c-decaBDE. Monitoring data also shows that recycling contributes to significant environmental pollution and health risks for local populations, particularly in developing countries where recycling occurs in the informal sector. Technical solutions are available in the waste sector to achieve more sustainable waste management e.g. by sorting out components containing hazardous chemicals are not available on an industrial scale and especially in developing countries. A restriction on c-decaBDE might have an economic impact on the recycling industry, but the economic costs and benefits are hard to predict. At present, recycling of c-decaBDE containing plastics and textiles is not known to occur to a great extent and available information suggests that the socioeconomic impact of not recycling c-decaBDE may be limited.
6. On a country or regional basis an analysis of the economic impacts to recycling facilities needs to be undertaken. What could be defined as an optimal solution depends very much on the economic and cultural context in which the system operates. The cost of labour, the structure of the economy including the important informal sector, the existing regulatory framework and the possibilities and limits of law enforcement have to be taken into account in order to find solutions that can improve the situation with regard to environmental impacts, occupational hazards and economic revenue.

7. Based on the information submitted during the risk management evaluation and the collective experience reported, there may be challenges for some sectors, i.e., legacy spare parts for the aerospace and automotive industries. Some parties identified challenges for recycling. Because of the concerns about articles, products in use, and recycled products containing decaBDE being exported especially to developing countries and countries with economies in transition, other experts opposed recycling exemption due to lack of capacity to identify and analyse products containing deca BDE. Additional risk management measures could include an obligation to label new articles that contains decaBDE.

8. However, a number of non-POP chemical alternatives are already on the market for the substitution of c-decaBDE in plastics and textiles. Furthermore, non-chemical alternatives and technical solutions such as non-flammable materials and physical barriers, respectively, are also available. Annex F information and other available information indicates that textile-, furniture- and electronics markets are in transition away from the use of c-decaBDE and that substitutions have been performed or are in progress for most, if not all, known applications.

9. A positive impact on human health and the environment can be expected from a global reduction or elimination of c-decaBDE. BDE-209, the main constituent of c-decaBDE, and its degradation products is widely detected in the indoor and outdoor environments and is found in some organisms at levels close to or at reported effect concentrations for developmental-, neurotoxic-, and endocrine disruptive effects.

10. The Committee recommends, in accordance with paragraph 9 of Article 8 of the Convention, the Conference of the Parties to the Stockholm Convention to consider listing and specifying the related control measures of the decabromodiphenyl ether component (BDE-209) of c-decaBDE in Annex A with specific exemptions for some critical legacy spare parts that still need to be defined in the automotive and aerospace industries.

1. Introduction

11. On 13 May 2013, Norway as a Party to the Stockholm Convention, submitted a proposal to list decabromodiphenyl ether (commercial mixture, c-decaBDE) in Annexes A, B and/or C to the Convention. The proposal (UNEP/POPS/POPRC.9/2) was submitted in accordance with Article 8 of the Convention and was reviewed by the POPs Review Committee (POPRC) at its ninth meeting in October 2013, where the Committee agreed that the criteria in Annex D were met. At its tenth meeting in October 2014, the Committee evaluated the draft risk profile for c-decaBDE (UNEP/POPS/POPRC.10/10/Add.2) in accordance with Annex E, adopted this (UNEP/POPS/POPRC.10/10) and decided to establish an intersessional working group to prepare a risk management evaluation for the substance (Decision POPRC-10/2).

12. In the present document, the abbreviation c-decaBDE is used for technical or commercial decaBDE products. Decabromodiphenyl ether (BDE-209) refers to the single fully brominated polybrominated diphenylether (PBDE), which elsewhere sometimes is denoted as decaBDE.

1.1 Chemical identity of the proposed substance

13. The risk management evaluation concerns c-decaBDE and its main component, BDE-209. C-decaBDE is a commercial PBDE formulation that is widely used as an additive flame retardant in textiles and plastics, additional uses are in adhesives and in coatings and inks (ECHA 2013b). C-decaBDE consist predominantly of the congener BDE-209 ($\geq 97\%$), with low levels of other PBDE congeners such as nonabromodiphenyl ether (0.3-3%) and octabromodiphenyl ether (0-0.04%). Chen et al. (2007) reported that the octaBDE and nonaBDE content of two c-decaBDE products from China was in the range 8.2 to 10.4% suggesting that a higher degree of impurities may be found in some commercial mixtures. Historically a range of 77.4-98% of BDE-209, and smaller amounts of the congeners of nonaBDE (0.3-21.8%) and octaBDE (0-0.85%) have been reported (ECHA, 2012a; U.S. EPA, 2008; RPA, 2014). Total tri-, tetra-, penta-, hexa- and heptaBDEs are typically present at concentrations below 0.0039% w/w (ECB 2002; ECHA 2012a). Trace amounts of other compounds, thought to be hydroxybrominated diphenyl compounds can also be present as impurities. In addition, polybrominated dibenzo-p-dioxins and polybrominated dibenzofurans (PBDD/Fs) have been reported as impurities in some c-decaBDE products (Ren et al., 2011).

14. Chemical data on the main component of c-decaBDE, BDE-209, are presented in Figure 1 and in Tables 1 and 2 below (ECHA, 2012a). According to available information, c-decaBDE is currently available from several producers and suppliers globally (Ren et al., 2013; RPA, 2014) and is marketed under different trade names (Table 1).

Figure 1. Structural formula

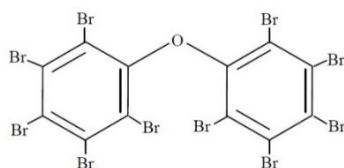


Table 1

Chemical identity of c-decaBDE and its main constituent BDE-209

CAS number:	1163-19-5 ¹
CAS name:	Benzene, 1,1'-oxybis[2,3,4,5,6-pentabromo-]
IUPAC name:	2,3,4,5,6-Pentabromo-1-(2,3,4,5,6-pentabromophenoxy)benzene
EC number:	214-604-9
EC name:	Bis(pentabromophenyl) ether
Molecular formula:	C ₁₂ Br ₁₀ O
Molecular weight:	959.2 g/mole
Synonyms:	decabromodiphenyl ether, decabromodiphenyl oxide, bis(pentabromophenyl) oxide, decabromo biphenyl oxide, decabromo phenoxybenzene, benzene 1,1' oxybis-, decabromo derivative, decaBDE, DBDPE ² , DBBE, DBBO, DBDPO
Trade names	DE-83R, DE-83, Bromkal 82-ODE, Bromkal 70-5, Saytex 102 E, FR1210, Flamecut 110R, FR-300-BA, which was produced in the 1970s, is no longer commercially available (ECA, 2010).

¹In the past CAS no. 109945-70-2, 145538-74-5 and 1201677-32-8 were also used. These CAS no. have now formally been deleted, but may still be in practical use by some suppliers and manufacturers.

²DBDPE is also used as an abbreviation for Decabromodiphenyl Ethane CAS no. 84852-53-9.

Table 2

Overview of relevant physicochemical properties of c-decaBDE and its main constituent BDE-209

Property	Value	Reference
Physical state at 20°C and 101.3 kPa	Fine, white to off-white crystalline powder	ECB (2002)
Melting/freezing point	300-310°C	Dead Sea Bromine Group (1993), cited in ECB (2002)
Boiling point	Decomposes at >320°C	Dead Sea Bromine Group (1993), cited in ECB (2002)
Vapour pressure	4.63×10 ⁻⁶ Pa at 21°C	Wildlife International Ltd (1997), cited in ECB (2002)
Water solubility	<0.1 µg/L at 25°C (column elution method)	Stenzel and Markley (1997), cited in ECB (2002)
n-Octanol/water partition coefficient, K _{ow} (log value)	6.27 (measured – generator column method) 9.97 (estimated using an HPLC method)	MacGregor and Nixon (1997), Watanabe and Tatsukawa (1990), respectively, cited in ECB (2002)
Octanol-air partition coefficient K _{oa} (log value)	13.1	Kelly et al. (2007)

1.2 Conclusions of the Review Committee, Annex E information

15. At its 10th meeting the Committee concluded that, “C-decaBDE is a synthetic substance with no known natural occurrence that is used as a flame retardant in many applications worldwide. Releases of c-decaBDE to the environment are continuing in all regions investigated. BDE-209

(or decaBDE), the main constituent of c-decaBDE is persistent in the environment and bioaccumulates and biomagnifies in several species of fish, birds and mammals as well as in food webs. There is evidence for adverse effects to critical endpoints including reproduction, survival, nerve- and endocrine systems. C-decaBDE is also degraded to lower brominated PBDEs, with known PBT/vPvB and POP properties. Lower brominated congeners contribute in the outcome of BDE-209 toxicity. Due to debromination and historical reservoirs of c-penta- and c-octaBDE congeners in the environment, organisms are exposed to a complex mixture of PBDEs that in combination pose a higher risk than BDE-209 alone. Measured BDE-209 levels in some species of biota, including higher trophic levels such as birds and mammals in source and remote regions are close to reported effect concentrations and indicate that BDE-209 together with other PBDEs pose a significant concern for human health and the environment. C-decaBDE with its main constituent BDE-209 is likely, therefore, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects, such that global action is warranted”.

16. The Committee also decided to establish an ad hoc working group to prepare a risk management evaluation that includes an analysis of possible control measures for decaBDE in accordance with Annex F of the Convention for consideration at its next meeting.

1.3 Data sources

17. The risk management evaluation was developed using information contained in the risk profile (UNEP/POPS/POPRC.10/10/Add.2) and Annex F information submitted by Parties and other stakeholders including non-governmental organizations as well as industry. Eight Parties and Observers submitted information: Australia, Canada, China, Japan, Mali, The Netherlands, Serbia, and USA. Four non-governmental Observers submitted information; European Automobile Manufacturers Association (ACEA), Bromine Science and Environmental Forum (BSEF), ICL-Industrial Products, Paxmyer AB as well as the International POPs Elimination Network (IPEN). All Annex F submissions are available on the Convention website (www.pops.int).

18. Scientific literature obtained from scientific databases such as ISI Web of Science and PubMed was included as well as "grey" literature such as government reports, risk- and hazard assessments, industry fact sheets etc.

1.4 Status of the chemical under international conventions and forums

19. In 1992, brominated flame retardants (BFRs) were given priority in the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) action plan. In 1998 c-decaBDE along with the other PBDEs was included in the list of "Chemicals for Priority Action" as well in the Joint Assessment and Monitoring Programme in OSPAR. OSPAR has promoted actions in the EU on risk-reduction strategies for c-decaBDE and electronic waste legislation.

20. In 1995, OECD Member countries agreed to oversee a voluntary industry commitment (VIC) by some of the global manufacturers of BFRs, among them c-decaBDE, to take certain risk management actions. The VIC was implemented in the United States, Europe and Japan. C-decaBDE production has since ceased in Europe and continues to be phased out in the United States. In parallel to this work, OECD conducted an investigation of the waste management practices in member countries with respect to products containing BFRs. The results of this investigation are documented in the Report on the Incineration of Products Containing Brominated Flame Retardants (OECD 1998). A Screening Information Data Sets (SIDS) Initial Assessment Profile (SIAP) on BDE-209 was prepared under the Environment, Health and Safety (EHS) Programme of the OECD and adopted by SIAM 16 and later endorsed by the OECD Joint Meeting in 2003. The Hazard/Risk Information Sheets for c-decaBDE and four other BFRs were updated in 2005, 2008 and 2009 (OECD 2014). PBDEs, including BDE-209, are chemicals of concern due to potential for endocrine disruption in the WHO/UNEP "State of the science of endocrine disrupting chemicals" (WHO/UNEP 2013).

1.5 Any national or regional control actions taken

21. C-decaBDE has been under scrutiny for its potential health and environmental impacts for more than a decade. Steps to restrict the use of c-decaBDE have been taken in some countries and regions, as well as by some of the major electronic companies (for an overview: UNEP/POPS/POPRC.9/2, Ren et al., 2011).

22. In Europe, regulations on c-decaBDE are in place in the EU and Norway. With the European Restriction of Hazardous Substances Directive (RoHS), the use of PBDEs, including c-decaBDE was banned in electronic and electrical equipment (EEE) in the EU at concentrations above 0.1% by weight of homogeneous material. Although this legislation came into force in February 2008, medical equipment was initially exempt. In June 2011 however, this exemption was removed and medical

devices fall within the scope of RoHS with effect from 22 July 2014. In 2012 c-decaBDE was identified as a PBT/vPvB (persistent, bioaccumulative and toxic/ very persistent, very bioaccumulative) substance in the EU and included in the Candidate List of substances of very high concern (SVHCs) under the Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (REACH). The EU are now considering a proposal to restrict the manufacture, uses and placing on the market of c-decaBDE as a substance and as a constituent of other substances, or in mixtures, if the concentration is equal or greater than 0.1% by weight. Articles containing c-decaBDE in concentrations greater than 0.1% by weight are also proposed to be restricted. However, derogations are suggested for articles on the second hand market, for EEE covered by the existing ban for these products, for articles used in the aviation and automotive sectors such as in production, maintenance, repair or modification of any aircraft or component eligible for installation produced in accordance with a type certificate or restricted type certificate (ECHA 2015) and for legacy spare parts used for the repair and maintenance of out of production vehicles. In addition, the available evidence seems to suggest that the proposed restrictions will not have an additional negative impact on the recycling materials. Further information should be collected to confirm this lack of impact on recycling. In Norway production, import, export, placing on the market and use of c-decaBDE at concentrations 0.1 % or more as a substance and in preparations and in articles are prohibited. The ban, which entered into force in 2008, includes all uses except the use of c-decaBDE in means of transportation. In addition, c-decaBDE is included in the Waste regulations which prescribes that waste containing c-decaBDE at or above 0.25% must be handled as hazardous waste.

23. In North America, the first restriction was adopted in Canada in 2008 with a ban on manufacture of PBDEs, including c-decaBDE, under the PBDE Regulations (Environment Canada 2008). In August 2010, Environment Canada and Health Canada published a Final Revised Risk Management Strategy for PBDEs which reiterated the objective of reducing the concentration of PBDEs in the Canadian environment to the lowest level possible. This resulted in agreement with three large worldwide producers of c-decaBDE to voluntarily phase-out the import of c-decaBDE to Canada. The voluntary agreement included a phase-out of c-decaBDE exports and sales for EEE by the end of 2010, for transportation and military uses by the end of 2013 and for all other uses by the end of 2012 (Environment Canada 2010). On April 4 2015, Canada published proposed regulations to prohibit the use, sale, offer for sale and import of tetraBDE, pentaBDE, hexaBDE, heptaBDE, octaBDE, nonaBDE and decaBDE and products containing them (e.g. resins, mixtures, polymers). The regulatory proposal excludes manufactured items. Canada has consulted on its plan to regulate PBDEs in products other than in mixtures, polymers and resins: <http://www.chemicalsubstanceschimiques.gc.ca/fact-fait/glance-bref/pbde-eng.php>. A voluntary phase out is also ongoing in the U.S. On December 17, 2009, as a result of negotiations with the United States Environment Protection Agency (U.S. EPA), the two U.S. producers of c-decaBDE and the largest U.S. importer announced commitments to voluntary phase out c-decaBDE in the U.S. (Annex F USA). The commitments consisted of reductions in the domestic manufacture, import, and sales of c-decaBDE starting in 2010. The U.S. EPA then encouraged other importers of c-decaBDE to join this initiative. As part of this encouragement, the U.S. EPA developed a Design for the Environment and Green Chemistry alternatives assessment for c-decaBDE to aid users in selecting suitable alternatives. In addition, the U.S. EPA proposed an update to the PBDE Significant New Use Rule (SNUR) and simultaneously proposed a Toxic Substances Control Act (TSCA) section 4 test rule for c-pentaBDE, c-octaBDE, and c-decaBDE. As proposed, the test rule would require development of information necessary to determine the effects of manufacturing, processing, or other activities involving these c-PBDEs on human health or the environment. In the proposal, the U.S. EPA stated its intention to promulgate the SNUR for anyone who intends to manufacture (including import) or process any of the chemicals for an activity that is designated as a significant new use, and to promulgate a TSCA section 4 test rule if it determines that manufacture (including import) or processing of c-PBDEs, including in articles, has not ceased by December 31, 2013. In addition, the U.S. EPA helped establish the Furniture Flame Retardancy Partnership (as part of the U.S. EPA's Design for the Environment Program). This is a joint venture between the Furniture Industry, Chemical Manufacturers, Environmental Groups, and the U.S. EPA to better understand fire safety options for the furniture industry. This type of group has helped the textile and foam industries to quickly transition away from BFRs (U.S. EPA, 2014b). Additionally, in the U.S., several states have also imposed restrictions on the manufacture and/or use of c-decaBDE in certain applications, including in mattresses, mattress pads and other bedding products, seating, furniture and electronic products (U.S. EPA, 2014a). Up-to-date information on state regulations can be found in the U.S. State-level Chemicals Policy Database, see <http://www.chemicalspolicy.org/chemicalspolicy.us.state.database.php> (LSCP 2015).

24. In Asia, restrictions have been adopted in China, India and Korea. In the revision of the Chinese RoHS legislation (Administrative Measure on the Control of Pollution Caused by Electronic Information Products) a restriction on the use of c-decaBDE in EEE was adopted (BSEF 2012).

According to Annex F information from China, PBDEs are not allowed in EEE at concentrations above 0.1% by weight for environmental labelling of products. E-waste must be handled in accordance with the legislation on the Waste of Electrical and Electronic Equipment (Jinhui et al., 2015; BSEF, 2015a). Furthermore, it has been reported that in China e-waste containing PBDE FRs should be separated out. It should be disposed of as hazardous waste. (Jinhui et al. 2015). China also recently announced that they will prohibit the use of PBDEs in cars with a concentration limit of 0.1 % from 1 January 2016. The restriction will apply to car parts for passenger cars containing fewer than nine seats (category 1M vehicles). The standard applies only to Chinese manufacturers and international companies involved in joint ventures with Chinese manufacturers. For existing models already on the road or in production, the standard will be phased in and will apply from 1 January 2018 (Chemical Watch 2015). Korea implemented a law in 2008, which covers end-of-life and restrictions on electronic products and vehicles. Exemptions, limit values and restricted substances are the same as the EU RoHS Directive. C-decaBDE is exempted from the list of hazardous substances in polymeric applications under the Recycling of Resource in Electronic Equipment and Automobiles' Regulation (BSEF 2012). Similarly to the EU end of life vehicle directive, legacy spare parts for out of production vehicles are exempted from this restriction. In India, the e-waste (management and handling) Rules came into effect in May 2012. The chapter on the Restriction of hazardous substances under the e-waste rules restricts the use of PBDEs in EEE with a threshold limit of 0.1% (BSEF, 2012, 2015b). In Japan, under the Chemical Substances Control Law, the annual production or import volumes of BDE-209 have to be reported along with shipment volumes (Annex F, Japan).

25. In addition to the above measures taken by countries, initiatives to voluntarily phase-out c-decaBDE have been taken by industry. The member companies of the BSEF moreover agreed with the U.S. EPA and Canadian authorities to voluntarily phase out production, import and sales of c-decaBDE in the United States and Canada as of the end of 2013. Also, the automotive industry represented by ACEA has committed in its latest input into the public SEAC consultation on the EU REACH Restriction to completely phase out DecaBDE globally, latest by mid of 2018 for current production and new developments. Phase out is also ongoing in North America and China. Many electronics firms have already eliminated or committed to eliminating c-decaBDE in accordance with the EU RoHS, including Philips, Electrolux, Sony, Dell, Intel, Sharp, Apple and Hewlett Packard (Renet et al., 2011). Other industrial stakeholders have also implemented/ launched voluntary initiatives. In Germany there has been a voluntary agreement for the use and production of all PBDEs on the part of the German industry since 1986 because of concerns about brominated dioxins/furans that could be present in products (Leisewitz & Schwarz, 2001). The commitment was only of limited effect (Leisewitz and Schwarz, 2001). Furthermore, large global furniture producers, have phased-out the use PBDEs including c-decaBDE and several mattress producers globally now offer PBDE-free mattresses (see e.g. <http://mattresszine.com/mattress-news/pbde-free-manufacturer-product-list/>). In addition there are voluntary initiatives to control and reduce potential emissions of commercial decaBDE into the environment. The European Flame Retardant Association (EFRA) together with the industry's global organisation, the Bromine Science and Environmental Forum (BSEF), has moreover launched a voluntary initiative whereby member companies aim to manage, monitor and minimize industrial emissions of high production volume BFRs, including decaBDE through partnership with the supply chain (VECAP, 2012). This program, called the Voluntary Emissions Control Action Program (VECAP) started in Europe in 2004 but has later also been introduced in North America and in Japan.

2. Summary information relevant to the risk management evaluation

26. As discussed in the risk profile, c-decaBDE is produced in high quantities worldwide (UNEP/POPS/POPRC.10/10/Add.2, UNEP/POPS/POPRC.10/INF/5). In the past, c-decaBDE constituted 75-80% of the total global production of PBDEs (KemI, 2005; RPA, 2014). Furthermore, the total global amount of c-decaBDE produced in the period 1970-2005 was between 1.1-1.25 million tonnes, similar to the scale of production of PCBs (Breivik, 2002).

27. The many uses and applications of c-decaBDE is reviewed in the risk profile (UNEP/POPS/POPRC.10/10/Add.2, see also Table 1, UNEP/POPS/POPRC.11/INF/6) but can be roughly divided into two main categories – in plastics polymers and in textiles. As discussed in detail in the risk profile the c-decaBDE use within these applications varies between different countries and regions. Further as described in the risk profile, emissions of c-decaBDE to the environment occur at all its life cycle stages; during production, formulation and other first- and second-line uses at industrial/professional sites, as well as during service life of articles, their disposal as waste and during recycling operations (UNEP/POPS/POPRC.10/10/Add.2 and references within). The release and distribution of c-decaBDE to the environment via these routes is confirmed by monitoring data (UNEP/POPS/POPRC.10/INF/5), and are likely to occur over a long time-frame.

28. A number of emission assessments have been performed based on modelling (UK EA, 2009; RPA, 2014; ECHA, 2014a; Earnshaw et al., 2013). The assessments collectively indicate that emissions of c-decaBDE during service life and upon disposal of products (as waste) are the most important sources of release, and are in line with reported environmental monitoring data (UNEP/POPS/POPRC.10/10/Add.2). C-decaBDE also contributes to emissions of lower brominated PBDEs as well as brominated dioxins and furans (PBDD/F) which are unintentionally formed throughout the whole lifecycle of PBDEs like c-decaBDE (UNEP/POPS/POPRC.10/10/Add.2).

29. Control measures should be considered for all the above described sources of exposure and releases including production, use and in the waste management phase.

2.1 Identification of possible control measures

30. The objective of the Stockholm Convention (Article 1) is to protect human health and the environment from POPs. This may be achieved by listing c-decaBDE in Annex A, B and/ or C in the Convention, possibly accompanied with exemptions for certain uses and/or acceptable purposes. Given that the main constituent of c-decaBDE, BDE-209, is likely as a result of its long range environmental transport to lead to significant adverse human health and environmental effects such that global action is warranted (UNEP/POPS/POPRC.10/10/Add.2, UNEP/POPS/POPRC.10/10), and mindful of the precautionary approach set forth in Article 1 of the Convention, the aim of any risk reduction strategy for c-decaBDE should be to as far as possible reduce and eliminate emissions and releases of c-decaBDE. The most effective control measure would be to list c-decaBDE in Annex A of the Convention with no exemptions for production and use.

31. If c-decaBDE is listed in the Convention, the provisions of Article 6(1)(d)(ii) have to be fulfilled. This means that waste shall be disposed of in such a way that the POP content is destroyed or irreversibly transformed so that it does not exhibit the characteristics of POPs, or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the POP content is low. Parties should also consider emission reduction measures and the use of best available techniques and best environmental practices (BAT/BEP) in the waste management phase. In addition, Parties shall endeavour to develop appropriate strategies for identifying sites contaminated with c-decaBDE. If contaminated sites are identified and remediation is undertaken, it shall be performed in an environmentally sound manner.

32. In the event that the Conference of the Parties agrees on specific exemptions and/or acceptable purposes, emission reduction measures and the use of BAT/BEP during production and manufacture should also be considered. Additional measures linked to potential exemptions and/or acceptable purposes could include a requirement on proper and informative labelling or other means of identification of c-decaBDE-containing new products similar to what was agreed upon when listing HBCD (SC-6/13). Labelling of products containing POPs may be a necessary measure in order to effectively manage products upon becoming wastes. In addition, labelling of POP wastes containers is a basic safety feature and important for the success of any waste management system. Each waste container should be labelled to identify the container (e.g., ID number), the POP present and the hazard level (Basel Convention, 2015b).

33. Some Parties have identified the need for a possible exemption for recycling in line with listed BDEs. Noting that there are concerns about articles, products in use, and recycled products containing decaBDE being exported especially to developing countries and countries with economies in transition, African experts oppose a recycling exemption due to lack of capacity to identify and analyse products containing deca BDE. Furthermore, some transportation industry associations have identified a need for exemptions for the use of c-decaBDE in the repair, and modifications of aircrafts under existing type certificates and for functional legacy spare parts used for the repair and maintenance of out of production vehicles. The need for these exemptions has also been proposed under the ongoing restriction process in the EU where an exemption for the automotive industry is supported by SEAC. The Canadian Vehicle Manufacturer's Association raises a concern for a ban on production and use of c-decaBDE due to the requirement to provide service and replacement parts for vehicles already on the market. Further, according to The Boeing Company and the Aerospace and Defence industries Association of Europe, c-decaBDE is largely substituted in newer products, but presently not for all uses. In addition, the aviation and aerospace industry indicated a need for use of c-decaBDE as a FR in components and spare parts in airplanes including a range of polymer, textile and electrical items. The Automotive Industry represented by ACEA has requested an exemption for legacy spare parts with functional properties. Parts only with decorative properties may not be considered under the exemption. Their request is related to the testing requirements of original vehicles which are no longer in mass production and often have not been for quite some time, the possibility of testing does not exist in particular for functional components. It is furthermore likely that

manufacturers of spare parts of such functional components will stop their manufacture. This can ultimately result in unavailable or untested and thus dangerous replacement parts, or non-compliance with national obligations to deliver such parts for at least 10 years after mass production. In a worst case, vehicles may not be repairable and thus would have to be wasted.

34. C-decaBDE phase-out could include FR substitution, resin/material substitution and product redesign as well as re-evaluation of fire-safety requirements. As further discussed in chapter 2.3 of this document, alternatives, although with different hazard profiles, to all uses of c-decaBDE are available and accessible (ECHA 2014a; U.S. EPA, 2014a). Moreover, for a wide range of the applications where c-decaBDE is used other FRs have already replaced c-decaBDE (KemI 2005).

2.2 Efficacy and efficiency of possible control measures in meeting risk reduction goals

35. In order to reduce c-decaBDE emissions control measures at all life cycle stages need to be in place.

36. Although waste is recognized as an important source to c-decaBDE emissions, it was recently reported that articles in service life are the largest source of c-decaBDE emissions (RPA, 2014; ECHA, 2014a). For articles, various possible risk management options could be considered. However, the control measure that most effectively will abate global emissions is to globally ban the production and use of c-decaBDE in articles and avoid recycling of products containing c-decaBDE. According to information presented in Section 2.3, the phase-out of c-decaBDE in new products is technically feasible and may be accomplished within a short time-frame given that alternatives for all known uses are available and accessible. Articles in use will however contribute to environmental emissions for some time after a global ban or restriction on use has entered into force. Exactly how long products will continue to be a source of c-decaBDE emissions is difficult to predict. The estimated service life for products containing c-decaBDE varies between products (i.e. EEE or upholstery) and between global regions. Moreover, c-decaBDE is used in such a wide range of products that estimating service lifetimes for each type of product is challenging. An average of 10 year service life was used in European emission estimates (Earnshaw et al., 2013). According to Buekens and Yang (2014) EEE have an average service life of 3-12 years globally, with larger appliances/objects having longer service life. In China, the estimated service life is 10-16 years for most EEE products except computers that are reported to have a service life of no more than 4-6 years (Yuan, 2015). In some developing countries, service lives of different c-decaBDE products may be even longer.

37. In addition to releases from articles during service life, releases from products and articles upon becoming waste are also of significant concern (UK EA 2009; ECHA 2014 a,b). Following a listing of c-decaBDE in the Stockholm Convention a concentration level for low POP content would typically be established in cooperation with the Basel Convention, which also typically will be tasked with determining the methods that constitutes environmentally sound disposal. Introducing waste management measures, including measures for products and articles upon becoming waste, in accordance with Article 6 of the Convention, would ensure that wastes containing c-decaBDE at concentrations above the low POP content are disposed of in an effective and efficient way such that their POPs content is destroyed or otherwise disposed of in an environmentally sound manner. These measures would also address proper waste handling, collection, transportation and storage and ensure that emissions and related exposures to c-decaBDE from waste are minimized. Establishment of the low POP value and the guidelines developed by the Basel Convention will help Parties to dispose of waste containing c-decaBDE in an environmentally sound manner (UNEP/CHW.12/INF/9).

38. C-decaBDE is expected to be present in plastics and textiles in several waste streams such as "End of Life Vehicles" (ELV), e-waste, textile- and mixed waste. Information on c-decaBDE levels in these waste streams is limited. For the global measures to be efficient, proper waste handling could require identifying BDE-209 containing materials to facilitate destruction of the POP content in the waste (UNEP/CHW.12/INF/9). In waste streams, materials containing c-decaBDE could be sorted out, either manually or by use of automated sorting and separation systems. Automated sorting will not always be feasible as c-decaBDE containing materials cannot be readily identified without the use of advanced technical equipment or because the c-decaBDE containing waste is mixed with other materials which makes the sorting more technically challenging. However, establishing an inventory of c-decaBDE containing wastes may assist Parties as well as the industry in identifying waste fractions that may contain c-decaBDE, thereby allowing proper, although more crude sorting of the waste also by manual methods. According to newly published studies by the Nordic Council of Ministers (NCM), e-waste treatment processes with significant low-technology elements, including manual disassembly and separation of e-waste, can currently achieve significantly better plastic recycling than highly mechanised and automated alternatives. Lower-technology approaches carry

relatively higher costs and may otherwise appear unattractive in a sector where technological advance seems vital.

39. Two guidance documents, developed under the Stockholm Convention,¹ have identified common technologies and approaches for identification and sorting out wastes containing polybrominated dipenylethers (PBDEs) listed under the Convention, as well as for their recycling. These methods are compatible with both manual and automated sorting of wastes. The recycling industry, however, in practice separates plastics based on total bromine content, not individual BFRs (UNEP/POPS/POPRC.6/2/Rev.1).

40. A recent Dutch study reported the fate of POP-BDEs (including BDE-209) in plastic waste streams. In general, POP-BDEs were found in very few single cars, or e-waste. However, BDE-209 was frequently found (92-100%) in the shredded material from e-waste or cars and in recycled plastic pellets (100%) at higher concentrations than other POP-BDEs. This is often due to the fact that these waste streams are being mixed during shredding (IVM/IVAM, 2013). In Europe, an extended producer responsibility scheme is formulated in the ELV directive (2000/53/EC) which requires that materials from ELVs are being recycled in order to meet the stringent recycling quota of 85%. Legal recycling obligations are existing or emerging also in other countries (e.g. already existing in Korea and emerging in India). The overall recycling rate of ELV in the EU reaches approximately 85% (EUROSTAT/2015). Sweden reported that plastic from ELVs usually ends up in the Shredder Light Fraction (SLF), which is mainly incinerated, and in some cases specific fractions are being landfilled. In Norway, BDE-209 was identified in car upholstery from Asia, in levels of 1.5-2.5% w/w, and the waste components are considered hazardous if they contain more than 0.25% c-decaBDE and incinerated after shredding. Large plastic parts from ELV in Germany are mainly recycled but about 10% are reused. The SLF with high calorific value is incinerated or used for energy recovery, while the low calorific value fraction, which has higher mineral content, can be used for landfill construction or the back-filling of mines (RPA, 2014). In the recent Dutch study, BDE-209 was not found in European ELV parts but was detected in 59% of the ELV parts of older US and Asian cars assembled before 2001. Analysed and concentrations ranged from < 2 – 23,000 µg/g (IVM/IVAM, 2013 and Tables 2 and 3, respectively, in UNEP/POPS/POPRC.11/INF/6). Collectively these studies illustrate the need to sort out and remove c-decaBDE containing parts prior to destruction (i.e. shredding) and recycling operations might be an important and effective measure to avoid further distribution of c-decaBDE contained in waste. However, it should be noted that separating deca-BDE containing parts can be impractical due to the diversity of deca-BDE containing parts in ELVs. Sorting technologies after shredding that would be able to separate c-decaBDE containing fractions are not available on an industrial scale and especially in developing countries. Policies on extended producer responsibility in which a producer's responsibility for a product is extended to the waste stage of a product's life cycle, could play a key role in implementing these practices. The automotive industry has indicated that existing and emerging recycling quotas in the EU cannot be met without a derogation for ELV recycling.

41. Destruction of c-decaBDE containing waste in accordance with Article 6.1 d(ii) and 6.2 of the Convention would contribute to the elimination of emissions and exposure from waste. Different techniques for handling POPs-containing waste in an environmentally sound manner are available (Basel Convention 2015a, b; Stockholm Convention, 2012a). Controlled incineration, where the FR decomposes in the incineration process, is one way to dispose of waste containing c-decaBDE (ECHA, 2014). Incineration at high temperatures is generally considered the effective manner to destroy POPs like c-decaBDE/PBDEs or products containing these chemicals, such as in hazardous waste incinerators and by cement kiln co-incineration (Basel Convention, 2015a). Experimental evidence shows that under some conditions, including in state-of-the art municipal solid waste incineration facilities, incineration of POPs waste may lead to formation of polybrominated dibenzo-dioxins (PBDD), polybrominated dibenzofurans (PBDF), brominated-chlorinated dibenzo-p-dioxins (PXDD) and dibenzofurans (PXDF) (NCM, 2005; ECA, 2011; Stockholm Convention, 2012a; Weber and Kuch, 2003). These incineration products formed from waste containing c-decaBDE may be destroyed at the very high continuous operating temperatures with their emissions to the environment controlled to some extent via the flue gas treatment systems, though contaminated fly ash will also be formed which requires disposal in a hazardous waste landfill. The incineration efficiency and the operating conditions of the flue gas treatment systems are of great importance to the

¹ Guidance for the inventory of polybrominated dipenylethers (PBDEs) listed under the Stockholm Convention on POPs; Guidance for the inventory of polybrominated dipenylethers (PBDEs) listed under the Stockholm Convention on POPs.

resulting emissions of dioxins (NCM, 2005; 5EBFRIP, 2005). A number of countries and regions globally have the capacity to incinerate POPs, such as in hazardous waste incinerators or by co-processing in cement kilns. However, a general overview of the global capacity or the capacity for incineration is not available. It has to be considered that technically sufficient incineration capacities for hazardous waste are missing for POPs, even in industrialised countries. As a consequence on a short term basis transportation efforts with related environmental impact have to be considered. Other countries such as the Netherlands has over-capacities.

42. Where neither destruction nor irreversible transformation is the environmentally preferable option, for waste with a POP content above the low POP content, other environmentally sound disposal techniques may be used. Specially engineered landfills may be one option, however, the long-term fate of c-decaBDE in landfills is not well understood and landfills are believed to be the most prominent c-decaBDE emission source from waste (ECHA, 2014a). Monitoring of landfill leachates has shown the presence of BDE-209 (SFT, 2009; Chen et al., 2013) and BDE-209 was also found to be the dominant PBDE congener in landfill sediments (SFT, 2009). However, currently in many countries landfilling is the most common way of waste disposal, leading to c-decaBDE containing waste accumulating in the landfills (U.S. EPA, 2007). Waste containing c-decaBDE above the low POP content level can be landfilled only in specially engineered landfills, designed to prevent leaching and spreading of hazardous chemicals, as described by the Basel Convention guidance (Basel Convention, 1995, 2015a,b; Stockholm Convention, 2012a). Waste containing c-decaBDE below the low POP content level shall be disposed of in an environmentally sound manner in accordance with pertinent national legislation and international rules, standards and guidelines.

43. An additional concern is sludge (biosolids) from wastewater treatment. This sludge may be used as a fertilizer on agricultural soil and has been found to contain BDE-209 in many instances (de Wit et al., 2005; NEA 2012; NERI, 2003; Ricklund et al., 2008a, b; Earnshaw et al., 2013). In many countries sludge from wastewater treatment plants is incinerated or disposed of in landfill due to high-levels of environmental pollutants. If decaBDE concentration in sludge when considered as waste surpasses the low POP limits as defined in the convention text article 6 para 2 c it should be considered as hazardous waste. The prevention and minimization of POP wastes are the first and most important steps in the overall environmentally sound management of such wastes. The Stockholm Convention BAT/BEP Guidelines underlines the importance of source reduction including minimization of quantity of wastes and reduction of toxicity and other hazard characteristics (Stockholm Convention, 2012a). In its Article 4, paragraph 2, the Basel Convention calls on Parties to “ensure that the generation of hazardous wastes and other wastes is reduced to a minimum”. Waste prevention should be the preferred option in any waste management policy. According to the framework for the environmentally sound management of hazardous wastes and other waste, the need to manage wastes and/or the risks and costs associated with doing so are reduced by not generating wastes and ensuring that generated wastes are less hazardous (UNEP, 2013a).

44. Another option of waste management is energy recovery. Plastic containing FR can be destroyed in incinerators for energy recovery. Incineration with energy recovery is a process whereby the energy generated during the combustion of plastic waste is recovered and used to produce heat and/or electricity for domestic or industrial use. In the EU, it has been reported that some of the shredded plastic waste fractions from ELV are incinerated for energy recovery (IVM/IVAM, 2013; RPA, 2014). In Germany in 2010, 40% of the shredded fraction from ELV was incinerated for energy recovery while large plastic parts from ELV were mainly recycled and 10% were reused (RPA, 2014).

45. Prohibiting recycling of materials containing c-decaBDE would contribute to the elimination of risks associated with the recycling process and continuing exposure through products and wastes. Waste management measures in line with Article 6 (d) of the Convention to reduce or eliminate releases from stockpiles and waste, including products and articles upon becoming wastes, containing c-decaBDE above the low POP content will be required to reduce emissions of c-decaBDE. POPRC recommendations on elimination of PBDEs from the waste stream note that the objective is to eliminate PBDEs from the recycling streams as swiftly as possible. Failure to do so will inevitably result in wider human and environmental contamination and the dispersal of PBDEs into matrices from which recovery is not technically or economically feasible and may result in loss of long-term credibility of recycling (Decision POPRC-6/2).

46. Although materials containing c-decaBDE can be recycled several times with only a small loss of the c-decaBDE content (Hamm et al., 2001; as cited in Earnshaw et al., 2013) this practice will continue to spread c-decaBDE to the environment as well as human exposure. The fraction of the recycled plastics used to produce new articles is unknown (ECHA 2014a). However, the more recycled products with low concentrations of BDE-209 there are on the market, the more difficult it will be to identify waste containing c-decaBDE. As a part of the mixed plastic waste to be recycled,

plastic containing c-decaBDE will likely spread into new products that will be difficult to track. BDE-209 has been found in products made from recycled plastics, including food contact articles (FCA) (Samsonck and Puype 2013; Puype et al., 2015). BDE-209 was measured in 10 out of 49 items in concentrations varying between 10 and 1922 mg/kg (Samsonck and Puype, 2013). In a recent study, BDE-209 was found in FCA such as thermo-cup lids and an egg cutter made from recycled e-waste (Puype et al., 2015). These studies evidently show that products made from recycled material containing c-decaBDE re-enters the market and that some of these, such as toys and FCA, are products that are used in a way that has the potential to pose a threat to human health.

47. Furthermore, some c-decaBDE containing waste ends up in countries that do not have the infrastructure or the technology to dispose waste in an environmental sound manner. Developing countries face economic challenges and lack the infrastructure for sound hazardous waste management, and have particular challenges in this regard (ILO 2012). As environmentally responsible waste management options are highly technological and require high financial investment, there is currently a high level of transboundary, often illegal, movement of e-waste into developing countries for cheaper recycling (SAICM/ICCM.2/INF36). Available estimates of transboundary exports of e-waste are highly variable (reviewed by Breivik et al., 2014). Furthermore, it was reported that of the amount of e-waste collected in developed countries and sent for recycling, 80 per cent ends up being shipped to developing countries to be recycled by hundreds of thousands of informal workers (ILO, 2012). Unregulated recycling processes may pose a risk to workers and the public through exposure to toxic chemicals (U.S. EPA, 2014a; Bi et al., 2007; Qu et al., 2007; Tue et al., 2010; Tsydenova and Bengtsson 2011). For example, EEE containing c-decaBDE and other toxic substances are often recycled under conditions that results in a relatively high release of BDE-209 to the environment and contamination of the sites (Zhang et al., 2014), children (Xu et al., 2014) and exposure of workers (Tue et al., 2010). As described above, developing countries lack infrastructure for sound hazardous waste management and waste management is typically dealt with in the informal sector using rudimentary techniques, where open burning and dumpsites are common destinations for c-decaBDE-containing articles and electronic wastes (Li et al., 2013; Gao et al., 2011; ILO, 2012).

48. In the past years, the infrastructure for collecting and recycling electronics has grown considerably, mostly in Europe and parts of Asia, using automated technologies for harvesting metals and plastics from electronics. Between 25% and 30% of the e-waste generated each year is composed of plastic and less than 10% of this plastic is currently recycled. Based on a Dutch mass flow analysis, 22% of the POP-BDE in e-waste is expected to end up in recycled plastics. The same study shows that in the automotive sector, 14% of the POP-BDE is expected to end up in plastics recycling, while an additional 19% is expected to end up in second-hand parts (reuse) (IVM 2013). Furthermore, BDE-209 was detected in 100% of the isolation material and carpet padding tested and in 25 % of the plastic toys; both of these products were made from recycled plastics (IVM 2013). In the U.S. approximately 15-20% of post-use EEE was recycled and between 80 – 85% was disposed of in landfills or incinerated (U.S. EPA, 2007). The situation regarding the management of textile waste in both Europe and other regions is uncertain. The European Chemicals Agency (ECHA) however stipulates that c-decaBDE containing textiles are currently not recycled in the EU (ECHA, 2014a). There are uncertainties in the level of recycling of textile within parties and in terms of decaBDE content. Thus it is difficult to define whether a restriction on recycling of textiles containing decaBDE will have economic implications for the textile recycling industry.

49. At present around 20% of all plastic waste in the EU is recycled annually on average, of which only a smaller fraction is flame retarded plastic (RPA, 2014; ECHA, 2014a, EERA 2015). In the EU today 30 % of the WEEE contains FR and only some 5 % of the plastics fed into specialized plastics recycling plants for WEEE in average consist of plastics with BFRs (EERA 2015; ECHA, 2014a). In the U.S. EEE recycling is expected to increase in the future due to state law requirements, but in 2012 only 9 % of the total plastic waste generated was recovered for recycling (U.S. EPA, 2014a,c). For textiles, no or very limited material recycling takes place in the EU and in the U.S. (ECHA, 2014a; U.S. EPA, 2014a; RPA, 2014).

50. Available literature on BDE-209 levels in waste streams from Europe shows that BDE-209 levels are below detection limit in mixed plastics from mixed small household appliances (C2), small household appliances (P32) and mixed flat screen TVs (P42), while mixed plastics from CRT monitors (P31) and CTR TVs i.e. older computers and TVs may contain 3200 and 4400 ppm BDE-209 on average (Wager et al., 2011). A study of e-waste in Nigeria reported that BDE-209 was detected in 15 % (24 of 159) of the TVs tested. The concentration ranged from 0.086 to as much as 23.7 % with an average of 5.7 %. C-decaBDE was detected in 4.5 % of the tested PC CRTs (10 of 224). In computer monitors the concentrations ranged from 0.26- 5.4 %, average of 1.28 %.

51. Commercial PBDE mixtures c-pentaBDE (tetra- and pentaBDE) and c-octaBDE (hexa- and heptaBDE) are listed in Annex A of the Convention with specific exemptions for recycling. To support Parties in the implementation of strategies to reduce the recycling of materials containing PBDEs, POPRC (Decision POPRC-6/2, UNEP/POPS/POPRC.6/2/Rev.1) outlined a series of recommendations that are relevant to c-decaBDE as well. In summary, POPRC recommended to eliminate PBDEs from the recycling streams as soon as possible. To meet this recommendation articles containing PBDEs should be separated from the waste stream before recycling. Failure to do so will inevitably result in wider human and environmental contamination and the dispersal of PBDEs into matrices from which recovery is not technically or economically feasible. Furthermore, PBDEs should not be diluted since this would not reduce the overall quantity in the environment.

52. In order to sort out c-decaBDE containing wastes for environmentally sound management and to avoid and/or minimize recycling of articles that contain c-decaBDE, effective screening and separation techniques are necessary for material containing FR. When screening and separation techniques are not readily available and concentrations are assumed to be above the low POP level, caution should be exercised and recycling avoided. Furthermore, waste, products and articles containing c-decaBDE should not be exported to developing countries since there is generally limited capacity or technology to treat the waste in an environmentally sound manner and protection of workers is limited or lacking.

53. Production and down-stream industrial use of c-decaBDE also contributes to the c-decaBDE emissions (UNEP/POPS/POPRC.10/10/Add.2). Although emissions in these stages of the life-cycle are generally assumed to be small (ECHA, 2014a), the environmental impact of industrial production and use can be high and likely depend on the technology used as well as management practices. The absence of decreasing trends in the environment following voluntary measures by the industry to reduce emissions during production and industrial use (ECHA, 2014a) suggests that the emissions during service life and the waste stage are much higher than during production, and that a ban on production is necessary to fully eliminate c-decaBDE releases in these phases of its life-cycle as well as from articles in use.

54. A ban on the production and use of the BDE-209-component of c-decaBDE, together with waste management measures to reduce or eliminate releases from stockpiles and waste, including products and articles upon becoming wastes, would be an efficient way to eliminate all emissions of BDE-209 and can also be considered as the most appropriate option for the phase-out of BDE-209 under the Stockholm Convention.

55. The alternative option would be to list the BDE-209-component of c-decaBDE in Annex A, B and/ or C with exemptions and/or acceptable uses. However, according to the Annex F information submitted by Parties, technically feasible alternatives appear to be available for all applications. However, already in October 2014, some industry observers have raised a concern regarding service and replacement of legacy spare parts in articles already in use and identified a possible need for exemptions in the transportation sector. The aviation and vehicle industry are in the process of phasing out c-decaBDE, and some materials and components could still contain c-decaBDE. The vehicle industry represented by ACEA has already indicated to globally phase out c-deca-BDE by the middle of 2018 for current production and new developments. Thus, an exemption is only required for some legacy spare parts with functional properties. In addition, a small number of Parties have suggested the possibility of a need for a recycling exemption in line with what has been agreed for previously listed POP-BDEs. Other parties oppose a recycling exemption due to lack of capacity to identify and analyse products containing deca BDE.

2.3 Information on alternatives (products and processes) where relevant

56. The U.S. EPA and ECHA recently published comprehensive assessments of chemical alternatives to c-decaBDE (U.S. EPA, 2014a; ECHA, 2014a). The U.S. EPA assessment provides detailed human health and ecological hazard information for 29 substances and mixtures that have been identified as potentially alternatives to c-decaBDE in a variety of applications (see Table 4, UNEP/POPS/POPRC.11/INF/6). The report published by ECHA identified 13 chemicals for further assessment and evaluation as alternatives to c-decaBDE (ECHA, 2014a; see Table 5, UNEP/POPS/POPRC.11/INF/6). Other assessments of alternatives to c-decaBDE have also been conducted in the past (LSCP, 2005; Illinois, 2006; CPA 2007; DME, 2007; ECB, 2007; Washington, 2008; Maine, 2010; ENFIRO, 2013). The research project, ENFIRO, assessed substitution options for selected BFRs by comparing information on hazard and by testing fire-and application performance for different uses.

57. To date, most assessments of alternatives to c-decaBDE/BDE-209 have focused on the replacement of c-decaBDE with alternative chemicals (i.e. a chemical that have flame retardant properties that can be substituted directly for c-decaBDE in articles). However, alternative techniques to improve fire safety also exist and are also described in some of the assessments (ECHA, 2014a; U.S. EPA, 2014a).

58. An overview over the available c-decaBDE alternatives is provided in Sections 2.3.2-2.3.5 below and UNEP/POPS/POPRC.11/INF/6.

59. Presented below (Table 3) are the categories of materials and sectors/products in which c-decaBDE has been or is currently used globally (see also further info in Tables 1, 6, 7 in UNEP/POPS/POPRC.11/INF/6).

Table 3

Summary of polymers where c-decaBDE is used as a FR and their end-use application by category

Polymer Group	End-Use Applications								
	Electronics	Wire and Cable	Public Buildings	Construction Materials	Automotive	Aviation	Storage and Distribution Products	Textiles	Waterborne emulsions & coatings
Polyolefins ¹ (PE, PP, EVA)	X	X	X	X	X	X	X	X	X
Styrenics ² (PS, HIPS, ABS)	X		X	X	X	X	X		
Engineering Thermoplastics ³ (Polyesters (PET, PBT), PA, PC, PC-ABS, PEE-HIPS)	X	X	X	X	X	X		X	X
Thermosets ⁴ (UPE, epoxies, melamine-based resins)	X		X	X	X	X	X	X	X
Elastomers ⁵ (EPDM rubber, thermoplastic PUR, EVA)	X	X	X	X	X	X	X	X	X
Waterborne emulsions and coatings ⁶	X	X	X	X	X			X	X

Source: U.S. EPA, 2014a (Table 2.3.1)

¹Polyolefins: polyethylene (PE), polypropylene (PP), ethylene vinyl acetate (EVA).

²Styrenics: polystyrene (PS), high-impact polystyrene (HIPS), acrylonitrile butadiene styrene (ABS).

³Engineering Thermoplastics: polyesters (polybutylene terephthalate (PBT), polyethylene terephthalate (PET)), polyamides (PA, nylons), polycarbonate (PC) and PC-ABS, polyphenylene ether- high-impact polystyrene (PE-HD), PE ether HIPS.

⁴Thermoset plastics: unsaturated polyesters (UPE), epoxies, melamine-based resins.

⁵Elastomers: ethylene propylene diene monomer rubber (EPDM rubber), thermoplastic polyurethanes (thermoplastic PUR), EVA.

⁶Waterborne emulsions and coatings: acrylic-, polyvinyl chloride (PVC)-, ethylene vinyl chloride- and urethane-emulsion.

2.3.1 Alternative substances

60. Different considerations are relevant when selecting a replacement for c-decaBDE. The Stockholm Convention Article 3 paragraph 3 requires Parties that have regulatory and assessment schemes for new chemicals to take measures to regulate with the aim of preventing the production and use of new chemicals that exhibit the characteristics of POPs. In addition, in accordance with Article 3 paragraph 4, Parties should take the POPs criteria in Annex D into account when conducting assessments of chemicals currently in use. According to the POPRC guidance on alternatives and substitutes, alternatives should moreover be available, accessible, efficient and technically feasible (UNEP/POPS/POPRC.5/10/Add.1). In addition, a replacement substance should ideally not substantially increase costs -neither costs of manufacturing or costs incurred as a result of harm to the environment and human health. For the downstream user, manufacturing costs may however not necessarily be the most critical point when substituting one chemical for another. For example, for engineering polymers, which are materials with exceptional mechanical properties, overall function is considered more important than price (KemI, 2005). Furthermore, in applications where chemical substitutes are being considered, an evaluation should first be conducted to address whether flame retardancy is needed and if so how appropriate fire safety can be achieved without adverse

environmental and human health consequences (ECHA 2014a). For example, and as discussed in chapter 2.3.5 below, in EEE, removing sources of ignition or reducing operative voltage requirements can eliminate the need for FRs (LCSP, 2005).

61. According to ECHA (2014a), the industry's choice of a new substitute chemical "will depend on when a possible further regulatory action is envisaged and the ease with which the alternative can be used to substitute c-decaBDE". In other words downstream users are assumed to be less likely to choose an alternative substance subject to current-or future regulatory risk management. They are also assumed to select a so called drop-in alternative i.e. an alternative substance with similar technical properties to the chemical already in use that can be phased in to the manufacturing process with minimal efforts. Nonetheless, substitution to an alternative chemical may necessitate additional changes in product formulation or movement to different classes of polymers, and product manufacturers transitioning to new FRs may have to test a number of chemicals or chemical combinations to determine if they meet performance requirements in final products (U.S. EPA, 2014a).

62. The hazard profiles generated by the U.S. EPA (U.S. EPA, 2014a; Table 4, UNEP/POPS/POPRC.11/INF/6) show that "some of the chemical alternatives have similar hazard profiles to c-decaBDE; other alternatives have trade-offs in hazard endpoints; some alternatives have preferable profiles compared to c-decaBDE. FRs with similar profiles are persistent, potentially bioaccumulative, and tend to have hazards for carcinogenicity, developmental neurotoxicity and repeated dose toxicity. Other alternatives are associated with the concern for hazard based on different endpoints, for example aquatic toxicity, and present hazard trade-offs when compared to c-decaBDE. The large polymers are anticipated to be safer because their large size limits bioavailability. Unfortunately, their long-term fate in the environment is unknown and halogenated polymers may generate halogenated dioxins and furans during combustion. Combustion by-products are not assessed in the report" (U.S. EPA, 2014a). Similar conclusions may be drawn based on the information on hazard and risk given in ECHA (2014a).

63. Among the different categories of chemical alternatives, BFRs would appear to be able to act as drop in replacements for a wide range of the known c-decaBDE applications (ECHA 2014a; U.S. EPA, 2014a). In addition, viable non-halogenated FR/polymer combinations have been identified as alternatives for most c-decaBDE uses. Some of the non-halogenated FR/polymer combinations may also have better performance than c-decaBDE/polymer (ENFIRO, 2013; see Table 8, UNEP/POPS/POPRC.11/INF/6).

64. From an industrial point of view i.e. a technical and economic perspective focused on manufacturing costs, decabromodiphenyl ethane (DBDPE) is identified as the most feasible replacement substance for c-decaBDE (ECHA 2014a). According to Environment Canada, DBDPE is a cost-effective replacement for c-decaBDE applications relevant to Canadian manufacturers, and a switch from c-decaBDE to DBDPE is said to be "likely ongoing" in USA and Canada (ECHA 2014a). DBDPE is also identified as the most likely substitute to c-decaBDE in the EU (ECHA, 2014a). However, U.S. EPA has identified DBDPE as "high hazard for developmental toxicity" and "a high hazard for bioaccumulation". These end-points were assigned using values from predictive models and/or professional judgement. The identification as "very high hazard for persistence" was based on empirical data (US EPA, 2014a). In addition, DBDPE is undergoing substance evaluation in the EU based on the concern that it may exhibit PBT/vPvB properties (ECHA 2014b, UK EA 2007). Other substances may also act as technically feasible reasonably priced alternatives for specific uses of c-decaBDE. Ethylene bis (tetrabromophthalamide) (EBTBP) is identified as another bromine-containing FR that can replace c-decaBDE in many of its applications (ECHA, 2014a). However, according to ECHA (2014a) which have compared the market price of c-decaBDE to that of its alternatives, information from the supply website Alibaba.com suggests that EBTBP is more expensive than both c-decaBDE and DBDPE. EBTBP may therefore be a less attractive alternative than DBDPE from a cost of manufacturing perspective. Nevertheless, one should keep in mind that the cost does not take into account the effectiveness of the alternative.

65. While alternative substances for replacing c-decaBDE in plastics, textiles and other uses are further discussed in sections 2.3.2- 2.3.4 below detailed information on the environmental- and health hazards of the c-decaBDE alternatives identified by the U.S. EPA (2014) is provided in Table 4, UNEP/POPS/POPRC.11/INF/6. Similarly, a detailed overview of the 13 alternative substances identified in the EU restriction proposal, their applicability for different uses, price, loading, environmental and health properties and economic feasibility is given in Table 5, UNEP/POPS/POPRC.11/INF/6 (for further details see also ECHA, 2014a). The viable non-halogenated FR/polymer combinations identified in the ENFIRO project are presented in Table 8,

UNEP/POPS/POPRC.11/INF/6, while other alternatives identified in the Annex F process are presented in Table 9, UNEP/POPS/POPRC.11/INF/6.

2.3.2 Plastics

66. The plastics industry is by far the major user of FR and the largest quantities of FR are supplied to raw-material manufacturers (KemI, 2005). The amount of c-decaBDE used in plastics and textiles globally varies but up to 90% of c-decaBDE ends up in plastic and electronics while the remaining ends up in coated textiles, upholstered furniture and mattresses (ECHA, 2014a; US EPA, 2014a). Like any other additives, a FR is selected by the raw material manufacturer for its inherent properties and compatibility with the polymer and to fulfil the specifications of the final product established by industrial customers (e.g. a car or furniture manufacturer). In the automotive sector this means that the specification of the end customer is only prescribing the performance requirements of the components. It is not prescribing the material choice of the suppliers.

67. For c-decaBDE in plastics the largest down-stream uses are in EEE applications and include casings for EEE, wire and cable, and small electrical components (U.S. EPA, 2014a; see Table 1, UNEP/POPS/POPRC.11/INF/6). In the U.S., the main reported use was in the front and back panels of televisions made of high impact polystyrene (HIPS) (Levchick, 2010), but c-decaBDE was also used in electronic connectors made from glass-filled PBT or nylons. Other identified uses of c-decaBDE flame-retarded plastics are in buildings, construction materials, in storage and distribution products such as plastic pallets, in the transportation sector (cars, airplanes, trains and ships). Because of the restrictions on the use of c-decaBDE in EEE in important markets like Europe and China, many large electrical- and electronic companies have transitioned away from using c-decaBDE (KemI, 2005; U.S. EPA, 2014a). End-applications where c-decaBDE has been phased-out include front and back panels of televisions made of HIPS, electronic connectors made from glass-filled polybutylene terephthalate (PBT) or nylons (Levchik, 2010 in U.S. EPA, 2014a). A ban on EE medical equipment entered into force in the EU on 22 July 2014. However, c-decaBDE flame retarded plastics are still used globally in a variety of EEE including household appliances and tools such as vacuum cleaners (in both the casings and internal components), and washing machines. In these appliances, the housings are typically made from polypropylene (PP), HIPS or ABS (U.S. EPA 2014a; Levchick, 2010). Another use that is still ongoing globally is in small electrical parts, such as light sockets or decorative lights and wires and cables which are usually made from high density polyethylene (PE), PP or polyphenylene (PPE) (U.S. EPA, 2014a; Levchick, 2010). Globally c-decaBDE is also still used in the plastics PBT and polyamides (PA), which are found in electrical, automotive, and plumbing parts such as housings, switches and other smaller internal parts of larger electrical equipment (Weil and Levchik 2009). For most plastic polymer applications where c-decaBDE is commonly used other FRs are available and already applied (KemI 2005).

68. The aviation industry still uses c-decaBDE in electrical wiring and cables, interior components, and EEE in older airplanes and spacecraft's. In the transport sector, c-decaBDE continues to be used in plastics for EEE, reinforced plastics, under hood and in inner parts as well as in the interiors of cars. It is also used in other means of transportation (U.S. EPA, 2014a; see Table 1, UNEP/POPS/POPRC.11/INF/6). Most of the flame retarded plastics used in vehicles are found in the engine compartment (often polyamides). In addition, the firewall between the engine and the cabin is an important flame retarded part. However, it should be noted that in Europe fire-safety requirements for vehicles are not very strict and most of the automotive plastics are therefore not flame retarded (IVM/IVAM, 2013). Most global car manufacturers nonetheless follow the US Federal Motor Safety Standard (FMVSS) 302 for their global production. In addition, for omnibuses, fire safety measures acc. to the UNECE 118 have to be fulfilled in all UNECE countries.

69. C-decaBDE is reportedly still used in toys in China (Annex F China; Chen et al. 2009), and in the synthetic rubber industry as a FR in conveyor belts for use in mines, including underground coal mines, and in the manufacture of ventilation bands used as seals around air ducts in mine ventilation systems (Annex F Australia). Until recently, c-decaBDE was also used in plastic shipping pallets in the U.S. (U.S. EPA, 2014a), but the company producing these pallets is no longer in business (U.S. EPA, personal communication) and three U.S. states (Maine, Oregon and Vermont) have prohibited the manufacture, sale and distribution of shipping pallets containing c-decaBDE (Maine, 2008; Oregon, 2011; Vermont, 2013).

70. For plastics in EEE, substitution strategies range from exchange of the resin system and FR, to complete redesigns of the product itself. Alternative techniques such as redesign are further described in section 2.3.3 below. According to the EU restriction proposal, which assessed different alternatives to c-decaBDE, eight possible alternative chemicals appear to be possible substitutes for c-decaBDE in plastic polymers (ECHA, 2014a):

- (a) Decabromodiphenyl ethane (DBDPE);
- (b) Bisphenol A bis(diphenyl phosphate) (BDP/BAPP);
- (c) Resorcinol bis(diphenylphosphate) (RDP);
- (d) Ethylene bis(tetrabromophthalimide) (EBTBP);
- (e) Magnesium hydroxide (MDH);
- (f) Triphenyl phosphate (TPP);
- (g) Aluminium trihydroxide (ATH);
- (h) Red phosphorous.

71. In addition, one manufacturer has reported the availability of green fire retardant systems suitable as alternatives to c-decaBDE. An overview of plastic polymers containing c-decaBDE and the alternative FRs for these uses, including down-stream applications, is provided in Tables 5-9, UNEP/POPS/POPRC.11/INF/6.

72. Detailed information on uses/applications, loading, costs and hazard for the identified alternatives to c-decaBDE in plastics, is reported in Tables 5 and 9, UNEP/POPS/POPRC.11/INF/6. Typically c-decaBDE is used in plastics/polymers at loadings of 10-15% by weight, though in some cases loadings as high as 20% have been reported (ECHA, 2012c). According to the manufacturer, Paxymmer® has excellent, proven performance in PP and PE with addition levels ranging from 2-32% depending on the downstream application and use. Reported loadings and cost for other alternatives used in plastics range from 1-60% and 1-12 €/kg respectively (see Tables 5 and 9, UNEP/POPS/POPRC.11/INF/6).

73. In certain uses, plastics have to fulfil fire safety regulatory requirements as mandatory specifications. Compliance with the fire requirements for plastics is controlled with well-defined flammability tests such as the International Electrotechnical Commission (IEC), or in the regulations and approval procedures of the Underwriters' Laboratories Inc. (UL), the latter mainly operating on the US market (KemI, 2005). However, although these fire regulations are mandatory for the market, there are no fire regulations that require the use of certain FRs in order to comply with these standards or regulations. Hence, it is up to the manufacturers to decide which technique to use. The ideal chemical FR for plastics should be compatible (i.e. not alter the mechanical properties of the plastic), not change the colour of the plastic, have good light stability, and be resistant towards ageing and hydrolysis. Further, an ideal chemical FR should match and begin its thermal behaviour before the thermal decomposition of the plastics, not cause corrosion, not have harmful physiological effects, and not emit or at least emit low levels of toxic gases. It should ideally also be as cheap as possible. However, as indicated earlier, function is generally more important than price for engineering polymers and price is not necessary the most important factor when selecting an alternative (KemI, 2005). As indicated above fire safety requirements for vehicles in Europe are not very stringent. Most global car manufacturers nonetheless follow the safety standard of the US Federal Motor Safety Standard (FMVSS) 302 for their global production. In addition, for omnibuses, fire safety measures acc. to the UNECE 118 have to be fulfilled in all UNECE countries.

74. In summary, efficient and technically feasible alternatives to the use of c-decaBDE as a FR in plastics (and synthetic rubber) are available and accessible on the market (ECHA, 2014a). DBDPE may be the most likely drop-in substitute for c-decaBDE in most plastics, but other alternatives or non-chemical techniques may offer a more sustainable long-term alternative to c-decaBDE than DBDPE (ECHA, 2014a).

2.3.3 Textiles

75. C-decaBDE has traditionally been applied to textiles as a back-coating in combination with antimony oxide (ATO) as a synergist (LCSP, 2005). Halogen-ATO can only be applied topically in a resin binder. C-decaBDE is first mixed with ATO to form an aqueous dispersion, which is then mixed with a polymer emulsion containing e.g. natural or synthetic rubber, EVA, styrene-butadiene copolymer or PVC (ECHA, 2012c). The c-decaBDE/ATO FR mix can account for 18 to 27% of the total weight of the product (Washington, 2006). Lighter fabrics usually require higher FR loadings than heavier fabrics. Fire resistant back-coatings are effective on a wide range of fabrics, including polyamide/nylon, polypropylene, acrylics, and blends such as nylon-polyester.

76. In the U.S. c-decaBDE is used in textile applications for transportation (public transit buses, trains, aviation and ships), in draperies for use in public occupational spaces, in furniture of high-risk occupational areas such as nursing homes, hospitals, prison and hotels, and in military for tarps, tents

and protective clothing, but are not used in consumer clothing (LCSP 2005; BSEF 2007 as cited in U.S. EPA, 2014a). However, in several U.S. states the use of c-decaBDE in residential upholstery and mattresses is no longer allowed (LCSP, 2015). In the EU, c-decaBDE is also used in domestic draperies and furniture (in foams, fillings and back-coatings, predominantly in countries with certain fire safety standards such as the UK (ECHA, 2014a). In Japan, vehicle seats accounts for 60% of the c-decaBDE use while an additional 15 % is reportedly used for other textile applications (Sakai et al., 2006). According to U.S. furniture industry sources in 99% of cases, chemical FRs will not be needed to meet pending national standards for residential upholstery (Illinois, 2007; Maine, 2007a). The same may be true in Europe. When testing 320 combinations of 20 cover fabrics and 18 fillings of upholstered furniture for the EU market, 38% of the combinations without FRs passed both match and cigarette test, and in the group that passed only cigarette test the FR-free combination accounted for 62% (CBUF as cited in Guillaume et al., 2008).

77. The lack of labelling, and information on FR use in consumer products makes it difficult to assess human exposure sources. Various eco- or green-labelling certifications may indicate that the product is FR-free. However, FRs are still widely used in furniture. For example, in a study analysing 102 polyurethane foam samples from residential couches purchased in U.S from 1985 to 2010, FRs were detected in 85% of the samples. For sofas purchased after 2005, tris (1,3-dichloroisopropyl) phosphate (TDCPP) was detected in 52%, and components associated with the Firemaster550 mixture were detected in 18% of the samples. In addition, a mixture of non-halogenated organophosphate FRs were observed in 13% of the samples (Stapleton et al., 2012). The textile covering the foam, which is where c-decaBDE could be expected was not analysed in this study.

78. Substitution of c-decaBDE in textiles is not straight forward due to the complexity of the end-products and the wide array of possible substitution approaches. These approaches include substitute FRs, alternative fibres, inherently fire resistant fibres, barrier layers, and nonwovens. However, a number of affordable options are available to replace c-decaBDE uses in furniture, mattresses, draperies and other textile applications. Substitution options for textiles range from brominated additive FRs such as DBDPE, to alternative techniques and inherent flame-resistant materials, which are described in Section 2.3.3 of the present document.

79. Based on its technical compatibility with existing processes and its price compared to c-decaBDE several European industry stakeholders have confirmed that DBDPE would be the preferred alternative to c-decaBDE in textiles (ECHA, 2014a; RPA, 2014; Klif, 2008). However, a focus on “drop-in” solutions may limit the innovative thinking that is needed to find effective and environmentally sound solutions (LCSP, 2009).

80. Some c-decaBDE substitutes exist for synthetics, but their water solubility results in limited durability as they “wash out” during laundering. Natural fibres are easier to chemically flame retard than synthetics, and there are several chemical non-halogen c-decaBDE substitutes available for natural cellulose or protein fibres such as cotton, wool, rayon (viscose, modal and lyocell), and linen. They include:

- (a) Ammonium polyphosphates;
- (b) Dimethylphosphono (N-methylol) propionamide;
- (c) Phosphonic acids such as (3-{[hydroxymethyl]amino}-3-oxopropyl)-dimethyl ester;
- (d) Tetrakis (hydroxymethyl) phosphonium urea ammonium salt.

81. Co-polymerization refers to inclusion of an additive in the fibre melt spinning process which makes the FR a physically part of the fibre matrix. The most common FR for polyester is polyethylene terephthalate with built-in phosphorus on the polyester backbone. This modified polyester is used in the majority of textile applications, is wash resistant, and is thought to be a good substitute for the c-decaBDE/antimony flame retardant. Polyester accounts for 30% of the world fibre production (see Figure 1, UNEP/POPS/POPRC.11/INF/6). Applications include clothing and draperies. Draperies that employ inherently flame resistant polyester can be laundered in water since the phosphate FRs are part of the polymer backbone and are not water soluble (LCSP, 2005).

82. Both ECHA (2014a) and U.S. EPA (2014a) have considered risk-hazard information on the identified alternatives. While there is no single replacement for c-decaBDE for textiles applications (Table 11 and 12, UNEP/POPS/POPRC.11/INF/6), the multitude of options on the market make it clear that viable approaches exist (LCSP, 2005). The identification of several halogenated and non-halogenated FRs in a study of chemicals commonly used in textile strengthen this (KemI, 2014, see Table 13, UNEP/POPS/POPRC.11/INF/6). The following seven substances were identified as the most likely chemical alternatives to the use of c-decaBDE in textiles (ECHA, 2014a):

- (a) Aluminum trihydroxide (ATH);
- (b) Magnesium hydroxide (MDH);
- (c) Tris(1,3-dichloro-2-propyl) phosphate (TDCPP);
- (d) Ethylene bis(tetrabromophthalimide) (EBTBP);
- (e) 2,2'-oxybis[5,5-dimethyl-1,3,2-dioxaphosphorinane] 2,2'-disulphide;
- (f) Tetrabromobisphenol A bis (2,3-dibromopropyl ether) (TBBPA) (only in polymer applications);
- (g) Red phosphorous;
- (h) Decabromodiphenyl ethane (DBDPE).

2.3.4 Other uses

83. In addition to the use in textiles and plastics c-decaBDE is used in sealants, adhesives, architectural foam, and coatings as well as in some applications in buildings and construction. C-decaBDE is used in wall and roof panels, which are typically made from unsaturated polyester (UPE) glass composites; floor tiles; and commercial grade carpeting. C-decaBDE is also used in e.g. in insulation materials, and in roofing materials such as membranes and films for use under roofs to protect building areas (Table 1, UNEP/POPS/POPRC.11/INF/6). C-decaBDE can also be found in ducting elements such as the duct covering or insulation. The EU restriction proposal for c-decaBDE identified the following six chemicals as alternative substances for these applications:

- (a) Magnesium hydroxide (MDH);
- (b) Aluminum trihydroxide (ATH);
- (c) Ethylene bis(tetrabromophthalimide) (EBTBP);
- (d) Substituted amine phosphate mixture (P/N intumescent systems);
- (e) Red phosphorous
- (f) Decabromodiphenyl ethane (DBDPE).

2.3.5 Alternative techniques and inherent flame-resistant materials

84. Alternatives that eliminate the need for chemical FRs through material substitution or design while meeting relevant fire safety standards and performance requirements are preferable, especially when they include chemicals of low toxicity and contain recyclable or compostable materials (New York State, 2013). The assessments of technical and economic feasibility of alternatives to c-decaBDE are primarily focused on alternative chemicals that directly can substitute c-decaBDE in articles (Section 2.3.2 above). However, flame retardancy can be achieved through the use of alternative techniques such as inherent flame-resistant material, use of different technical solutions i.e. barriers or complete redesign of the product. For example, power supplies can be shielded with metal to eliminate FRs or even be removed from the product as has been done with printers and rechargeable phones (LCSP, 2005). Inherent flame-resistant materials can meet fire code standards without special processing or chemical additives. Furthermore, the protection is incorporated into the fibres and is less likely to be worn away or washed out (DuPont, 2010). The mentioned alternative techniques can be used in a multitude of materials and applications, and are used in textiles, electronics, aircraft, and ground transportation vehicles and may be used in place of c-decaBDE in some instances. Examples of different alternative techniques, their attributes, and end-use products relevant to this assessment are given in Tables 14 and 15, UNEP/POPS/POPRC.11/INF/6.

Plastics

85. An alternative to the use of chemical FRs is redesign of the product itself. Redesign has successfully replaced c-decaBDE in several EEE applications. Redesigns of the product such as (i) separating high-voltage components that need greater ignition protection from low-voltage components and (ii) reducing operating voltage requirements and therefore reducing the need for flame-retarded enclosure materials.

86. Another product redesign alternative is to remove the power supply from the product. This is common in many devices including printers and rechargeable phones. These separate power supplies are typically black boxes connected to the power cord but not included in the unit itself. The separate power supply reduces the fire retardancy requirements of the electronic enclosure. To change product designs and their implementation would require a higher level of research and development activities

than the substitution of c-decaBDE with an alternative chemical FR but may be more sustainable as a long-term alternative.

87. Metal or inherently flame-resistant plastic can be used as alternative materials in certain electronic products. Options that eliminate the need for FRs through material substitution while meeting fire safety standards and performance specifications are considered preferable, particularly when product materials are derived from chemicals of lower toxicity and the products and/or materials are able to be recycled or composted (CPA, 2015). Material substitution that eliminates/reduce the need for chemical FRs has been shown possible by Apple Inc., which phased out BFRs (including c-decaBDE) in many of its computer products such as laptops, computer monitors, central processing units and servers (Apple Inc.). Apple Inc. replaced electronic encasements previously made of polycarbonate with encasements made of aluminium alloy, thereby eliminating the need to use FRs (Apple Inc.). A number of international producers of electronic equipment (Ericsson Network Technologies, Electrolux, IBM, Atlas Copco, Sony Ericsson, and Hewlett Packard) reported that they have phased-out- or never used c-decaBDE in their products (KemI, 2005).

88. Introduction of flame resistant metal barriers that separate or isolate the most flammable parts from the rest of the product and eliminates the need for FRs such as c-decaBDE has also been shown (LCSP, 2005).

89. In the EU assessment (ECHA, 2014a) various alternative techniques that could be used to replace c-decaBDE as a FR in plastics were identified. These include intumescent systems, nanocomposites, expandable graphite, smoke suppressants, polymer blends, use of inherently flame retardant materials and product redesign. These alternatives techniques are described in detail in Table 14 of UNEP/POPS/POPRC.11/INF/6. Another option is layering where an article is produced using layers of highly FR filled polymer and low or non-flame retarded polymer. This apparently gives a similar level of fire performance as would be achieved if the entire polymer had been treated, while helping to retain the mechanical properties of the polymer (ECHA, 2012c).

90. The use of inherently flame retardant materials is an additional alternative technique that can be considered. Halogenated polymers such as PVC have FR properties because they release halogen radicals during combustion. The effect is often enhanced by the addition of synergists such as ATO to halogenated polymer blends. However, like BFRs may PVC form dioxins and acids upon combustion and are therefore not a preferred alternative FR material (Blomqvist et al., 2007a). The following are polymer materials that are inherently flame-retardant and which might be considered as a substitute to c-decaBDE-based polymers like poly(butylene terephthalate) (PBTE) or polyamide/ nylon (PA) (DME, 2006):

(a) Halogen-free polyketone (this is considerably more costly than PBTE and PA);

(b) High performance thermoplastics such as polysulphone, polyaryletherketone (PAEK) or polyethersulphone (PES).

91. For certain uses, inherently flame retardant materials can include re-design solutions using metal enclosures and others. Polymers that char such as polyimides, polyaramides, liquid crystal polyesters, polyphenylene sulphide, polyarylenes and many thermosets also tend to have a greater resistance to fire. Where the base polymer has FR properties, depending on the end use, a sufficient level of fire performance may be achieved without the need for chemical FRs or much lower loadings may be required (ECHA, 2012c).

92. Some examples of new inherently flame retarded materials are mentioned in literature or in commercial websites, and these are often promoted as replacements for c-decaBDE (ECHA, 2012c; Albemarle, 2013; Great Lakes, 2013; PR Newswire, 2010). It may be necessary to change product designs to adopt these alternative materials and their implementation would require higher level of research and development activities than the substitution of c-decaBDE with a FR drop in chemical replacement. However, a safer environmental and public health profiles are additional benefits.

Textiles

93. An alternative approach to achieve flame retardancy in furniture is redesign of products to incorporate non-flammable materials or barrier technologies (LCSP, 2005). Product design choices can successfully meet all current and pending fire safety standards. Two approaches are suitable: 1) use of cover fabrics made from materials that are inherently fire resistant, 2) use of fire-resistant barriers between the cover fabric and the flammable cushioning foam.

94. There is a tremendous variation in the flame resistance of various fibres and fabrics. FR use in textiles can be avoided if the material itself is non-flammable or has low flammability. A number of synthetic fibres are inherently flame resistant, including aramid, viscose, novoloid, polyamides, and

melamine. Some of these fibres are starting to be significantly used in furniture upholstery and mattresses. Traditionally, they have been used to meet the strictest standards for applications such as fire fighter turnout gear, clothing for astronauts, and clothing for race car drivers. Inherently flame resistant fibres like polyhaloalkenes contain halogens such as polyvinyl chloride and vinyl bromide, while others are halogen free, including polyaramides and melamine fibres (LCSP, 2005; see Table 10, UNEP/POPS/POPRC.11/INF/6). Other inherently flame-retarded materials include rayon with a phosphorus additive, polyester fibres, and aramids (Weil and Levchik, 2009). Furthermore, some natural materials like leather and wool have inherently fire-resistant properties. Depending on the tightness of the weave, they can meet fire safety requirements without any additional FR treatment. Some natural materials such as wool may therefore be used as barrier materials in furniture (Klif, 2011).

95. Blending natural and synthetic fibres is another approach since the natural fibres are more effectively flame retarded. Fibre blending is a common method of reducing the flammability of flammable fibres. Polyester is usually blended with cotton and this 'poly-cotton' blend, can pass the simple vertical strip flammability test, if it has lower than 50% polyester content. Furthermore, cotton-nylon blends are commonly used to reduce the flammability of cotton (Gnosys et al., 2010) as well as cotton or polyester blended with melamine. Some fabrics for upholstery, mattresses and drapery are made from blends of several inherently fire resistant fibres mixed with fibres of lower flame performance. In some cases, fibres with a better "feel" such as cotton or polyester can be combined with more flame resistant fibres, such as melamine, to form a fabric that performs well in both comfort and fire performance (LCSP, 2005).

96. An important aspect of furniture and mattress fire protection is the use of barriers between the surface fabric and the interior foam core. In mattresses, industry has made a shift and fire resistant barriers are now commonly used (Maine 2007b; IKEA 2014). Fire barriers are made from inherently flame-retarded fibres such as wool, para aramids, melamines, modacrylics, or glass fibre, and do not rely on the use of flame retardant chemicals. Moreover, many of these fibres are made from non-halogen materials. Some barriers can also be made of blends of inexpensive fibres and expensive inherently fire-resistant fibres. These barriers protect the mattress, futon or box spring core material from combustion. They fully encapsulate the interior materials and must be combined with fire-resistant border seams, tape, and threads (LCSP 2005). In addition to the use of fibre blends, many manufacturers use cotton-batting materials treated with boric acid. These cotton materials are the lowest-cost barrier technology and are used to help meet fire safety requirements. However, the use of boric acid is of concern since it is suspected to be a human reproductive toxicant. Animal studies have reported adverse effects on reproduction in rats and mice exposed to dietary boric acid prior to- and during mating (Weir and Fisher 1972; NTP 1990 as stated in New York State Department of Health 2013). Plastic films have also been used as barriers, especially films made of inherently flame-resistant plastics such as neoprene (polychloroprene) (LCSP, 2005).

97. In textiles, like in plastics, fire safety may also be achieved by the use of intumescent systems (Klif, 2011; U.S. EPA, 2014a). Intumescence is the formation of a foamed char, which acts as heat insulation. An intumescent system is generally a combination of a source of carbon to build up char, an acid generating compound and a decomposing compound to generate blowing gases to produce foamed char (Weil and Levchik, 2009). This foam attains a thickness of 10 to 100 times that of the originally applied coating and insulates the substrate material through its low thermal conductivity, making intumescent systems efficient at reducing flammability and the exposure of fume gases (KemI, 2006). Several intumescent systems linked to textile applications have been on the market for about 20 years, and have successfully shown their great potential. Intumescent systems include use of expandable graphite impregnated foams, surface treatments and barrier technologies of polymer materials (Klif, 2011). Intumescent systems may not be applicable to the same sets of textiles as BFR-based back-coatings.

2.3.6 Fire-safety standards, requirements and solutions

98. Society needs systems to reduce and prevent fires and protect human lives. Fires cause injury, deaths and destruction of properties worldwide every year. On the other hand, in countries with stringent fire safety regulations the use of some FRs and resulting environmental contamination and human body burden is reportedly higher than in other countries with more flexible regulations for the fulfilment of the fire requirements (Klif, 2011). This indicates that awareness about these issues is important when seeking to replace hazardous FRs.

99. A study comparing fire statistics from Europe, the USA and New Zealand concluded that smoking and cooking, in combination with the presence of upholstered furniture and textile, are the most common cause and accident pattern in fatal domestic fires (NIFV, 2009). Men, children and

elderly are the most frequent victims, and alcohol use is another major aspect of fatal domestic fires. Most fatal fires occur in the living room or bedroom at night during the weekend and involves (upholstered) furniture, textiles, technical appliances or clothing. In Europe, upholstered furniture played an important role in almost 50% of all fatalities in domestic fires, and in USA upholstered furniture first ignited in 18% of home fire deaths (ACFSE, 2001; NFPA, 2013). Polyurethane foam from upholstered furniture is a major contributor to increased toxic smoke (Molyneux et al., 2014; Stec et al., 2011). Statistics from Norway indicate that 23% of all the domestic fires start in the kitchen while 19 and 9 % start in the living room and bedroom, respectively containing upholstered furniture (NFPA, 2014).

100. The fire performance of a material or product is mainly tested for ignitability, ease of extinguishment, rate of flame spread, rate of heat release and smoke formation (Weil and Levchik 2009). The fire requirements of products are often dependent on the intended use (e.g. higher requirements for institutional buildings compared to domestic houses). Typically, fire regulations prescribe the use of verified technical standards developed by standardisation organisations such as ISO, International Electrotechnical Commission (IEC) or European Committee for Standardization (CEN) and safety consulting and certification companies such as the Underwriters' Laboratory INC (UL). However, neither national fire-safety regulations nor technical standards require use of specific FR chemicals to meet fire safety requirements. Furthermore, performance of products in these test standards does not always correlate to performance in a practical fire situation. UK, Ireland and California previously relied on open flame tests for upholstered furniture, which led to a higher use of BFRs and increased body burdens (UNEP/POPS/POPRC.10/10/Add.2, UNEP/POPS/POPRC.10/INF/5). The test guidelines for the UK regulation are now under revision. A possible change from the current "match- and cigarette test" that requires fabric covers to be tested over non-combustion-modified polyurethane foam, to tests that require the actual final composite to be assessed for fire performance (DBIS 2014). DBIS believes this will give a reduction of up to 50% of FR currently used. Californian furniture flammability standards have been changed such that future use of FRs can be excluded (TB117-2013).

101. FRs can temporarily slow the spread of fires and subsequent heat release for a short time in order to enable people to escape, but they may also increase the toxicity of emissions. Toxic emissions may be reduced by introducing a barrier material in combination with the FR. Fire toxicity is the largest cause of death and injury in fires but is usually not taken into account by regulators. Several toxic gases are produced during fire, some of which are linked to the presence of BFRs while others are not. Combustion of materials containing halogenated FRs during accidental fires and burning flame-retarded waste can increase the toxicity of fire effluents by increasing the release of CO, acid gases such as hydrogen bromide, and brominated and chlorinated dioxins and furans (Simonson et al., 2000; Blomqvist et al., 2007b, Shaw et al., 2010). Furthermore, studies indicate that BFRs in combination with antimony produce high yields of CO and HCN, two main asphyxiants in fires (Molyneux et al., 2014; Stec et al., 2011). An overall reduction of flame-retarded materials may therefore lead to a smaller risk of health problems for the general public and fire fighters, if fire safety can be achieved by other means. In line with these findings, the overall fire safety benefit of using these substances to fulfil fire safety requirements has been questioned by a group of scientists (Jayakody et al., 2000; DiGangi et al., 2010).

102. In domestic and institutional buildings, fire safety can be strengthened by yearly educational campaigns focusing on safe use of electric components, candles, fireplaces, stoves, and new generation smoke detectors etc. Requirements of easy access to escape routes and fire-fighting equipment such as fire hose, automatic sprinklers, fire extinguishers and fire-blankets are important measures to prevent and reduce loss from fires and to ease the escape from burning buildings. A further safety solution include the "reduced ignition propensity" (RIP) cigarettes which are meant to be self-extinguishing when left unattended. This has apparently reduced cigarette fire fatalities by 41% in New York State. This is now mandatory in all the U.S., Canada, Australia and the EU. Solutions for electrical products could include a built-in heat sensor that shuts off the object if it becomes too warm. Regular control and changing of electrical wiring system are also fire preventive.

103. During storage e.g. in warehouses, fire safety can be strengthened by management practices. According to Annex F information from IPEN, fire safety when using plastic pallets may be met without FRs by implementing systems such as pallet storage management practices (e.g. how high the pallets are stacked and how close together stacks of pallets are) and/or by using sprinkler systems.

104. According to information provided by the aviation industry, aerospace products are subject to stringent airworthiness regulations and certification specification which set performance standards, including flammability. An overview of the process is described in Section 2.1 of ECHA, 2014). These fire resistance- and safety requirements are intended to prevent and/or control fires both in

flights, where options for escape are limited and post-crash, where evacuation from fuel-fed fires is the primary concern. These drive the choice of substances to be used. Aircraft parts and components are expected to withstand fire for a specified time depending on the area and application and materials used in interiors must not generate toxic smoke or excessive heat when on fire. For these reasons materials such as FRs is applied in hot and fire sensitive areas (e.g., around engines). Airworthiness authorities such as the European Aviation Safety Agency (EASA), Civil Aviation Administration of China (CAAC), Transport Canada Civil Aviation (TCCA), Agência Nacional de Aviação Civil (ANAC), Australian Civil Aviation Safety Authority (CASA), and U.S. Federal Aviation Administration (FAA) are responsible for establishing, administering and enforcing flammability standards.² These flammability standards for the aviation sector have been demonstrated to significantly reduce the probability of death from fire in a survivable accident by a factor of three over the past 40 years (FAA, 2010) (Boeing Company, pers. comm.).

2.4 Summary of information on impacts on society of implementing possible control measures

105. A positive impact on human health and the environment can be expected from a global reduction or elimination of c-decaBDE. POPRC-10 concluded that BDE-209, the main constituent of c-decaBDE, at present exposure and effect levels are likely to lead to significant adverse human health and environmental effects as a result of its long-range environmental transport such that global action is warranted (UNEP/POPS/POPRC.10/10/Add.2).

2.4.1 Health, including public, environmental and occupational health

106. BDE-209 is widely detected in the global environment and some species have high body burdens, in particular some species of birds, but also otter and fox living in urban and suburban areas (UNEP/POPS/POPRC.10/10/Add.2). Furthermore, in some organisms such as frogs, fish and birds BDE-209 levels are close to or within the range of reported effect concentrations for developmental-, neurotoxic- and endocrine disruptive effects. BDE-209 concentrations in Arctic cod, a key species of Arctic ecosystems, were reported to be at a level that can lead to adverse effects, which in turn can have a negative impact on Arctic cod populations and the whole Arctic ecosystem. Adding to this concern is the potential for low-dose and combined effects between BDE-209 and other similarly acting PBDEs as well as the potential for multiple stressor effects (UNEP/POPS/POPRC.10/10/Add.2, UNEP/POPS/POPRC.7/INF/16). A positive impact of imposing control measures is a decrease in emissions, which over time will reduce exposure and bioaccumulation in humans and wildlife. A global ban or restriction of c-decaBDE is therefore a measure that will contribute to protect and preserve Arctic organisms and ecosystems, which are considered to be at particular risk from POPs (AMAP 2009; UNEP/POPS/POPRC.7/INF/16).

107. Within a short time period, the most positive effect of imposing global control measures would possibly be on the indoor environment and public health; with c-decaBDE levels in dust being reduced and ultimately eliminated by ending the use in indoor textiles and equipment. Imposing control measures would also ensure that levels in agricultural products like milk/milk products, various meat products and fish decrease over time. In humans, exposure to BDE-209 takes place already in the early phases of human development and continues throughout life. It is found in human blood, plasma, breast milk and it is transferred to the foetus via the placenta during critical stages of development. The main sources for human exposure presently known are dust and contaminated food (UNEP/POPS/POPRC.10/10/Add.2). Due to their hand-to-mouth behaviour, infants and toddlers have higher body burdens of BDE-209 and other PBDEs than adults and have been identified as vulnerable groups that could be at risk, particularly due to the neuroendocrine and neurodevelopmental toxicity

² Examples of civil flammability standards:

EASA (e.g., CS 25.853, Appendix F) – <https://www.easa.europa.eu/system/files/dfu/CS-25%20Amdendment%2016.pdf>

CAAC (e.g., 第25.853 条, 附录F) – <http://www.caac.gov.cn/B1/B6/201112/P020111209503321901800.pdf>

TCCA (e.g. 525.853, Appendix F) –

<https://www.tc.gc.ca/eng/acts-regulations/regulations-sor96-433.htm#v>

ANAC (references US 14 CFR 25)

<http://www2.anac.gov.br/biblioteca/rbac/RBAC25EMD136.pdf>

CASA – (e.g., Part 90 Subdivision 3.2, references 14 CFR 25.853) –

http://www.comlaw.gov.au/Details/F2011C00871/Html/Text#_Toc306971168

FAA (e.g., §25.853, Appendix F) –

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title14/14cfr25_main_02.tpl

observed in animal studies (UNEP/POPS/POPRC.10/10/Add.2). Eliminating or restricting the use of c-decaBDE will therefore be particularly beneficial for the developing child.

108. Eliminating or restricting the use of c-decaBDE will also lead to better protection of worker health, particularly in developing countries where personal protection equipment is limited, and will also reduce human and environmental exposure to toxic degradation products including lower brominated PBDEs, brominated dioxins and furans (PBDD/PBDF), pentabromophenol and hexabromobenzene. Toxic degradation products, including PBDD/Fs may be formed different ways; during thermal processing (extrusion, molding and recycling), plastics production, photolysis, food preparation (cooking of fish) and waste disposal (Vetteret al., 2012; Kajiwara et al., 2008, 2013a,b; Hamm et al., 2001; Ebert and Bahadir 2003; Weber and Kuch 2003; Thoma and Hutzinger 1987; Christiansson et al., 2009; UNEP/POPS/POPRC.6/INF/6). Regarding occupational exposure, elevated BDE-209 levels have been reported in a number of professions (UNEP/POPS/POPRC.10/10/Add.2). Moreover, a study of 12 firefighters in the U.S. showed that they had elevated BDE-209 concentrations in their blood (contributing >50% of total PBDE concentration in serum) as well as elevated amounts of PBDD/Fs (Shaw et al., 2013). The authors of the study “suggested that PBDD/Fs may contribute substantially to dioxin-like toxicity in individual firefighters”, and that occupational exposure to these compounds during firefighting is significant. Thus, the exposure is likely to contribute to adverse health outcomes, an assumption underpinned by data also from other studies where firefighters are known to have elevated rates of cancer including four types that are potentially related to exposure to PCDD/Fs such as multiple myeloma, non-Hodgkin’s lymphoma, prostate, and testicular cancer (Hansen et al., 1990; IARC 2010; Le Masters et al., 2006; Kang et al., 2008). On the other hand studies suggest that when appropriate measures are in place, such as personal protection equipment and a ventilation system, exposure can be significantly reduced. A recent study showed that by applying appropriate risk management measures in a Swedish electronics recycling facility BDE-209 does not pose a risk to worker’s health (Rosenberg et al., 2011; Thuresson et al., 2006). However, worker’s in developing countries and countries with economies in transition are likely to be more exposed to BDE-209 and other substances than workers in developed countries because risk reduction measures are typically not in place or not fully enforced (Tsydenova and Bengtsson, 2011; UNEP/POPS/POPRC.10/10/Add.2; ILO 2012).

109. BDE-209 levels are generally highest near wastewater discharges and in areas around electronic waste and recycling plants (UNEP/POPS/POPRC.10/10/Add.2). Environmentally sound management of waste is therefore important in order to achieve an adequate level of protection of human health and the environment. This is in particular important in developing countries where waste handling often occurs under conditions without the use of modern industrial processes, and where worker protection is often inadequate. Considering the wide use of c-decaBDE in EEE, and that e-waste is the world's fastest growing waste stream (StEP, 2013) EEE in use and upon becoming waste are of particular concern. Last year nearly 50 million tonnes of e-waste were generated worldwide, about 7 kg for every person on the planet. Furthermore, millions of tonnes of old electronic goods are exported to developing countries and countries with economies in transition, primarily to South-East Asia, and to an increasing degree West Africa and Eastern Europe. Increasingly, Senegal, Uganda, Morocco, Colombia, Peru, Kenya, South Africa, Cambodia and Iraq are also destinations for end of life products and articles (Ni and Zeng, 2009; Zoeteman et al., 2010; Schlupe et al., 2009 in ILO 2012). Treatment in these countries usually occurs in the informal sector, causing significant environmental pollution and health risks for local populations. Women and children constitute a significant proportion of the workforce (ILO 2012). In China, which today receives the highest proportion of all e-waste globally, levels of BDE-209 in soil at e-waste sites and recycling plants are very high (ILO 2012; Wang et al., 2010, 2011a,b, 2014; Gao et al., 2011, Li et al., 2013). In addition to the occupationally exposed dismantlers, people residing near production and recycling facilities also have elevated blood levels of BDE-209 (see UNEP/POPS/POPRC.10/10/Add.2). In Bangladesh and Nicaragua, children living and working at a waste disposal sites have a combination of BDE-209 and other hazardous chemicals in their blood (Linderholm et al., 2011; Athanasiadou et al., 2008). Open burning of e-waste containing PBDEs is moreover estimated to release tons of PBDD/Fs and PCDD/Fs into the environment (Zennegg et al., 2009). Ma et al., (2009) reported that TEQ PBDD/F concentrations from an e-waste recycling facility in China exceeded the TEQPCDD/F concentrations in environmental samples. Moreover, c-deca BDE-containing plastic e-waste also find their way to food contact articles made from recycled plastics where it contributes to human exposure and risk (Samsonek and Puype 2013; Puype et al., 2015). Although recycling of materials that do not contain hazardous chemicals is environmentally and economically beneficial, recycling of materials containing POPs and other hazardous chemicals should be avoided to protect human health and the environment. Avoiding recycling of POP-containing materials also lowers the risk that contaminated materials is exported to developing countries. Avoiding recycling of POP-containing materials is also important to protect the credibility

of recycling, stimulate to sustainable management of waste flows and increase innovation in the recycling industry as well as other industries. Negative aspects of not allowing such recycling could on the other hand include loss in material being recycled (resources), additional costs to recycling companies due to separation/dismantling efforts and increased use of virgin materials (resources) (UNEP/POPS/POPRC.6/2/Rev.1). With regards to the challenges faced by developing countries due to e-waste ILO (2012) highlights the complexity of illegal transport of e-waste and proposes several solutions, amongst others that effective regulation and enforcement must be combined with incentives for recyclers in the informal sector not to engage in destructive processes and formalization of the informal e-waste recycling sector. Others suggest that proper law enforcement and international collaboration are keys in solving the problem of illegal transports (Ni and Zeng, 2009). The available literature suggests different approaches to e-waste management and recycling (e.g. Bleher et al. 2014, UNEP 2012, UNEP/POPS/POPRC.6/2/Rev.1). Some of the suggested approaches which include 1) not-allowing recycling of POP-containing waste, 2) recycling of non-BFR plastics and incineration of POP-contaminated plastics combined with energy recovery and 3) recycling of all plastics including BFR plastics below a legally determined threshold level are compliant with the objectives of the Stockholm Convention and should be feasible also for developing countries. The different approaches differ in how they handle the FR/ c-decaBDE containing fraction and the economic gain for the industry (Bleher et al. 2014).

2.4.2 Agriculture, including aquaculture and forestry

110. Elimination of c-decaBDE would benefit agriculture as well as human and wildlife health by ending further widespread dispersal of a POP substance to soil. Contamination of agricultural soil with BDE-209 is a global problem partly linked to the use of sewage sludge as a fertilizer (UNEP/POPS/POPRC.10/10/Add.2). As shown by Sellström (2005) and de Wit (2005) levels of BDE-209 were 100-1000 fold higher at sites fertilized with sewage sludge compared to reference sites. When soil is amended with sludge, BDE-209 is transferred to biota, and can ultimately accumulate in organisms at the top of the food chain (UNEP/POPS/POPRC.10/10/Add.2). Applying sewage sludge to agricultural land is a way of managing sewage sludge while at the same time exploiting essential plant nutrients and organic matter in agriculture. However, as discussed above the practice contributes to the environmental releases of BDE-209. It may also contribute to human and ecological risks due to the occurrence of organic contaminants, such as BDE-209 in sludge. Accordingly, any measures to reduce the levels of BDE-209 in sewage sludge and/or measures to better control the use of sewage sludge as a fertilizer, is likely to have a positive effect by reducing BDE-209 levels in agricultural products over time.

2.4.3 Biota (biodiversity)

111. A phase-out of c-decaBDE is essential to avoid an increase of levels in wildlife already at risk. Reported adverse effects raise concerns that c-decaBDE may cause effects at population- and ecosystem level, and ultimately have implications for biodiversity (see section 2.4.1 above UNEP/POPS/POPRC.10/10/Add.2). In addition to posing a threat to Arctic ecosystems and biodiversity, both alone or in combination with other POPs (UNEP/POPS/POPRC.10/10/Add.2, UNEP/POPS/POPRC.7/INF/16), it is of concern that c-decaBDE and other substances alone or in combination can delay development and metamorphosis in frogs at environmentally relevant concentrations (Shricks et al., 2006; Qin and Xia 2010) and alter the anatomy and function of the male frog vocal system (Ganser 2009). The IUCN Red List of Threatened Species™ has identified amphibians, and among them frogs, as being the most threatened vertebrate group assessed, with around 41% at risk of extinction and urges that immediate action must be taken to protect the remaining populations of amphibians across the world (IUCN 2014, see also Stuart et al. 2004). Extinctions and large-scale declines of amphibian species have been attributed to habitat loss, pollution, fires, climate change, disease and over-exploitation (IUCN, 2014; Hayes et al., 2010). Anthropogenic chemicals may contribute to the decline in amphibian populations by influencing the immune system/ immune response, larval development and growth, ability to avoid predation, reproductive success and survival rates (Carey and Bryant 1995, see also Hayes et al., 2010). The alterations in the male frog vocal system and the delayed metamorphosis/development induced by c-decaBDE exposure may have implications for lifetime fitness (mating success, predation etc.) and ultimately population recruitment (van Allen et al., 2010; Hayes et al., 2010). Thus, the adverse effects observed in frogs suggests that c-decaBDE can be one of the pollutants contributing to declines in global frog populations.

2.4.4 Economic aspects and social costs

112. Based on information such as price, accessibility and availability of different alternatives as well as information on regulatory measures and use in different countries, the socioeconomic costs of

implementing a ban and/ or restriction on the use of c-decaBDE are considered small and outweighed by the benefits of an elimination/ regulation. An important factor as discussed in the EU restriction proposal is that although c-decaBDE is currently less expensive than the alternatives assessed, the difference in cost might gradually change in response to the increasing demand for alternatives (ECHA, 2014a).

113. The costs incurred by those manufacturers that still produce c-decaBDE depend on how a restriction/ban affects the production and market of chemical alternatives to c-decaBDE. It also depends on the technical costs associated with a transition from c-decaBDE to other alternatives at the manufacturing plants (ECHA, 2014a). However, c-decaBDE is known to be manufactured in only a few countries worldwide and a restriction/ban on the manufacture will therefore yield no direct cost (or impact) for the majority of countries worldwide, and will only affect the small number of manufacturers which still produce c-decaBDE, some of which already produce and sell alternatives. Moreover, available information suggests alternatives can be manufactured in the same manufacturing plants/production lines as c-decaBDE. Thus, transition costs for the manufacturing industry globally are assumed to be low.

114. The restriction could also affect the economy of c-decaBDE importers/vendors as well as down-stream industrial/professional users. However, most importers/vendors also import and sell other substances, including alternatives to c-decaBDE (ECHA, 2014a). Similarly, importers of c-decaBDE-containing articles may also continue to import articles with alternative FRs. Concerning down-stream industrial/professional users it is known that their capability to switch to alternatives may differ. Though most down-stream industrial/ professional users are able to transition to c-decaBDE alternatives without major additional costs, comments received from the aviation industry during a public consultation in the EU suggests that it may be difficult to immediately replace c-decaBDE in products used in aircrafts and defence hardware (ECHA, 2014a). According to the aerospace industry, this is mainly due to technical challenges, costs and time related to the development, qualification, and certification of alternative materials for aircrafts due to stringent safety and technical performance requirements, and the complexity in the supply chain (ECHA, 2014a). Similar concerns have been raised by some automotive associations, which have requested exemptions for some legacy spare parts but not for parts in ongoing production. The reasoning of automotive industry is different, as it is only dealing with practical feasibility of a substitution especially in legacy spare parts with functional properties.

115. Listing of c-decaBDE in the Stockholm Convention without a recycling exemption would mean that fractions containing c-decaBDE above a low POP content value are not to be recycled. This might have an impact on material recycling from products containing c-decaBDE. In particular, recycling of waste electrical- and electronic plastic (WEEP) and plastic from end-of-life vehicles could be affected (e.g. IVM/IVAM, 2013; see also Section 2.2.). Current volume of plastic being recycled is limited and the plastic fraction containing c-decaBDE is small (Sinha-Khetriwal et al., 2005; Widmer et al., 2005; Hicks et al., 2005; Streicher-Porte et al., 2005; see also section 2.2 paragraphs 47 and 48). The processes for recycling of ELV and WEEE is currently focused on metal recovery, and the plastic fraction are found to be less valuable because of the quality (Sinha-Khetriwal et al., 2005), Widmer et al., 2005; Hicks et al., 2005; Streicher-Porte et al., 2005). Therefore the socio-economic impact of taking the required measures so that such plastic products upon becoming waste are not recycled is considered to be low.

116. The recycling of plastic is in general desirable because of resource efficiency, but should be balanced with the importance to avoid recycling plastic containing hazardous chemicals. If in the future such material recycling is increasing, separation techniques would then have to be applied to ensure the quality of the recycled plastic material. This can lead to costs to society either in form of investment in equipment for sorting plastics waste and/or increase the need for manual labour. In the absence of achieving effective means of identifying decaBDE in waste, the impact for recycling might be significantly higher than assumed as any material containing bromine may in practice be excluded, limiting further the amount of material available for recycling. Post shredder technology to sort out the valuable plastic fraction is costly, as well as technology to extract bromine. If large throughputs are required, it can represent a barrier to market entry for new players in the WEEE recycling market.

117. On a country or regional basis an analysis of the economic impacts to recycling facilities needs to be undertaken. What could be defined as an optimal solution depends very much on the economic and cultural context in which the system operates (Sinha-Khetriwal et al., 2005). The cost of labour, the structure of the economy including the important informal sector, the existing regulatory framework and the possibilities and limits of law enforcement have to be taken into account in order to find solutions that can improve the situation with regard to environmental impacts, occupational hazards and economic revenue (Sinha-Khetriwal et al., 2005). Environmental benefits and socio

economic gain due to increased quality and use of the recycled plastic (less use of virgin plastic), as well as a higher market price may then outweigh the higher cost for recycling.

118. The market price of recycled plastic material is determined by its quality, its substitutability to replace virgin plastic and the price of virgin plastics. The presence of hazardous chemicals negatively affects the market price of recycled material (NCM, 2015b). A conclusion of a study by the Swedish Chemicals Agency (KemI) is that one of the main barriers to increase the use of recycled materials in new products is the risk that the material may contain hazardous substances (KemI, 2012). This finding is also supported by other sources (including Wäger et al., 2010; Stenvall et al., 2013; NCM, 2015b) which all highlight hazardous substances as being an obstacle to the recycling of material from WEEE products.

119. Recycling materials that contain decaBDE into various new articles may make it difficult to identify which articles contain decaBDE and treat later on. Furthermore, it is important to have control of the waste streams to avoid that decaBDE ends up in new articles leading to adverse effects in humans and economic costs due to an increase in health problems (NCM, 2014b; Bellanger et al., 2015; Hauser et al., 2015; Trasande et al., 2015; Legler et al., 2015; HEAL, 2014; see also paragraph 122). Techniques and approaches to effectively separate waste containing PBDEs, and treat them separately, are available (ECHA Background Document, 2015; Sinha-Khetriwal et al., 2005; Widmer et al., 2005; Hicks et al., 2005; Streicher-Porte et al., 2005; see also the guidance³). Thus a concentration limit for mixtures and articles placed on the market is necessary to ensure that a) majority of plastic articles can be recycled and b) decaBDE is not present in high concentrations in articles made from recycle (RAC/SEAC, 2015). When installing more advanced technologies the necessary capital expenditure is considerable but thereafter the running costs are low (NCM 2014a, 2015c). Although separation techniques can mean higher operational and running cost this is likely offset by the improved and enhanced material recycling (NCM 2014a, 2015c). Lower-technology approaches, such as separation, sorting or simpler shredding of WEEE may result in relatively higher costs depending on the cost for labour work, but can also be a benefit to the society due to a higher employment. WEEE treatment processes with significant low-tech elements, can currently achieve significantly better quality to the recovered plastic than highly mechanised and automated alternatives and also higher quantified benefits (NCM, 2015a; NZMOE, 2013). The overall cost is offset by the enhanced material recycling. In addition this delivers considerable environmental benefits (NCM, 2015c).

120. According to document UNEP/POPS/COP.7/INF/22, “Waste management influences all parts of society and the economy. It concerns local, regional and national authorities and requires a legal framework, a financial mechanism, and an effective coordination between citizens and authorities at all levels. Furthermore, good waste management is not feasible without an adequate level of investment. To ensure a coherent waste management system, it is important all actions at different levels follow a commonly agreed strategy. It is therefore necessary, or at least useful, (for national and regional authorities) to discuss and decide upon a national waste management strategy. The successful implementation of any waste management system, particularly in developing countries, may require the transfer of appropriate technologies and capacity-building in accordance with Article 12 of the Convention.”

121. Besides the costs to industry, restricting the placing on the market of c-decaBDE may affect the employment in companies manufacturing the substance, as well as in actors in the supply chain including importers/exporters of c-decaBDE itself and c-decaBDE containing articles. Similarly, the employment in waste collection, sorting, recycling businesses may also be affected. The impact on employment depends e.g. on whether companies also produce and/or sell the alternatives substituting c-decaBDE. According to ECHA (2014) there are no reasons to assume differences in the labour inputs required in the production of c-decaBDE or alternative-based articles and products, and the negative impact to employment in one company (if any) should mainly be offset by positive impacts in other companies. In other words, the impacts on employment are mainly distributional and not a cost to the society as such. However, the redeployment of staff always includes some adjustment costs, e.g. related to temporary unemployment of workers when finding new jobs, although it is difficult to place a figure on these adjustment costs in practice (ECHA, 2014). Similar mechanisms will likely also affect employment in the waste- and recycling industry (see e.g. ILO, 2012; NCM, 2015b). Reduced profits will generally pull towards less employment, while potential new tasks, like

³ Guidance for the inventory of polybrominated diphenylethers (PBDEs) listed under the Stockholm Convention on POPs.

sorting, may increase the employment needs. The net effect on employment in the recycling sector is therefore uncertain.

122. With further regard to social costs, a new report prepared by the Nordic Council of Ministers and recent scientific publications suggests that EDCs like c-decaBDE are a great economic burden to society (NCM 2014b; Bellanger et al., 2015; Hauser et al., 2015; Trasande et al., 2015; Legler et al., 2015). According to the report by the Nordic Council of Ministers, negative effects on male reproductive health caused by EDCs costs the EU countries at least somewhere between 59 and 1200 million euros per year in lost work capacity and higher health care costs. Similar findings are reported by Hauser et al. (2015), who stipulates the costs of male reproductive disorders and diseases in the EU to nearly 15 billion euros per year (15000 millions). Bellanger et al. (2015), which perhaps is the most relevant of these studies, suggests that PBDEs along with other EDCs contribute substantially to neurobehavioural deficits and disease in the EU, with a high probability of >150 billion euro costs/year. However, the publications by the Nordic Council of Ministers, Bellanger et al. (2015) and Hauser et al. (2015) centres on specific EDCs, disorders and diseases and the total costs to society attributable to EDCs are likely much higher than indicated by these studies alone. According to Trasande et al. (2015) median costs of only those EDCs which with the highest probability can be linked to disorders and diseases, is 157 billion euros annually i.e. 1.23 % of EU gross domestic product. This finding is supported by a previous report prepared by the Health and Environment Alliance (HEAL) in the EU (HEAL, 2014). The report which includes costs related to treatment of human infertility, cryptorchidism, hypospadias, breast cancer, prostate cancer, ADHD, autism, overweight, obesity and diabetes, but not testicular cancer, stipulates that the total costs in the EU related to exposure to EDCs may be as high as 13–31 billion euros/year (HEAL, 2014).

123. Adding to the costs to the health- and welfare systems are costs relating to management of c-decaBDE containing waste and remediation of contaminated soil and sediment, which based on experience with other POPs such as PCB has shown both time consuming and costly.

124. According to the EU restriction proposal a restriction on production and use of c-decaBDE as suggested in the EU is considered a proportional measure to control the risks arising from its production and use. More specifically, the cost-effectiveness is indicated to be in the same order of magnitude (or lower) as previous restrictions under REACH on mercury, a chemical that in previous EU assessments of mercury and phenyl mercury were considered to be of equivalent level of concern to persistent, bioaccumulative and toxic substances (PBTs) and to have long range transport properties (ECHA, 2014a).

2.4.5 Movement towards sustainable development

125. Elimination of c-decaBDE is consistent with sustainable development plans that seek to reduce emissions of toxic chemicals and that links chemical safety, sustainable development and poverty reduction. Environmentally sound management of "toxic chemicals" including waste is part of Agenda 21 and the Rio declaration on environment and development (UNCED, 1992a,b). It is also part of the Strategic Approach to International Chemical management (SAICM). The Global Plan of Action of SAICM contains specific measures to support risk reduction by promoting the use of safe and effective alternatives to chemicals, including non-chemical alternatives to organic chemicals that are highly toxic, persistent and bioaccumulative (UNEP, 2006). The Overarching Policy Strategy of SAICM includes POPs as a class of chemicals to be prioritized for halting production and use and substitution with safer substitutes.

126. For circular economy, design for recycling and labelling is important to improve the quality and quantity of recycled materials (NCM, 2014c). Applying techniques and systems that allow components containing hazardous chemicals to be sorted out and disposed of in an environmentally sound manner, will make waste management more sustainable, in particular with regards to material recovery, recycling and reuse (see Section 2.2).

127. In developing countries formalization of the e-waste recycling sector i.e. the integration of the informal sector into formal waste management, can present a way forward to create sustainable employment while at the same time reducing the negative environmental- and health impacts of recycling activities resulting from the release of POPs and other hazardous chemicals (ILO, 2012).

2.5 Other considerations

128. Listing c-decaBDE in Annex A without exemptions would involve control measures that are straight forward to communicate and therefore should be effective and suitable, even in countries that have limited chemical regulatory infrastructure. Information on alternatives is readily available, and can be easily communicated as needed. With regard to environmental monitoring and biomonitoring, c-decaBDE can be added to existing programmes for monitoring other POPs. Countries that lack the

needed infrastructure to adequately monitor production and uses of c-decaBDE may require additional resources and infrastructure. However, recent developments in analytical chemistry allows BDE-209, the main congener of c-decaBDE, to be monitored and measured in parallel to other PBDEs, such as the tetra-, penta-, hexa- and heptaBDE congeners listed in the Convention, without substantial additional costs. Such advanced mass-spectrometric methods give precise information about the quantities of BDE-209 in a matrix and is therefore typically used to determine levels in environmental and biota samples. Mass-spectrometric methods can also be used to determine BDE-209 levels in products/ articles in use and in waste, but is not the standard method used by waste treatment and recycling companies which typically rely on cruder sorting methods based on total bromine content for screening and sorting (UNEP/POPS/POPRC.6/2/Rev.1). Advanced analytical technologies are not available to the waste management sector on an industrial scale.

129. Parties to the Convention, for which any amendments have entered into force, have to meet the obligations under the Convention. To assist Parties in meeting their obligations, the Stockholm Convention has in the past developed inventory guidance's for listed POPs, the objective of which has been to provide step-by-step guidance to enable Parties to establish inventories of newly listed POPs and develop strategies/action plans (Decision SC-6/12, UNEP 2014a,b). The purpose of the inventory is to assist Parties in collecting national baseline data on the listed POPs, information that can be of use to national focal points for the Convention, the coordinator of the NIP review and update process, and task teams responsible for establishing the inventory. It will also be of interest to other stakeholders concerned with the elimination of listed Pops. In addition, also other types of guidance have been developed for example guidelines developed under Basel Convention.

130. Identifying which and whether articles/products contain a certain chemical can be a challenge. Recognizing these challenges, SAICM identified the global need for information on Chemicals in Products (CiP) throughout the whole lifecycle of the product, at the International Conference on the Chemical Management (SAICM/ICCM.2/15). A voluntary program to share information about chemicals in products in the global value chain was initiated.

131. To develop effective strategies that can lead to the elimination of c-decaBDE, Parties need to acquire a sound understanding of their national situation concerning these chemicals. If c-decaBDE is listed in the Convention, the Conference of the Parties may therefore update the "Guidance for the inventory of polybrominated diphenyl ethers (PBDEs) listed under the Stockholm Convention on Persistent Organic Pollutants" to assist Parties to the Convention in meeting their obligations under the Convention and assisting them in their phase-out of c-decaBDE (UNEP 2014a).

3. Synthesis of information

3.1 Summary of risk profile information

132. At its 10th meeting in 2014 the POPs Review Committee adopted the risk profile and decided that the decabromodiphenyl ether component (BDE-209) of c-decaBDE is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects, such that global action is warranted.

133. BDE-209 is highly persistent in soil and sediments, but it is also known to debrominate to lower brominated PBDEs in the environment and biota. Due to debromination, organisms are moreover co-exposed to a complex mixture of PBDEs, including the already listed POPs BDEs.

134. BDE-209 is an ubiquitous global contaminant that is detected in urban, rural and remote regions across the globe. In the Arctic and other remote regions BDE-209 is found in various environmental compartments including air, sediment, snow, ice and biota. Both oceanic and atmospheric processes contribute to the long-range environmental transport of BDE-209, but binding to atmospheric particles is believed to be the main mechanism.

135. Due to the extremely low water solubility of BDE-209 the most important exposure route in aquatic and terrestrial food webs is through the diet. Although some studies do not demonstrate BDE-209 bioaccumulation and trophic dilution has been observed (TMF<1), bioaccumulation has been reported for a number of aquatic and terrestrial organisms. The equivocality in the available bioaccumulation data of BDE-209 largely reflects species differences in uptake, metabolism and elimination.

136. C-decaBDE is widely detected in biota and high body burdens have been demonstrated in some species. BDE-209 can transfer from mother to off-spring and exposure takes place during early development. Maternal transfer to eggs and offspring has been reported in fish, amphibians, birds and reindeer. In humans, exposure to BDE-209 takes place in the early phases of development in utero via

placental transfer and postnatally via mother's milk. In addition, infants and toddlers are reported to have higher body burdens of BDE-209 and other PBDEs than adults due to a higher exposure to dust.

137. There is evidence that BDE-209 can result in adverse effects to reproductive health and output in fish, earthworm, mouse and rats as well as developmental- and neurotoxic effects in amphibians, rodents and humans. Furthermore, there is a concern that BDE-209 and other PBDEs combined may cause developmental neurotoxicity in both humans and wildlife at environmentally relevant concentrations. Available toxicity data shows that BDE-209 may act as an endocrine disruptor, and interfere with thyroid hormone homeostasis in fish, amphibians, rat, mice and humans, and possibly with steroid hormone homeostasis. In combination, debromination and co-exposure to BDE-209 and other similarly acting PBDEs, as well as the high persistency of BDE-209 in sediments and soils, increase the likelihood for chronic long-term adverse effects.

3.2 Summary of risk management evaluation information

138. A positive impact on globally sustainable development is expected from elimination of c-decaBDE. However, if production, use and waste management of c-decaBDE are not controlled, the levels in the environment including humans and wild life will likely continue to increase, even in remote locations.

139. C-decaBDE is a synthetic substance with no known natural occurrence. Today c-decaBDE is manufactured only in a few countries globally. Many countries have already restricted or initiated voluntary programs to end the use of c-decaBDE. This has successfully led to use of alternative FRs, redesign or alternative methods to fulfil the FR requirements of the product. However, the environmental releases of c-decaBDE and its main constituent BDE-209 are continuing in all regions investigated.

140. Although releases may also occur during production, c-decaBDE emissions are mainly attributed to releases from articles in use and waste. A global ban on production and use of c-decaBDE combined with proper waste management measures is therefore essential to achieve a future reduction in exposure of humans and the wildlife.

141. C-decaBDE has many applications and is used in many different sectors of society. It is used in EEE like computers and TVs, in wires and cables as well as in adhesives, sealants, coatings, inks and pipes. C-decaBDE is also extensively used in commercial textiles for public buildings, in textiles for domestic furniture and in the transportation sector. Globally up to about 90% of c-decaBDE ends up in plastics, primarily in electronics, while the remaining ends up in coated textiles, upholstered furniture and mattresses.

142. The automotive and aviation industry are in the process of phasing out c-decaBDE. However, some industry observers have raised a concern for service and some legacy spare parts for use in articles already in use, as well as for aircrafts currently in production under existing type certificates. The justification provided relates to technical and economic issues, and suggests a possible need for exemptions in the transportation sector. However, fire-safety requirements and certification schemes do not necessarily require the use of c-decaBDE or other FRs. In the case that replacement with another FR is necessary, chemical alternatives are available that can substitute c-decaBDE in most plastic and textile applications which are still in mass production. However due to the requirements for changes in some legacy spare parts which would need testing often in original vehicles, which are no longer in mass production and often have not been for many years, the possibility of testing does not exist. It is furthermore likely that manufacturers of such legacy spare parts will stop their manufacture. This can ultimately result in unavailable or untested and thus dangerous replacement parts, or non-compliance with national obligations to deliver such parts for at least 10 years after mass production. Yet, in many cases, flame retardancy can also be achieved through the use of alternative techniques such as inherent flame-resistant material and use of different technical solutions i.e. barriers or complete redesign of the product. These alternative techniques can be used in a multitude of materials and applications, and are used in textiles, electronics, aircraft, and in other means of transportation.

143. The service-life of products containing c-decaBDE varies globally but an average of 10 years can be estimated, hence end-of-life products will enter the waste stream for many years and be a source to future emissions. According to the Convention (Article 6(1)(d)(ii)), waste containing c-decaBDE should be disposed of in such a way that their POPs content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of POPs or otherwise disposed of in an environmentally sound manner, thereby efficiently removing the emissions and related exposures to c-decaBDE in waste. Different techniques for handling POPs containing waste in an environmentally sound manner are available. Controlled incineration, in state of the art facilities with continuous monitoring, and strict compliance with Convention BAT/BEP guidelines, is one way to dispose of

waste containing c-decaBDE and may allow energy recovery. Incineration at high temperatures is generally considered to effectively destroy POPs like c-decaBDE, with formation of small amounts dioxins and furans. Where destruction or irreversible transformation does not represent the environmentally preferred option, or the POPs content is low, countries may allow such wastes to be disposed by other environmentally sound methods e.g. in specially engineered landfills.

144. Sorting and separating waste fractions can be used to achieve more sustainable waste management, and separation techniques includes manual and automated sorting of waste components also those containing hazardous chemicals, such as brominated FRs. Advanced separation techniques are already in use in the waste management sector but are not widely available yet. However, in developing countries, waste handling mostly occurs in the informal sector where modern industrial processes are not used, and sorting is conducted manually without the use of adequate protection and ventilation resulting in human and environmental exposures. In developing countries, integration of the informal sector into formal waste management, can present a way towards increased sustainability.

145. A small number of Parties have suggested a possible need for a recycling exemption. Others opposed on exemption for recycling because they were concerned about articles, products in use, and recycled products containing decaBDE being exported especially to developing countries and countries with economies in transition due to lack of capacity to identify and analyse products containing deca BDE. Yet, recycling of materials containing c-decaBDE will inevitably result in wider human and environmental contamination and dispersal of PBDEs. It should be avoided if the aim is to eliminate emissions and exposure to c-decaBDE. It was recently reported that plastic pellets from recycled material contaminated with c-decaBDE is subject to export and that this recyclate may end up in products where they can pose a hazard to human health. Recent studies have detected c-decaBDE in food-contact materials and in children's toys made from plastic pellets originating from recycled plastic. Moreover, the socio-economic impacts of not allowing recycling of c-decaBDE above a POP limit value to be determined could be limited, an important reason being that recycling rates of c-decaBDE containing plastics and textiles are low. However the automotive industry sector has indicated that they need to meet a stringent recycling quota of 85% in Europe and without a recycling exemption, these legal obligations cannot be fulfilled. However, based on the information received and assessed in this RME, the socio-economic impact of taking the required measures so that such plastic products upon becoming waste are not recycled is considered to be low.

146. Labelling of newly produced articles containing decaBDE could be useful when articles become waste.

3.3 Suggested risk management measures

147. The most efficient control measure to reduce the releases of c-decaBDE would be to list the decabromodiphenyl ether component (BDE-209) of c-decaBDE in Annex A without exemptions. Listing the decabromodiphenyl ether component (BDE-209) of c-decaBDE in Annex A would also mean that the provisions of Article 3 on export and import and of Article 6 on identification and sound disposal of stockpiles and waste would apply.

148. Based on the information submitted during the risk management evaluation and the collective experience reported, there may be challenges for some sectors, i.e., legacy spare parts for the aerospace and automotive industries. Some parties identified challenges for recycling. Because of the concerns about articles, products in use, and recycled products containing decaBDE being exported especially to developing countries and countries with economies in transition, other experts opposed recycling exemption due to lack of capacity to identify and analyse products containing deca BDE. Additional risk management measures could include an obligation to label new articles that contains decaBDE.

4. Concluding statement

149. Having decided that the decabromodiphenyl ether component (BDE-209) of c-decaBDE, is likely, as a result of long-range environmental transport, to lead to significant adverse effects on human health and/or the environment such that global action is warranted;

150. Having prepared a risk management evaluation and considered the management options and noting that non-persistent organic pollutant alternatives to decabromodiphenyl ether are available;

151. The Persistent Organic Pollutants Review Committee recommends, in accordance with paragraph 9 of Article 8 of the Convention, the Conference of the Parties to the Stockholm Convention to consider listing and specifying the related control measures of the decabromodiphenyl ether component (BDE-209) of c-decaBDE in Annex A with a specific exemption for some critical

legacy spare parts that still need to be defined in the automotive and aerospace industries. Since the information on small and medium enterprises in the textile industry in developing countries is very limited, it is not possible to conclude that exemptions are unnecessary for them.

References

- ACAP, Arctic Contaminants Action Programme (2007). Final Report of Phase I of the ACAP Project on Brominated Flame Retardants (BFRs) Phase I: Inventory of sources and identification of BFR alternatives and management strategies. AMAP Report 2007:6, SFT Report TA-2440/2008.
- AMAP. Arctic Monitoring and Assessment Programme (2009). Arctic Pollution 2009, Oslo. 83 pp.
- ACFSE (2001) The Fire Safety of Upholstered furniture, Alliance for Consumer Fire Safety in Europe, Belgium.
- Albemarle (2013). Product selector guide. [Online] Available at: <http://www.albemarle.com/>. [Accessed 15 November 2013].
- Apple Inc.[Online] Available at: <http://www.apple.com/environment/toxins/>[Accessed 6 July 2015].
- Athanasiadou M, Cuadra SN, Marsh G, Bergman A, Jakobsson K. Polybrominated diphenyl ethers (PBDEs) and bioaccumulative hydroxylated PBDE metabolites in young humans from Managua, Nicaragua. *Environ Health Perspect.* 2008 Mar;116(3):400-8.
- The Basel Action Network (BAN), The Silicon Valley Toxics Coalition (SVTC), Toxics Link India, SCOPE (Pakistan), Greenpeace China. Exporting harm: the high-tech trashing of Asia. Seattle, WA, and San Jose, CA;February 25th, 2002.
- Basel Convention (2015a). Draft Technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with hexabromodiphenyl ether and heptabromodiphenyl ether, and tetrabromodiphenyl ether and pentabromodiphenyl ether.
- Basel Convention (2015b). Draft updated general technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (Draft of 1 December 2014). [Online] Available at: <http://www.basel.int/Implementation/POPsWastes/TechnicalGuidelines/tabid/2381/Default.aspx> [Accessed 6 July 2015].
- Basel Convention (1995). Basel Convention Technical Guidelines on Specially Engineered Landfill (D5).
- Bellanger M, Demeneix B, Grandjean P, Zoeller RT, Trasande L. Neurobehavioral Deficits, Diseases and Associated Costs of Exposure to Endocrine Disrupting Chemicals in the European Union. *J Clin Endocrinol Metab.* 2015 Mar 5;jc20144323. [Epub ahead of print] PubMed PMID: 25742515.
- Bi XH, Thomas GO, Jones KC, Qu WY, Sheng GY, Martin FL, (2007). Exposure of electronics dismantling workers to polybrominated diphenyl ethers, polychlorinated biphenyls, and organochlorine pesticides in South China. *Environ Sci Technol* 41(16):5647-5653.
- BIR, Bureau of International Recycling. [Online] Available online at: http://www.bir.org/industry/textiles/?locale=en_US [Accessed 11 March2015].
- Bleher, D (2014). Global circular economy of strategig metals –best-of-two-worlds approach (Bo2W). Recycling options for WEEE plastic components. p-1-15.
- Blomqvist P, Andersson P and Simonson M (2007a). Fire emissions of organics into the atmosphere. *Fire Technology* 43, 213-231.
- Blomqvist P, Andersson P and Simonson M (SP) and van den Berg M and Canton RF (IRAS) (2007b). Review of fire emissions from products with and without BFRs and the hazard of exposure for fire fighters and clean-up crews. Report from SP (SP Technical Research Institute of Sweden) and IRAS (Institute for Risk Assessment Sciences): 74, pp1-39.
- Breivik K, Armitage JM, Wania F, Jones KC (2014). Tracking the global generation and exports of e-waste. Do existing estimates add up? *Environ Sci Technol.* 48(15):8735-43.
- Breivik K, Sweetman A, Pacyna J, Jones K (2002). Towards a global historical emission inventory for selected PCB congeners – a mass balance approach: 1. Global production and consumption. *Sci Total Environ* 290:181-198
- BSEF, Bromine Science and Environmental Forum (2015a).[Online] Available at: <http://www.bsef.com/regulation/asia-pacific/china> [Accessed 5 March2015].
- BSEF, Bromine Science and Environmental Forum (2015b).[Online] Available at: <http://www.bsef.com/regulation/asia-pacific/india>. [Accessed 5 March 2015]

- BSEF, Bromine Science and Environmental Forum (2012). Brominated flame retardant: decabromodiphenyl ether fact sheet. October 2012. [Online] Available at: http://www.bsef.com/uploads/Deca_factsheet_25-10-2012.pdf [Accessed 6 July 2015].
- BSEF, Bromine Science and Environmental Forum. (2007). About Bromine. [Online] Available at: <http://www.bsef.com/>. [Accessed October 2007].
- Buekens A and Yang J (2014). Recycling of WEEE plastics: a review. *J. Mater. Cycles Waste Manage.* 16, 415–434.
- Buser AM, Morf LS, Taverna R, Bader HP, Scheidegger R (2007a). Temporal behaviour of the anthropogenic metabolism of selected brominated flame retardants: Emissions to the environment. BFR 2007, 4th International Workshop on Brominated Flame Retardants, Amsterdam, The Netherlands, 24-27 April, 2007.
- Carey C, Bryant CJ. Possible interrelations among environmental toxicants, amphibian development, and decline of amphibian populations. *Environ Health Perspect.* 1995 May;103 Suppl 4:13-7.
- CBUF, Sundström, B. (ed.) (1995): Fire Safety of Upholstered Furniture – The final report on the CBUF research programme. Appendix A7 Furniture Calorimeter test protocol Report EUR 16477 EN Directorate-General Science (Measurements and Testing). European Commission. Published by Interscience Communication Ltd, London.
- Chemical Watch (2015). China to place restrictions on hazardous substances in cars six substances to be prohibited. <https://chemicalwatch.com/24517/china-to-place-restrictions-on-hazardous-substances-in-cars>
- Chen S, Ma YJ, Wang J, Chen D, Luo XJ, Mai BX (2009). Brominated flame retardants in children's toys: Concentration, composition, and children's exposure and risk assessment. *Environ Sci Technol*; 43:4200–4206.
- Chen D, Mai B, Song J, Sun Q, Luo Y, Luo X, (2007a). Polybrominated Diphenyl Ethers in Birds of Prey from Northern China. *Environ Sci Technol* 41(6):1828-1833.
- Christiansson A, Eriksson J, Teclechiel D, Bergman A. (2009). Identification and quantification of products formed via photolysis of decabromodiphenyl ether. *Environ Sci Pollut Res Int* 16(3):312-21.
- CPA, Clean Production Action (2007). The Green Screen for Safer Chemicals version 1.0: Evaluating Flame Retardants for TV Enclosures. [Online] Available at: http://www.chemicalspolicy.org/downloads/Green_Screen_Report.pdf. [Accessed 6 July 2015].
- CPA, Clean Product Action (2015). <http://www.cleanproduction.org/news/article/greenscreen-science-at-its-best>
- Danish EPA, Danish Environmental Protection Agency(2007). Mapping of decabromodiphenyl ether (decaBDE) in other products than electrical and electronic products.
- DiGangi J, Blum A, Bergman A, de Wit CA, Lucas D, Mortimer D, Schecter A, Scheringer M, Shaw SD, Webster TF, (2010). San Antonio statement on brominated and chlorinated flame retardants. *Environ Health Perspect* 118:516 – 518.
- DME, Danish Ministry of the Environment (2007). Health and Environmental Assessment of Alternatives to Deca-BDE in Electrical and Electronic Equipment.
- DME, Danish Ministry of the Environment (2006). Deca-BDE and Alternatives in Electrical and Electronic Equipment, Environmental project No. 1141/2006, pp. 1-93. Authors: Lassen C. et al.
- DBIS, 2014, Department for Business Innovation & Skills, London UK. Furniture and Furnishings (Fire) (Safety) Regulation 1988; Consultation on proposed amendments to Schedule 5 –the Match Test-Part 1 and Schedule 4 -the Cigarette Test, August 2014.
- De Wit C, Ulla Sellström U, Nadja Lundgren N, Mats Tysklind M (2005). Higher brominated diphenyl ethers in earthworms and reference and sewage-sludge amended soils. *Organohalogen Compounds - Volume 67*.
- Dong Y, Fu S, Zhang Y, Nie H, Li Z (2014) Polybrominated diphenyl ethers in atmosphere from three different typical industrial areas in Beijing, China. *Chemosphere* S0045-6535(14)01363-0. doi: 10.1016/j.chemosphere.2014.11.043

- DuPont. (2010). Inherent versus Treated Flame Resistant Fabrics. [Online] Available at: http://www2.dupont.com/Personal_Protection/en_US/products/Nomex/nomexind/nomex_industrial_faq.html#5QD. [Accessed 6 July, 2015].
- ECA, Environment Canada (2011) Environmental Monitoring and Surveillance in Support of the Chemicals Management Plan. PBDEs in the Canadian Environment. Environment Canada Fact sheet.p. 1-10.
- ECA, Environment Canada (2010) Proposed risk management strategy for polybrominated diphenyl ethers (PBDEs).
- ECA, Environment Canada (2008). The Polybrominated Diphenyl Ethers Regulations (SOR/2008-218) under the Canadian Environmental Protection Act, 1999.
- ECB, European Chemicals Bureau (2007). Review on production processes of decabromodiphenyl ether (decaBDE) used in polymeric application in electrical and electronic equipment, and assessment of the availability of potential alternatives to decaBDE. Institute on Health and Consumer Protection.
- ECB, European Chemicals Bureau (2002). European Union Risk Assessment Report: Bis(pentabromophenyl) ether. 1st priority list, Volume 17, Luxemburg: European Communities.
- ECHA, European Chemicals Agency (2015). Annex XV restriction report proposal for a restriction. Substance name: Bis(pentabromophenyl) ether, IUPAC name: 1,1'-oxybis(pentabromobenzene), EC number: 214-604-9, CAS number: 1163-19-5. European Chemicals Agency, Helsinki, Finland prepared in collaboration with the Norwegian Environment Agency. Version number: 1.0.
- ECHA, European Chemical Agency (2014b). Decision on substance evaluation pursuant to Article 46 (1) of regulation (EC) NO 1907/2006 for 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene], CAS No 84852-53-9 (EC No284-366-9)
- ECHA, European Chemicals Agency (2013b). ECHA dissemination portal. [Online] Available at: <http://echa.europa.eu/web/guest/information-on-chemicals/registered-substances> [Accessed 12 November 2013].
- ECHA European Chemicals Agency (2012a). Support Document Bis(pentabromophenyl) ether [decabromodiphenyl ether] (Member State Committee, 29 November 2012).
- ECHA, European Chemicals Agency (2012b). Agreement of the member state committee On the identification of bis(pentabromophenyl) ether [decabromodiphenyl ether], (Member State Committee, 29 November 2012).
- ECHA, European Chemicals Agency (2012c). Annex XV dossier. Proposal for Identification of a PBT/vPvB Substance. Bis(pentabromophenyl)ether (decabromodiphenyl ether; decaBDE). July 2012-final. Submitted by the United Kingdom, August 2012. [Online] Available at: http://echa.europa.eu/documents/10162/13638/SVHC_AXVREP_pub_EC_214_604_9_decabromodiphenylether_en.pdf [Accessed 6 July 2015].
- Ebert J, Bahadir M (2003). Formation of PBDD/F from flame-retarded plastic materials under thermal stress. *Environ Int.* 2003;29(6):711-6.
- EFSA, European Food Safety Authority Panel(2011). European Food Safety Authority Panel on Contaminants in the Food Chain (CONTAM). Scientific Opinion on Polybrominated Diphenyl Ethers (PBDEs) in Food. *EFSA Journal*, 9 (5), 2156. doi.10.2903/j.efsa.2011.2156. [Online] Available at: <http://www.efsa.europa.eu/en/efsajournal/doc/2156.pdf> [Accessed 6 July 2015].
- Ebert J, Bahadir M (2003) Formation of PBDD/F from flame-retarded plastic materials under thermal stress, *Environ Int* 29: 711-716.
- EBFRIP, European Brominated Flame Retardant Industry Panel. (2005): Recycling of bromine from plastics containing brominated flame retardants in state-of the-art combustion facilities.
- ENFIRO (2013). Final Report Summary - ENFIRO (Life Cycle Assessment of Environment-compatible Flame Retardants (Prototypical case study)).[Online] Available at:http://cordis.europa.eu/publication/rcn/15697_en.html [Accessed 6 July 2015].
- Earnshaw MR, Jones KC, Sweetman AJ (2013). Estimating European historical production, consumption and atmospheric emissions of decabromodiphenyl ether. *Sci tot Environ* 447: 133-142.
- EUROSTAT (2015) information accessed October 2015 at <http://ec.europa.eu/eurostat/web/waste/key-waste-streams/elvs>

- FAA (2010), Fire Safety Highlights - <http://www.fire.tc.faa.gov/pdf/2010highlights.pdf>
- Gao S, Hong J, Yu Z, Wang J, Yang G, Sheng G, Fu J (2011). Polybrominated diphenyl ethers in surface soils from e-waste recycling areas and industrial areas in South China: concentration levels, congener profile, and inventory. *Environ Toxicol Chem.* 30(12):2688-96.
- Ganser, LR (2009), Anatomy and Function of the African Clawed Frog Vocal System is Altered by the Brominated Flame Retardant, PBDE-209. University of Miami 2009. Open Access Dissertations. Paper 245. [Online]Available at: http://scholarlyrepository.miami.edu/oa_dissertations [Accessed 6 July 2015].
- Gnosys, University of Bolton & Oakdene Hollins 2010. Fire Retardant Technologies: safe products with optimised environmental hazard and risk performance, s.l.: s.n.
- Great Lakes (2013). Emerald Innovation™ 1000. [Online]Available at: http://www.greatlakes.com/Flame_Retardants/Products/Emerald_Innovation_1000. [Accessed 19 November 2013].
- GuillaumeE, Chivas C and Sainrat A (2008). Regulatory issues and flame retardant usage in upholstered furniture in Europe. [Online] Available at:<http://www.see.ed.ac.uk/FIRESEAT/2008.html>
- Hamm S, Strikkeling M, Ranken PF, Rothenbacher KP (2001).Determination of polybrominated diphenyl ethers and PBDD/Fs during the recycling of high impact polystyrene containing decabromodiphenyl ether and antimony oxide. *Chemosphere* 44(6):1353-60.
- Hansen, ES (1990). Acohort study on the mortality of firefighters.Br.J.Ind.Med.47, 805–809.
- Hayes TB, Falso P, Gallipeau S, Stice M (2010). The cause of global amphibian declines: a developmental endocrinologist's perspective. *J Exp Biol.* 15;213(6):921-33.
- Hauser R, Skakkebaek NE, Hass U, Toppari J, Juul A, Andersson AM, Kortenkamp A, Heindel JJ, Trasande L (2015).Male Reproductive Disorders, Diseases, and Costs ofExposure to Endocrine-Disrupting Chemicals in the European Union. *J ClinEndocrinol Metab.* 5:jc20144325. [Epub ahead of print]
- HEAL, Health and Environment Alliance (2014) Health costs in the European Union – How much is related to EDCs?[Online]Available at: http://www.env-health.org/IMG/pdf/18062014_final_health_costs_in_the_european_union_how_much_is_realted_to_edcs.pdf[Accessed 6 July 2015].
- IARC, International Agency for Research on Cancer (2010).Monographs on the evaluation of carcinogenic risks to humans.Volume 98.Painting, firefighting, and shiftwork. [Online] Available at: <http://www.monographs.iarc.fr/ENG/Monographs/vol98/mono98-7.pdf>[Accessed 6 July 2015].
- IKEA 2014. Sustainability report FY14. [Online]Available at: http://www.ikea.com/ms/no_NO/pdf/sustainability_report/sustainability_report_2014.pdf
- Illinois, Illinois Environmental Protection Agency (EPA) (2007). Report on Alternatives to the Flame Retardant DecaBDE: Evaluationof Toxicity, Availability, Affordability, and Fire Safety Issues. A report to the Governor and the General Assembly.
- Illinois, Illinois Environmental Protection Agency (EPA) (2006). A Report to the General Assembly and the Governor In Response to Public Act 94-100 DecaBDE Study: A Review of Available Scientific Research.
- ILO, International Labour Office (2012). The global impact of e-waste: Addressing the challenge. Author Karin Lundgren. Program on Safety and Health at Work and the Environment (SafeWork), Sectorial activities Department (SECTOR), Geneva, pp 1-71.
- IUCN, International Union for Conservation of Nature (2915). [Online] Available at:<http://www.iucn.org/about/>. [Accessed 02 February.2015].
- IVM (2013) POP Stream, POP-BDE waste streams in the Netherlands: analysis and inventory (R13-16). Institute for Environmental Studies, The Netherlands.
- Jayakody C, Myers D, Sorathia U, Nelson GL. 2000. Fire-retardant characteristics of waterblown molded flexible polyurethane foam materials. *J Fire Sci* 18:430-455.
- Jinhui L, Yuan C, Wenjing X. Polybrominated diphenyl ethers in articles: a review of its applications and legislation. *Environ Sci Pollut Res Int.* 2015 May 20. [Epub ahead of print] PubMed PMID: 25987476.

- Kajiwar, N., J. Desborough, S. Harrad, and H. Takigami. (2013). Photolysis of brominated flame retardants in textiles exposed to natural sunlight ENVIRONMENTAL SCIENCE-PROCESSES & IMPACT 15:653-660.
- Kajiwar N, Takigami H (2013b). Emission behavior of hexabromocyclododecanes and polybrominated diphenyl ethers from flame-retardant-treated textiles. Environ Sci Process Impacts.15(10):1957-63.
- Kajiwar, N., Y. Noma, and H. Takigami. (2008). Photolysis studies of technical decabromodiphenyl ether (DecaBDE) and ethane (DeBDethane) in plastics under natural sunlight. Environmental Science & Technology 42:4404-4409.
- Kang, D., Davis, L.K., Hunt, P., Kriebel, D., 2008. Cancer incidence among male Massachusetts firefighters, 1987–2003. Am. Ind. Hyg. Assoc. 51, 329–335.
- Kelly BC, Ikonomou MG, Blair JD, Morin AE, Gobas FA (2007). Food web-specific biomagnification of persistent organic pollutants. Science 2007;13;317(5835):236-9. Erratum in: Science. 2007;318(5847):44.
- Kemi, Swedish Chemical Agency (2014). Chemicals in textiles – Risks to human health and the environment. Report from a government assignment. Report 6/14, pp 1-140. [Online] Available at: <http://www.kemi.se/Documents/Publikationer/Trycksaker/Rapporter/Report6-14-Chemicals-in-textiles.pdf> Accessed 6 July 2015].
- Kemi, Swedish Chemical Agency (2012). Material Recycling without Hazardous Substances – Experiences and future outlook of ten manufacturers of consumer products. Report PM 14/12, pp 1-88. [Online] Available at: <https://www.kemi.se/Documents/Publikationer/Trycksaker/PM/PM14-12-Recycled-materials.pdf> [Accessed 6 July 2015].
- Kemi, Swedish Chemical Agency (2006). Survey and technical assessment of alternatives to TBBPA and HBCDD. Report 1/06. Author: Posner, pp 1-43. [Online] Available at: https://www.kemi.se/Documents/Publikationer/Trycksaker/PM/PM1_06.pdf [Accessed 6 July 2015].
- Kemi, Swedish Chemical Agency (2005). Survey and technical assessment of alternatives to Decabromodiphenyl ether (decaBDE) in plastics. Authors: Posner S, Börås. Report No 1/05, pp 1-34. [Online] Available at: https://www.kemi.se/Documents/Publikationer/Trycksaker/Rapporter/Rapport1_05.pdf [Accessed 6 July 2015].
- Kim M, Guerra P, Theocharides M, Barclay K, Smyth SA, Alae M (2013a). Polybrominated diphenyl ethers in sewage sludge and treated biosolids: effect factors and mass balance. Water Res. Nov 1;47(17):6496-505.
- Kim, M., et al. (2013b). "Parameters affecting the occurrence and removal of polybrominated diphenyl ethers in twenty Canadian wastewater treatment plants." Water Res 47(7): 2213-2221.
- Klif, Climate and Pollution Agency (2011). Exploration of management options for HBCDD. Report to the 8th meeting of the UNECE Task Force on Persistent Organic Pollutants, Montreal 18-20 May 2010 (updated 18 August 2010). Report TA-2818/2011. Authors: Posner S, Roos S, Olsson E., Swerea IVF AB pp 1-84. [Online] Available at: <http://www.miljodirektoratet.no/old/klif/publikasjoner/2818/ta2818.pdf> [Accessed 6 July 2015].
- Klif, Climate and Pollution Agency Norway (2008). Current State of Knowledge and Monitoring requirements for emerging "new" brominated flame retardants in flame retarded products and the Environment. Report TA-2462/2008. [Online] Available at: <http://www.miljodirektoratet.no/old/klif/publikasjoner/2462/ta2462.pdf> [Accessed 6 July 2015].
- LCSP, Lowell Center for Sustainable Production (2015). US State-level Chemicals Policy Database. [Online] Available at: <http://www.chemicalspolicy.org/chemicalspolicy.us.state.database.php> [Accessed 16 March 2015].
- LCSP, Lowell Center for Sustainable Production (2009). A new way of thinking: The Lowell Center Framework for Sustainable Products. University of Massachusetts Lowell.
- LCSP, Lowell Center for Sustainable Production (2005). Decabromodiphenylether: An investigation of non-halogen substitutes in electronic enclosure and textile applications. University of Massachusetts Lowell.

- Legler J, Fletcher T, Govarts E, Porta M, Blumberg B, Heindel JJ, Trasande L. Obesity, Diabetes, and Associated Costs of Exposure to Endocrine-Disrupting Chemicals in the European Union. *J Clin Endocrinol Metab*. 2015 Mar 5;jc20144326. [Epub ahead of print]
- LeMasters GK, Genaidy AM, Succop P, Deddens J, Sobeih T, Barriera-Viruet H, Dunning K, Lockett J (2006). Cancer risk among firefighters: a review and meta-analysis of 32 studies. *J Occup Environ Med*. 2006;48(11):1189-202.
- Levchik, S. (2010). Uses of Decabromodiphenyl Oxide (DecaBDE) Flammability Standards Design for the Environment Kick Off Meeting, Crystal City, VA.
- Li Y, Duan YP, Huang F, Yang J, Xiang N, Meng XZ, Chen L (2013). Polybrominated diphenyl ethers in e-waste: Level and transfer in a typical e-waste recycling site in Shanghai, Eastern China. *Waste Manag*.S0956-053X(13)00409-1.
- Leisewitz and Schwarz, 2001.
- Lin, Y.-M., et al. (2012). "Emissions of Polybrominated Diphenyl Ethers during the Thermal Treatment for Electric Arc Furnace Fly Ash." *Aerosol and Air Quality Research* 12: 237-250.
- Linderholm L, Jakobsson K, Lundh T, Zamir R, Shueb M, Nahar N, Bergman Å. Environmental exposure to POPs and heavy metals in urban children from Dhaka, Bangladesh (2009). *J Environ Monit*. 2011;13(10):2728-34.
- Ma J, Addink R, Yun SH, Cheng J, Wang W, Kannan K. Polybrominated dibenzo-p-dioxins/dibenzofurans and polybrominated diphenyl ethers in soil, vegetation, workshop-floor dust, and electronic shredder residue from an electronic waste recycling facility and in soils from a chemical industrial complex in eastern China. *Environ. Sci. Technol.*, 43 (2009), pp. 7350–7356.
- Maine, Maine Department of Environmental Protection (2010). Decabromodiphenyl Ether Flame Retardant in Plastic Pallets: A Safer Alternatives Assessment. By Pure Strategies Inc.
- Maine (2008). Second Regular Session - 124th Maine Legislature. An Act To Clarify Maine's Phaseout of Polybrominated Diphenyl Ethers. [Online] Available at: http://www.mainelegislature.org/legis/bills/bills_124th/billtexts/HP110501.asp [Accessed 16 March 2015].
- Maine, Maine Department of Environmental Protection and Maine Center for Disease Control and Prevention (2007a), Brominated Flame Retardants: Third Annual Report to the Maine Legislature (p.25-26, 35), January 2007.
- Maine, Maine Department of Environmental Protection and Maine Center for Disease Control and Prevention (2007b), Brominated Flame Retardants: Third Annual Report to the Maine Legislature (p.26, 35), January 2007 2007b.
- Molyneux, Stec AA, Hull R (2014). The effect of gas phase flame retardants on fire effluent toxicity, *Polymer Degradation and Stability* 106:36-46
- Morf LS, Buser AM, Taverna R, Bader H-P, Scheidegger R (2008). Dynamic substance flow analysis as a valuable risk evaluation tool a case study for brominated flame retardants as an example of potential endocrine disrupters. *CHIMIA Int J Chem*62:424–31.
- Morf, LS, Buser AM, Taverna R, Bader HP, Scheidegger R. (2007). Efficient measures in waste management as a key factor to reduce emissions of BFRs: Case study results for DecaBDE in Switzerland and global implications. *Organohalogen Compounds*, 69, 916-919.
- Morf L, Smutny R, Taverna R, Daxbeck H. Selected polybrominated flame retardants, PBDEs and TBBPA—substance flow analysis. Berne: Swiss Agency for the Environment, Forests and Landscape; 2003.
- NCM, Nordic Council of Ministers (2015a). WEEE Plastics Recycling. A guide to enhancing the recovery of plastics from waste electrical and electronic equipment. Authors: John B et al. [Online] Available at: <http://dx.doi.org/10.6027/ANP2015-713> [Accessed 6 July 2015].
- NCM, Nordic Council of Ministers. (2015b). Economic Policy Instruments for Plastic Waste – A review with Nordic perspectives. Report TemaNord 2014:569. Authors: Hennlock M et al. [Online] Available at: <http://norden.diva-portal.org/smash/get/diva2:791794/FULLTEXT02.pdf> [Accessed 6 July 2015].
- NCM, Nordic Council of Ministers (2015a). Plastic value chains: Case: WEEE (Waste Electric and electronic equipment) Part 2 report Baxter et al., Report TemaNord 2015:510 . [Online] Available at:

http://www.norden-ilibrary.org/environment/plastic-value-chains-case-weee-waste-electrical-and-electronic-equipment_tn2015-510

NCM, Nordic Council of Ministers (2014a). Plastic value chains. Case: WEEE (Waste Electric and electronic equipment) in the Nordic region. Baxter et al., Report TemaNord 2014:542 [Online] Available at: <http://norden.diva-portal.org/smash/get/diva2:721021/FULLTEXT01.pdf> [Accessed 6 July 2015].

NCM, Nordic Council of Ministers (2014b). The Cost of Inaction - A Socioeconomic analysis of costs linked to effects of endocrine disrupting substances on male reproductive health. Authors: Olsson I.M. et al. Report TemaNord 2014:557 [Online] Available at: <http://norden.diva-portal.org/smash/get/diva2:763442/FULLTEXT04.pdf> [Accessed 6 July 2015].

NCM, Nordic Council of Ministers (2014c). Addressing resource efficiency through the Ecodesign Directive. A review of opportunities and barriers. Authors: Dalhammar C. et al. Report TemaNord 2014:511, [Online] Available at: <http://www.diva-portal.org/smash/get/diva2:710881/FULLTEXT01.pdf> [Accessed 6 July 2015].

NCM, Nordic Council of Ministers (2005). Measurements During Incineration of Waste Containing Bromine. Report TemaNord 2005:529 Authors: Borgnes D. et al. [Online] Available at: <http://norden.diva-portal.org/smash/get/diva2:702261/FULLTEXT01.pdf> [Accessed 6 July 2015].

NEA, Norwegian Environment Agency (2012). Some environmentally harmful substances in sewage sludge – occurrence and environmental risk. Report TA-3005/2012. pp 1-37. [Online] Available at: <http://www.miljodirektoratet.no/old/klif/publikasjoner/3005/ta3005.pdf> [Accessed 6 July 2015].

NERI Technical Report No. 481 2003. Polybrominated Diphenyl Ethers (PBDEs) in Sewage Sludge and Wastewater Method Development and Validation. National Environmental Research Institute Ministry of the Environment. Denmark. pp.1-34.

New York State Department of Health (2013) Report of the New York State Task Force on Flame Retardant Safety [Online] Available at: <http://www.health.ny.gov/environmental/investigations/flame/docs/report.pdf> [Accessed 6 July 2015].

NFPA, National Fire Protection Association (2013). Home structure fires. [Online] Available at: <http://www.nfpa.org/~media/Files/Research/NFPA%20reports/Occupancies/oshomes.pdf> [Accessed 6 July 2015].

NFPA, The Norwegian Fire Protection Association (2014). [Online] Available at: <http://www.brannvernforeningen.no/Brannstatistikk/Boligbranner-antatt-arrestet> [Accessed 6 July 2015].

Ni, H.-G.; Zeng, E.Y. 2009. "Law enforcement and global collaboration are the keys to containing e-waste tsunami in China", in *Environmental Science & Technology*, Vol. 43, No. 11, pp. 3991–3994.

NIFV, Netherlands institute for safety (2009). Consumer fire safety: European statistics and potential fire safety measures. Authors: M. Kobes (BBE, MIFireE), K. Groenewegen, (Ter Morsche), M.G. Duyvis, J.G. Post. Report commissioned by Consumer Council, Austrian Standards Institute, pp 1-57. [Online] Available at: <http://www.verbraucherrat.at/content/01-news/05-archiv-2009-2010/01-studie-brandschutz/firesafetyconsumer.pdf> [Accessed 6 July 2015].

NTP (National Toxicology Program). 1990. Final Report on the Reproductive Toxicity of Boric Acid (CAS NO. 10043-35-3) in CD-1 Swiss Mice. National Toxicology Program. NTP Report no.90-150

NZMOE (2013). Brominated flame retardant research. Cost-benefit analysis of sorting options for e-waste plastics. Draft report to New Zealand Ministry for the Environment. October 2013. s.1-15.

Odabasi M, Bayram A, Elbir T, Seyfioglu R, Dumanoglu Y, Bozlaker A, Demircioglu H, Altiohk H, Yatkin S, Cetin B (2009). Electric arc furnaces for steel-making: hot spots for persistent organic pollutants. *Environ Sci Technol.* 43(14):5205-11.

OECD, Organisation for Economic Co-operation and Development (2014): Risk management of installations and chemicals. Brominated Flame Retardants. [Online] Available at: <http://www.oecd.org/env/ehs/risk-management/brominatedflameretardants.htm> [Accessed; 27 February 2014].

OECD, Organisation for Economic Co-operation and Development (1998). Waste Management Policy Group 1998. Report on incineration of products containing brominated flame retardants. pp. 1-11.

OSPAR, The Convention for the Protection of the marine Environment of the North-East Atlantic (2009). OSPAR Background Document on certain brominated flame retardants – Polybrominated

Diphenylethers, Polybrominated Biphenyls, Hexabromo Cyclododecane, Update 2009. Hazardous Substances Series. OSPAR Commission.

Oregon (2011). Decabrominated diphenyl ether and other flame retardants banned in Oregon products. Interpretive and Policy Guidance from the Oregon Health Authority. [Online] Available at: http://3vlyi21yjf3t3ecx1148lncocyk.wpengine.netdna-cdn.com/wp-content/uploads/2011/02/PBDEGuidance.Final_.pdf [Accessed 6 July 2015].

Palm A, Cousins IT, Mackay D, Tysklind M, Metcalfe C, Alaee M (2002). Assessing the environmental fate of chemicals of emerging concern: a case study of the polybrominated diphenyl ethers. *Environ Pollut* 117:195–213.

PR Newswire, 2010. ICL-IP Launches Polyquel™ Eco-Friendly Polymeric Flame Retardants. [Online] Available at: <http://www.prnewswire.com/news-releases/icl-ip-launches-polyqueltm-eco-friendly-polymeric-flame-retardants-93928309.html> [Accessed 6 July 2015].

Puype F, Samson J, Knoop J, Egelkraut-Holtus M, Ortlieb M (2015). Evidence of waste electrical and electronic equipment (WEEE) relevant substances in polymeric food-contact articles sold on the European market. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess*. 2015 Jan 19. [Epub ahead of print].

Qin, X., X. Xia, (2010). Thyroid disruption by technical decabromodiphenyl ether (DE-83R) at low concentrations in *Xenopus laevis*. *J Environ Sci* 22(5): 744–751.

Qu WY, Bi XH, Sheng GY, Lu SY, Fu H, Yuan J, (2007). Exposure to polybrominated diphenyl ethers among workers at an electronic waste dismantling region in Guangdong, China. *Environ Int* 33(8):1029–1034.

RAC/SEAC (2015). Background document to the Opinion on the Annex XV dossier proposing restrictions on Bis(pentabromophenyl) ether, IUPAC name: 1,1'-oxybis(pentabromobenzene), EC number: 214-604-9, CAS number: 1163-19-5 ECHA/RAC/RES-O-0000006155-77-01/D, ECHA/SEAC/RES-O-0000006155-77-03/F. European Chemicals Agency.

Ren Z, Xiao X, Chen D, Bi X, Huang B, Liu M, Hu J, Peng P, Sheng G, Fu J. (2014). Halogenated organic pollutants in particulate matters emitted during recycling of waste printed circuit boards in a typical e-waste workshop of Southern China. *Chemosphere*. 2014;94:143–150.

Ren, G., Z. Wang, Z. Yu, Y. Wang, S. Ma, M. Wu, G. Sheng, and J. Fu. (2013). Primary investigation on contamination pattern of legacy and emerging halogenated organic pollutants in freshwater fish from Liaoh River, Northeast China. *Environmental Pollution* 172:94–99.

Ren M, Peng P, Cai Y, Chen D, Zhou L, Chen P, Hu J. PBDD/F impurities in some commercial deca-BDE. *Environ Pollut*. 2011;159(5):1375–80.

Ricklund N, Kierkegaard A, McLachlan MS, Wahlberg C (2008a). Mass balance of decabromodiphenyl ethane and decabromodiphenyl ether in a WWTP. *Chemosphere* 74: 389–394.

Ricklund, N., A. Kierkegaard, (2008b). "An international survey of decabromodiphenyl ethane (deBDEthane) and decabromodiphenyl ether (decaBDE) in sewage sludge samples." *Chemosphere* 73(11): 1799–1804.

Rosenberg C, Hämeilä M, Tornaeus J, Säkkinen K, Puttonen K, Korpi A, Kiilunen M, Linnainmaa M, Hesso A. Exposure to flame retardants in electronics recycling sites. *Ann Occup Hyg*. 2011;55(6):658–65. doi: 10.1093/annhyg/mer033.

RPA, Risk and Policy Analysts P (2014). Multiple Framework Contract with Re-opening of competition for Scientific Services for ECHA. Reference: ECHA/2011/01 Service Request SR 14:Support to an Annex XV Dossier on Bis-(pentabromophenyl) ether (DecaBDE). Authors: Georgalas B, Sanchez A, Zarogiannis. [Online] Available at: http://echa.europa.eu/documents/10162/13641/annex_xvi_consultant_report_decabde_en.pdf [Accessed 6 July 2015].

RTKnet.org. [Online] Available at: http://www.rtknet.org/db/tri/tri.php?database=tri&reptype=f&reporting_year=2013&first_year_range=&last_year_range=&facility_name=&parent=&combined_name=&parent_duns=&facility_id=&city=&county=&state=&zip=&district=&naics=&primall=&chemcat=&corechem=y&casno=001163195&casno2=&chemname=&detail=-1&dtype=T&rsei=y&sortp=D [Accessed 6 July 2015].

Sakai SI, Hirai Y, Aizawa H, Ota S, Muroishi Y (2006). Emission inventory of deca-brominated diphenyl ether (DBDE) in Japan. *J. Mater. Cycles Waste Manage*. 8:56–62.

- Samsonak J, Puype F (2013). Occurrence of brominated flame retardants in black thermo cups and selected kitchen utensils purchased on the European market. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess* 30:1976-86. doi: 10.1080/19440049.2013.829246.
- Schriks M, Zvinavashe E, Furlow JD, Murk AJ (2006). Disruption of thyroid hormone-mediated *Xenopus laevis* tadpole tail tip regression by hexabromocyclododecane (HBCD) and 2,2',3,3',4,4',5,5',6 nona brominated diphenyl ether (BDE206). *Chemosphere* 65(10):1904-8.
- Sellstrom U, C. De Wit, N. Lundgren, and M. Tysklind (2005). Effect of Sewage-Sludge Application on Concentrations of Higher-Brominated Diphenyl Ethers in Soils and Earthworms. *Environ. Sci. Technol.*, 39: 9064-9070.
- SFT, Norwegian Pollution Control Authority (2009). Polybrominated diphenyl ethers and perfluorinated compounds in the Norwegian environment. Report TA-2450. [Authors: Skoog K, Hauglid-Formo G, Økland T. Edited by: Bergfald & Co AS. [Online] Available at: <http://www.miljodirektoratet.no/old/klif/publikasjoner/2450/ta2450.pdf> [Accessed 6 July 2015]
- Shaw SD, Berger ML, Harris JH, Yun SH, Wu Q, Liao C, Blum A, Stefani A, Kannan K. Persistent organic pollutants including polychlorinated and polybrominated dibenzo-p-dioxins and dibenzofurans in firefighters from Northern California. *Chemosphere*. 2013 Jun;91(10):1386-94. doi: 10.1016/j.chemosphere.2012.12.070. Epub 2013 Feb 8. Erratum in: *Chemosphere*. 2014;102:87.
- Shaw SD, Blum A, Weber R, Kannan K, Rich D, Lucas D, Koshland CP, Dobraca D, Hanson S, Birnbaum LS (2010). Halogenated flame retardants: do the fire safety benefits justify the risks? *Rev Environ Health*. 25: 261-305.
- Simonson, Margaret et al (2000): TV case study, a life cycle analysis. SPSwedish National Testing and Research Institute Fire Technology SP Report 2000:13, 2000
- Sinha-Khetriwal, D., Kraeuchi, P., and Schwaninger, M. (2005). A comparison of electronic waste recycling in Switzerland and in India. *Environ. Impact Assess. Rev.* 25: 492–504
- Sjödin A, Hagmar L, Klasson-Wehler E, Kronholm-Diab K, Jakobsson E and Bergman A (1999). Flame retardant exposure: polybrominated diphenyl ethers in blood from Swedish workers. *Environmental Health Perspectives*, 107, 643-648.
- Stapleton HS, Sharma S, Getzinger G, Ferguson PL, Gabriel M, Webster TF and Blum A (2012). Novel and high volume use of flame retardants in US couches reflective of the 2005 PentaBDE phase out. *Environmental Science & Technology*, 46, 13432-13439.
- Stec AA, Hull R (2011.) Assessment of the fire toxicity of building insulation materials, *Energy and Buildings* 43:498-506.
- Stenvall, E., Tostar, S., Boldizar, A., R.St.J. Foreman, M., Moller, K. (2013). "An analysis of the composition and metal contamination of plastics from waste electrical and electronic equipment (WEEE)", *Waste Management*, vol33, pp 915–922.
- StEP - Solving the E-waste problem (2013). Annual report 2012/2013. [Online] Available at: http://www.step-initiative.org/files/step/StEP_AR/StEP_AR.html [Accessed online: 6 July 2015].
- Stockholm Convention (2012a) Guidance on best available techniques and best environmental practices for the recycling and disposal of articles containing polybrominated diphenyl ethers (PBDEs) listed under the Stockholm Convention on Persistent Organic Pollutants; Draft July 2012.
- Stockholm Convention (2012b). Guidance for the inventory of polybrominated diphenyl ethers (PBDEs) listed under the Stockholm Convention on Persistent Organic Pollutants.
- Streicher-Portea, M., Widmerb, R., Jainc, A., Baderd, H-P., Scheideggere, R., and Kytziaf, S. (2005). Key drivers of the e-waste recycling system: Assessing and modelling e-waste processing in the informal sector in Delhi. *Environ. Impact Assess. Rev.* 25: 472–491
- SAICM, Strategic Approach to International Chemicals Management (2009). Background information in relation to the emerging policy issue of electronic waste, paper presented at the International Conference on Chemicals Management, Geneva, 11–15 May (SAICM/ICCM.2/INF36).
- Stuart SN, Chanson JS, Cox NA, Young BE, Rodrigues AS, Fischman DL, Waller RW (2004). Status and trends of amphibian declines and extinctions worldwide. *Science*. 3;306(5702):1783-6.

- Tang, Z., et al. (2014). "Polybrominated Diphenyl Ethers in Soils, Sediments, and Human Hair in a Plastic Waste Recycling Area: A Neglected Heavily Polluted Area." *Environmental Science & Technology* 48(3): 1508-1516.
- TB117-2013. Technical Bulletin 117-2013. Requirements, Test Procedure and Apparatus for Testing the Smolder Resistance of Materials Used in Upholstered Furniture. State of California Department of Consumer Affairs.
- Thoma H, Hutzinger O, 1987. Pyrolysis and GC/MS-analysis of brominated flame 602 retardants in on line operation. *Chemosphere* 16, 1353–1360.
- Thuresson K, Bergman K, Rothenbacher K, Herrmann T, Sjölin S, Hagmar L, Pöpke O, Jakobsson K. Polybrominated diphenyl ether exposure to electronics recyclingworkers--a follow up study. *Chemosphere*. 2006 Sep;64(11):1855-61.
- Tomy GT, Pleskach K, Oswald T, Halldorson T, Helm PA, MacInnis G, et al (2008). Enantioselective bioaccumulation of hexabromocyclododecane and congener specific accumulation of brominated diphenyl ethers in an eastern Canadian Arctic marine food web. *Environ Sci Technol* 42:3634–9.
- Trasande L, Zoeller RT, Hass U, Kortenkamp A, Grandjean P, Myers JP, DiGangi J, Bellanger M, Hauser R, Legler J, Skakkebaek NE, Heindel JJ. Estimating Burden and Disease Costs of Exposure to Endocrine-Disrupting Chemicals in the European Union. *J Clin Endocrinol Metab*. 2015 Mar 5;jc20144324. [Epub ahead of print]
- Tsydenova O, Bengtsson M (2011). Chemical hazards associated with treatment of waste electrical and electronic equipment. *Waste Management* 31:45-58.
- Tue NM, Sudaryanto A, Binh Minh T, Isobe T, Takahashi S, Hung Viet P, Tanabe S (2010). Accumulation of polychlorinated biphenyls and brominated flame retardants in breast milk from women living in Vietnamese e-waste recycling sites. *Science of the Total Environment* 408 (2010) 2155–2162.
- UK EA, United Kingdom Environment Agency (2009). Environmental risk evaluation report. Decabromodiphenyl ether (CAS no. 1163-19-5). Authors Brooke, D.N., Burns, J., Crookes, M.J. and Dungey, S.M Report to the. 290 pp.
- UK EA, United Kingdom Environment Agency (2007). Environmental Risk Evaluation Report: 1,1'-(Ethane-1,2-diyl) bis[pentabromobenzene] (CAS No. 64852-53-9). Environment Agency, Bristol, UK. Science Report no.:SCH00507BM0R-E-P. Authors: Dungey S. et al. [Online] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/290840/scho0507bmor-e-e.pdf [Accessed 6 July 2015].
- UNCED 1992a, United Nations Conference on Environment and Development Rio de Janeiro, Brazil, 3 to 14 June 1992. AGENDA 21. [Online] Available at: <https://sustainabledevelopment.un.org/index.php?page=view&nr=23&type=400> [Accessed 6 July 2015].
- UNCED 1992b, United Nations Conference on Environment and Development Rio de Janeiro, Brazil, 3 to 14 June 1992. Rio Declaration on Environment and Development. [Online] Available at: <http://www.unep.org/Documents.Multilingual/Default.asp?documentid=78&articleid=1163> [Accessed 6 July 2015].
- UNEP, United Nations Environment Programme (2014a). Draft revised guidance for the inventory of polybrominated diphenyl ethers (PBDEs) listed under the Stockholm Convention on POPs (31 March 2014). [Online] Available at: <http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-NIP-GUID-InventoryPBDE.En.docx> [Accessed 6 July 2015].
- UNEP, United Nations Environment Programme (2014b). Draft revised guidance for the inventory of perfluorooctane sulfonic acid (PFOS) and related chemicals listed under the Stockholm Convention (31 March 2014). [Online] Available at: <http://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-NIP-GUID-InventoryPFOS.En.docx> [Accessed 6 July 2015].
- UNEP, United Nations Environment Programme (2012). Guidance on best available techniques and best environmental practices for the recycling and disposal of articles containing polybrominated diphenyl ethers (PBDEs) listed under the Stockholm Convention on Persistent Organic Pollutants. http://www.unido.org/fileadmin/user_media/Services/Environmental_Management/Stockholm_Convention/Guidance_Docs/UNEP-POPS-GUID-NIP-2012-BATBEPBDEs.En.pdf
- UNEP, United Nations Environment Programme (2006). Strategic Approach to International Chemicals Management SAICM texts and resolutions of the International Conference on Chemicals

Management. Comprising the Dubai Declaration on International Chemicals Management, the Overarching Policy Strategy and the Global Plan of Action ISBN: 978-92-807-2751-7.

Recycling: From e-waste to resources, Sustainable Innovation and Technology Transfer Industrial Sector Studies. Solving the E-Waste Problem (StEP) Initiative Final report, July 2009. 1-120 pp. Authors Schluep, M. et al. 2009. [Online] Available: http://www.unep.org/pdf/Recycling_From_e-waste_to_resources.pdf [Accessed 6 July 2015].

U.S. EPA, U.S. Environmental Protection Agency (2015). Toxics Release Inventory (TRI) Program. [Online] Available at: <http://www.epa.gov/tri/> [Accessed 10 March 2015].

U.S. EPA, U.S. Environmental Protection Agency (2014a). An alternatives assessment for the flame retardant decabromodiphenyl ether (decaBDE). <http://www.epa.gov/oppt/existingchemicals/pubs/actionplans/aa-for-deca-full-version.pdf> [Accessed 6 July 2015].

U.S. EPA, U.S. Environmental Protection Agency (2014b). What is the Furniture Flame Retardancy Partnership? [Online] Available at: http://www2.epa.gov/sites/production/files/2013-12/documents/ffr_foam_alternatives_fact_sheet.pdf [Accessed 6 July 2015].

U.S. EPA, U.S. Environmental Protection Agency (2014c). Common Wastes & Materials – Plastics. [Online] Available at: <http://www.epa.gov/osw/conserve/materials/plastics.htm> [Accessed 6 July 2015].

U.S. EPA, U.S. Environmental Protection Agency (2010). An Exposure Assessment of Polybrominated Diphenyl Ethers. National Center for Environmental Assessment, U.S. Environmental Protection Agency, Washington DC; EPA/600/R-08/086F. Available from the National Technical Information Service, Springfield, VA. [Online] Available at: <http://www.epa.gov/ncea> [Accessed 6 July 2015].

U.S. EPA, U.S. Environmental Protection Agency (2008). Toxicological Review Of Decabromodiphenyl Ether (BDE-209) (CAS No. 1163-19-5). In Support of Summary Information on the Integrated Risk Information System (IRIS). Report EPA/600/R-08/086F, pp. 1-126. Authors: Donohue JM et al. [Online] Available at: <http://www.epa.gov/iris/toxreviews/0035tr.pdf> [Accessed 6 July 2015].

U.S. EPA, U.S. Environmental Protection Agency (2007). Dermal Exposure Assessment: A Summary of EPA Approaches. [Online] Available at: <http://cfpub.epa.gov/ncea/cfm/recorddisplay.cfm?deid=183584>. [Accessed 18 November 2013].

Van Allen BG, Briggs VS, McCoy MW, Vonesh JR. Carry-over effects of the larval environment on post-metamorphic performance in two hylid frogs. *Oecologia*. 2010;164(4):891-8.

VECAP, The Voluntary Emissions Control Action Programme (2014). Sound results from a proactive industry. European annual progress report 2013.

VECAP, The Voluntary Emissions Control Action Programme (2012). Maintaining Momentum - European Annual Progress Report 2012, Brussels: VECAP.

VECAP, The Voluntary Emissions Control Action Programme (2010a). The Voluntary Emissions Control Action Programme. Annual progress report 2010a.

VECAP, The Voluntary Emissions Control Action Programme (2010b). Benchmarking for success. North American annual progress report 2010.

Vermont (2013). No. 85. An act relating to the regulation of octaBDE, pentaBDE, decaBDE, and the flame retardant known as Tris in consumer products. [Online] Available at: <http://legislature.vermont.gov/assets/Documents/2014/Docs/ACTS/ACT085/ACT085%20As%20Enacted.pdf> [Accessed 6 July 2015].

Vetter W, Bendig P, Blumenstein M, Hägele F (2012). Cooking processes with food; The heating of the flame retardant BDE-209 in fish generated toxic polybrominated dibenzofurans. *Organohalogen Compounds* 74, 620-623 (2012).

Wang S, Zhang S, Huang H, Niu Z, Han W (2014). Characterization of polybrominated diphenyl ethers (PBDEs) and hydroxylated and methoxylated PBDEs in soils and plants from an e-waste area, China. *Environmental Pollution*, 184, pp.405–413.

Wang Y, Luo C, Li J, Yin H, Li X, Zhang G (2011a). Characterization of PBDEs in soils and vegetations near an e-waste recycling site in South China. *Environ Pollut.* 159(10):2443-8.

- Wang, J., et al. (2011b). Polybrominated diphenyl ethers in water, sediment, soil, and biological samples from different industrial areas in Zhejiang, China. *J Hazard Mater* 197: 211-219.
- Wang, J., et al. (2011d). Polybrominated diphenyl ethers in water, sediment, soil, and biological samples from different industrial areas in Zhejiang, China. *J Hazard Mater* 197: 211-219.
- Wang Bin, Fukuya Iino, Gang Yu, Jun Huang, and Masatoshi Morita (2010b). The Pollution Status of Emerging Persistent Organic Pollutants in China. *Environmental Engineering Science* Volume 27, Number 3.
- Wang, L.-C., et al. (2010d). Characterizing the Emissions of Polybrominated Diphenyl Ethers (PBDEs) and Polybrominated Dibenzo-p-dioxins and Dibenzofurans (PBDD/Fs) from Metallurgical Processes. *Environmental Science & Technology* 44(4): 1240-1246.
- Washington State Department of Health (2008). Alternatives to Deca-BDE in Televisions and Residential Upholstered Furniture. Department of Ecology. Olympia, WA.
- Washington (2006). Washington State Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan: Final Plan, Washington Department of Ecology and Washington Department of Health: 328.
- Weber R and Kuch B (2003) Relevance of BFRs and thermal conditions on the formation pathways of brominated and brominated-chlorinated dibenzodioxins and dibenzofurans. *Environment International*, 29:699-710.
- Wäger, P., Schluep, M., Müller, E. (2010), RoHS substances in mixed plastics from Waste Electrical and Electronic Equipment, Final Report, Empa, Swiss Federal Laboratories for Materials Science and Technology. pp. 1-99 [Online] Available at: http://new.weee-forum.org/system/files/documents/rohs20in20mixed20plastics_empa_final_2010200920171.pdf [Accessed 6 July 2015].
- Weil, E. D. and S. V. Levchik (2009). Flame Retardants for Plastics and Textiles: Practical Applications, Hanser.
- Weir RJ Jr, Fisher RS (1072). Toxicologic studies on borax and boric acid. *ToxicolAppl Pharmacol*. 23(3):351-64.
- WHO, World Health Organization(2014). Fact sheet on reduced ignition propensity (RIP) cigarettes. [Online] Available at: http://www.who.int/tobacco/industry/product_regulation/factsheetreducedignitionpropensitycigarettes/en/ [Accessed 6 July 2015].
- WHO/UNEP, World Health Organization and the United Nations Environment Programme (2013). State of the Science of Endocrine Disrupting Chemicals-2012. An assessment of the state of the science of endocrine disruptors prepared by a group of experts for the United Nations Environment Programme and World Health Organization. p1- 296. Eds: Bergman Å, Heindel JJ, Jobling S, Kidd KA and Zoeller T. IOMC (Inter-organizational program for the sound management of chemicals). [Online] Available at: <http://www.who.int/ceh/publications/endocrine/en/> [Accessed 6 July 2015].
- Widmera, R., Oswald-Krapf, H., Sinha-Khetriwalb, D., Schnellmann, M., Bo`nia, H. (2005). Global perspectives on e-waste. *Environ. Impact Assess. Rev.* 25: 436–458
- Xu X, Liu J, Zeng X, Lu F, Chen A, Xia H (2014) Elevated serum polybrominated diphenyl ethers and alteration of thyroid hormones in children from Guiyu, China, *PLoS ONE* 9 (11):1-18.
- Yang Q, Qiu X, Li R, Liu S, Li K, Wang F (2013). Exposure to typical persistent organic pollutants from an electronic waste recycling site in Northern China. *Chemosphere* 91:205–211.
- Yu X, Zennegg M, Engwall M, Rotander A, Larsson M, Ming Hung W, Weber R (2008) E-waste recycling heavily contaminates a Chinese city with chlorinated, brominated and mixed halogenated dioxins. *Organohalogen Compounds* 70:813-816.
- Yuan C. (2015). Management of PBDEs Flame Retarded Plastics from WEEE in China. Basel Convention Regional Centre for Asia and the Pacific. Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology in Asia and the Pacific, China. Presentation. [Online] Available at: www.synergies.pops.int [Accessed 6 July 2015].
- Zennegg M, Xiezhi Y, Wong MH, Weber RR (2009). Fingerprints of chlorinated, brominated and mixed halogenated dioxins at two e-waste recycling sites in Guiyu China. *Organohalogen Compd.*, 71 (2009), pp. 2263–2267

Zhang, Y., et al. (2013d). Polybrominated diphenyl ethers in soil from three typical industrial areas in Beijing, China. *J Environ Sci (China)* 25(12): 2443-2450.

Zhang S, Xu X, Wu Y, Ge J, Li W, Huo X (2014). Polybrominated diphenyl ethers in residential and agricultural soils from an electronic waste polluted region in South China: distribution, compositional profile, and sources. *Chemosphere*, 102:55-60.

Zoeteman, B.C.J; Krikke, H.R.; Venselaar, J. 2010. Handling WEEE waste flows: On the effectiveness of producer responsibility in a globalizing world, in *International Journal of Advanced Manufacturing Technology*, Vol. 47, pp. 415–436.

Appendix B: Risk management evaluation on hexachlorobutadiene



**Stockholm Convention
on Persistent Organic
Pollutants**

Persistent Organic Pollutants Review Committee
Ninth meeting
Rome, 14–18 October 2013

**Report of the Persistent Organic Pollutants Review Committee
on the work of its ninth meeting**

Addendum

Risk management evaluation on hexachlorobutadiene

At its ninth meeting, by its decision POPRC-9/2, the Persistent Organic Pollutants Review Committee adopted a risk management evaluation for hexachlorobutadiene on the basis of the draft contained in document UNEP/POPS/POPRC.9/5. The text of the risk management evaluation, as amended, is set out in the annex to the present addendum. It has not been formally edited.

Annex

HEXACHLOROBTADIENE

RISK MANAGEMENT EVALUATION

Prepared by the ad hoc working group on hexachlorobutadiene
Persistent Organic Pollutants Review Committee

18 October 2013

Table of Contents

Executive summary	4
1. Introduction	5
1.1 Chemical identity of the proposed substance	5
1.2 Conclusions of the Review Committee regarding Annex E information	6
1.3 Data sources	7
1.4 Status of the chemical under international conventions	7
1.5 Any national or regional control actions taken	7
2. Summary information relevant to the risk management evaluation	9
2.1 Additional relevant information on sources, releases and measures	9
2.2 Identification of possible control measures	14
2.3 Efficacy and efficiency of possible control measures in meeting risk reduction goals	16
2.4 Information on alternatives (products and processes) where relevant	17
2.5 Summary of information on impacts on society of implementing possible control measures	18
2.6 Other considerations	18
3. Synthesis of information	18
4. Concluding statement	20
References	21

Executive summary

1. The European Community and its Member States submitted a proposal to list hexachlorobutadiene (HCBD) in Annex A, B and/or C to the Stockholm Convention pursuant to paragraph 1 of Article 8 of the Convention. The risk profile of HCBD was adopted by the eighth meeting of the Persistent Organic Pollutants Review Committee in October 2012. The Committee decided (1) that HCBD is likely, as a result of its long range environmental transport, to lead to significant adverse human health and environmental effects such that global action is warranted; (2) to prepare a risk management evaluation that includes an analysis of possible control measures for HCBD and (3) to invite parties and observers to submit to the Secretariat the information specified in Annex F before 11 January 2013, as well as additional information relevant to Annex E, in particular data on sources of emissions such as the intentional production of HCBD and/or unintentional releases.

2. HCBD is a halogenated aliphatic compound which has been used in several technical and agricultural applications e.g. as intermediate in the chemical industry or as a product. In the past it was intentionally produced and applied e.g. as a solvent (for rubber and other polymers), as a "scrubber" to recover chlorine-containing gas or to remove volatile organic components from gas, as hydraulic, heat transfer or transformer fluid, in gyroscopes, in the production of aluminium and graphite rods and as a plant protection product. HCBD is not known to be currently intentionally produced or used. To limit the possible remaining uses and to prevent re-introduction of other uses, listing of HCBD in Annex A without any specific exemptions would be the most efficient control measure for intentional sources. As a consequence, HCBD would be submitted to the provisions of Article 3 of the Convention and the requirement to eliminate its production, use, import and export. All applications seem to have ceased, though specific information on intentional production and use is lacking for the current situation and for the past 30 years. This indicates that substitution has taken place and that alternatives are available. Additional costs for eliminating the intentional production and use of HCBD are not expected. Cost increases for consumers are not expected, since the alternatives are already in use. Health and the environment could be protected and benefited from the ban of HCBD, as the re-introduction of HCBD and related risks would be prevented and any currently unidentified intentional production and use around the world should end.

3. HCBD is unintentionally formed and released from industrial processes and other sources. Relevant sources are the production of chlorinated hydrocarbons, production of magnesium, and incineration processes. Releases can be minimized by alternative production processes, improved process control, emission control measures, or by substitution of the relevant chlorinated chemicals. Listing of HCBD in Annex C would subject this substance to the measures under Article 5 of the Convention, and establish the goal of continuing minimization and, where feasible, ultimate elimination of HCBD releases. This would include an obligation to promote best available techniques (BAT) and best environmental practices (BEP) for HCBD sources. Cost efficient BAT and BEP to reduce releases of unintentionally produced HCBD are available and described in relevant documents. Countries already have obligations to implement control measures for other unintentionally produced persistent organic pollutants (POPs) (hexachlorobenzene (HCB), pentachlorobenzene (PeCB), polychlorinated biphenyls (PCB), and polychlorinated dibenzo-*p*-dioxins and dibenzofurans PCDD/PCDF) under the Convention. These will be similar to those for HCBD. Emissive uses of perchloroethylene, trichloroethylene, and carbon tetrachloride have been phased out in several applications; for the remaining industrial uses, processes have been improved in a way that less product is consumed in the process and the production volumes of perchloroethylene and trichloroethylene are declining in numerous signature states to relevant Conventions¹. Furthermore, when safer and technically feasible and cost-effective alternatives for specific uses of perchloroethylene and trichloroethylene, the unintentional generation of HCBD can be reduced by substituting chlorinated chemicals by alternatives. This demonstrates that measures to reduce unintentional releases of HCBD through listing in Annex C would positively impact human health and the environment. Additional costs for applying BAT and BEP and for control measures and emission inventories are considered low. Monitoring of HCBD will induce additional costs. Additional costs for implementation of measures to reduce releases of HCBD, enforcement and supervision are considered low as the control measures for other unintentional POPs such as PCDD/PCDF are already applied. Monitoring capacity for HCBD is needed in developing countries and countries with economies in transition.

4. Examples document the potential for HCBD releases from former waste disposal. There is no insight into the total amount of waste sites worldwide, nor into their releases. Listing of HCBD in Annex A and/or C would subject HCBD to the measures under Article 6 of the Convention and would establish the goal of identifying sites contaminated with HCBD and managing them in a manner protective of human health and the environment. BAT and BEP to minimise releases from waste disposal are available (BC, 1997). Countries have already introduced corresponding measures. The proposed measure would require the development of strategies to identify, to the extent practicable, existing waste stockpiles, and to manage them in an environmentally sound manner e.g. by appropriate treatment of relevant landfill leachate. Such measures would positively impact human health and the environment.

¹ CEH Marketing Research Report: "C2 Chlorinated Solvents" (2012); abstract available at <http://www.ihs.com/products/chemical/planning/ceh/c2-chlorinated.aspx>

Additional costs for identifying relevant landfills, establishing corresponding inventories and sound management of releases are considered low.

5. Having prepared a risk management evaluation and considered the management options, in accordance with paragraph 9 of Article 8 of the Convention, the Committee recommends that the Conference of the Parties to the Stockholm Convention should consider listing and specifying the related control measures for HCBd in Annexes A and C.

1. Introduction

1.1 Chemical identity of the proposed substance²

6. The European Union and its Member States submitted a proposal to list hexachlorobutadiene (HCBd) in Annex A, B and/or C to the Stockholm Convention on 10 May 2011 (UNEP/POPS/POPRC.7/3), together with a detailed dossier to support the proposal (UNEP/POPS/POPRC.7/INF/4).

7. HCBd is a halogenated aliphatic compound, mainly generated as a by-product in the manufacture of chlorinated aliphatic compounds (primarily tri- and tetrachloroethene and tetrachloromethane). It has also been used as a pesticidal fumigant.

Name and registry number

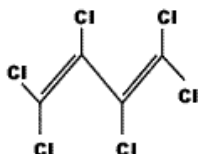
Common name:	Hexachlorobutadiene
IUPAC Name:	1,1,2,3,4,4-hexachlorobuta-1,3-diene
Synonym:	HCBd; perchloro-1, 3-butadiene; perchlorobutadiene; 1,3-hexachlorobutadiene; 1,3-butadiene, 1,1,2,3,4,4-hexachloro-; 1,3-butadiene, hexachloro-; hexachlorobuta-1,3-diene; ^{3,4,5}
CAS registry numbers:	87-68-3
Common trade names:	C-46, Dolen-pur, GP40-66:120, UN2279 ⁶

Structures

Molecular formula³: C₄Cl₆, Cl₂C=CClClC=CCl₂

Molecular weight: 260.76 g/mol

Chemical structure :



Physical-chemical properties

8. HCBd has low water solubility and quite a high vapour pressure compared to other listed persistent organic pollutants (POPs) (UNEP/POPS/POPRC.2/14/Add.2). The substance is lipophilic based on a log K_{ow} close to 5 (cf. Table 1). The substance can volatilize due to its Henry's law constant from moist soil and water (HSDB, 2012). According to IPCS (1994) it has a turpentine-like odour. Selected physico-chemical properties (the majority of the values have been determined experimentally) are listed in Table 1 (quoted from UNEP/POPS/POPRC.8/3).

² UNEP/POPS/POPRC.8/16/Add.2.

³ Mackay et al. (2006).

⁴ UNEP/POPS/POPRC.7/INF/4.

⁵ ACToR (2012).

⁶ IPCS (1994).

Table 1: Physical-chemical properties of HCB

Property	Value	Information source according to UNEP/POPS/POPRC.8/16/Add.2
Melting Point (°C)	-21	
Boiling Point (°C)	215	Horvath 1982, Lide 2003, all cited in Mackay et al. 2006
Density (g/cm ³ at 20°C)	1.68	Horvath 1982 cited in Mackay et al. 2006
Water solubility (mg/L at 25°C):	3.2	Shake flask-HPLC, Banerjee et al. (1980) cited in SRC PhysProp Database (2012)
Vapour pressure (Pa at 20°C and 100°C)	20 and 2926	Person and McConell (1975) cited in Mackay et al. (2006) Environment Canada (1999)
Henry's law constant (Pa m ³ /mol)	1044 (experimental), 2604 (calculated)	Warner et al. (1987) cited in Mackay et al. (2006)
Log Kow	4.78, 4.9	Shake flask-HPLC Banerjee et al. (1980), Sangster (1993), Hansch et al. (1995), cited (and recommended value) in Mackay et al. (2006) Shake-flask-GC, both phases, Chiou (1985), cited in Mackay et al. (2006)
Log Koa at 10°C	6.5	Vulykh et al. (2005)
Log Koc	Reported range: 3.7 to 5.4	HSDB (2012)
Physical state	Liquid	

1.2 Conclusions of the POPs Review Committee regarding Annex E information

9. The POPs Review Committee has conducted and evaluated a risk profile in accordance with Annex E at its eighth meeting held in Geneva from 15 to 19 October 2012. The Committee, by its decision POPRC-8/2, adopted the risk profile for hexachlorobutadiene (UNEP/POPS/POPRC.8/16/Add.2) and:

(a) Decided, in accordance with paragraph 7 (a) of Article 8 of the Convention, that hexachlorobutadiene is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects such that global action is warranted;

(b) Also decided, in accordance with paragraph 7 (a) of Article 8 of the Convention and paragraph 29 of decision SC-1/7 of the Conference of the Parties, to establish an ad hoc working group to prepare a risk management evaluation that includes an analysis of possible control measures for hexachlorobutadiene in accordance with Annex F to the Convention;

(c) Invited, in accordance with paragraph 7 (a) of Article 8 of the Convention, parties and observers to submit to the Secretariat the information specified in Annex F before 11 January 2013, as well as additional information relevant to Annex E in particular data on sources of emissions such as the production of hexachlorobutadiene and/or unintentional releases.

1.3 Data sources

10. The risk management evaluation is primarily based on:

(a) information that has been provided by parties and observers. Responses regarding the information specified in Annex F of the Stockholm Convention (risk management) have been provided by the following parties and observers :⁷

- (i) Parties: Canada, Croatia, Estonia, Mexico, Nigeria, Romania, Slovakia, Sri Lanka
- (ii) Observers: no information submitted
- (b) decision POPRC-8/2 (UNEP/POPS/POPRC.8/16);
- (c) the risk profile for hexachlorobutadiene (UNEP/POPS/POPRC.8/16/Add.2);
- (d) the exploration of management options for HCBd (UNECE 2007).

In addition to the above-mentioned sources, information has been gathered from other open information sources and literature. Such information sources are listed in the Reference section.

1.4 Status of the chemical under international conventions

11. HCBd is subject to a number of international treaties and regulations:

(a) In December 2009, HCBd has been proposed to amend Annex I (prohibition of production and use) of the Aarhus Protocol on Persistent Organic Pollutants (POPs) under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP), according to Decision 2009/1. The amendment will come into force when two thirds of the Parties have adopted the amendment.

(b) The UNECE has included HCBd in Annex II of the Protocol on Pollutant Release and Transfer Registers (PRTRs) to the Aarhus Convention on access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters.

(c) HCBd is currently under a review process by the Chemical Review Committee (CRC) for inclusion under the Rotterdam Convention. The review process was initiated by notifications of final regulatory action to ban or severely restrict HCBd by Canada and Japan (<http://www.pic.int>) (Thailand, 2011).

(d) HCBd is on the List of Substances of Possible Concern, Section B under the OSPAR Commission for the Protection of the Marine Environment of the Northeast Atlantic. Section B lists substances which are of concern for OSPAR but which are adequately addressed by European Commission initiatives or other international forums.

Additional information on the status of the chemical under international conventions has not been provided by parties or observers who submitted Annex F information.

1.5 Any national or regional control actions taken

12. HCBd is considered in several regional and national control actions:

(a) In the European Union, Decision No 2455/2001/EC on a first list of priority substances of the adopted EU Water Framework Directive 2000/60/EC listed HCBd in its Annex. In addition, HCBd is regarded as a priority hazardous substance and thus it is subject to a step-wise cessation or phasing out of discharges, emissions and losses. Quality standards for surface and marine water have been set in the European Directive 2008/105/EC and will presumably be renewed through a European Directive 2013/xx/EC. HCBd was incorporated in the EU Directive 88/347/EEC, which regulated the discharges of certain dangerous substances by means of limit values and quality objectives;

(b) In the European Union, the production, placing on the market and use of HCBd is prohibited since the substance has been incorporated in the EU POPs Regulation in 2012 (Regulation (EC) No 850/2004);

(c) In the European Union, HCBd is incorporated in the Pollutant Release and Transfer Registers by means of Decision 2006/61/EC. Remarkably, reporting is obligatory for water and land above limit values of 1 kg/year, but it is not required for emissions to air;

(d) HCBd is included in the second Priority Substances List of the Canadian Environmental Protection Act, 1999 (CEPA1999). In July 2003, HCBd was added to Schedule 1 (List of Toxic Substances) to CEPA 1999. Later, in 2006, HCBd was added to the Virtual Elimination List (UNECE 2007);

⁷ Annex F information provided by parties and observers is available at the SC website (see <http://chm.pops.int/Convention/POPsReviewCommittee/LatestMeeting/POPRC8/POPRC8Followup/SubmissiononHCBd/tabid/3069/Default.aspx>); status of the website evaluated for the present document: 14.02.2013.

- (e) The manufacture, use, sale, offer for sale and import of HCBd in Canada is prohibited under the Prohibition of Certain Toxic Substances Regulations, 2012 which came into force on March 14, 2013 (<http://www.ec.gc.ca/lcpe-cepa/eng/regulations/detailReg.cfm?intReg=207>);
- (f) HCBd is on the Domestic Substances List. HCBd is not included and will not be considered for addition to the National Pollutant Release Inventory;
- (g) In Canada, HCBd is being monitored in air under the Northern Contaminants Program (NCP) at Alert (Nunavut) (Annex F, Canada 2013);
- (h) In Canada, HCBd has been monitored in wildlife and water/sediments (Annex F, Canada 2013);
- (i) Ontario's Water Resources Act has a "provincial water quality objective" of 0.009 µg/L for HCBd in discharge as well as in ambient water. In addition, this province has a "leachate quality criteria" for HCBd set at 0.5 ppm. Waste that produces a leachate with concentrations equal or greater than 0.5 ppm HCBd when performing the Toxicity Characteristic Leaching Procedure is defined as a "leachate toxic waste" in the Revised Regulations of Ontario Regulation 347 (UNECE 2007);
- (j) In the U.S., national emission standards that require the use of best available control technologies have been developed for sources categories emitting HCBd, including rubber tire production, chlorine production, and miscellaneous organic chemical processes (1990 Clean Air Act 112B) (UNECE 2007);
- (k) In the US, HCBd is among the chemicals for which emissions/releases must be reported as part of the U.S. Toxics Release Inventory (TRI) program (see above). HCBd is also listed in the following Acts as (UNECE 2007):
- (i) A hazardous air pollutant (HAP) under the U.S. Clean Air Act;
 - (ii) A hazardous constituent under the Resource Conservation and Recovery Act (RCRA);
 - (iii) A hazardous substance under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, also known as Superfund); and
 - (iv) A candidate for the Drinking Water Contaminant List under the Safe Drinking Water Act.
- (l) In California, HCBd is listed on the current (February 8, 2013) Proposition 65 list of Chemicals Known to the State of California to Cause Cancer or Reproductive Toxicity. HCBd was added to the list on May 3, 2011 for its carcinogenic properties.⁸ HCBd in water discharges is regulated under the California Toxics Rule; the limit is 0.44 µg/l (UNECE 2007).
- (m) HCBd is on the Massachusetts Toxics Use Reduction Act (TURA) Chemicals List.⁹ The TURA requires Massachusetts companies that use large quantities of specific toxic chemicals to evaluate and plan for pollution prevention opportunities, implement them if practical, and measure and report their results on an annual basis.
- (n) In Mexico, the use of HCBd as a plant protection product is not registered. Production and import for this use is prohibited (Annex F, Mexico 2013).
- (o) In Mexico, HCBd has a maximum allowable limit of 0.5 mg/L in leachate (above this limit, residues are considered toxic to the environment) (NOM-052-SEMARNAT-2005). HCBd is included in GRENA (North American emergency response guide). The Guide has been jointly elaborated by Transport Canada (Transport Canada), the US Department of transportation (DOT) and the Secretariat of communications and transportation of Mexico. A water quality value for HCBd for the protection of the aquatic life is set to 0.0009 mg/L for freshwater and 0.03 mg/L for marine water (See Annex F, Mexico, 2013).
- (p) European Union initiatives call for sediment and organisms to be uncontaminated with HCBd, and specify a water quality objective of 0.1 µg/l (UNECE 2007).
- (q) Several regulations are in place in Germany relating to: the Ordinance on Hazardous Substances, Maximum Workplace Concentrations, Technical Guidelines for Clean Air ('self-classification' of HCBd according to the TA-Luft leads to maximum allowed emissions of 20 mg/m³ for a mass flow of 0.1 kg/h), Catalogue of Chemicals with a High Water Contaminating Potential, Wastewater Disposal (emissions of 1 g/ton HCBd are permissible) and Transport Regulations (UNECE 2007).

⁸ See State of California's Environmental Protection Agency Office of Environmental Health Hazard Assessment List of Chemicals Known to the State to Cause Cancer or Reproductive Toxicity (February 8, 2013) (accessed March 13, 2013). http://oehha.ca.gov/prop65/prop65_list/newlist.html.

⁹ See <http://www.mass.gov/dep/toxics/tura/reports.htm#chemicals>

(r) HCBd is on the Master List¹⁰ of the German Federal Environment Agency (UBA). The list is part of the publication “Substances classified as carcinogenic, mutagenic and toxic for reproduction (CMR) and other substances of concern in consumer products”, which deals with chemical substances in consumer-relevant articles that may be of concern for health or the environment.

(s) HCBd is on a list of phase out substances (KEMI: PRIO Database), a web-based tool elaborated by the Swedish Chemicals Agency (KEMI) intended to be used to preventively reduce risks to human health and the environment from chemicals.¹¹

(t) In Japan, HCBd is designated as Class I Specified Chemical Substances under the Chemical Substances Control Law (CSCL). A person who intends to operate a business of manufacturing, import or use of a Class I Specified Chemical Substance shall obtain permission (the manufacture, import or use of these chemical substances is prohibited in principle).¹²

(u) The World Health Organization recommends a guideline value for drinking water of 0.6 µg/litre (WHO, 2004).

13. Additional information on national or regional control actions has not been provided by parties or observers who submitted Annex F information.

2. Summary information relevant to the risk management evaluation

2.1 Additional relevant information on sources, releases and measures

Production

14. HCBd is not known to be currently intentionally produced or used. HCBd is usually a by-product of the production of chlorinated chemicals. BUA (1991) states that HCBd is not a target product of the chemical industry in Germany. It arises as a by-product from certain processes, particularly during low-pressure chlorolysis for the production of perchloroethylene and trichloroethylene but also during other processes. However, HCBd as a by-product has been partly sold for commercial uses. This could be considered “commercial production”. In the following, the term “intentional production” means “commercial production”. Unintentional formation means the generation as an unwanted waste by-product in the production of chlorinated chemicals, but also other possible sources of unintentional formation of HCBd such as the manufacture of magnesium and incineration processes. As a consequence, there is a certain overlap between measures targeting intentional production and unintentional generation. Control measures targeting intentional production and unintentional generation as an unwanted waste by-product in the production of chlorinated chemicals, can be identical.

15. The following processes are relevant in this respect according to BUA (1991):

Process	HCBd concentration in the raw product	Remarks
Low pressure chlorolysis for the manufacturing of perchloroethylene and carbon tetrachloride	5%	HCBd is recycled in the process together with other high-boiling by-products
Optimised low pressure chlorolysis for the manufacturing of perchloroethylene and carbon tetrachloride	0.2 to 0.5%	The HCBd containing residue is treated by distillation and result in a residue containing 7 to 10% HCBd. The latter residue is incinerated.
Manufacturing of hexachlorocyclopentadiene	0.2 to 1.11 %	
Manufacturing of tetrachloride and trichloroethylene from acetylene and chlorine and subsequent decomposition to carbon tetrachloride and trichloroethylene	0.4%	

16. BUA (1991) also describes three possible processes for the direct production of HCBd. In Germany such processes were not applied at that time. Whether these were ever used for industrial manufacturing of HCBd is not clear. (1) Intentional production, (2) unintentional generation and (3) stockpiles are possible anthropogenic sources of

¹⁰ Downloadable at <http://www.uba.de/uba-info-medien-e/4092.html>

¹¹ See http://www2.kemi.se/templates/PRIOEngframes____4144.aspx

¹² Comment from Japan, 2013.

HCBD. There are no natural sources of HCBD in the environment (BUA 1991, Environment Canada 2000); (for details see UNEP/POPS/POPRC.8/16/Add2, section 2.1 on sources).

(1) Intentional production:

17. It seems that HCBD is no longer intentionally produced in the UNECE region including in the US and Canada (see UNEP/POPS/POPRC.8/16/Add.2). Data about intentional production outside of the UNECE region are not available. However, monitoring data from China (Li et al., 2008; Juang et al., 2010) suggest that intentional production and/or unintentional generation and release have continued at least until recently.

18. Data on quantities of HCBD produced as by-product in the manufacture of chlorinated hydrocarbons are difficult to quantify. Therefore the information is summarised as follows :

19. According to UNEP/POPS/POPRC.8/16/Add.2, the intentional production of HCBD in Europe ended in the late 1970s (Van Der Honing 2007). HCBD was never generated as a commercial product in the US or Canada (Lecloux, 2004), at least not in commercial quantities (ATSDR, 1994). Data about intentional production outside of the UNECE region are not available (Lecloux, 2004).

20. HCBD was produced in high volumes between 1970 and 1980. Worldwide production of HCBD was estimated at 10,000 tons in 1982. Cesars database (2001)¹³ report refers to US EPA (1980), which estimates the annual American production to be between 7.3 and 14.5 million pounds per year (3,300 to 6,600 tonnes/year). According to TOXNET,¹⁴ in 1975, the total US production of HCBD was reported to be 8.0 million pounds (3,600 tonnes/year). Cesars database also reported the import of 0.2 to 0.5 million pounds (0.1 to 0.2 tonnes/year) from Germany between 1970 and 1974.

21. The unintentional HCBD waste by-product, generated during the production of chlorinated chemicals, was higher than the intentional production by 14,000 tons in 1982 in the US alone (IPCS, 1994 as cited in Lecloux, 2004). This is more or less in line with information from US EPA (2003): the annual HCBD waste generation was of 8 million pounds (3,600 tonnes) in 1975, and had increased to 28 million pounds (12,000 tonnes) in 1982.

22. In 1979, about 4,500 tonnes of HCBD were generated in Germany, of which 1021 tonnes was exported, 3,400 tonnes incinerated and 100 tonnes landfilled. In 1991, the figures have decreased to a quantity between 550 to 1,400 tonnes of which about 300 tonnes were exported as a product, and 250 to 1,100 tonnes were recycled in the process (BUA 1991).

23. In 1980, about 10,000 tonnes of HCBD were generated, in the former European Union of which 1,000 tonnes was exported, 5,580 to 6,120 tonnes incinerated and 1,600 to 2,440 tonnes was landfilled. In 1990, in Western Europe, a HCBD quantity of 2,000 to 49,900 tonnes was estimated (BUA 1991).

24. Some sources indicated that there has been production in Austria.¹⁵ In a 2001 report from the Austrian Umweltbundesamt (UBA AT, 2001), emission standards for HCBD have been provided, which suggest HCBD has been produced in Austria, however, actual data on production could not be retrieved.

25. HCBD has never been produced in Canada but was mainly released as a by-product from the production of tetrachloroethylene. It was also a by-product from the manufacture of trichloroethylene, carbon tetrachloride, vinyl chloride, allyl chloride, and epichlorohydrin. It could be found in the fly ash during refuse combustion. It is no longer imported, and the two Canadian tetrachloroethylene producers ceased the production in 1985 and 1992 (CCME 1999).

26. On the one hand, there is some information indicating that intentional production and/or use may still be relevant at least until recently:

(a) According to a UNEP press release in 2001, HCBD has been classified as a high-volume production chemical by the Organization for Economic Cooperation and Development (OECD), with one country reporting that its factories were producing more than 10,000 tonnes annually;

(b) The European Directive 88/347/EEC and Decision 92/446/EEC mentioned “industrial plants using HCBD for technical purposes” as a possible source for HCBD releases.

27. On the other hand, there is some information indicating that current or recent intentional production and/or use is at least not in significant quantities or relevant :

(a) A 1998 report from New Zealand report indicates that HCBD is prioritised by OECD for the collection of a Screening Information Data Set to permit a more comprehensive risk assessment. There are no data that indicate

¹³ Cesars database, Canadian Centre for Occupational Health & Safety (2001).
<http://www.ccohs.ca/products/databases/samples/cesars.html>

¹⁴ See <http://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+2870>

¹⁵ See e.g. <http://monographs.iarc.fr/ENG/Monographs/vol73/mono73-14.pdf>

that it is produced or imported by a member state in quantities more than 1,000 tonnes in 1997. The classification of HCBd as High Production Volume (HPV) could not be confirmed in the OECD database;¹⁶

- (b) HCBd has not been reported by the EU Industry as an HPVC¹⁷ or LPVC¹⁸ within ESIS;¹⁹
- (c) HCBd has not been reported as an HPV²⁰ within the US HPV database.²¹

28. The trade with HCBd is not regulated under the Rotterdam Convention. Canada provided a Notification of Final Regulatory Action to the Secretariat of the Rotterdam Convention in 2008 for its regulatory action controlling the use of this substance under the *Prohibition of Certain Toxic Substances Regulations, 2005*. Japan had previously submitted a Notification of Final Regulatory Action for HCBd in 2005. Although these notifications were considered in 2009 by the Chemicals Review Committee (the technical expert body under the Rotterdam Convention), the notification from Japan did not meet all criteria and HCBd has not been recommended for listing under the Rotterdam Convention to date. Some additional data were submitted by Thailand and Hungary in 2009. HCBd has not been included in the European regulation 689/2009 on the export and import of dangerous chemicals. Thus, no data on international trade of HCBd could be retrieved from the European database EDEXIM.²²

29. Specific data on quantities of intentional production and use of HCBd during the past 30 years are not available. In conclusion, there is no specific information on the current production and use, however, possibly remaining intentional production and use (particularly in quantities below the limits for HPVCs/HPVs) cannot be excluded.

30. Canada, Mexico, Nigeria, Slovakia and Sri Lanka reported that HCBd is not produced in these countries (Annex F, Canada, Mexico, Nigeria, Slovakia and Sri Lanka, 2013). Additional information on the production of the chemical has not been provided by parties or observers who submitted Annex F information.

(2) Unintentional production:

31. HCBd can be unintentionally produced during the manufacture of chlorinated chemicals. For example HCBd is still unintentionally generated during the production of chlorinated hydrocarbons, particularly of perchloroethylene and trichloroethylene, but also during other processes (for information on the quantities generated see above).

32. HCBd can generally be destroyed or recycled in the plant. However, total elimination of industrial HCBd emissions is currently not feasible, as the production of the relevant chlorinated hydrocarbons results in the generation of HCBd as an unintentional by-product. Releases can be minimised by technical abatement measures to very low levels, but are not eliminated with the current industrial practices. In Germany HCBd could not be identified in off-gases from an incineration of production residues from a tetrachloroethene/tetrachloromethane plant (Dow 1992b quoted from BUA 1991/2006). According to Dow Germany the releases to the atmosphere from the incineration of production residues from tetrachloroethene/tetrachloromethane production in Germany in 1998 were estimated at 60 g (Dow 2005 quoted from BUA 1991/2006). Other techniques, such as the use of closed loop systems and the substitution of chlorinated hydrocarbons by alternatives that are not leading to unintentional formation of HCBd, and that prove to be technically and economically feasible and also advantageous from a life cycle management point of view, will be necessary to further minimise and ultimately eliminate HCBd releases.

33. Other sources of unintentional formation of HCBd are the manufacture of magnesium and incineration processes (e.g. motor vehicle emissions, incineration processes of acetylene, incineration of chlorine residues). Deutscher and Cathro (2001) observed HCBd generation during the electrolytic production of magnesium in a laboratory-scale electrolytic cell. Lenoir et al. (2001) observed the by-product formation of organochlorine compounds including HCBd from incineration processes of acetylene, which was indicated as being present in flames of all incineration processes. Releases from incinerators have been reported in WWF (2005) and INERIS (2005). In 2003, according to the Association of Plastic Producers (Syndicat des Producteurs de Matières Plastiques, SPMP) in France, HCBd has been detected in the effluents of an incinerator eliminating chlorine residues (INERIS 2005). It was also reported that HCBd releases can take place during waste incineration, and that combustion sources of HCBd are similar to those of dioxins, furans and hexachlorobenzene (Environment Canada 2000). Also, emissions from motor vehicles have been indicated as source for HCBd (WWF 2005).

¹⁶ Comment from the Netherlands, 2013.

¹⁷ High Production Volume Chemicals; Substances with a production or import volume in excess of 1000 tonnes/year.

¹⁸ Low Production Volume Chemicals; Substances with a production or import volume between 10 and 1000 tonnes/year.

¹⁹ ESIS = Existing Substance Information System of the European Commission:
<http://esis.jrc.ec.europa.eu/index.php?PGM=hpv>

²⁰ Chemicals produced or imported into the United States in quantities of 1 million pounds or more per year.

²¹ <http://www.epa.gov/hpvis/>

²² Comment from the Netherlands, 2013.

34. Waste-water treatment plants are a possible secondary source of HCBd. HCBd entering such plants can be released to water and soil via sewage sludge (ESWI 2011).

(3) Stockpiles:

35. Examples document the potential of HCBd releases from former waste disposal such as hazardous waste disposal sites or industrial facility waste disposal sites. One example of HCBd stockpiles in waste dumps is the Devil's swamp area in Louisiana (US). At the Orica dump in Australia, large quantity of HCB contaminated with HCBd and other organochlorines are stored in drums (approximately 20,000 tonnes) (Rae, 2012). The examples document the potential of HCBd releases from former waste disposal. At Weston Quarries (UK), properties built on quarry spoil next to the waste dump had to be demolished for excessive indoor HCBd concentrations (Nicole, 2004; Barnes et al., 2002; Crump et al., 2004). There is no insight into the total amount of waste sites worldwide, nor on their releases (Crump et al., 2004).

Use

36. HCBd was used in several technical and agricultural applications and as an intermediate in the chemical industry or as a product. It was applied as a solvent (for rubber and other polymers); as a "scrubber" to recover chlorine-containing gas or to remove volatile organic components from gas; as hydraulic, heat transfer or transformer fluid; in gyroscopes; or in the production of aluminium and graphite rods. The former use of HCBd as a plant protection product has stopped in the EU. It is unclear whether the use as a fumigant for treating grapes has also stopped outside the EU (UNEP/POPS/POPRC.8/16/Add2, section 2.1.2). The European Chemicals Agency (ECHA) classification and labelling inventory indicates that there are 65 notifiers for HCBd.²³ HCBd is furthermore listed in the ECHA inventory of pre-registered substances with an envisaged registration deadline in 2010. Nevertheless, so far, no registration for HCBd has been submitted to ECHA. This suggests that there are no EU companies which produce or import HCBd in high volumes (i.e. > 1,000 tpa). The number of entries in the classification and labelling (C&L) inventory²⁴ and the fact that pre-registrations have been submitted to ECHA at least indicate that HCBd is of certain interest for EU companies, although pre-registrations could also have been submitted due to strategic reasons instead of real registration obligations.

37. Mexico reported that the use of HCBd as a fungicide is not registered in the country. Therefore, its use, production and import for this use are prohibited (Annex F, Mexico, 2013). Additional relevant information on uses has not been provided by parties or observers who submitted Annex F information.

38. It has been indicated by several sources that HCBd has been used as laboratory reagent (Haskoning 2002, ATSDR 1994, WWF 2005, INERIS 2005). However, it is unknown if HCBd is still being used for this purpose (Haskoning 2002 quoted from ESWI 2011). According to Article 3 paragraph 5, the use for laboratory-scale research or as a reference standard is excluded from the Stockholm Convention.

Releases

39. Most of the specific information on HCBd releases is scarce and obsolete (UNEP/POPS/POPRC.8/16/Add2, section 2.1.3).

40. Comparatively recent release estimates are available for Europe and the US. Recently estimated releases to air and surface water are in the same order of magnitude (up to several hundred kilograms per year) in Europe for the period from 2007 to 2009 and in the US for the period from 2007 to 2010. Release estimates from unintentional sources in Canada in 2004 are comparatively low (below 100 g for some sources, including products or mixtures containing HCBd as a contaminant, chemical industry, vinyl chloride monomer manufacture). Also, HCBd was not detected in municipal solid waste and hazardous waste incinerators. There were no data available for other sources, including hazardous landfill leachate and long range transport (EC 2004).²⁵ Former releases in the UNECE region were significantly higher (e.g. 454 tons released to the environment in 1975 in the US; about 2 tons in 2000 in the US; and 2.59 tons in 2000 in UNECE Europe).

41. In 2011, the most recent reporting year for the U.S. Environmental Protection Agency's Toxics Release Inventory (US TRI), the on- and off-site disposal or other releases of HCBd totalled 1,187 pounds (538 kg) with 9 US facilities reporting. The majority of these HCBd releases were fugitive air emissions (794 pounds or 360 kg) and point source air emissions (270 pounds or 122 kg).²⁶ In 2010, the most recent reporting year for the European Pollutant Release and Transfer Register (E-PRTR), releases of HCBd from industrial activities totalled 88.9 kg with 11 facilities reporting. These HCBd releases were releases to water from waste and wastewater management (9

²³ <http://clp-inventory.echa.europa.eu/SummaryOfClassAndLabelling.aspx?SubstanceID=80395&HarmOnly=no?fc=true&lang=en>

²⁴ EU database containing classification and labelling (C&L) information on notified and registered substances received from manufacturers and importers (<http://echa.europa.eu/web/guest/information-on-chemicals/cl-inventory-database>).

²⁵ <http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=81EBD5A7-0C9C-4CB0-86FD-849869B75715>

²⁶ Source: U.S. Toxics Release Inventory at http://iaspub.epa.gov/triexplorer/tri_release.chemical.

facilities; 69.5 kg), production and processing of metals (1 facility; 17.0 kg) and chemical industry (1 facility; 2.35 kg).²⁷ Release data from the E-PRTR and the US TRI are not directly comparable, as for the E-PRTR it is only necessary to report releases of HCBd to water above an emission limit of >1 kg per year. Reporting of releases to air is not obligatory, and corresponding releases are thus not reported.

42. Currently, the most important known source of HCBd in the 27 EU Member States (EU 27) is due to the manufacture of chlorinated chemicals (particularly tri- and tetrachloroethene and tetrachloroethylene) through chlorolysis. The estimated amount of HCBd released during this process varies between ~0.7 kg/year up to possible ~500 kg/year (EC 2012). Urban waste-water treatment plants are the second main sources of HCBd. HCBd in wastewater treatment stations accumulate in the sewage sludge. A total amount of HCBd which ends up in the sewage sludge in EU 27 is estimated to be approximately 6 kg/year. It must be noted that this estimation is based on the sewage sludge contamination data from China, since no data from European facilities were identified (EC 2012).²⁸

43. For the non-UNECE regions, information is scarce. There is still a potential for unintentional release of HCBd from production of chlorinated chemicals in most parts of the world. Reports from South India suggest substantial ongoing HCBd emissions from industry despite the lack of corresponding data for, e.g. Asia. Data of Juang et al. (2010) indicate that there are still considerable sources in South-East Asia.

44. HCBd is on the list of chemicals subject to reporting on emissions registration and transfer of pollutants from Mexico (Annex F, Mexico 2013). The main emission/discharge sources of HCBd are (a) unintentional release during the production of chlorinated hydrocarbons, (b) emission from disposed waste of chlorinated hydrocarbons, (c) emissions from other commercial uses and (d) emission from magnesium production (Annex F, Nigeria, 2013). Additional information on releases has not been provided by parties or observers who submitted Annex F information.

45. To conclude, while in the UNECE region releases of HCBd generated as an unintentional by-product have decreased by orders of magnitude over the last decades, though still continue, there is a crucial lack of information about intentional production or unintentional formation in non-UNECE countries. Reductions in the UNECE-region can be expected to be largely due to technical investments (minimization, recycling or destruction of the by-product on site and waste management). No estimates of the costs associated with such technical investments are available in the literature or from submissions by parties for Annex F information on HCBd.

²⁷ Release data accessible at <http://prtr.ec.europa.eu/PollutantReleases.aspx>

²⁸ The estimation was made by using average contamination data for China derived from Cai et al. (2007) and the quantity of sewage sludge generated in EU 27 to calculate the estimated quantity of HCBd released with sewage sludge in EU 27.

Possible measures

46. Possible measures can be directed at the relevant anthropogenic sources of HCBd: (1) intentional production, (2) unintentional formation and (3) stockpiles. Figure 1 illustrates relevant sources and possible control measures for HCBd.

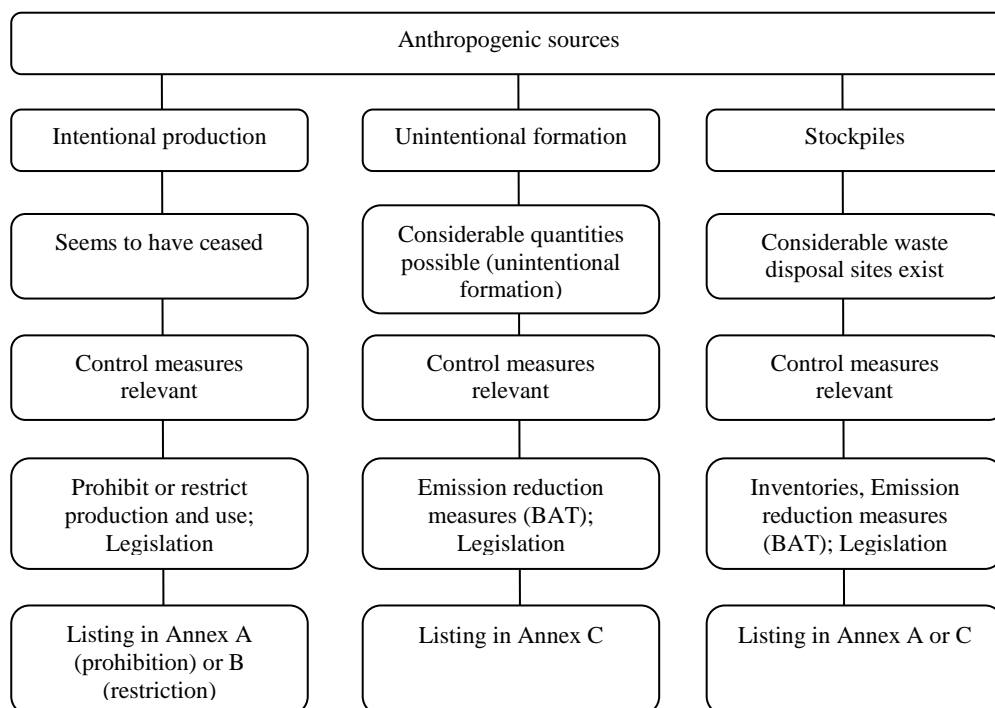


Figure 1: Relevant sources and possible control measures for HCBd

(Note: use for laboratory-scale research or as a reference standard is not considered; such use is excluded from the Convention according to Article 3(5); natural sources are out of the scope of the Convention: according to article 5, measures are related to anthropogenic sources)

2.2 Identification of possible control measures

Control measures for releases from intentional production

47. HCBd has been intentionally produced in the past. Intentional production and use seem to have ceased, though specific information on current intentional production and use and for the past 30 years is lacking. The most efficient control measure would be the prohibition of the production and use of HCBd and HCBd containing articles and products. Although information on substitutes for commercial use of HCBd has not been submitted to the Committee, the significantly decreased use indicates that substitution has taken place and thus, technically feasible, economically viable alternatives are available.

48. Data on possible current production and use are completely lacking and there is no insight in international trade. Only a limited amount of countries have regulated production and use. To limit possibly remaining uses at the global scale and to prevent re-introduction of other uses, listing of HCBd in Annex A, without any specific exemptions, could be the primary control measure for intentional production and use under the Convention. As a consequence, HCBd would be subject to the provisions of Article 3 of the Convention, with the requirement to eliminate its production, use, import and export.

Control measures for releases from unintentional generation

49. HCBd is unintentionally generated and released from industrial processes. Unintentional releases of HCBd can be minimised by abatement techniques and legislation. Possible measures to minimise releases from unintentional formation as by-product are e.g. to modify processes and process control or destruction and/or in-process recycling of HCBd according to BAT and BEP, or to apply alternative processes, such as closed loop systems or the substitution of the associated chlorinated hydrocarbons in various uses to avoid HCBd by-product formation. Listing of HCBd in Annex C would subject the chemical to the measures under Article 5 of the Convention, and establish the goal of continuing minimization and, where feasible, ultimate elimination of HCBd releases. This would include an obligation to promote best available techniques (BAT) and best environmental practices (BEP) for HCBd sources.

(1) Manufacture of chlorinated chemicals:

50. HCBd can be unintentionally generated during the manufacture of chlorinated chemicals. For example HCBd is still unintentionally generated during the production of chlorinated hydrocarbons. Emissions of HCBd due to by-product formation can be minimized by improved process control or alternative production processes, by emission control measures or by substitution. In case significant amounts of HCBd are being formed, there should be strict control to minimize and, where feasible, eliminate such releases. Emission control shall be based on applying BAT (UNECE 2007).

51. Currently, high temperature incineration is usually operated in developed countries as an emission control technique for residues from the production of chlorinated chemicals. In France, stripping is also applied as a control technique for HCBd removal in one chlorinated solvent producing plant. In the US, most of the disposed waste from chlorinated hydrocarbon manufacturing processes is incinerated. In Europe, HCBd emissions to air from chlor-alkali production sites have decreased to almost zero (UNECE 2007). Although incineration may be utilized in developed countries, it may not be the most cost-effective option in all countries. For example, in some countries (e.g. small island countries) appropriate waste treatment facilities may not be available and additional costs may be incurred to store and then ship wastes to out-of-country treatment facilities.

52. Production processes for the simultaneous manufacturing of tetrachloroethene and tetrachloromethane are either the high-pressure or the low-pressure chlorolysis process. For the production of tetrachloroethene, other processes are applied. In principle, all production processes for tetrachloroethene may produce traces of HCBd. The low-pressure chlorolysis process tends to produce more HCBd than the high-pressure process. However, the HCBd formed in the low-pressure chlorolysis process can be drastically reduced in a subsequent distillation step, followed by incineration of the HCBd containing off-gas (UNECE 2007).

53. Relevant BAT is specified in the BREF Document on production of Large Volume Organic Chemicals (EC BREF LVOC, 2003). The document specifies BAT for pollution prevention and minimisation for the sector and for the control of pollutants and residues (EC BREF LVOC, 2003, section 6). Primary and secondary measures aiming to reduce/minimise emissions of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/PCDF) and/or chlorinated hydrocarbons from chemical production are also described in Section VI.F Part III Chapter 4 of the UNEP BAT and BEP guidelines (UNEP 2007). This section focuses on processes for the manufacture of industrial chemicals that could theoretically give rise to persistent organic pollutants (particularly those chemicals listed in Annex C of the Stockholm Convention). Most of the processes described share common steps, including chlorination of organic or inorganic raw materials, purification of the products, separation of product streams (usually by distillation), destruction of high-molecular-weight side products and recycle or sale of hydrogen chloride. Efficient separation and destruction of chlorinated organic side products, which may include persistent organic pollutants, is key to best available techniques applicable to these processes, as is the associated guidance for any incorporated incineration processes (UNEP 2007). Related to chlorinated chemicals, it is outlined that the process to generate trichloroethylene and perchloroethylene involves chlorination, oxychlorination and pyrolysis, by-product will include chemicals listed in Annex C. These materials can be separated from final product by distillation and isolated in a fraction known as heavy ends. Many years ago, heavy ends material was commonly landfilled; however, since the 1970s, hazardous waste incineration, or thermal destruction with recovery and reuse of HCl, is by far the more common treatment (UNEP 2007). It can be concluded that specific BAT is already common practice in the manufacturing of the chlorinated chemicals. Measures already taken for other POPs will also be effective for HCBd. Monitoring of HCBd will induce additional costs. Additional costs for implementation of measures to reduce releases of HCBd, enforcement and supervision are considered low as the control measures for other unintentional POPs such as PCDD/PCDF are already applied. Monitoring capacity for HCBd is needed in developing countries and countries with economies in transition.

54. As the manufacturing of some chlorinated chemicals (e.g. perchloroethylene, trichloroethylene,) is identified as a potential source of HCBd emission, reducing and ultimately eliminating their production when safer technically feasible and cost-effective alternatives are available could be an effective way to prevent the unintentional formation of HCBd and other POPs. This is particularly relevant when the manufacturing process does not use techniques aiming at reducing the by-production of HCBd. Information is available on some substitutes for relevant chlorinated chemicals (TURI, 2006; 2008; 2012).

(2) Production of magnesium:

55. There may be substantial amounts of by-product formation from non-chemical facilities producing magnesium (UNECE 2007, Denier van der Gon et al. 2007). The available information particularly indicates possible releases from production of magnesium by electrolysis (Deutscher and Cathro 2001). The main global production of magnesium is currently carried out by the reduction of the oxide at high temperatures with silicon. Nevertheless, industrial magnesium production by electrolysis is still relevant. However, no publications on measured HCBd air emissions from industrial magnesium production have been found. Possible emissions of HCBd from the production of magnesium can potentially be controlled by using measures based on the use of BAT, consisting of scrubbing and incineration of off-gases. The off-gases are treated in a series of wet scrubbers and wet electrostatic precipitators,

before finally being subject to incineration. Water from the off-gas treatment is transferred to a wastewater treatment plant. Since wastewater treatment plants are usually not specifically designed to remove HCBd and other POPs, this may result in discharges of HCBd and other POPs directly into water. These measures aim to reduce or minimise the emissions of hydrocarbons (including HCBd) and PCDD/PCDF and are described in chapter 10.4.1.3 (emissions to air) and 10.4.2 (emissions to water) of the draft BREF document for the production of non ferrous metals (EC BREF NFM 2009). They are also consistent with the approach of Annex V of the Aarhus Protocol on Persistent Organic Pollutants (BAT to control emissions of POPs from major stationary sources) (UNECE 2007). Primary and secondary measures aiming to reduce or minimise emissions of PCDD/PCDF and/or chlorinated hydrocarbons from magnesium production are also described in Section VI.B Part III Chapter 4 (see table 11 and Table 12) of the UNEP BAT and BEP guidelines (UNEP 2007).

(3) Other potential sources for unintentional formation of HCBd:

56. Other sources of unintentional formation of HCBd concern incineration processes (e.g. motor vehicle emissions, incineration processes of acetylene, incineration of chlorine residues). Lahaniatis et al. 1977 identified HCBd in fly ash samples from waste incineration in the Netherlands. Further specific information on these sources is lacking. For HCBd formed as a by-product in incineration processes, there is a relation to PCDD/PCDF and other unintentional POPs releases formed by combustion. Most measures taken to reduce such POPs releases will lead to a significant reduction of releases of HCBd. BAT and BEP relevant to unintentionally produced POPs for various types of incinerators and other thermal sources are described in the UNEP BAT and BEP guidelines, in Section V, and in several EU BAT reference documents. BAT includes providing for appropriate incineration conditions. BAT and BEP relevant to unintentionally produced POPs from motor vehicles are described in the UNEP BAT and BEP guidelines, in section VI.H. BAT includes banning of halogenated scavengers, and fitting motor vehicles with an oxidation catalyst or particulate filter.

Control measures for releases from stockpiles

57. Examples document the potential of HCBd releases from former waste disposal locations such as hazardous waste disposal sites or industrial facility waste disposal sites. There is no insight into the total amount of waste sites worldwide, nor on their releases. There is a need to determine ways to ensure better data collection and reporting of HCBd wastes and releases in order to track progress in reducing and eliminating these sources of contamination. Leachate monitoring and control plays a central role in the management of landfills. Possible measures to control releases from stockpiles are e.g. to establish an inventory of the relevant landfills and the control and sound management of releases (particularly leachate) from relevant waste disposal sites or restoration/decontamination of waste disposal sites.

58. As a result of environmental and health problems experienced with historic and abandoned landfill sites and due to the high costs associated with remediation of contaminated sites, many countries have introduced the specially engineered landfill concept. Engineering standards for landfills, including management of leachate, and further information on sustainable waste management are described in the technical guidelines of the Basel Convention on specially engineered landfill (BC 1997).

59. Listing of HCBd in Annex A and/or C would subject HCBd to the measures under Article 6 of the Convention, and establish the goal of identifying stockpiles consisting of or containing chemicals listed in Annex A or C and managing them in a safe, efficient and environmentally sound manner.

2.3 Efficacy and efficiency of possible control measures in meeting risk reduction goals

Intentional production

60. Although information on substitutes for commercial use of HCBd is not readily available, all applications seem to have ceased, though specific information on intentional production and use is lacking and the significantly decreased use indicates that substitution has taken place. Critical uses have not been identified. The elimination of the intentional production is therefore considered technically feasible.

61. In the UNECE region additional costs for eliminating the intentional production and use of HCBd are not expected, since industry has already substituted this use (UNECE 2007). Specific cost implications outside of the UNECE region cannot be assessed in detail, but it is expected that there are no additional costs as there is no specific information on intentional production of HCBd.

62. Cost increases for consumers are not expected, since the substitutes are already in use and the measures to address unintentional releases have to be taken to reduce other releases (UNECE 2007).

Unintentional generation

63. BAT and BEP to minimise unintentional generation of HCBd are described in relevant documents (see above) and are technically feasible. The technical measures required to minimise releases of unintentionally produced HCBd are already required according to existing BAT and BEP in the industrial manufacturing of chemicals and magnesium and for other possible sources (motor vehicle emissions and incineration processes). BAT and BEP as described in the

relevant documents are being applied for other unintentionally produced substances such as hexachlorobenzene (HCB), pentachlorobenzene (PeCB), polychlorinated biphenyls (PCB) and PCDD/PCDF and will be effective for HCB as well. Monitoring of HCB will induce additional costs. Additional costs for implementation of measures to reduce releases of HCB, enforcement and supervision are considered low as the control measures for other unintentional POPs such as PCDD/PCDF are already applied. Monitoring capacity for HCB is needed in developing countries and countries with economies in transition.

64. The most relevant known sources for HCB releases as a by-product during the production of certain chlorinated chemicals can be minimized by improved process control, alternative production processes, emission control measures or by substitution (UNECE 2007). For the production of chlorinated hydrocarbons, incinerations at high temperatures and stripping have proved to be cost-effective measures to reduce emissions. However, incineration may not be the most cost-effective option in all countries, and there are concerns regarding the possible unintentional formation of POPs, as noted in Part II of Annex C to the Convention. HCB emissions in the US and Europe have significantly decreased due to decreased unintentional formation and deployment of emission control measures. In many cases, current control measures and application of BAT and BEP to address other unintentionally produced POPs are likely to also reduce emissions of HCB. There are no extra costs involved for industry if these existing BAT and BEP measures are already implemented. If measures are taken to reduce PCDD/PCDF, there are no extra costs to industry for the reduction of HCB emissions from magnesium production (UNECE 2007). According to Nigeria, control measures, when effectively applied, would eliminate emission of HCB; however, the risks of application of control measures need be further studied. Some of the measures, like substitution of production processes, maintenance, substitution of raw materials, green chemistry have been documented. However, for nations needing capacity building, technical and funding assistance may be necessary (Annex F, Nigeria, 2013).

65. In addition, the substitution of the relevant chlorinated chemicals in their specific applications can contribute to reducing the production of these substances and can thus contribute to reducing corresponding HCB releases. Technically feasible and cost-effective alternatives to perchloroethylene and trichloroethylene are available for certain applications and could be employed as part of BAT to reduce HCB emissions

66. There will be additional costs for monitoring, namely for chemical analysis, even if monitoring programmes for other POPs (e.g. PCDD/PCDF, HCB and PCB) are already established. Within the UNECE region, control costs are expected to be very low and could consist of extra costs for measuring of HCB content in products or from unintentional emissions, and for conducting emission inventories (UNECE 2007). According to Mexico, costs should be considered for monitoring environmental levels in order to demonstrate that levels decrease as a consequence of the control measures taken.

Stockpiles

67. As a consequence of listing HCB in Annex A and or C, parties to the Convention would have to identify existing stockpiles and waste and to manage them in a safe, efficient and environmentally sound manner. Costs for identifying relevant landfills and establishing corresponding inventories are considered low. Costs for managing existing technically engineered landfills in an environmentally sound manner already arise for such landfills and will not significantly change. The Convention does not oblige parties to undertake remediation measures for contaminated sites. If such measures would be undertaken, they shall be performed in an environmentally sound manner and very significant costs would arise.

68. Examples of contaminated sites due to former waste disposal operations show that remediation costs and the cost for the protection of the environment and health can be significant. For example, in the case of the Orica dump in Australia (see section 2.1), the recovery and destruction of approximately 20,000 tonnes HCB contaminated with HCB and other organochlorines would require significant financial efforts. At Weston Quarries in the UK (see section 2.1), significant costs arose due to demolition of properties for health protection reasons.. Corresponding costs do not necessarily arise due to the listing of HCB in the Stockholm Convention, but for the protection of the environment and health.

69. HCB often arises in combination with other organochlorine pollutants (e.g. with HCB as in the case of the Orica dump) which are already regulated, among others, through the Stockholm Convention. The measures taken for one substance are therefore often effective for the other substance as well. In such cases there are no additional costs.

2.4 Information on alternatives (products and processes) where relevant

70. It seems that HCB is no longer intentionally produced and used in the UNECE region including in the US and Canada; specific information on current intentional production and use and for the past 30 years is lacking. This indicates that substitution has taken place and alternatives are available, though specific information on these was not provided to the Committee. Neither the requests have been received nor any particular needs identified for specific exemptions on HCB.

71. Emissive uses of chlorinated hydrocarbons have been phased out or are stringently regulated in various signature states, since a range of alternatives exists and are in practice for many of those applications.

2.5 Summary of information on impacts on society of implementing possible control measures

Intentional production

72. The intentional production of HCBd appears to have stopped worldwide. Benefits for health, the environment and the society from a prohibition of the production and use of HCBd could be maintained, as the re-introduction of HCBd and related risks would be prevented. A beneficial effect could be expected with the elimination of any currently unidentified intentional production and use around the world. Relevant negative impacts are not expected.

Unintentional generation

73. Cost efficient BAT and BEP to reduce releases of unintentionally produced HCBd are available and described in relevant documents (UNEP 2007, EC BREF LVOC 2003, EC BREF NFM 2009). Countries already have obligations to implement control measures for other unintentionally produced POPs (HCB, PeCB, PCB, PCDD/PCDF) under the Convention. These may be similar to those for HCBd. Emissive uses for chlorinated hydrocarbons have been phased out or are stringently regulated in various signature states, since a range of alternatives exist and are in practice for many of those applications. Measures to reduce unintentional releases of HCBd through listing in Annex C would positively impact human health and the environment. Additional costs for applying BAT and BEP and for control measures and emission inventories are considered low. According to Canada, the costs of inventories are relative and would differ in each country. For Canada, there are no known intentional sources, but considering all of the various unintentional by-product sources listed in the paper, considerable effort would be needed to research all of the potential sources and establish which sources may be emitting. This would need to be flagged as soon as possible to ensure that sufficient resources were devoted to the research and development of the inventories. The 4th statement in the conclusion is about unintentional by-product formation and states that measures to reduce other POPs will also reduce HCBd releases. This is very difficult to characterize in an emissions inventory and requires detailed information from facilities on past releases.

Stockpiles

74. HCBd is unintentionally released from existing waste disposal sites. BAT and BEP to minimise releases from waste disposal sites are available and described (BC 1997). Countries have already introduced corresponding measures (e.g. specially engineered landfill concept). Listing of HCBd in Annex A and/or C would require developing strategies to identify existing stockpiles, and to manage them in an environmentally sound manner. Such measures would positively impact human health and the environment. Costs for identifying relevant landfills, establishing corresponding inventories and sound management of releases are difficult to estimate because they are country-dependent and site dependent. The costs of remediation of contaminated sites are significant.

2.6 Other considerations

75. Specific relevant facts on information and public education have not been provided by parties or observers who submitted Annex F information.

76. Canada reports that HCBd is monitored in (1) air (HCBd is being monitored under the Northern Contaminants Program (NCP) at Alert (Nunavut)), (2) wildlife (a screening study on organochlorine contaminants in plasma and eggs of Svalbard glaucous gulls conducted in 2005 by Verreault et. al., HCBd was one of the substances looked at, however HCBd was not detected in eggs or plasma.) and (3) water/sediments (the St. Clair River Remedial Action Plan includes regular monitoring. HCBd is one of the organic compounds being monitored in water and suspended sediments. A report was created in conjunction with the Ontario Ministry of the Environment on Concentrations and Trends of Nutrients, Major Ions, Trace Metals and Organic Contaminants in the St. Clair River from 1987-1999) (Annex F, Canada, 2013). HCBd is not among the chemicals currently monitored in air, water and food in Slovakia (Annex F, Slovakia, 2013).

3. Synthesis of information

Risks and need for action

77. According to the risk profile, HCBd meets all screening criteria, i.e. long-range environmental transport, bioaccumulation, persistence and toxicity. The POPs Review Committee decided that HCBd is likely, as a result of its long-range environmental transport, to lead to significant adverse human health and environmental effects such that global action is warranted.

Sources

78. HCBd is not known to be currently intentionally produced or used. HCBd was used in several technical and agricultural applications. HCBd was used as an intermediate in the chemical industry or as a product. It seems that HCBd is no longer intentionally produced and used in the UNECE region including in the US and Canada. Data about intentional production and use outside of the UNECE region are not available. There is no specific information that the intentional production or use of HCBd still takes place. It seems that the intentional production and relevant use have ceased, though specific information on intentional production and use is lacking for the current situation and

for the past 30 years. Monitoring data from China suggest that intentional production and/or unintentional formation has continued at least until recently.

79. HCBd is still unintentionally generated during the production of chlorinated hydrocarbons, particularly of perchloroethylene and trichloroethylene but also during other processes. It can generally be destroyed or recycled in the plant. However, a total cessation of industrial HCBd emissions is currently not achieved with existing technology. Reduction and elimination of industrial emissions of HCBd may be achieved through modified processes and BAT and BEP methods which lead to the reduction and elimination of emissions of HCBd from chlorinated solvent production. Substitution of the relevant chlorinated chemicals in specific applications can also contribute to a limited extent to reduce the production quantities of these substances and can thus also slightly contribute to reducing the corresponding HCBd releases. Other sources of unintentionally produced HCBd concern the manufacture of magnesium and incineration processes.

80. Examples document the potential for HCBd releases from former waste disposal sites. This indicates that there may be significant quantities of HCBd present in existing waste stocks. However, there is no insight into the total amount of HCBd in waste sites worldwide, nor into their releases.

Existing control

81. HCBd is subject to a number of international treaties and regulations such as the UNECE Aarhus Protocol on POPs and the UNECE PRTRs pursuant to the Aarhus Convention on access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters. HCBd is currently under a review process for inclusion under the Rotterdam Convention, and it is included in several relevant lists of substances of concern (e.g. in the EU Water Framework Directive, OSPAR, European PBT working group). Moreover, HCBd is considered in numerous regional and national control actions.

Releases and control measures and their efficacy and efficiency

82. In the present document, an overview of the sources of releases of HCBd from current activities and related possible control measures is given. Possible release sources are (1) intentional production (which seems to have ceased), (2) unintentional formation (as a by-product from the chemical industry, magnesium industry, incineration processes) and (3) release from former waste disposal.

(1) Intentional production:

83. Intentional production and use seem to have ceased though specific information on intentional production and use is lacking for the current situation and for the past 30 years. To limit the possibly remaining uses and to prevent the re-introduction of other uses, listing of HCBd in Annex A without any specific exemptions could be the primary control measure for intentional sources under the Convention. As a consequence, HCBd would be submitted to the provisions of Article 3 of the Convention and to the requirement to eliminate its production, use, import and export.

84. All applications seem to have ceased. This indicates that substitution has taken place and that alternatives are available. Additional costs for eliminating the intentional production and use of HCBd are not expected. Cost increases for consumers are not expected since the substitutes are already in use. Health and the environment could benefit from a ban of HCBd, as the re-introduction of HCBd and related risks would be prevented and any currently unidentified intentional production and use around the world would end.

(2) Unintentional formation:

85. HCBd is unintentionally produced and released from industrial processes. Relevant sources are the production of chlorinated hydrocarbons, production of magnesium and other potential sources (incineration processes). Unintentional releases from the production of chlorinated hydrocarbons, due to by-product formation, can be minimized by improved process control, alternative production processes, or by emission control measures. Emissive uses for chlorinated hydrocarbons have been phased out or are stringently regulated in various signature states, since a range of alternatives to the use of chlorinated chemicals exist and are in practice for many of those applications. Releases from the production of magnesium can be controlled by emission control measures consisting of scrubbing and incineration of off-gases. Releases from incineration and other thermal processes are related to the releases of PCDD/PCDF and other unintentionally produced POPs formed by combustion. Most measures taken to reduce such POP releases will also lead to a significant reduction of HCBd releases. Listing of HCBd in Annex C would subject this substance to the measures under Article 5 of the Convention, and establish the goal of continuing minimization and, where feasible, ultimate elimination of HCBd releases. This would include an obligation to promote BAT and BEP for HCBd sources.

86. Cost efficient BAT and BEP to reduce releases of unintentionally produced HCBd are available and described in relevant documents. Countries already have obligations to implement control measures for other unintentionally produced POPs (HCB, PeCB, PCB, PCDD/PCDF) under the Convention. These may be similar to those for HCBd. Furthermore, technically feasible and cost-effective alternatives for specific uses of perchloroethylene, trichloroethylene, and tetrachloromethane are available. Measures to reduce unintentional releases of HCBd through

listing in Annex C would positively impact human health and the environment. Additional costs for applying BAT and BEP, for control measures and for emission inventories are considered low. Monitoring of HCBd will induce additional costs. Additional costs for implementation of measures to reduce releases of HCBd, enforcement and supervision are considered low as the control measures for other unintentional POPs such as PCDD/PCDF are already applied. Monitoring capacity for HCBd is needed in developing countries and countries with economies in transition.

(3) Release from former waste disposal:

87. Examples document the potential for HCBd releases from former waste disposal. There is no insight into the total amount of waste sites worldwide, nor into their releases. Listing of HCBd in Annex A and/or C would subject HCBd to the measures under Article 6 of the Convention, and would establish the goal of identifying sites contaminated with HCBd and managing them in a manner protective of human health and the environment.

88. BAT and BEP to minimise releases from waste disposal sites are available. Countries have already introduced corresponding measures (e.g. specially engineered landfill concept). The proposed measure would require to develop strategies to identify existing waste stockpiles, and to manage them in an environmentally sound manner e.g. by the appropriate treatment of relevant landfill leachate. Such measures would positively impact human health and the environment. Additional costs for identifying relevant landfills, establishing corresponding inventories and sound management of releases are difficult to estimate because they are country-dependent and site dependent. The cost of remediation of contaminated sites is significant.

4. Concluding statement

89. Having evaluated the risk profile for HCBd, the Committee concluded that this chemical is likely, as a result of long-range environmental transport, to lead to significant adverse effects on human health and/or the environment, such that global action is warranted.

90. The Committee prepared this risk management evaluation and concluded that although HCBd is not known to be currently intentionally produced or used, it is important to prevent its re-introduction and manage the risks associated with its unintentional release.

91. HCBd is generated as an unintentional by-product from industrial processes (particularly the production of chlorinated hydrocarbons, production of magnesium). Measures to minimise releases from these sources, and technically feasible, cost-effective substitutes to key chlorinated hydrocarbons are known and already applied in countries that are parties to the Stockholm Convention.

92. Like other unintentionally produced POPs listed in the Convention (HCB, PeCB, PCB and PCDD/PCDF), HCBd is unintentionally generated during combustion and other thermal processes and industrial processes. Most measures to reduce unintentional releases of POPs from such processes will lead to significant reduction of HCBd releases. Monitoring of HCBd will induce additional costs. Monitoring capacity for HCBd is needed in developing countries and countries with economies in transition.

93. HCBd is released to an unknown extent from former waste disposal sites. Control measures to minimise such releases are available. There is no insight into the total amount of waste sites worldwide and it would be useful to establish information on the existence of relevant sites and manage them appropriately.

94. The Stockholm Convention aims at protecting human health and the environment from POPs, while being mindful of the Precautionary Approach as set forth in Principle 15 of the Rio Declaration on Environment and Development. It seeks to adopt measures to eliminate releases from intentional POP production and use, to reduce or eliminate releases of unintentionally produced POPs, and to reduce or eliminate POP releases from stockpiles and wastes, in support of the goal agreed at the 2002 Johannesburg World Summit on Sustainable Development of ensuring that by the year 2020, chemicals are produced and used in ways that minimize significant adverse impacts on the environment and human health.

95. Having prepared a risk management evaluation and considered the management options, in accordance with paragraph 9 of Article 8 of the Convention, the Committee recommends the Conference of the Parties to the Stockholm Convention to consider listing and specifying the related control measures for HCBd in Annexes A and C.

References

- Annex F submissions on HCBd by January 2013, available at <http://chm.pops.int/Convention/POPsReviewCommittee/LatestMeeting/POPRC8/POPRC8Followup/SubmissiononHCBd/tabid/3069/Default.aspx>
- ATSDR 1994: U.S. Department of Health and Human Services, Public Health Service Agency for Toxic Substances and Diseases Registry, Toxicological Profile for Hexachlorobutadiene, May 1994.
- Barnes et al., 2002: Barnes G, Baxter J, Litva A, Staples B. 2002: The social and psychological impact of the chemical contamination incident in Weston Village, UK: a qualitative analysis. *Soc Sci Med.* 55 (12):2227-41.
- BC 1997: Basel Convention, Technical Guidelines on Specially Engineered Landfill (D5), Basel Convention series/SBC No. 02/03, First Published in 1997 and reprinted in November 2002.
- BUA 1991/2006: Gesellschaft Deutscher Chemiker, Hexachlorbutadien. BUA-Stoffbericht 263 (BUA Ergänzungsberichte XII; BUA Stoffbericht 62 (August 1991) Ergänzungsbericht (Februar 2006)). Weinheim, VCH.
- Cai et al., 2007: Q.-Y. Cai, C.-H. Mo, Q.-T. Wu, Q.-Y. Zeng, A. Katsoyiannis, Occurrence of organic contaminants in sewage sludges from eleven wastewater treatment plants, China, *Science Direct, Chemosphere* 68 (2007) 1751-1762.
- CCME 1999: Canadian Council of Ministers of the Environment, Hexachlorobutadiene - Canadian Water Quality Guidelines for the Protection of Aquatic Life, 1999.
- CEH 2012: Abstract of the CEH Marketing Research Report: "C2 Chlorinated Solvents" (2012); available at <http://www.ihs.com/products/chemical/planning/ceh/c2-chlorinated.aspx>
- Crump et al., 2004: Crump D, Brown V, Rowley J, Squire R (2004) Reducing Ingress of Organic Vapours into Homes Situated on Contaminated Land. *Env. Technol.* 4(25): 443-450.
- Denier van der Gon et al. 2007: Hugo Denier van der Gon, Maarten van het Bolscher, Antoon Visschedijk, Peter Zandveld. Emissions of persistent organic pollutants and eight candidate POPs from UNECE–Europe in 2000, 2010 and 2020 and the emission reduction resulting from the implementation of the UNECE POP protocol, *Atmospheric Environment* 41 (2007) 9245-9261.
- Deutscher et Cathro 2001: R.L. Deutscher, K.J. Cathro. Organochlorine formation in magnesium electrowinning cells. *Chemosphere* 43 (2001) 147 -155.
- EC BREF LVOC 2003: EUROPEAN COMMISSION, Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques in the Large Volume Organic Chemical Industry, February 2003.
- EC BREF NFM 2009: EUROPEAN COMMISSION, Integrated Pollution Prevention and Control (IPPC), Draft Reference Document on Best Available Techniques for the Non-Ferrous Metals Industries, Working draft in progress, July 2009.
- EC 2012: European Commission, Draft Commission staff working Document. The Document presents a draft of the second European Union Implementation Plan on Persistent Organic Pollutants. Brussels, (2012).
- Environment Canada 2000: Priority Substance List Assessment Report, Hexachlorobutadiene, ISBN 0-662-29297-9. <http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl2-lsp2/hexachlorobutadiene/index-eng.php>, November 2000.
- ESWI 2011: BiPRO, Study on waste related issues of newly listed POPs and candidate POPs, BiPRO as part of the Consortium ESWI on behalf of the European Commission, DG Environment, Final Report, 13 April 2011.
- Haskoning 2002: E. van de Plassche and A. Schwegler, Royal Haskoning, The Netherlands, Hexachlorobutadien, 2002.
- HSDB, 2012: Hazardous Substances Data Bank; Hexachlorobutadiene. Division of Specialized Information Services, National Library of Medicine (<http://toxnet.nlm.nih.gov/>, last revised 10/12/2011).
- INERIS 2005: J.-M. Brignon, Hexachlorobutadiene, HCBd, INERIS –DRC- MECO, Version No. 1, Mai 05.
- IPCS 1994: International Programme on Chemical Safety, Environmental Health Criteria 156, Hexachlorobutadiene, World Health Organization.
- Juan et al., 2010: Juang D-F, Lee C-H, Chen W-C, Yuan C-S 2010: Do the VOCs that evaporate from a heavily polluted river threaten the health of riparian residents? *Sci. Tot. Env.* 408(20): 4524–4531.
- Lahaniatis et al. 1997: E.S. Lahaniatis, H. Parlar, F. Korte. Über das Vorkommen chlorierter Kohlenwasserstoffe in Flugaschen von Müllverbrennungsanlagen. *Chemosphere* No. 1, pp 11 – 16, 1977.
- Lecloux, 2004: Lecloux A.: Hexachlorobutadiene – Sources, environmental fate and risk characterization, Science Dossier, Euro Chlor representing the chlor-alkali industry, 2004; www.eurochlor.org, 43p.

Lenoir et al 2001: D. Lenoir, A. Wehrmeier, S.S. Sidhu, P.H. Taylor. Formation and inhibition of chloroaromatic micropollutants formed in incineration processes, *Chemosphere* 43 (2001) 107-114.

Li et al., 2012: Li, MT, Hao LL, Sheng LX, Xu JB 2008: Identification and degradation characterization of hexachlorobutadiene degrading strain *Serratia marcescens* HL1. *Bioresource Technology* 99(15): 6878–6884.

Nicole, 2004: NICOLE (Network for Contaminated Land in Europe), Report of the Nicole workshop, 2004, Nicole Projects Reporting Day, February 2004, Runcorn, UK.

Ian Rae, comment on the first draft risk profile, April 2012.

Thailand 2011: Submission of information specified in Annex E to the Stockholm Convention pursuant to Article 8 of the Convention.

TURI 2006: Five chemicals alternatives assessment study.

http://www.turi.org/About/Library/TURI_Publications/2006_Five_Chemicals_Alternatives_Assessment_Study

TURI 2008: Trichloroethylene factsheet.

http://www.turi.org/About/Library/TURI_Publications/Massachusetts_Chemical_Fact_Sheets/Trichloroethylene_TCE_Fact_Sheet/Printable_Trichloroethylene_TCE_Fact_Sheet

TURI 2012: Assessment of alternatives to perchloroethylene for the dry cleaning industry.

<http://www.turi.org/content/download/7399/134622/file/Perc%20Alternatives%20Assessment%20for%20Dry%20Cleaning%20Industry.pdf>

UBA AT 2001: Umweltbundesamt Austria. BAT for Large Volume Organic Chemicals and Production in Austria, Vienna, 2001.

UNECE 2007: Exploration of management options for Hexachlorobutadiene (HCBD), Paper for the 6th meeting of the UNECE CLRTAP Task Force on Persistent Organic Pollutants, Vienna, 4-6 June 2007. 20 June 2007.

UNEP 2007: GUIDELINES ON BEST AVAILABLE TECHNIQUES AND PROVISIONAL GUIDANCE ON BEST ENVIRONMENTAL PRACTICES relevant to Article 5 and Annex C of the Stockholm Convention on Persistent Organic Pollutants, May 2007, Geneva, Switzerland.

UNEP/POPS/POPRC.8/16: Report of the Persistent Organic Pollutants Review Committee on the work of its eighth meeting. Geneva, November 2012.

UNEP/POPS/POPRC.8/16/Add.2: Risk profile on hexachlorobutadiene. Geneva, 1 November 2012.

US EPA 2003: U.S. Environmental Protection Agency, Office of Water Health Effects. Support Document for Hexachlorobutadiene. EPA 822-R-03-002, February 2003.

US EPA 2012b: Great Lakes Binational Toxics Strategy, Appendix 1, Persistent toxic substances focused on by the Canada-United States strategy for the virtual elimination of persistent toxic substances in the Great Lakes

Verreault et al., 2005: Verreault J. and R. Letcher, D.C.G. Muir, S. Chu, W.A. Gebbink, G.W. Gabrielsen. 2005. New Organochlorine Contaminants and Metabolites in Plasma and Eggs of Glaucous Gulls (*Larus Hyperboreus*) from the Norwegian Arctic.

WWF 2005: WWF, Stockholm Convention “New POPs”, Screening Additional POP Candidates, April 2005.