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HEAL-CPES - Follow-up comments to CARACAL 48 discussion on **ECHA regulatory strategy for flame retardants**

The Health and Environment Alliance (HEAL) and its member organisation the Cancer Prevention and Education Society (CPES) thank ECHA for developing the Regulatory strategy for flame retardants, and the European Commission for organising a discussion on this important topic during the CARACAL 48 meeting as well as the opportunity to send follow-up comments. The restriction roadmap released last year includes an important commitment to consider a comprehensive restriction on all flame retardants.

The proposed regulatory strategy for flame retardants is an important step in the right direction of applying a broad and generic grouping approach to restricting them, but it is not fully delivering on necessary regulatory action. To completely realise the commitments made in the restriction roadmap, while also addressing regrettable substitution, the strategy must further develop recommendations that cast a wider regulatory net on flame retardants.

We support a regulatory approach towards flame retardants that is comprehensive and takes into account the latest scientific evidence to better protect the public's health and the environment. In order for the strategy to do so, it must support a faster, broader group restriction for flame retardants, including organophosphorus flame retardants (OPFRs), polymer flame retardants, and recycled products containing flame retardants. Justifying more regulatory delays for OPFRs for instance, based on the need for further data generation is neither acting in the public's best interest, nor the reality of the current state of the science.

To this end, we would like to provide additional information to support the strategy recommendations. Accounting for the large body of peer-reviewed scientific literature on this topic would strengthen the strategy and its intended purpose to further minimise the harm of flame retardants on both the environment and humans, particularly the young and future generations.

Broadening the recommended scope for restriction:

We would like to provide additional scientific data for consideration to broaden the scope of the recommended restriction proposed in the strategy. Specifically, there are four areas we would like to offer feedback on in more detail, which include:

- **Regrettable substitution: organophosphorus flame retardants**
- **Increasing use of polymeric flame retardants**
- **End-of-life hazards in recycling and disposal**
- **Efficacy of flame retardants vs. other fire safety interventions**

1. Regrettable substitution: Organophosphorus flame retardants (OPFR)

As a result of regulatory and industry voluntary action, older generation flame retardants particularly the PBDEs are increasingly being replaced with OPFRs.[1] [2] In fact, the HBM4EU study found, "OPFR metabolites, particularly BDCIPP and DPHP, have ubiquitous distribution in Europe, with limited differences between countries, perhaps due to the open market conditions."[3] Based on the robust published scientific literature on OPFRs, we argue that there is sufficient evidence to support immediate regulatory action due to OPFR's growing use and associated irreversible human health and environmental hazards.

We are concerned with the proposed approach in the strategy contingent on ongoing and planned data generation to verify the hazards of OPFRs. Waiting for the United States National Toxicology Program (US NTP) studies on the carcinogenicity of tris(2-chloro-1-methylethyl) phosphate (TCPP) (technical report still unavailable) does not justify delaying regulatory action on tris(2-chloroethyl) phosphate (TCEP), tris(2-chloro-1-methylethyl) phosphate (TCPP), tris[2-chloro-1- (chloromethyl)ethyl] phosphate (TDCP). The restriction roadmap already identifies these substances as CMRs in childcare articles. Data generation under current REACH provisions is also notorious for taking years, while substances such as OPFRs are increasingly being used and people remain exposed. In addition, the strategy mentions a restriction for professional uses of BMP and TBNPA based on their carcinogenic properties, but does not provide details on the related timeline and next regulatory steps.

Waiting on more data on OPFRs until 2025 to reassess their hazards will unnecessarily delay scientifically justified regulatory action that is urgently needed now, in essence allowing for continued use of OPFRs as regrettable substitutes.[4] A list of the scientific reviews to support broadening the scope of a recommended restriction to include OPFRs without delay are listed in Appendix A.

Reviews of the literature cite mounting evidence that OPFRs are increasingly being found in surface and groundwater and sediment due to their high solubility in water. Studies also discuss the relatively high prevalence of OPFRs detected in indoor air, house dust, and food from numerous sources in industrial and consumer products (i.e. building materials, textiles,

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[1] Blum, A., Behl, M., Birnbaum, L., et al. (2019). Organophosphate Ester Flame Retardants: Are They a Regrettable Substitution for Polybrominated Diphenyl Ethers? *Environ. Sci. Technol. Lett.* 6:(11) 638–649. DOI: 10.1021/acs.estlett.9b00582.

[2] Yang, J. et al. (2019) 'A Review of a Class of Emerging Contaminants: The Classification, Distribution, Intensity of Consumption, Synthesis Routes, Environmental Effects and Expectation of Pollution Abatement to Organophosphate Flame Retardants (OPFRs).', International journal of molecular sciences, 20(12). Available at: https://doi.org/10.3390/ijms20122874.

[3] Van der Schyff, V. et al. (2023). Exposure to flame retardants in European children — Results from the HBM4EU aligned studies.*International Journal of Hygiene and Environmental Health.*247:(114070). Available at: https://doi.org/10.1016/j.ijheh.2022.114070.

[4] Blum, A., Behl, M., Birnbaum, L., et al. (2019). Organophosphate Ester Flame Retardants: Are They a Regrettable Substitution for Polybrominated Diphenyl Ethers? *Environ. Sci. Technol. Lett.* 6:(11) 638–649. DOI: 10.1021/acs.estlett.9b00582.

electronics, childrens' articles, recycled plastics, food contact material etc).[5] [6] [7] [8] In fact, OPFRs are a common chemical class applied to a number of infant products and were measured at concentrations up to 7% by weight.[9] In addition, data shows increasing levels of OPFRs and their metabolites detected in the human body and breastmilk.[10] [11] [12] [13] The use of OPFRs in infant products likely contributes to the higher levels of OPFRs detected in infant and toddler urine samples in the US[14] and is likely why infants living in homes that had a higher number of infant products were associated with higher urinary levels of OPFRs.[15] And in fact, based on the levels of OPFRs measured in infants urine, researchers estimated that 2-9% of infants were receiving exposures that were above the acceptable daily dose established by the US Consumer Product Safety Commission for an increased health risk.[16] Similarly, the HBM4EU

[5] Dou, M. and Wang, L. (2022) 'A review on organophosphate esters: Physiochemical properties, applications, and toxicities as well as occurrence and human exposure in dust environment', Journal of Environmental Management, 325(Pt B), p. 116601. Available at: https://doi.org/10.1016 /j.jenvman.2022.116601.

[6] Hu, Z. et al. (2021) 'Organophosphate Esters in China: Fate, Occurrence, and Human Exposure.', Toxics, 9(11). Available at: https://doi.org/10.3390/toxics9110310.

[7] Li, J. et al. (2019) 'A review on organophosphate Ester (OPE) flame retardants and plasticizers in foodstuffs: Levels, distribution, human dietary exposure, and future directions.', Environment international, 127, pp. 35–51. Available at: https://doi.org/10.1016/j.envint.2019.03.009.

[8] Zhang, Q. et al. (2022) 'A review of organophosphate esters in soil: Implications for the potential source, transfer, and transformation mechanism.', Environmental research, 204(Pt B), 112122. Available at: https://doi.org/10.1016/j.envres.2021.112122.

[9] Stapleton, H.M. (2011). Identification of Flame Retardants in Polyurethane Foam Collected from Baby Products. *Environ. Sci. Technol.* 45:(12), 5323–5331. Available at: https://doi.org/10.1021/es2007462.

[10] Wang, X., Hales, B.F. and Robaire, B. (2021) 'Effects of flame retardants on ovarian function.', Reproductive toxicology (Elmsford, N.Y.), 102, pp. 10–23. Available at: https://doi.org/10.1016 /j.reprotox.2021.03.006.

[11] Hammel, S.C. et al. (2022). Young infants' exposure to organophosphate esters: Breast milk as a potential source of exposure. Environment International. 143:(106009). Available at: https://doi.org/10.1016/j.envint.2020.106009.

[12] Zheng, G. (2022). Organophosphate esters and their metabolites in breast milk from the United States: breastfeeding is an important exposure pathway for infants. *Environ. Sci. Technol. Lett.* 2021, 8, 3, 224–230. Available at: https://doi.org/10.1021/acs.estlett.0c00916.

[13] Chupeau, Z. et al. (2020) 'Organophosphorus Flame Retardants: A Global Review of Indoor Contamination and Human Exposure in Europe and Epidemiological Evidence.', International journal of environmental research and public health, 17(18). Available at: https://doi.org/10.3390/ijerph17186713.

[14] Butt, C.M. et al. (2014). Metabolites of Organophosphate Flame Retardants and 2-Ethylhexyl Tetrabromobenzoate in Urine from Paired Mothers and Toddlers. *Environ. Sci. Technol.* 48:(17), 10432-8. Available at: doi: 10.1021/es5025299.

[15] Hoffman, K. et al. (2015). High Exposure to Organophosphate Flame Retardants in Infants: Associations with Baby Products. *Environ. Sci. Technol.* 49(24), 14554−14559. Available at: https://doi.org/10.1021/acs.est.5b03577.

[16]Hoffman, K. et al. (2017). Estimated Tris(1,3-dichloro-2-propyl) Phosphate Exposure Levels for U.S. Infants Suggest Potential Health Risks. *Environ. Sci. Technol. Lett.* 4:(8), 334–338. Available at: https://doi.org/10.1021/acs.estlett.7b00196.

study analysed OPFR metabolites in children's urine in eight European countries and found that DPHP and BDCIPP, were detected most frequently and at the highest levels in all countries.[17]

Epidemiological, *in vitro,* and *in vivo* studies also indicate a potential wide breadth of associated adverse health outcomes linked to OPFRs exposure including carcinogenicity, mutagenicity, and reprotoxicity (CMR), endocrine disruption (ED), neurotoxicity, developmental toxicity, specific target organ toxicity (STOT), and respiratory and dermal sensitisation.[18] [19] [20] In fact, a large portion of the literature indicates that neurotoxicity, in particular, is a general intrinsic hazard of OPFRs.[21] [22] [23] As ECHA's screening report and the current scientific literature suggest, certain vulnerable populations such as pregnant women, foetuses, young children, workers, and marginalised communities are at particular risk of harm from increased OPFRs exposure.[24] [25] [26] [27]

The potential disproportionate impacts of OPFRs on these vulnerable groups provide sufficient justification to include OPFRs in a proposed restriction. Furthermore, chemical replacement of flame retardants should be thoroughly evaluated for health and environmental effects before being put on the market. Additionally, alternative non-

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[17] Van der Schyff, V. et al. (2023). Exposure to flame retardants in European children — Results from the HBM4EU aligned studies.*International Journal of Hygiene and Environmental Health.*247:(114070). Available at: https://doi.org/10.1016/j.ijheh.2022.114070.
[18] Ibid.
[19] Hu, Z. et al. (2021) 'Organophosphate Esters in China: Fate, Occurrence, and Human Exposure.', *Toxics,* 9(11). Available at: https://doi.org/10.3390/toxics9110310
[20] Patisaul, H. et al. (2021). [Beyond Cholinesterase Inhibition: Developmental Neurotoxicity of Organophosphate Ester Flame Retardants and Plasticizers | Environmental Health Perspectives | Vol. 129, No. 10 (nih.gov)].
[21] Blum, A. et al. (2019) 'Organophosphate Ester Flame Retardants: Are They a Regrettable Substitution for Polybrominated Diphenyl Ethers?', Environmental science & technology letters, 6(11), pp. 638–649. Available at: https://doi.org/10.1021/acs.estlett.9b00582.
[22] Patisaul, H.B. et al. (2021). 'Beyond Cholinesterase Inhibition: Developmental Neurotoxicity of Organophosphate Ester Flame Retardants and Plasticizers.', Environmental health perspectives, 129(10), p. 105001. Available at: https://doi.org/10.1289/EHP9285.
[23] Zhao, J.-Y. et al. (2022) 'A systematic scoping review of epidemiological studies on the association between organophosphate flame retardants and neurotoxicity', Ecotoxicology and Environmental Safety, 243, p. 113973. Available at: https://doi.org/10.1016/j.ecoenv.2022.113973.
[24] European Chemical Agency. (2018). Screening report: An assessment of whether the use of TCEP, TCPP, and TDCP in articles should be restricted. Available at: https://echa.europa.eu/documents/10162/17233/screening_report_tcep_tcpp_td-cp_en.pdf/e0960aa7-f703-499c-24ff-fba627060698?t=1523014289559.
[25] Doherty, B.T. et al. (2019) 'Organophosphate Esters: Are These Flame Retardants and Plasticizers Affecting Children's Health?', *Current environmental health reports*, 6(4), pp. 201–213. Available at: https://doi.org/10.1007/s40572-019-00258-0.
[26] Hu, Z. et al. (2021) 'Organophosphate Esters in China: Fate, Occurrence, and Human Exposure.', *Toxics*, 9(11). Available at: https://doi.org/10.3390/toxics9110310.
[27] Hayes, K. et al. (2021) 'Occupational risk of organophosphates and other chemical and radiative exposure in the aircraft cabin: A systematic review.', *The Science of the total environment*, 796, p. 148742. Available at: https://doi.org/10.1016/j.scitotenv.2021.148742.

chemical fire safety management strategies should be considered in crafting policy alongside data on replacement flame retardants.

2. Increasing use of polymeric flame retardants

The strategy also importantly identifies a trend in the increasing use of oligomeric or polymeric flame retardants in the EU market, which pose additional regulatory challenges as polymers are not currently required to be registered under REACH. This loophole must be closed as it allows unregistered flame retardants to enter the EU market without any required data on their intrinsic hazards, in direct contradiction with REACH's no data, no market principle.

Furthermore, data suggests that some reactive flame retardants migrate from polymers and may be associated with adverse health outcomes.[28] In fact, many of the OPFRs used in polymers are linked to the range of environmental and human health endpoints.[29] [30] Another major challenge that ECHA highlights in the strategy is the difficulty or impossibility of separating the reactive flame retardant from the polymer material during recycling and disposal. We will go into more detail on this topic in the next section, but the main point here is that the increasing use of polymeric flame retardants undermines achieving a clean and safe circular economy. Therefore, we also urge ECHA to consider the literature about polymeric flame retardants and use this new data to recommend developing a restriction on these substances.

3. End-of-life hazards in recycling and disposal

We support the Commission's and ECHA recognising the importance of reducing downstream impacts from flame retardants in the strategy. The significant hazards posed by end-of-life recycling and disposal of materials containing flame retardants from sources such as recycled e-waste are of paramount importance in the discussion of a future restriction scope. [31]

There is important research demonstrating flame retardants' irreversible harms to human health and the environment due to their toxic lifecycle, specifically during end-of-life

[28] Li, J. et al. (2019) 'A review on organophosphate Ester (OPE) flame retardants and plasticizers in foodstuffs: Levels, distribution, human dietary exposure, and future directions.', Environment international, 127, pp. 35–51. Available at: https://doi.org/10.1016/j.envint.2019.03.009.
[29] Doherty, B.T. et al. (2019) 'Organophosphate Esters: Are These Flame Retardants and Plasticizers Affecting Children's Health?', Current environmental health reports, 6(4), pp. 201–213. Available at: https://doi.org/10.1007/s40572-019-00258-0.
[30] Patisaul, H.B. et al. (2021) 'Beyond Cholinesterase Inhibition: Developmental Neurotoxicity of Organophosphate Ester Flame Retardants and Plasticizers.', Environmental health perspectives, 129(10), p. 105001. Available at: https://doi.org/10.1289/EHP9285.
[31] Ma, Y. et al. (2021) 'Human exposure to halogenated and organophosphate flame retardants through informal e-waste handling activities - A critical review.', Environmental pollution (Barking, Essex : 1987), 268(Pt A), p. 115727. Available at: https://doi.org/10.1016/j.envpol.2020.115727.

recycling/downcycling and disposal.[32] [33] [34] [35] Two reports detected brominated flame retardants (BFR) and brominated dioxins in new consumer products including children's toys, hair accessories, and kitchen utensils stemming from plastic recycling. These reports bring to light evidence of e-waste contamination in consumer products.[36] [37] In addition, as ECHA rightly points out in regards to FR's toxic life-cycle, "Uncontrolled burning and dismantling/recycling of electronic and electric waste that contains brominated or chlorinated FR can result in contamination and formation of brominated and chlorinated dioxins and furans; these substances are highly toxic, thus causing concern both for the health of individuals and for the environment."[38]

Overall, a large body of literature covers flame retardants and end-of-life hazards (see Appendix B for list of references). There is evidence in particular of exposure to informal e-waste activities and their disproportionate impact on low- and moderate-income countries, which contribute to health and environmental disparities globally.[39]

In considering this research, we urge ECHA to include recycled materials containing flame retardants in the recommended restriction scope. Moving forward, it is also critical that the European Commission raises the standards for products with recycled materials to correspond to the same limits as those of substances used in virgin materials. This is a necessary step in protecting the public's health and the environment from flame retardants contaminating recycled materials and achieving a truly safe and clean circular economy.

4. Efficacy of flame retardants vs. other fire safety interventions

[32] Arnika Association, The Health and Environment Alliance (HEAL), International POPs Elimination Network (IPEN). (2018). Toxic loophole: Recycling hazardous waste into new products. Available at: https://www.env-health.org/wp-content/uploads/2018/10/Toxic_Loophole-Arnika.

[33] Lucas et al. (2018). Methods of Responsibly Managing End-of-Life Foams and Plastics Containing Flame Retardants: Part I. *Environ Eng Sci*. 35(6): 573–587. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5994144/.

[34] Lucas et al. (2018). Methods of Responsibly Managing End-of-Life Foams and Plastics Containing Flame Retardants: Part II. *Environ Eng Sci*. 35(6): 573–587. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5994147/.

[35] Morin,. N.A.O. (2017). The presence and partitioning behavior of flame retardants in waste, leachate, and air particles from Norwegian waste-handling facilities. *Journal of Environ Health Sciences*. 62: 115-132. Available at: https://doi.org/10.1016/j.jes.2017.09.005.

[36] Straková, J. et al. (2018). Toxic loophole: Recycling hazardous waste into new products. Available at: https://www.env-health.org/wp-content/uploads/2018/10/Toxic_Loophole-Arnika. Arnika Association, The Health and Environment Alliance (HEAL), International POPs Elimination Network (IPEN).

[37] Petrlík, J., et al. (2018). Toxic Soup: Dioxins in Plastic Toys. Arnika Association, The Health and Environment Alliance (HEAL), International POPs Elimination Network (IPEN), and BUND (Bund für Umwelt und Naturschutz Deutschland). Available at: www.env-health.org/wp-content/uploads/2018/11/Toxic_Soup_brochure_en_web04-1.pdf

[38] European Chemical Agency. (2023). Regulatory strategy for flame retardants. Available at: https://echa.europa.eu/documents/10162/2082415/flame_retardants_strategy_en.pdf/9dd56b7e-4b62-e31b-712f-16cc51d0e724?t=1679045593845.

[39] Ma, Y. et al. (2021) 'Human exposure to halogenated and organophosphate flame retardants through informal e-waste handling activities - A critical review.', Environmental pollution (Barking, Essex : 1987), 268(Pt A), p. 115727. Available at: https://doi.org/10.1016/j.envpol.2020.115727.

Finally, as the strategy suggests, there is a critical need to assess the actual efficacy from use of flame retardants and open flame tests compared with other non-hazardous fire safety interventions. In fact, a report from the EU commission supports the conclusion that non-flammability requirements such as open flame tests are not indicative of real-life scenarios and these requirements have little bearing on fire safety overall.[40] Instead, flame retardants may actually be compounding the injuries and harms associated with exposure to toxic fumes and smoke during a fire that contain such hazards as carbon monoxide, cyanide, dioxins and furans.[41] [42] [43] [44]

A new consensus statement compiled by experts in the field puts forth a comprehensive list of policy recommendations that prioritise innovation and intelligent product design in lieu of chemical flame retardants use.[45] [46] [47] And as ECHA has reiterated when referring to challenges and uncertainties,

> [G]enerally controlling release of, and exposure to, hazardous flame retardants during and after service life must focus on inherently safe material design. In other words, hazardous flame retardants may need to be phased out, or there may need to be a demonstrably very low mobility of the flame retardant or degradation products in the material, combined with dedicated end-of-life collection and waste management systems (including recycling and destruction e.g. via incineration), as well as controlled use by industrial or professional users.[48]

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[40] Arcadis EBRC, Report for European Commission (DG Health and Consumers) - Evaluation of data on flame retardants in consumer products – Final report 17.020200/09/549040, Brussels, 2011. http://ec.europa.eu/consumers/safety/news/flame_retard ant_substances_study_en.pdf

[41] Page, J. et al. (2023).A new consensus on reconciling fire safety with environmental & health impacts of chemical flame retardants. Environment International 173:(107782). Available at: https://www.sciencedirect.com/science/article/pii/S0160412023000557.

[42] Zhang, M. et al. (2016). Brominated flame retardants and the formation of dioxins and furans in fires and combustion. *Journal of Hazardous Materials.* 304, 26-39. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0304389415301412

[43] Fent, K.W. et al. (2020). Flame retardants, dioxins, and furans in air and on firefighters' protective ensembles during controlled residential firefighting. *Environment International.* 140, 105756. Available at: https://doi.org/10.1016/j.envint.2020.105756.

[44] Blomqvist, P., Rosell, L. & Simonson, M. (2004). Emissions from Fires Part II: Simulated Room Fires. *Fire Technology* 40, 59–73. Available at: https://doi.org/10.1023/B:FIRE.0000003316.63475.16.

[45] Fidra. (2022). Sustainable Fire Safety: promoting fire safety through intelligent furniture design and sound chemical management. Available here: https://www.fidra.org.uk/wp-content/uploads/Sustainable-Fire-Safet

[46] Page, J. et al. (2023).A new consensus on reconciling fire safety with environmental & health impacts of chemical flame retardants. Environment International 173:(107782). Available at: https://www.sciencedirect.com/science/article/pii/S0160412023000557.

[47] Fidra. (2023). Managing Chemicals of Concern within a Circular Economy: The Impacts and Solutions for Chemical Flame Retardant Use in UK Mattresses. Available at: The Impacts & Solutions for Chemical Flame Retardant Use in UK Mattresses: Evidence Review - Fidra

[48] European Chemical Agency. (2023). Regulatory strategy for flame retardants. Available at: https://echa.europa.eu/documents/10162/2082415/flame_retardants_strategy_en.pdf/9dd56b7e-4b62-e31b-712f-16cc51d0e724?t=1679045593845.

Taking into account this evidence, it is clear that flame retardants may be posing more health risks than benefits for fire safety. **In order to minimise the hazards associated with the use of flame retardants, regulatory chemical management that accurately reflects the known benefits and risks associated with flame retardants' use vs. more sustainable alternatives must be used to better inform member states' flammability standards and regulations.**

Conclusion

There is a large body of scientific evidence justifying urgent and strong regulatory action and a broad grouping approach to restrict flame retardants in the EU. HEAL and CPES urge ECHA to consider the additional scientific evidence presented here in order to strengthen the recommendations under the strategy on flame retardants for a group restriction. Furthermore, it is imperative that current scientific literature is continuously monitored, scrutinised, and incorporated into REACH regulatory action. The literature on chemicals thought to be unproblematic or lacking data in the past may well be shown to have scientific evidence demonstrating associated harmful effects to human health and environment at present or in the near future.

Appendix A.

Recent OPFR reviews

Blum, A. et al. (2019) 'Organophosphate Ester Flame Retardants: Are They a Regrettable Substitution for Polybrominated Diphenyl Ethers?', Environmental science & technology letters, 6(11), pp. 638–649. Available at: https://doi.org/10.1021/acs.estlett.9b00582.

Chen, Y. et al. (2020) 'A review on organophosphate flame retardants in indoor dust from China: Implications for human exposure.', Chemosphere, 260, p. 127633. Available at: https://doi.org/10.1016 /j.chemosphere.2020.127633.

Chupeau, Z. et al. (2020) 'Organophosphorus Flame Retardants: A Global Review of Indoor Contamination and Human Exposure in Europe and Epidemiological Evidence.', International journal of environmental research and public health, 17(18). Available at: https://doi.org/10.3390/ijerph17186713.

Doherty, B.T. et al. (2019) 'Organophosphate Esters: Are These Flame Retardants and Plasticizers Affecting Children's Health?', Current environmental health reports, 6(4), pp. 201–213. Available at: https://doi.org/10.1007/s40572-019-00258-0.

Dou, M. and Wang, L. (2022) 'A review on organophosphate esters: Physiochemical properties, applications, and toxicities as well as occurrence and human exposure in dust environment', Journal of Environmental Management, 325(Pt B), p. 116601. Available at: https://doi.org/10.1016 /j.jenvman.2022.116601.

Guo, Y. et al. (2022) 'An overview of organophosphate esters and their metabolites in humans: Analytical methods, occurrence, and biomonitoring', The Science of the Total Environment, 848, p. 157669. Available at: https://doi.org/10.1016/j.scitotenv.2022.157669.

Hayes, K. et al. (2021) 'Occupational risk of organophosphates and other chemical and radiative exposure in the aircraft cabin: A systematic review.', The Science of the total environment, 796, p. 148742. Available at: https://doi.org/10.1016/j.scitotenv.2021.148742.

Hu, Z. et al. (2021) 'Organophosphate Esters in China: Fate, Occurrence, and Human Exposure.', Toxics, 9(11). Available at: https://doi.org/10.3390/toxics9110310.

Li, J. et al. (2019) 'A review on organophosphate Ester (OPE) flame retardants and plasticizers in foodstuffs: Levels, distribution, human dietary exposure, and future directions.', Environment international, 127, pp. 35–51. Available at: https://doi.org/10.1016/j.envint.2019.03.009.

Liu, Y. et al. (2021) 'Organophosphate (OP) diesters and a review of sources, chemical properties, environmental occurrence, adverse effects, and future directions.', Environment international, 155, p. 106691. Available at: https://doi.org/10.1016/j.envint.2021.106691.

Ma, Y. et al. (2021) ‘Human exposure to halogenated and organophosphate flame retardants through informal e-waste handling activities - A critical review.’, Environmental pollution (Barking, Essex : 1987), 268(Pt A), p. 115727. Available at: https://doi.org/10.1016/j.envpol.2020.115727.

Maddela, N.R., Venkateswarlu, K. and Megharaj, M. (2020) ‘Tris(2-chloroethyl) phosphate, a pervasive flame retardant: critical perspective on its emissions into the environment and human toxicity.’, Environmental science. Processes & impacts, 22(9), pp. 1809–1827. Available at: https://doi.org/10.1039 /d0em00222d.

Patisaul, H.B. et al. (2021) ‘Beyond Cholinesterase Inhibition: Developmental Neurotoxicity of Organophosphate Ester Flame Retardants and Plasticizers.’, Environmental health perspectives, 129(10), p. 105001. Available at: https://doi.org/10.1289/EHP9285.

Van der Schyff, V. et al. (2023). Exposure to flame retardants in European children — Results from the HBM4EU aligned studies.*International Journal of Hygiene and Environmental Health.*247:(114070). Available at: https://doi.org/10.1016/j.ijheh.2022.114070.

Wang, C. et al. (2020) ‘Review of emerging contaminant tris(1,3-dichloro-2-propyl)phosphate: Environmental occurrence, exposure, and risks to organisms and human health.’, Environment international, 143, p. 105946. Available at: https://doi.org/10.1016/j.envint.2020.105946.

Wang, X. et al. (2020) ‘A review of organophosphate flame retardants and plasticizers in the environment: Analysis, occurrence and risk assessment.’, The Science of the total environment, 731, p. 139071. Available at: https://doi.org/10.1016/j.scitotenv.2020.139071.

Wang, X. et al. (2022) ‘Potential adverse outcome pathways with hazard identification of organophosphate esters’, The Science of the Total Environment, 851(Pt 1), p. 158093. Available at: https://doi.org/10.1016/j.scitotenv.2022.158093.

Wang, X., Hales, B.F. and Robaire, B. (2021) ‘Effects of flame retardants on ovarian function.’, Reproductive toxicology (Elmsford, N.Y.), 102, pp. 10–23. Available at: https://doi.org/10.1016 /j.reprotox.2021.03.006.

Yan, Z. et al. (2021) ‘The potential connections of adverse outcome pathways with the hazard identifications of typical organophosphate esters based on toxicity mechanisms.’, Chemosphere, 266, p. 128989. Available at:https://doi.org/10.1016/j.chemosphere.2020.128989.

Yang, J. et al. (2019) ‘A Review of a Class of Emerging Contaminants: The Classification, Distribution, Intensity of Consumption, Synthesis Routes, Environmental Effects and Expectation of Pollution Abatement to Organophosphate Flame Retardants (OPFRs).’, International journal of molecular sciences, 20(12). Available at: https://doi.org/10.3390/ijms20122874.

Yao, C., Yang, H. and Li, Y. (2021) ‘A review on organophosphate flame retardants in the environment: Occurrence, accumulation, metabolism and toxicity.’, The Science of the total environment, 795, p. 148837. Available at: https://doi.org/10.1016/j.scitotenv.2021.148837.

Zhang, Q. et al. (2022) ‘A review of organophosphate esters in soil: Implications for the potential source, transfer, and transformation mechanism.’, Environmental research, 204(Pt B), p. 112122. Available at: https://doi.org/10.1016/j.envres.2021.112122.

Zhao, J.-Y. et al. (2022) ‘A systematic scoping review of epidemiological studies on the association between organophosphate flame retardants and neurotoxicity’, Ecotoxicology and Environmental Safety, 243, p. 113973. Available at: https://doi.org/10.1016/j.ecoenv.2022.113973.

Appendix B:

Recent articles on flame retardants and recycling

Balasch, A. et al. (2022) 'Exposure of e-waste dismantlers from a formal recycling facility in Spain to inhalable organophosphate and halogenated flame retardants.', Chemosphere, 294, p. 133775. Available at: https://doi.org/10.1016/j.chemosphere.2022.133775.

Chen, T. et al. (2019) 'Thyroid function and decabromodiphenyl ethane (DBDPE) exposure in Chinese adults from a DBDPE manufacturing area.', Environment international, 133(Pt A), p. 105179. Available at: https://doi.org/10.1016/j.envint.2019.105179.

Chibwe, L. et al. (2023) 'Target and Nontarget Screening of Organic Chemicals and Metals in Recycled Plastic Materials', Environmental Science & Technology [Preprint]. Available at: https://doi.org/10.1021 /acs.est.2c07254.

Gravel, S. et al. (2020) 'Multi-exposures to suspected endocrine disruptors in electronic waste recycling workers: Associations with thyroid and reproductive hormones.', International journal of hygiene and environmental health, 225, p. 113445. Available at: https://doi.org/10.1016/j.ijheh.2019.113445

Guo, L.-C. et al. (2022) 'Associations between serum polychlorinated biphenyls, halogen flame retardants, and renal function indexes in residents of an e-waste recycling area', The Science of the Total Environment, p. 159746. Available at: https://doi.org/10.1016/j.scitotenv.2022.159746.

Harrad, S., Drage, D., et al. (2022) 'Elevated concentrations of halogenated flame retardants in waste childcare articles from Ireland', Environmental Pollution (Barking, Essex: 1987), p. 120732. Available at: https://doi.org/10.1016/j.envpol.2022.120732.

Hoang, A.Q. et al. (2022) 'Comprehensive characterization of halogenated flame retardants and organophosphate esters in settled dust from informal e-waste and end-of-life vehicle processing sites in Vietnam: Occurrence, source estimation, and risk assessment', Environmental Pollution (Barking, Essex: 1987), 310, p. 119809. Available at: https://doi.org/10.1016/j.envpol.2022.119809.

Kajiwara, N. et al. (2022) 'Recycling plastics containing decabromodiphenyl ether into new consumer products including children's toys purchased in Japan and seventeen other countries.', Chemosphere, 289, p. 133179. Available at: https://doi.org/10.1016/j.chemosphere.2021.133179.

Li, Q. et al. (2021) 'Insights into Persistent Toxic Substances in Protective Cases of Mobile Phones: Occurrence, Health Risks, and Implications.', Environmental science & technology, 55(9), pp. 6076–6086. Available at: https://doi.org/10.1021/acs.est.0c07603.

Lu, R. et al. (2023) ‘Organophosphate flame retardants and plastics in soil from an abandoned e-waste recycling site: significant ecological risks derived from plastic debris’, Environmental Science and Pollution Research International [Preprint]. Available at: https://doi.org/10.1007/s11356-023-26625-x.

Ma, S. et al. (2022) ‘New Insights into Human Biotransformation of BDE-209: Unique Occurrence of Metabolites of Ortho-Substituted Hydroxylated Higher Brominated Diphenyl Ethers in the Serum of e-Waste Dismantlers’, Environmental Science & Technology [Preprint]. Available at: https://doi.org /10.1021/acs.est.2c02074.

Ma, Y. et al. (2021) ‘Human exposure to halogenated and organophosphate flame retardants through informal e-waste handling activities - A critical review.’, Environmental pollution (Barking, Essex : 1987), 268(Pt A), p. 115727. Available at: https://doi.org/10.1016/j.envpol.2020.115727.

Mäkinen, M.S.E. et al. (2009) ‘Respiratory and dermal exposure to organophosphorus flame retardants and tetrabromobisphenol A at five work environments.’, Environmental science & technology, 43(3), pp. 941–947. Available at: https://doi.org/10.1021/es802593t.

Matsukami, H. et al. (2022) ‘Silicone wristband- and handwipe-based assessment of exposure to flame retardants for informal electronic-waste and end-of-life-vehicle recycling workers and their children in Vietnam’, The Science of the Total Environment, p. 158669. Available at: https://doi.org/10.1016 /j.scitotenv.2022.158669.

Molla, A.S. et al. (2021) ‘Chemicals of concern in construction and demolition waste fine residues: A systematic literature review’, Journal of Environmental Management, 299, p. 113654. Available at: https://doi.org/10.1016/j.jenvman.2021.113654.

Paliya, S. et al. (2022) ‘Assessment of polybrominated diphenyl ether contamination and associated human exposure risk at municipal waste dumping sites.’, Environmental geochemistry and health [Preprint]. Available at: https://doi.org/10.1007/s10653-022-01208-w.

Pantelaki, I. and Voutsa, D. (2022) ‘Occurrence and removal of organophosphate esters in municipal wastewater treatment plants in Thessaloniki, Greece’, Environmental Research, 214(Pt 2), p. 113908. Available at: https://doi.org/10.1016/j.envres.2022.113908.

Singh, V. et al. (2022) ‘Effects of Polybrominated Diphenyl Ethers on Hormonal and Reproductive Health in E-Waste-Exposed Population: A Systematic Review’, International Journal of Environmental Research and Public Health, 19(13), p. 7820. Available at: https://doi.org/10.3390/ijerph19137820.

Sorais, M. et al. (2020) ‘Landfills represent significant atmospheric sources of exposure to halogenated flame retardants for urban-adapted gulls.’, Environment international, 135, p. 105387. Available at: https://doi.org/10.1016/j.envint.2019.105387.

Stubbings, W.A. and Harrad, S. (2014) 'Extent and mechanisms of brominated flame retardant emissions from waste soft furnishings and fabrics: A critical review', Environment International, 71, pp. 164–175. Available at: https://doi.org/10.1016/j.envint.2014.06.007.

Suzuki, G. et al. (2021) 'Emission of Dioxin-like Compounds and Flame Retardants from Commercial Facilities Handling Deca-BDE and Their Downstream Sewage Treatment Plants.', Environmental science & technology, 55(4), pp. 2324–2335. Available at: https://doi.org/10.1021/acs.est.0c06359.

Tongue, A.D.W. et al. (2021) 'Interspecies comparisons of brominated flame retardants in relation to foraging ecology and behaviour of gulls frequenting a UK landfill.', The Science of the total environment, 764, p. 142890. Available at: https://doi.org/10.1016/j.scitotenv.2020.142890.

Wu, X. et al. (2022) 'Organophosphate ester exposure among Chinese waste incinerator workers: Urinary levels, risk assessment and associations with oxidative stress', The Science of the Total Environment, p. 158808. Available at: https://doi.org/10.1016/j.scitotenv.2022.158808.

Zapata-Corella, P. et al. (2022) 'Presence of novel and legacy flame retardants and other pollutants in an e-waste site in China and associated risks', Environmental Research, p. 114768. Available at: https://doi.org/10.1016/j.envres.2022.114768.

Zhao, L. et al. (2023) 'Co-occurrence and distribution of organophosphate tri- and di-esters in dust and hand wipes from an e-waste dismantling plant in central China', The Science of the Total Environment, 878, p. 163176. Available at: https://doi.org/10.1016/j.scitotenv.2023.163176.