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MANAGEMENT OF HALOGENATED FLAME RETARDED WASTES IN THE UNITED STATES –THE NEED FOR A CIRCULAR ECONOMY APPROACH

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Introduction

There is widespread recognition of the need to move away from a linear and towards a circular economy approach whereby materials are used as long as possible and are re-used/recycled at end-of-life. However, the incorporation of brominated and chlorinated flame retardants (BFRs, CFRs) and phosphorus flame retardants (PFRs) in a wide range of consumer goods and materials poses challenges for re-using and recycling those materials at end-of-life (EoL). Use of flame retardants (FRs) has grown since the 1970s and has been particularly high in furniture, cars/vehicles, building materials, and electrical and electronic equipment due to flammability standards in the United States (US) and internationally[1]. **Table 1** summarizes the major stocks of products containing flame retardants (FRs). Large volumes of products, vehicles and building materials containing FRs have accumulated over the past 40 years globally. After their first use, these products and materials may be resold or donated, resulting in continued exposures especially to low-wealth communities. Ultimately, most of these materials end up in the waste stream at EoL[2]. Recycling of FR-containing products can result in their inadvertent incorporation into products never intended to contain these chemicals[3].

The Stockholm Convention has listed the FRs polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD) as persistent organic pollutants (POPs). The 180 countries that ratified the Stockholm Convention are developing strategies to manage the flow of products and materials containing these FRs, including appropriate recycling strategies[4,5]. The US, which did not ratify the Stockholm Convention, has not developed a specific strategy for management of wastes containing PBDEs and HBCD. However, the US has initiated a movement towards a large-scale circular economy[6]. Materials containing FRs will require careful consideration under a circular economy, since the reuse of these materials might increase exposure risks if the FRs are not separated and contained[7].

This paper describes major stocks of products containing FRs and briefly addresses some management and recycling options in the US. Policy solutions are suggested to reduce health and environmental hazards at product EoL. Ultimately, the goal of this discussion is to consider preventative measures to the problem of waste containing FRs and other chemicals of concern as one component of moving towards a circular economy.

Materials and methods

We reviewed literature pertaining to FRs in products and impacts on waste management. We also conducted interviews with stakeholders and subject experts and hosted a participatory workshop on this topic in April 2016.

Results and discussion

Major stocks of polymeric wastes containing flame retardants and implications

1) Flexible polyurethane foam (FPUF) in furniture and consumer goods. According to the Polyurethane Foam Association, more than 544,000 tonnes of FPUF are produced and used annually in the U.S[8]. Of this, an estimated 120,000 tonnes were produced for furniture applications in 2015 and could contain FRs to comply with flammability standards. An estimated 30,000 tonnes of pentaBDE were used in

FPUF in North America between 1970 and 2004 (when use of pentaBDE was discontinued)[2]. PentaBDE-containing FPUF still in-use, plus flame retardants used in FPUF manufactured since 2004 (such as PFRs and mixtures like Firemaster 550), continue to be sources of indoor exposures[10]. In terms of EoL, the mass of furniture and furnishings in municipal solid waste (MSW) has increased from 2 million tonnes in 1960 to 10.5 million tonnes in 2013 (4.6% of total MSW)[7]. Infant and child products such as car seats also contain FRs[11], however the mass of FRs in these products is unknown[2]. Post-production FPUF is recycled into carpet padding, which dilutes but does not remove the flame retardants[12].

2) Polymers in vehicles. FRs were used in the transport sector for multiple types of polymers[2] (Table 1). Between 1970 and 2013, 15,000 tonnes of Penta-, 5,000 tonnes of Octa-, and 133,000 tonnes of deca-BDEs were used in the seating, textile backing, and other plastic components of cars and light trucks in North America[2]. These estimates represent a minimum value as it does not account for PBDEs in all polymers and, importantly, does not include large transportation vehicles which are subject to severe flammability standards. EoL vehicles are handled to produce automotive shredder residue (ASR) which comprises 25 - 30% of total car waste[4].

3) Plastics in electrical and electronic equipment (EEE) and related waste (WEEE). The largest total amount of flame retardant use is in plastics for electrical and electronic equipment (EEE), which can contain up to 15% FR by weight[4]. In the US, nearly 7.1 million tonnes of WEEE were generated in 2014[13] containing, on average, 20% plastic (1.4 million tonnes) and related FRs[5]. From 1970 to 2013, 9,200 tonnes of Penta-, 20,000 tonnes of Octa-, and 133,000 tonnes of Deca-BDE were used in EEE in North America[2].

4) Flame retardants in buildings and construction. Foam plastic building insulation (extruded and expanded polystyrene, polyurethane, and polyisocyanurate) represents a major use of BFRs and PFRs in construction applications. HBCD has been widely used in polystyrene insulation materials. Production of HBCD is expected to decline, but HBCD emissions and exposures may continue for a century or longer due to the long life-span of use and waste management considerations[14]. PFRs, notably tris(1-chloro-2-propyl) phosphate (TCPP), are also used extensively in hard and soft polyurethane foam insulation. Landfilling of insulation may be a significant contributor to environmental release of HBCD[14].

Table 1: Major categories and individual items which can – but may not always – contain flame retardants[15,16]

Management strategies for wastes containing flame retardants and related concerns

1) Landfilling. In the US, most waste containing FRs is sent to landfill. Several studies indicate that landfills are a source of BFRs, and increasingly PFRs, to the surrounding environment[17,18]. PFRs are of particular concern for leachate and ground water contamination due to their very high water solubility[18]. Also, landfills with open burn conditions (approx. 8300 in the US per year) are of significant concern[19] due to formation and release of mixed brominated and chlorinated dioxins and furans (PBDD/F) [20].

2) Recycling. Most FR-containing materials are not recycled in the US. However, the recycling of FPUF trim scrap into bonded carpet cushion results in a dilution of flame retardants, subjecting recyclers, carpet installers and consumers to exposure[7]. Also the export of e-waste and e-waste components to developing/ transitioning countries results in high exposure to populations living and working near recycling sites[21].

3) Thermal destruction/recovery. Thermal destruction is currently a minor waste treatment practice in the US. Due to the high calorific value of plastic, energy recovery can be considered preferable to landfilling. However, thermal treatment of BFR-containing polymers can be problematic because of increased corrosion and formation and releases of halogenated PCDD/F.

Research and policy recommendations for managing waste that contains flame retardants

The following are recommendations aimed at reducing the burden associated with handling FR-treated waste.

1) Development of appropriate flammability standards. The main driver for use of flame retardants in the US is flammability standards. For instance, upholstered furniture in the US contained FRs due the California regulation Technical Bulletin 117 (TB 117). This regulation has been updated (TB117-2013) to maintain fire safety and enable production of furniture without FRs, and since 2015, Californian law requires new furniture to be labeled if it contains FRs. FRs continue to be used in electronics, building insulation, and a variety of other products. However, there may be opportunities to similarly update flammability requirements for these products to maintain fire safety and reduce use of FRs. For instance, voluntary standards for electronics in the US are being updated and may give manufacturers flexibility to reduce FRs in plastic enclosures. Code requirements that apply to building insulation in the US are periodically revised and could follow the example set by Scandinavia to achieve building fire safety without FRs.

2) Minimizing "Regrettable Substitution" of FRs. The regrettable substitution of PentaBDE in FPUF by chlorinated and other PFRs illustrates that ending the use of one harmful chemical can result in even higher releases of and exposure to replacement chemicals in indoor air and dust. To minimize the problem of "regrettable substitution", a recent petition to the US Consumer Product Safety Commission (CPSC) asks for regulation of the entire class of additive organohalogen FRs (HFRs) in four categories of consumer products. The petition, which is supported by statements from scientists, is an innovative approach in the US to reducing regrettable substitutions. It is a first step since the petition does not address non-halogenated FRs of concern, like some PFRs.

3) Education. Researchers need to communicate and share knowledge to inform policy. Scientific consensus statements like the San Antonio Statement on Brominated and Chlorinated Flame Retardants not only document the consensus on health and environmental risks but also provide support and frameworks for improved policies to reduce chemicals of concern[22]. Initiatives such as Green Science Policy's Six Classes approach, which includes an educational webinar series, provides information on phasing out hazardous chemical classes including HFRs[23]. This initiative has shown promise for guiding decisions of manufacturers and purchasers to minimize use of these chemicals.

Stakeholders working in waste management and in recycling would benefit from knowledge-sharing regarding FRs and other chemicals of concern in the waste stream, just as those producing and selling FRs need to be aware of the complications arising from waste management of FR-containing products and materials. Those involved in waste management should consider joining efforts to reduce toxic chemicals in products as an "upstream" preventative measure. This could help advance goals for a more circular economy.

Conclusions

In summary, the need to move towards a circular economy is urgent. Management of EoL products and materials containing FRs presents significant challenges for achieving this goal. In the US, most FR-containing waste is landfilled. Recycling FR-containing polymers can result in advertent inclusion of FRs in new products. Reducing the production and use of FRs, by changing flammability standards that require their use, are likely to be more effective at reducing harm than improved waste management practices alone. Education can play a key role in effective control and management of FRs and FR-containing waste.

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References

1. Shaw, S.D., Blum, A., Weber, R., Kannan, K., Rich, D., Lucas, D., Koshland, C.P., Dobraca, D., Hanson, S., Birnbaum, L.S. (2010) Reviews on Environ Health 25(4) 261-305.
2. Abbasi, G., Buser, A.M., Soehl, A., Murray, M.W., Diamond, M.L. (2015) Environ Sci Technol 49(3):1521-1528.

3. Samsonek, J., Puype, F., (2013) Food Additives & Contaminants Part A 30, 1976-1986.
4. Stockholm Convention (2015a) 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. UNEP/POPS/COP.7/INF/22.
5. Stockholm Convention (2015b) Guidance for the Inventory of commercial Pentabromodiphenyl ether (c-PentaBDE), commercial Octabromodiphenyl ether (c-OctaBDE) and Hexabromobiphenyls (HBB) under the Stockholm Convention on Persistent Organic Pollutants. UNEP/POPS/COP.7/INF/27.
6. U.S. Chamber of Commerce. (2015) Achieving a Circular Economy: How the Private Sector is Reimagining the Future of Business.
7. Stapleton, H.M., Sjödin, A., Jones, R.S., Niehüser, S., Zhang, Y., Patterson, D.G. Jr. (2008) Environ Sci Technol 42(9):3453-3458.
8. Polyurethane Foam Association. Flexible Polyurethane Foam: Industry at a Glance. http://www.pfa.org/Library/IAG_no_logo.pdf
9. US EPA. (2015) Advancing sustainable material management: Facts and Figures 2013.
10. Imm P., Knobeloch L., Buelow C., Anderson H.A. (2009) Environ Health Perspect 117(12):1890-1895.
11. Stapleton, H.M., Klosterhaus, S., Keller, A., Ferguson, P.L., van Bergen, S., Cooper, E., Webster, T.F., Blum, A. (2011) Environ Sci Technol 45(12): 5323–5331.
12. DiGangi, J., Strakova, J. (2011) Toxic recycling. IPEN. http://www.akaction.org/wp-content/uploads/2015/07/2011-04_Research_Article_Survey_of_PBDEs_in_Recycled_Carpet_Padding.pdf
13. Baldé, C.P., Wang, F., Kuehr, R., Huisman, J. (2015) The global e-waste monitor – 2014. United Nations University, IAS – SCYCLE, Bonn, Germany.
14. Li, L., Weber, R., Liu, J., Hu, J. (2016) Environ Int. 91, 291-300.
15. Abbasi, G., Buser, A. M., Soehl, A., Murray, M. W., Diamond, M. L. (2015) Environ Sci Technol 49 (3), 1521–1528.
16. Janssen, S. (2005) Brominated Flame Retardants: Rising Levels of Concern; Arlington, VA.
17. Weber, R., Watson, A., Forter, M., Oliaei, F. (2011) Waste Manage Res 29(1), 107-121.
18. Eggen, T., Moeder, M., Arukwe, A. (2010) Sci Total Environ 408(21), 5147-5157.
19. U.S. Fire Administration. (2001) Landfill Fires. Topical fire research series, Volume 1, Issue 18.
20. Gullett, B.K., Wyrzykowska, B., Grandesso, E., Touati, A., Tabor, D.G., Ochoa, G.S. (2010) Environ Sci Technol 44, 394–399.
21. Labunska, I., Harrad, S., Wang, M., Santillo, D., Johnston, P. (2014) Environ Sci Technol 48, 5555-5564.
22. DiGangi, J., Blum, A., Bergman, Å., de Wit, C. A., Lucas, D., Mortimer, D., Schecter, A., Scheringer, M., Shaw, S. D., Webster, T. F. (2010) Environ. Health Perspect 118 (12), A516–A518.
23. Blum, A. (2016) Science 351 (6278), 1117.

Electronical and Electronic Equipment (EEE)	Building and Construction Materials
- Television and other electronic device casings - Computers and laptops, including monitors, keyboards and portable digital devices - Printed circuit boards - Telephones and cell phones - Refrigerators and freezers - Washers and dryers - Vacuum cleaners - Electrical and optical wires and cables - Small household appliances - Battery chargers	- Insulation materials (e.g. polystyrene and rigid polyurethane insulation foams; poly) - Electrical wires and cables, including those behind walls - Paints and coatings which are applied to a variety of building materials, including steel structures, metal sheets, wood, plaster and concrete - Structural and decorative wood products - Roofing components - Composite panels - Decorative fixtures
Furnishings	**Transportation (Cars, Airplanes, Trains, Ships)**
- Foam upholstery - Natural and synthetic filling materials and textile fibers - Curtains and fabric blinds - Carpets - Mattresses	- Seat textile covers and fillings - Headrests and armrests - Overhead compartments; roof liners - Textile carpets; mats; curtains - Sidewall and ceiling panels - Internal structures, dashboard/instrument panel - Insulation panels - EEE (stereo, GPS etc.); cables - Car bumpers