Office for Product
Safety & Standards

Technical Annex:

The use of recycled materials in consumer products and potential chemical safety concerns

Scoping study

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This work was commissioned by the Office for Product Safety and Standards (OPSS) for completion by WRAP.

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Written by: Hamish Forbes, Sarah Key, Costa Athanatos, Monika Zilionyte, Heather Portbury

1.0 Glossary of acronyms and terms

Acronyms and terms	Definition
ABS	Acrylonitrile Butadiene Styrene
Al	Aluminium
As	Arsenic
ATBC	Acetyltributylcitrate
Ba	Barium
BBP	Benzyl butyl phthalate. Sometimes written as BzBP
BDE209	Decabromodiphenyl ether
BDP	Bisphenol A bis(Diphenyl Phosphate)
Be	Beryllium
BFR	Brominated flame retardant
BP3	Benzophenone-3
BPA	Bisphenol A
BPF	Bisphenol F
BPS	Bisphenol S
Br	Bromine
BS	British Standards
Ca	Calcium
Cd	Cadmium
CEN	European Committee for Standardisation
Cl	Chlorine
CLP	Classification, labelling and packaging regulation
CMR	Carcinogenic, mutagenic or toxic to reproduction
CP	Chlorinated paraffin
Cr	Chromium
CRT	Cathode ray tube
Cu	Copper
DBDPE	Decabromodiphenyl ethane
DBP	Dibutyl phthalate
DCHP	Dicyclohexyl phthalate
DDT	Dichlorodiphenyltrichloroethane
DecaBDE	Decabromodiphenyl ether
DEHA	Diethylhydroxylamine
DEHP	Bis(2-ethylhexyl) phthalate
DEHT	Dioctyl terephthalate
DEP	Diethyl phthalate

DHXP	Dihexyl phthalate
DiBP	Diisobutyl phthalate
DIDP	Diisodecyl phthalate
DINCH	1,2-Cyclohexane dicarboxylic acid diisononyl ester
DINP	Diisononyl phthalate
DMF	Dimethylformamide
DMPP	Dimethylphenylpiperazinium
DnBP	Di-n-butyl phthalate
DnOP	Dioctyle phthalate
DNP	Di-n-nonyl phthalate
ECHA	European Chemicals Agency
EDX-RF	Energy dispersive x-ray fluorescence
EEA	European economic area
EEE	Electrical and electronic equipment
EHDPP	Ethylhexyl diphenyl phosphate
ELV	End of life vehicles
EoL	End of life
EPA	Environmental Protection Agency
ERD	Explicit recycling dataset
EU	European Union
EVA	Ethylene-vinyl acetate copolymer
FD	Full dataset
Fe	Iron
FPD	Flat-panel display
FR	Flame retardant
FTOH	Fluorotelomer alcohol
GC-MS	Gas chromatography-mass spectrometry
GM	Geometric mean
HBCDD	Hexabromocyclododecane
HDPE	High-density polyethylene
Hg	Mercury
HI	Hazard index: the sum of hazard quotients for toxics that affect the same target organ or organ system.
HIPS	High impact polystyrene
HPLC-ESI-MS/MS	High-performance liquid chromatography/electrospray ionization tandem mass spectrometry
HQ	Hazard quotient: the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. A HQ less than or equal to 1 indicates that adverse health effects are not considered likely to occur.
HRGC/HRMS	High resolution gas chromatography / High resolution mass spectrometry

ICT	Information and communications technology
IPEN	International Pollutants Elimination Network
ISO	International Organisation for Standardisation
JIG	Joint Industry Guide
K	Potassium
LCD	Liquid crystal display
LDPE	Low-density polyethylene
LOD	Limit of detection
LPCL	Low POP concentration limit
MCL	Maximum concentration limit
Mg	Magnesium
Mn	Manganese
MP	Methyl Paraben
Na	Sodium
NBFR	Novel brominated flame retardant
NFR	Novel flame retardant
NGO	Non-governmental organisation
Ni	Nickel
NOGE	Novolac glycidyl ethers
NPE	Nonylphenol ethoxylate
OctaBDE	Octabromodiphenyl ether
OPE	Octylphenol ethoxylate
OPFR	Organophosphate ester flame retardants
PAH	Polycyclic aromatic hydrocarbon
Pb	Lead
PBB	Polybrominated biphenyl
PBDD/F	Polybrominated dibenzo-p-dioxins and furans
PBDE	Polybrominated diphenyl ethers
PBDF	Polybrominated dibenzofurans
PBT	Persistent, bioaccumulative and toxic
PC	Polycarbonate
PCB	Printed circuit board
PCDD/DF	Polychlorinated dibenzodioxins
PCP	Pentachlorophenol
PE	Polyethylene
PentaBDE	Pentabromodiphenyl ether
PET	Polyethylene terephthalate
PFAS	Per- and polyfluoroalkyl substances

PFBS	Perfluorobutanesulfonic acid
PFCA	Perfluorinated carboxylic acid
PFDA	Perfluorodecanoic acid
PFH	Perfluorohexane
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonate
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
PFR	Phosphorus flame retardant
POP	Persistent organic pollutant
POP-BDE	Persistent organic pollutant-brominated diphenyl ethers
PP	Polypropylene
ppm	Parts per million
PP-PE	Polypropylene-polyethylene copolymers
PS	Polystyrene
PTFE	Polytetrafluoroethylene
PUF	Polyurethane foam
PVC	Polyvinyl chloride
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals regulation
RIVM	Dutch National Institute for Public Health and the Environment
RoHS	Restriction of Hazardous Substances directive
RWP	Residual waste plastics
S	Sulfur
Sb	Antimony
Sc	Scandium
SCCP	Short-chain chlorinated paraffins
Se	Selenium
SEM-EDS	Scanning electron microscopy with energy dispersive spectroscopy
Sm	Samarium
Sn	Tin
SSWP	Source segregated waste plastics
SVHC	Substance of very high concern
SVOC	Semi-volatile organic compound
TBBPA	Tetrabromobisphenol A
TBOEP	Tris(2-butoxyethyl)
TCC	Triclocarban
TCEP	Tris(2-carboxylethyl)phosphine

TCPP	Tris(1-chloro-2-propyl) phosphate
TDCPP	Tris(1,3-dichloro-2-propyl) phosphate
TDMPP	Tris(2,6-dimethoxyphenyl)phosphine
TEHP	Tris(2-ethylhexyl) phosphate
tetraBDE	Tetrabromodiphenyl ether
Ti	Titanium
Tl	Thallium
TPHP	Triphenyl phosphate
VOC	Volatile organic compound
vPvB	Very bioacumulative
WEEE	Waste electrical and electronic equipment
WFD	Waste Framework Directive
XPE	Chemical crosslinked polyethylene
XRF	X-ray fluorescence
Zn	Zinc
ZZS	Dutch national list for substances of very high concern

2.0 Literature Review Methodology

2.1.1 Search Process

The literature review stage used a combination of methodologies to identify possible evidence on the scale of recycling-based contamination of consumer products. Our key focus was on papers which related to the chemical hazard of consumer products in the groups of interest (defined in section 1.3 of the main report) with some evidence or speculation on the origin of those materials, and the relationship between those products and recycling (e.g. the product is believed to be made from recycled materials, or the product is expected to be recycled).

Searches were conducted using Science Direct and Google Scholar for literature published between the year 2000 and the current date which researched a chemical hazard and non-food consumer product, with any geographic focus. Searches were undertaken for different combinations of product group and analyte. As an example, one search string was: [vehicle AND consumer AND (perfluorinated OR "persistent organic pollutant" OR phthalate OR "heavy metal") AND (recycled OR recycling) -water]. In this particular case, the [-water] search term relates to our focus on consumer health safety concerns of products, when there is a ubiquity of papers relating to the environmental pollution and dangers to soil or water health from waste and recycling of products.

Alongside searches, a 'snowball' approach was taken by which when relevant papers were identified, they were examined in more detail both for references they cite and for papers in which they were subsequently cited. A good example of this is Chen et al. (2009) which was, to the author's knowledge, the first study examining brominated flame retardant (BFR) concentration in toys and potential exposure to children, including speculation on the recycling-based origin of the materials. As a result, it is very widely cited, and tracking the papers which have referenced this study highlighted many subsequent studies on the same topics in different geographic areas or product groups.

A third avenue of searching was based on review papers which aligned broadly with our research questions. In these cases the reviews were about chemical presence, *not* recycling-based chemical presence. As a result, the papers referenced were followed through to identify the extent to which they discussed recycling. Some notable review papers include reviews on the risk of plastic waste (Cook et al., 2020), a wide range of Semi-Volatile Organic Compounds in products (Lucattini et al., 2018), and chemicals in specific product groups like textiles (Rovira & Domingo, 2019).

Based on these methods for finding evidence, potentially relevant publications were then evaluated in two stages. Firstly, the title of the evidence was considered against our research questions and inclusion criteria. If inconclusive, the abstract or introduction of text was read and evaluated, and the full text was searched for any recycling related term (recycle, recycling, recycled etc.). From those which had sufficient relevant information, evidence was extracted.

Evidence extraction involved detailing, for each study:

- Bibliographic information, including the origin of the source (e.g. academic, governmental, non-governmental organisation (NGO)
- The geographic location of the study / the products analysed
- The scope of the analysis, whether products or recycling processes themselves
- The method and sample size
- The product groups analysed
- The analytes measured
- The scale of chemical presence identified
- Any evidence on consumer safety associated with that chemical presence
- The speculation or evidence of recycling in contributing to chemical presence

The product and analyte groups were matched to our product and chemical groups (see section 1.3 of the main report) as best as possible. However, due to inconsistencies between the product categories used here and those used by authors, perfect matches were not always possible.

All information was compiled in a spreadsheet using Microsoft Excel. To aid in analysis, evidence was split into datapoints based upon the product and analyte groups of focus. For example, if a single study analysed the presence of BFRs in both toys and furniture, this paper would be divided into two datapoints, one for each product group. If a study were to analyse both BFRs and phthalates in both toys and furniture, this would lead to four datapoints, one for each product-analyte combination. Where used, *papers* refers to unique publications and *datapoints* to unique product-analyte combinations within papers.

The following sections refer to two datasets: the *full dataset* (FD), which includes all datapoints found through the search system described, regardless of whether the paper authors make any allusion to the role of recycling (either than a product will be recycled, or is made from recycled content). The *explicit recycling dataset* (ERD) is a subset of the FD which includes only datapoints where the authors speculated that the product had been recycled, or would be recycled. The need for this distinction is detailed more in section 2.1.2.

2.1.1 Dataset filtering

Following the search process outlined in section 2.1.1, the FD compiled documenting the individual papers and datapoints considered to be of relevance to the investigation. This does not reflect every paper read or considered for inclusion but does reflect those which were considered and read in depth. The final number of papers in this database is 128, between which 257 potentially relevant datapoints were identified.

The FD does not include datapoints identified by the search process which focused on products outside of our scope. Some of the excluded datapoints had conclusions or findings which were of possible relevance, such as about recycling more broadly or unspecific product groups. In some cases, these were analyses of non-focus product groups included in the same study as product groups of focus. A few notable datapoints are detailed in Table 1:

Table 1: Examples of out of scope but possibly relevant papers

Example papers	Product groups analysed	Chemical groups analysed
(Puype et al., 2015; Samsonek & Puype, 2013)	Black polymeric kitchen utensils	Flame retardants
(Straková et al., 2018)	Hair accessories / clips	Flame retardants
(Bečanová et al., 2016)	Mixed ‘household plastics’	Perfluorinated chemicals
(Vojta et al., 2017)	Mixed ‘household plastics’	Flame retardants
(Wassenaar et al., 2017)	Paper and paperboard consumer products	List of chemical groups, some in scope and some not
(ChemSec, 2019; Kazulytė, 2019; RIVM & Ramboll, 2019)	Food contact packaging	Phthalates; Flame Retardants

These are not intended to be representative of the scale of research in these product areas. Rather, they act as a signpost to areas which could be fruitful avenues for further investigation, should an expanded scope be considered appropriate. These excluded datapoints are not detailed in the results section, which is organised by product group. However, some of the findings of these papers, where relevant, have informed the conclusions described in the main report.

The dataset was filtered to remove datapoints relating to the recycling process. This left 111 papers with 220 datapoints between them related specifically to products in the FD. The datapoints relating to products are discussed in section 2.1.4.2 of the main report of the main report. The datapoints relating to the recycling process are discussed in section 2.1.4.3 of the main report. These were coded for their reference to recycling: those which looked at products which were possibly made of recycled materials, those products which would reasonably be expected to be recycled, and those where the paper made no reference to recycling. The difference between being classified as a paper related to recycling and making no reference to recycling was often the matter of a single throw-away phrase by the authors when speculating on the source of contamination; this means that a number of the studies which do not refer to recycling could be showing recycling-based contamination, but this is not a route the authors consider. This is discussed as a limitation in section 2.1.2.

2.1.2 Limitations

The approach taken has some limitations. Firstly, by combining ‘snowball’ and search-based practices, the search has not been systematic and there may be some evidence which has been missed. We have attempted to minimise this where possible with targeted searches on product and analyte groups where no evidence was found after the first review stage, but it is still possible that relevant information has not been included here. This is particularly the case for governmental sources, which are less likely to be found through academic search engines. In some cases, government agencies related to consumer safety had a number of relevant studies, such as the National Institute for Public Health and the Environment (RIVM) in the Netherlands[1] and the Danish Environmental Protection Agency’s (EPA) surveys on chemicals in consumer products[2]. It is possible that there are more governmental agencies like these publishing relevant information which had not been picked up in other academic literature, nor our searches. However, we can be confident that the amount of evidence gathered has covered most of the high-profile peer reviewed work in this space as a result of the snowball methodology. When compared to a review paper from 2018 on semi-volatile organic compounds (SVOCs) in consumer products, which identified 57 papers relating to a wider range of chemicals without a focus on recycling (Lucattini et al., 2018), we have identified a far greater number despite the constraints: 111 papers relating to consumer products. The evidence presented here is therefore not exhaustive, but can be considered comprehensive.

A second limitation relates to the focus of searches on evidence of recycled materials through the use of recycling-based terms (‘recycling’, ‘recycled’, or the wildcard ‘recycl*’). As identified throughout the literature review findings (see section 2.1.1 of the main report), actual *evidence* of recycling is scarce, and the papers cited mostly rely on speculation about recycling. To paraphrase, such speculation typically operates along the lines of: ‘this chemical additive serves no purpose in the product, or is in the product at a scale below what would be required to serve a useful purpose, and therefore was likely not purposefully added to the product. We can theorise that its presence is a result of contamination during manufacturing, during transportation/end-of-life [for studies taking samples from waste and recycling centres], or as a direct result of recycled materials containing these additives being used in the manufacturing’. In many cases, this conjecture is the closest which can be achieved to evidence as the materials are insufficiently traced. However, the limitation this creates in relation to the search method is that to be identified through recycling-focused searches, authors had to speculate on the role of recycled materials in causing the chemical presence. This means that those papers which analyse similar products for similar analytes but do not speculate on the origin of the material were less likely to be identified. As a clear example, one Danish Environmental Protection Agency (EPA) paper identified levels of bromine small enough to imply non-purposeful addition, “even if there is no immediate other sources of content of bromine” (Andersen et al., 2014, p. 60). However, they do not examine the trace bromine further, nor do they speculate on how it might have got there, whether recycling-based impurity or not. The snowball methodology went some way to addressing this, provided the literature was identified by other authors, but it is likely that there is more literature available on consumer goods with no

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[1] *https://www.rivm.nl/en*

[2] *https://eng.mst.dk/chemicals/chemicals-in-products/consumers-consumer-products/danish-surveys-on-consumer-products/*

relation to recycling or material origins which we have not considered, and the FD therefore cannot be said to be complete.

As a result of this second limitation, the main analysis focused on the FD, which includes papers which make no reference to recycling, but do make reference to analyte groups and product groups of focus, as it was judged that the information contained therein would be of interest. However, because searches were not carried out for these products outside of the recycling-based searches and review articles discussed in section 2.1.1, it is likely in some cases that there is much more evidence relating to chemicals in consumer goods made from (believed) virgin materials. Given the number of product groups and analytes involved in this scoping study, a more systematic search of all evidence relating to toxic chemicals in consumer products regardless of origin falls beyond the scope and resource available.

3.0 Detailed product and analyte group literature review evidence

This annex presents a brief description for each product-focused datapoint used to inform the literature review analysis (see section 2.1.4.2 of the main report), including more information on sample size and findings than that presented in the main body of the report. It does not include those papers which described and observed the recycling process (see section 2.1.4.3 of the main report), unless they also involved the measurement of products. Where chemical concentrations are mentioned, they have been written as presented in the source paper. Where applicable, this has been converted to a single consistent measure, parts-per-million (PPM) in adjoining brackets. The papers are ordered by product group and then chemical group. Within these sections, they are ordered alphabetically by primary author's name.

This section can be navigated by reference to the heat matrix, which is available in Table 2. Each cell of the table, other than those where no data was identified, can be clicked to navigate to that product-analyte combination. Links at the top of each page in the following section can be followed to return to the heat matrix.

Table 2: Heat Matrix

Product Group / Analyte Category	Bisphenols	Flame retardants	Formaldehydes	Parabens	Perfluorinated chemicals	Other Persistent organic pollutants	Phthalates	Heavy metals	Other
Childcare articles and children's equipment	2	6	3	0	1	0	7	3	2
Clothing, textiles and fashion items	2	7	3	1	7	0	5	14	4
Cosmetics	1	0	0	4	0	0	3	1	3
Electrical appliances and equipment	0	26	0	0	2	0	0	8	0
Toys	1	17	0	1	0	2	7	9	1
Furniture	0	16	0	0	5	1	1	2	0
Motor vehicles	0	8	1	0	0	0	2	2	2
Other; mixture of priority and non-priority categories	2	11	1	0	1	3	4	2	3

3.1 Childcare articles and children's equipment

3.1.1 Bisphenols

Lassen et al. (2011) studied children's dummies for BPA. It was found that the shield and ring of 10-20% of dummies on the Danish market were made of polycarbonate containing BPA. The BPA exposure from dummies' shields to artificial sweat and saliva was studied, but the migration to both media was below the limit of detection (LOD) in 6 out of 8 examined dummies. The research concluded that there was no immediate health risk related to the use of BPA in baby dummies. There was no suggestion that recycling contributed to the presence of BPA.

Negev et al. (2018) studied 61 parts of non-toy childcare items including baby textiles, mattresses, diaper changing mats, feeding chairs, baths and aprons from Israel. BPA was found in 22% of samples, and 17% of test results exceeded the EU standard. Of those above the LOD, the mean concentration found was 1.03 ppm (EU standard is 0.1 ppm). The highest observed BPA level was 9.9 ppm in a PVC bath toy from a low cost online retailer. Two diaper changing mats had a level of 2.6 and 1.32 ppm. All other items that exceeded the EU limit had a concentration less than 0.5 ppm, but still 4 times higher than the limit. No comment was made on whether the products had been recycled.

Return to Heat Matrix.

3.1.2 Flame Retardants

Mikkelsen et al. (2015) studied 30 baby products including 10 car safety seats, 10 baby slings and 10 baby mattresses for BFRs and phosphorus flame retardants (FRs). The substances found in most samples in significant concentrations were phosphorus based FRs; Tris(2-carboxylethyl)phosphine (TCEP), TCPP and TDCPP. A concentration of more than 10,000 mg/kg [10,000 ppm] was observed in at least one sample. Based on XRF, two products may have contained BFRs with a content of up to 1 mg/kg [1 ppm]. This low level is below those that would suggest intended functionality, suggesting they are present as an impurity, although no source of this is suggested, recycling or otherwise. Migration to artificial sweat tests were performed for 7 products: 4 car baby seats, 2 baby slings and 1 baby mattress. It was concluded that, based on very conservative assumptions, there may be a risk of exposure to children in a worst-case scenario. However, in a more realistic scenario, the authors indicated that there may be "an undesirable risk associated with a single car seat, a baby sling and a baby mattress".

Miller et al. (2016) analysed 10 samples of 'baby gear' for Bromine (Br) content using XRF. The baby items that were found to contain at least 5 ppm bromine were a diaper change kit, vinyl bib, non-vinyl bib and quilted crib pad. The paper speculates that recycled e-waste is the source of unintentional Br contamination.

Negev et al. (2018) analysed 61 parts of 34 non-toy childcare (baby textiles, mattresses, diaper changing mats, feeding chairs, baths, aprons) for flame retardants, 27 of these tested for BFR or phosphorus flame retardant (PFR). The study screened 87 item parts from 48 items for bromine, found in 36% of samples, mean of 5.01 ppm. All of the flame retardant analyses were negative. The authors give three possible reasons: they did not test for DecaBDE, often found in products with flammability requirements; the type of tests undertaken; and the size or samples or LOD not able to detect the FRs they tested. For those with no flammability requirements, possibly no justification for producers to add FRs which carry

Go to Heat Matrix

additional costs, therefore may be unlikely to be found in products other than baby mattresses. The authors do not comment on the role of recycling.

Peng et al. (2020) analysed 41 playmats from Chinese markets for flame retardants. They found OPEs to be generally 1-2 orders of magnitude higher than PBDEs, reflecting usage trends in China. The median values were 13 ng/g (0.013 ppm) for PBDEs and 200 ng/g (0.2 ppm) for OPEs. Playmates were analysed for their main material: PBDEs and OPEs were far more abundant in PE and Ethylene-vinyl acetate copolymer (EVA) playmats (30 ng/g [0.03 ppm] and 28 ng/g [0.028 ppm] respectively, on average) than chemical crosslinked polyethylene (XPE) and PVC mats. They attribute this variation to “different raw materials and/or additives used in the manufacturing process”, but do not elaborate on why the raw materials may vary in PBDE content. In other words, recycling is not directly discussed. However, they note that in all the samples the PBDEs were insufficient for flame retardancy. Recycling could therefore possibly contribute to the contamination. Peng et al. (2020) also calculated the safety of the playmats for children in four age groups, modelling dermal contact, inhalation and hand to mouth pathways. They found the combined exposure to be 5-6 orders of magnitude lower than established reference of dose values, suggesting “no obvious health concern regarding the occurrence of PBDEs and OPEs in play mats”, though they do also point out that “play mats might act as passive samplers and absorb flame retardants while used indoor, thus posing children under higher risks”.

Poulsen (2020) surveyed 20 PUF products including child mattresses, tumbling mats, pillows and cot bumpers for BFRs. None contained BFRs above the detection limit (2.4 mg/kg [2.4 ppm]) and so the authors concluded that within these products there was no violation of flame retardant content regulations.

Stapleton et al. (2011) sampled 101 commonly used baby furniture items containing PUF in the US. Flame retardants were identified in 80 samples, with all but one identified as either chlorinated or brominated. TDCPP was the most common, with a detection frequency of 36%, followed by Firemaster500 mixture (17%). Five samples had congeners associated with PentaBDE despite phaseout, suggesting products with PentaBDE is still in use. The authors conclude that children may be at a greater exposure risk to TDCPP from these products than the average child or adult from upholstered furniture.

Return to Heat Matrix.

3.1.3 Formaldehydes

Mikkelsen et al. (2015) investigated 30 baby products including 10 car safety seats, 10 baby slings and 10 baby mattresses for the presence of formaldehyde, which was found at low concentrations in all items. It was suggested that the low concentration present indicated that the substances probably did not have an intended function in the product. The authors do not explicitly speculate on the role of recycling, however.

Poulsen et al. (2020) analysed 20 consumer products, 10 for babies and small children and 10 for older children and adults for Formaldehydes. The samples were mainly child mattresses, tumbling mat, pillows, cot bumpers. Based of SVOCs emitted, 9 substances were selected for risk assessment. Formaldehyde was the only substance examined which had an unacceptable risk scenario. This was a worst-case scenario in which a baby sleeping with multiple products in the zone of respiration. There was no suggestion that recycling contributed to the chemical presence.

Go to Heat Matrix

Tønning et al. (2008) looked at 13 products for babies, primarily textiles and plastics with upholstery and padding (pillows, baby carriers, nursing pillows, baby mattresses, aprons and disposable foam washcloths). It was found that pillows for baby feeding emitted formaldehyde and contained 25-65 μg/g [25-65 ppm]. It was highlighted that in a worst-case scenario, this could migrate to skin and contribute to the acceptable daily limit (but not exceed it). A nursing pillow contained 100 μg/g [100 ppm] but no comment was made on the migration. There was no suggestion that recycling contributed to the chemical presence.

Return to Heat Matrix.

3.1.4 Parabens

No datapoints were identified. Return to Heat Matrix.

3.1.5 Perfluorinated Chemicals

Mikkelsen et al. (2015) studied textiles from 8 baby car seats for 39 PFASs, but the concentration for all was below the detection limit, suggesting the addition was not intentional to impart an intended function. The authors do not speculate on the origin of the low concentration chemicals, recycling or otherwise.

3.1.6 Other Persistent Organic Pollutants

No datapoints were identified. Return to Heat Matrix.

3.1.7 Phthalates

Ishii et al. (2015) conducted a risk assessment of 7 phthalate in paper diapers for new-born babies produced in Japan. DEHP and DBP were found in top sheets at levels of 0.6 μg/g [0.6 ppm] and 0.2 μg/g [0.2 ppm] respectively. The estimated daily exposure to 7 phthalates was concluded as negligible. There was no suggestion recycling played a role in the chemical presence.

Llompart et al. (2013) studied rubber mulch from playgrounds in Spain and found phthalate plasticisers present in all samples. The rubber mulch is described as being made from recycled used tyres and tyre debris, and so that is speculated to be the source of phthalate contamination. The phthalates found in the majority of samples were DIBP, DBP, and DEHP. The most abundant was DEHP with concentrations ranging from 4-64 μg/g [4-64 ppm] in playground samples. DINP was found in 8 of 21 playground samples with values above 3600 μg/g [3600 ppm] in 5 of them. The authors suggest that “Uses of recycled rubber tires, especially those targeting play areas and other facilities for children, should be a matter of regulatory concern.”

Mikkelsen et al. (2015) studied 30 baby products including 10 car safety seats, 10 baby slings and 10 baby mattresses for phthalates. DIDP was one of the more commonly identified substances with higher concentrations in more samples, with one exceeding 10,000 mg/kg [10,000 ppm]. There was no suggestion that recycling contributed to chemical presence.

Negev et al. (2018) studied phthalates in 52 parts of non-toy childcare items including baby textiles, mattresses, diaper changing mats, feeding chairs, baths and aprons from Israel. As phthalates in non-PVC items is not regulated in Israel, levels were compared to European standards. Products where phthalates were detected included 3 nylon sheets, 2 baby mattresses, 5 diaper changing mats and one non-slip bathmat. In total, 15% exceeded the EU standard by mass for DEHP; with 65% detecting above LOD. For DINP, 7% were above the EU standard by mass with 10% above LOD.

Poulsen (2020) studied 20 consumer products including child mattresses, tumbling mats, pillows and cot bumpers for phthalates. Small quantities of phthalates were found in 6 of 20 products, with a maximum concentration of 65 mg/kg [65 ppm] (permitted limit is 500 or 1000 mg/kg [500 or 1000 ppm] depending on phthalate meaning there was no violation of regulations. The authors suggest that "the low phthalate content is likely due to impurities from other added components" but do not discuss what these impurities could be, such as if recycling could have played a role.

Strandesen et al. (2015) analysed 7 childcare articles and found that only one contained phthalates in concentrations above 0.05% [500 ppm]. There was no suggestion that recycling contributed to chemical presence.

Tønning et al. (2008) looked at 13 products for baby use, primarily textiles or plastics with upholstery or padding. A nursing pillow was the only product with phthalates above the regulated amount, with one sample containing a concentration of 144000 µg/g [144,000 ppm] DINP. DEHP was identified in an apron, but was not at a level that provided a risk. There was no suggestion that recycling contributed to chemical presence.

Return to Heat Matrix.

3.1.8 Heavy metals

Li and Suh (2019) reviewed 342 articles which covered 202 unique chemicals including lead in baby and children's items. The authors identified 7 reports about lead in these applications as a colourant, through which dermal contact is the exposure pathway. The review also suggests that recycling can “lead to the occurrence of chemicals in recycled products which might have completely different properties in retaining chemicals and different exposure patterns to humans”. They demonstrate that published literature on health risks of chemicals in consumer products largely focused on a handful of high-profile chemicals, namely phthalates, BPA, PBDE, lead, and several engineered nanomaterials. Also a tendency to focus on several functional use/product application combinations, leaving a "variety of the other combinations explored".

Mikkelsen et al. (2015) analysed 30 baby products: 10 car safety seats; 10 baby slings; 10 baby mattresses for heavy metals and lead. The authors summarised other studies showed: Car safety seats: Lead: found in textile at 7.5 mg/kg [7.5 ppm] in 1/50 samples. They concluded "the results from the screening analyses showed several unidentifiable compounds in low concentrations, i.e. in concentrations indicating that the substances probably did not have an intended function in the textile product". However, the authors do not discuss the origins of the contamination, whether recycling or otherwise.

Negev et al. (2018) studied heavy metals in 61 parts of non-toy childcare items including baby textiles, mattresses, diaper changing mats, feeding chairs, baths and aprons from Israel. As each category did not have their own standardised limits, toy standards were used as a reference. In baby textiles, no items exceeded the toy standard. In baby mattresses, one plastic mattress cover exceeded the toy standard for antimony, with a concentration of 6,890 ppm (limit of 560 ppm). For diaper changing mats, two items exceeded limits for trace metals: one exceeded cadmium and lead limits (774 and 992 ppm respectively, above standard of 560 ppm), the other exceeded cadmium limits at 235 ppm. Both items were white PVC with no paint or decoration, making the lead and cadmium presence unexpected. The authors do not speculate as to how the contamination occurred.

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3.1.9 Other

Mikkelsen et al. (2015) analysed 30 baby products: 10 car safety seats; 10 baby slings; 10 baby mattresses for phosphorus FR. 7 products with highest content phosphorus FR tested for migration to artificial sweat. The results showed PAHs were found in very low concentration in the 30 products analysed. At levels below those which would suggest intended functionality, "the substances primarily occur as impurities in the materials and that they do not have a technical function in the final products" but no description of the origin of the impurity. "The results from the screening analyses showed several unidentifiable compounds in low concentrations, i.e. in concentrations indicating that the substances probably did not have an intended function in the textile product". However, the authors do not discuss the origins of the contamination, whether recycling or otherwise.

Wassenaar et al. (2017) assessed the environmental risks of the 10 most used pharmaceuticals and their presence and content in diapers. As the chemicals identified were not on the ZZS list, they are also not in our priority list. Based on the available data, no issues in regard to ZZS content is expected for diaper waste. However, they stress the level of uncertainty in the research as “actual data on ZZS presence in waste streams are often lacking because there is no coherent analytical monitoring program for ZZS in waste”. At present in the Netherlands most diaper waste is incinerated. The authors mention it as a possible recyclate source due to being a large waste stream with ongoing projects to create a closed-loop system.

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3.2 Clothing, textiles and fashion items

3.2.1 Bisphenols

Li and Kannan (2018) analysed 74 tights samples from 6 countries (China, Japan, Korea, Portugal, Chile and US). BPS and BPA were found in 100% and 96% of the samples at median concentrations of 1430 and 14.3 ng/g, respectively [1.43 ppm and 0.014 ppm, respectively]. The highest BPA concentrations were found in tights made in China and Japan with 21-50% Spandex content. This paper also recognises the recycling of plastics to produce polyester and nylon yarn for applications such as tights. This report also found that high concentrations of bisphenols were linked to higher percentages of spandex in the garments.

Xue et al. (2017) analysed 77 pieces of textiles and infant clothing pieces from Asia and Latin America. BPA and BPS were found in 82% and 53% of samples respectively with a mean concentration of 366 [0.366 ppm] and 15 ng/g [0.015 ppm] respectively. The 14 socks (all 97-98% polyester) analysed had the highest BPA concentrations which a mean of 1810 ng/g [1.81 ppm]. This was 3 to 5 times higher than that found in raw textiles and greater than in clothes. The authors speculate that recycling could play a role in this: "in recent years, recycled plastic bottles made of polyethylene and polycarbonate have begun to be used for the production of polyester fibers woven into clothes, including socks", therefore it "seems likely that the source of BPA found in polyester-containing socks is from the recycled plastic bottles used as raw materials in the production of polyester". However, in polyester socks with high BPA concentrations, there was also blending with 1-2% Spandex and 1% rubber, and the authors suggest that the high concentration of BPA found in these samples is related to its combination with Spandex. The BPA concentrations in 100% polyester clothing was lower than the 97% and 98%, cited as evidence that the

Spandex may in fact be the driver. BPA and BPS in clothing made primarily of synthetic fibres were approximately 72 and 13 times greater than those found in clothing made exclusively from 100% cotton or a 60% cotton blend. The highest BPA level was found in 97% polyester (2300 ng/g [2.3 ppm]) followed by a 98% polyester blend (600 ng/g [0.6 ppm]). The lowest concentration was found in 100% cotton fabric (8.64 ng/g [0.086 ppm]). There were much lower concentrations of BPA in 100% polyester and 94% nylon clothing, with a similar trend observed for BPS.

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3.2.2 Flame Retardants

Miller et al. (2016) tested a range of clothing and jewellery pieces for Br content: 23 pieces of clothing; 93 costumes and accessories; 240 pieces of jewellery and accessories; 14 pieces of footwear and 160 Mardi Gras or holiday beads. These groups were analysed based on rate of items with Br detected, and the Br concentration. Footwear had the lowest detection rate: just over 40% had Br, none above 1000 ppm; in the jewellery and accessories group just over 50% had Br, most below 100 ppm but approximately 10% of the sample having above 10,000 ppm; for costumes and accessories just under 60% had Br, mostly between 5-100 ppm; more than 70% had some Br but most detection was below 1000 ppm. The most notable finding was the Mardi Gras beads: some 90% had Br detected, of which 51% had it in concentrations above 10,000 ppm, 27% between 100-10,000 Br. The Br presence was strongly correlated with presence of antimony, tin and gold, which leads the authors to conclude that “the common source is e-waste plastic” which had been recycled.

Schecter et al. (2009) analysed PBDE content of household dryer lint from 12 US and 7 German homes using GC MS. It was found that the median total PBDE in the US samples was more than 10 times higher than the median German levels. US levels ranged from 321 to 3073 ng/g [0.32 to 3.07 ppm] (median 803, mean 1138 ng/ng [0.8 and 1.14 ppm]) whereas German levels ranged from 330 to 2068 ng/g [0.33 to 2.07 ppm] (median 71, mean 361 ng/g [0.07 and 0.36 ppm]). PBDE contamination was found in all lint samples and it was stated that the source of this may be from the dryer electrical components and/or dust deposition onto clothing. There is no suggestion, therefore, of the role of recycling as a driver.

Straková & Petrlík (2017) analysed the black sections of 47 toy and beauty items using XRF. Of these, 15 had significant Br levels and were then further analysed for levels of specific PBDEs and HBCD. Eight accessory and beauty products were subject to further analysis due to their Br content: three hair clips, three hair combs, two headdresses. PentaBDE concentration ranged from<0.0005 ppm – 1.23 ppm; OctaBDE from 1.51 ppm – 513.65 ppm; DecaBDE from 6.43 pppm – 1402.6 ppm; HBCD from <0.01 – 7.71 ppm. Seven of the eight beauty items had OctaBDE above 10 ppm, therefore exceeding the POP regulation limit. One hairclip exceeded 1,000 ppm decaBDE, meaning it exceeded REACH regulatory limits. On explaining the presence of flame retardants in these products, the authors suggest that that "the composition and concentrations of BFRs in the samples shows the fact that the products were manufactured from recycled plastics obtained from electronic waste. In order to ensure non-flammability of the material, higher concentrations of the chemicals would have to be used".

Turner (2018b) examined 71 items of clothing, two of which contained PVC, with an XRF scanner for Br. As the focus of the study is on black plastics, items in this category include things such as: buttons; sunglasses; beads and necklaces;

bracelets and watch straps; protective clothing; shoes; hair bands; hair brushes; belts and wallets. Of the sample, 38 (54%) had Br detected within them. Br was detected at a range of 1.5 – 92,200 ppm, with mean and median of 3,850 and 53.9 ppm respectively. The evidence from this and other products tested in the paper lead the author to conclude that black polymers "are often sourced for new consumer goods from end of life WEEE, and as implicated more specifically for both old and new EEE plastic above".

Turner and Filella (2017a) collected 76 clothing and upholstery samples from Plymouth, UK and it was found that 18 of these contained Br pertaining to BFRs. They suggest that the ubiquity of low levels of Br across all the product categories in their study is a consequence of e-waste recycling, however this is a general conclusion of the paper and not specific to the clothing-upholstery category. They also highlight the role of flame retardant application on soft furnishings as being consistent with their findings of high Br and Sb concentrations.

Turner and Filella (2017b) analysed 78 clothing-accessories samples for Br concentrations. This included items such as raincoats, jewellery, rucksacks, shoes, spectacles etc. Of this sample, 22 (28%) had Br detected in them. Two of these had concentrations above 1,000 µg/g [1,000 ppm]; eight between 100-1,000 µg/g [100-1,000 ppm]; nine between 10-100 µg/g [10-100 ppm]. The two highest concentration items were necklace beads and plastic decorations on earrings. They state that the results “are consistent with the widespread recycling of electronic plastic waste”.

Wassenaar et al. (2017) conducted a literature review on a range of 368 substances and prioritised in accordance to presence and concentration as well as concern for human health. HCBD was found to be one of the substances of high concern. The authors do not necessarily suggest the chemical was present due to the recycling of textiles, but since 95% of textile waste in Netherlands is reused, they speculate that the chemicals present in textiles are likely to last throughout the garment lifetime and multiple owners, and could possibly be recycled into new products.

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3.2.3 Formaldehydes

Novick et al. (2013) studied 20 wrinkle-free clothing items (10 shirts and 10 trousers) bought online and manufactured mostly in Asia. Of the 20 samples, 3 had detectable formaldehyde levels and all of these were manufactured in China. One shirt contained 3,172 ppm, and two pairs of trousers contained 1,391 and 86 ppm respectively. The two highest results are 40 times greater than the international textiles regulations, which may be due to the wrinkle-free clothing undergoing more finishing. The authors also note that formaldehyde residues are often used for treating textiles, and that clothes bought online have less chance to off-gas compared to clothing bought in-store. There was no suggestion that the presence was contamination, rather being purposeful functional addition.

Piccinini et al. (2007) analysed 221 samples which were primarily clothing but also included some bed linen, taken from across EU member states. They were tested using a water extraction method and compared to European Ecolabel and Oeko-Tex standards (in absence of EU legislation on formaldehyde). 11% had formaldehyde levels above 30 ppm, which is above limit for Ecolabel voluntary scheme. 3% exceed the 75 ppm standard for adults used by Oeko-Tex standard 100. 11% of baby garments under 2 years showed formaldehyde release above 20 ppm, whereas by Japanese law and Oeko-Tex it should not be detectable. Two also exceeded Ecolabale 30 ppm limit. Shirts were the item with highest risk of exceeding 30 ppm, and 5 out of 10 ‘easy care’ shirts were above Ecolabel limit. There was no suggestion that the presence was contamination, rather being purposeful functional addition.

USGAO (2010) studied 180 items (165 clothing, 15 bed linen) bought from 10 national retailers, 2 military facilities and 1 store selling scout uniforms, from across the US. Of these, 10 items exceeded the limits for formaldehyde and ranged from 75.4 to 206.1 ppm (limit is zero formaldehyde for clothes < 3 years, and 75 ppm for 3+ years old). 9 items were adult items and 1 was a toddler item. Half of those exceeding limits were labelled as having fabric performance related to durable press, which indicates they have undergone additional treatment. There was no suggestion that the presence was contamination, rather being purposeful functional addition.

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3.2.4 Parabens

Li and Kannan (2018) analysed 74 tights samples from 6 countries in order to determine the concentration and profiles of 23 endocrine-disrupting chemicals through complete dissolution and ultrasonic extraction. The results detect much higher concentrations of the target chemicals samples collected from China, Japan, Korea, Portugal, Chile and the US. The median concentrations of parabens are up to 101x higher in tights samples purchased in China than other countries, "the high concentrations of bisphenols and parabens found in tights were linked to the high percentage of Spandex in the garment". The overall median estimated dermal exposure from all 23 analytes were 60, 175 and 348 pg/kg-bw/day for ankle, knee and full-length tights respectively, with bisphenols as the major share of exposure, then parabens and benzophenones. The authors made no comment on recycling.

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3.2.5 Perfluorinated Chemicals

Bečanová et al. (2016) analysed a total of 126 samples of new and used items for PFAAs (PFSAs and PFCAs) by HPLC-ESI-MS/MS in household textiles. The results show “the highest concentration of Σ_{15}PFAAs [sum of the 15 target PFAAs] was found in textile materials (77.61 μg/kg [0.08 ppm]), as expected, since specific PFAAs are known to be used for textile treatment during processing”. From the new textile materials, the highest concentration of PFAAs was present in the sample of stain resistant upholstery material produced in 2010 with a “predominant contribution of PFHpS (73.8 μg/kg [0.07 ppm]) at levels 23 times higher than PFOS (3.2 μg/kg [0.003 ppm])". The authors highlight the toxicity and possible impact to consumers and highlight the highest concentrations of PFASs to be found in construction and textile materials. No comment is made suggesting recycling played a role.

Guo et al. (2009) analysed 116 consumer products that were labelled as having fluorinated chemicals, or having properties common for articles treated with fluorinated chemicals, such as stain resistance. Of these, 26 samples related to consumer clothing and textiles. The results depicted that treated apparel contained 198 ng/g [0.198 ppm] TPFCA and in article membranes for apparel contained 124 ng/g [0.124 ppm] TPFCA. The authors concluded that within a home, carpets and textiles are classified as among the main sources of PFCAs. This also includes floor waxes and sealants / treating materials. The authors do not discuss recycling, suggesting rather purposeful addition.

Knepper et al. (2014) study analysed 16 outdoor jackets produced in Europe and Asia that were bought in Germany. Including 7 rain jackets, 1 softshell, 7 hard-shell, 1 working jacket. The results showed that PFASs were present in ranges of 0.03

µg/m^2 to 719 µg/m^2 in all jackets. Regulated PFOS detected in 5 jackets, with a range of 0.01 µg/m^2 to 0.05 µg/m^2, with PFOA in jackets concentration 0.02 ug to 4.59 ug / m^2. The authors conclude that "no correlation could be drawn with respect to the individual textile membranes, nor the price and quality of the jacket". One working jacket had single PFOA value 171 µg/m^2, almost 40x the next highest value. This suggests extreme water and oil repellence. The authors suggest this is driven by purposeful addition. To author's best knowledge, recycling processes for textiles made of or containing PFASs have never been successfully installed; going as far to say that with regards to textiles made of or containing PFAS "recycling is negligible”.

Liu et al. (2014) research continues the analysis in Guo et al. (2009) until 2011 purchasing like-for-like, or similar, replacements. The results are grouped as overall 95 samples from 35 products as a whole. The author highlights the presence of PFOA and PFOS in textiles with the highest concentration in nylon and cotton products, with a maximum level of 45.9 ng/g [0.046 ppm] and 81.3 ng/g [0.081 ppm] respectively. The trend over time shows PFCA in many products decreasing, PFOA still being detected in many products, a reduction of PFCAs both in short-chain and long-chain over study period and an increase in PFBS as alternative to PFOS in the samples. The results show strong evidence that TPFCAs have been “reduced in a majority of the products in recent years". The authors do not comment on recycling, suggesting rather purposeful addition.

Mikkelsen et al. (2015) mapped the Danish waste stream and tested 22 products for PFAS. Their study focused on products which had coatings, such as rainwear or snowsuits. They cite that such textile coating is the reason for 50% of global PFASs use. The authors found widespread occurrence of PFAS in rainwear, snowsuit and sleeping bags, with occasional examples in backpacks, soft shell jackets, baby carriers and similar items. PFAS was found above the detection limit in 15 samples, with concentrations ranging from 18 to 407 µg/m^2. The most detected PFAS were FTOHs and PFCAs - some 94% of the total PFAS in the samples. The authors highlight that PFAS risk depends on the route of exposure: it is completely absorbed after oral ingestion or inhalation, but is very difficult to absorb through dermal contact. They suggest “negligible exposure to PFASs” which “is not believed to cause health problems". The authors also consider possible destinations for waste. When garments are reused, they are deemed to not be significantly different from conditions by first use of garment, so chemicals could persist. PFAS containing clothes are often exported abroad, where they assume they are mainly disposed to landfill, which could lead to environmental release of the chemicals. They suggest that "surface-treated fabrics are not suitable” for recycling, and therefore do not believe there is much in the way of recycling such clothes.

RIVM and Ramboll (2019) conducted a mass flow analysis of PFOA within PTFE in clothing, textiles and workwear. The study concludes there are no exact numbers that quantify the amount of PFOA containing PTFE based textile waste or recycled quantities.

A study by Supreeyasunthorn et al. (2016) analysed 32 textile samples including clothing, indoor and outdoor textiles from Thailand to test for PFOS and PFOA by methanol extraction. The results showed the following average concentrations of chemicals: PFOS 0.18 µg/m^2 (0.02 to 0.61); PFOA 2.74 µg/m^2 (0.31 to 14.14). The PFOS average was below EU regulations. The average PFOA however, was above theoretical regulations (not regulated currently). The authors identified 68.75% of textile samples had PFOA above 1 µg/m^2 - suggesting it should be regulated. The highest PFOS was in blanket samples and the highest PFOA found in bags. The authors suggested that PFOA concentrations may be coming from various textile processes such as dyeing. PFOS and PFOA concentrations decreased with each subsequent wash, meaning it migrated from textiles to the environment. After 5 washes, 29.8% of PFOS concentration and 99% of PFOA concentration had been lost. The authors do not discuss an explicit role of recycling.

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3.2.6 Other Persistent Organic Pollutants

No datapoints were identified. Return to Heat Matrix.

3.2.7 Phthalates

Li et al. (2019) analysed 24 pieces of white infant cotton clothing bought from malls in China for phthalates after traditional laundering. The results showed cotton clothing absorbs phthalates more easily than other fabrics and that all target phthalates were found in all the tested infant cotton clothing samples. The authors concluded a 100% detection rate, meaning contamination of phthalates "in infant cotton clothing obtained from stores is ubiquitous, and traditional washing methods for infant cotton clothing in China cannot remove phthalates completely". During drying, clothing can absorb phthalates in indoor air, especially lower and medium molecular weight phthalates like DMP, DEP, DiBP and DBP. The median concentration of total phthalates was 4.15 µg/g [4.15 ppm], of which DEHP was the dominant phthalate. The estimated daily exposure values of 6 phthalates, ranging from 0.41 - 296 ng/kg-bw/day, of which DBP contributed the most, and skin surface contract was the most important. But compared with a study of house dust in Harbin, phthalates via dermal absorption for infants from cotton clothing were approximately 2 times lower than values from house air and dust. The results show the cumulative risk assessment median values are all far below 1, "based on the HI [hazard index] values, infant exposure to DiBP, DBP, and DEHP from cotton clothing are within the acceptable level". The authors do not discuss recycling as a source of contamination.

A Li et al. (2015) methodology paper tested rapid method for determination of 7 phthalate esters by solid phase extraction followed by GC-MS in printed textiles including baby waterproof fabrics and decorated waterproof tarpaulins. The results showed that baby waterproof fabric had DEHP at concentration of 33.4 g/kg [33,400 ppm], waterproof tarpaulin had DnOP at 0.16 g/kg [160 ppm] and printed textiles had DINP at 51.6 g/kg [51,600]. The concentrations identified were above the 0.1% [1,000 ppm] limitation of Oeko-Tex standard 100 and indicate that exposure may be harmful to health. However, the authors recognise that "there have been few previous reports for the determination of phthalate esters in textiles, especially in baby materials". This research did not discuss recycling.

Tang et al. (2020) analysed 67 samples of children’s clothing manufactured in 7 Asian countries, bought from various retail stores in Beijing, Seoul, London and New York. All clothes manufactured in China, South Korea, India, Indonesia, Cambodia, Bangladesh and Philippines were tested for 15 phthalates in the sampled clothing. These included DEP, DnBP, DiBP, Dimethylphenylpiperazinium (DMPP) and DEHP. The results showed DMP, DMEP, DEEP, BBP, DBEP, DnOP and Dioctyle phthalate (DNP) exhibited higher detection frequencies (>50%) with total concentrations of the total 15 chemicals being between 2.92-233 µg/g [2.92-233 ppm]. The authors highlighted that the six higher frequency chemicals contributed a median of 69.4% to the total concentrations - suggesting they were the dominant congeners distributed in textiles. The result highlight statistically significant differences in concentrations of DnBP, DMEP, BMPP, Dihexyl phthalate (DHXP), DnOP, DNP between countries.

India had highest median DnBP, DMEP and BMPP of 2.14-7.64, higher than China, South Korea and South-East Asia. However, the highest DnOP and DNP is in South-East Asia and China respectively, concluding that "the use of individual phthalates appears to vary widely by country". The authors compared findings to the maximum allowable dose levels in Californian legislation, determining reproductive risks from DnBP and DEHP from clothing by item type in range of 0.331 - 7.89 and 0.001 - 0.0076 respectively. The total DnBP and DEHP reproductive risk in 17.9% of samples exceeded acceptable levels but are identified as "low carcinogenic risk". The authors refer to recycling briefly, but the primary suggestion is of purposeful addition of phthalates. They conclude: “overall, we estimate that children's clothing is an important source of dermal exposure relative to other skin-contact products".

Wassenaar et al. (2017) reviewed the RIVM reports and additional data identifying 368 substances of potential concern, 54 of which are under Dutch ZZS classification. The most relevant phthalates for concern include: DCHP, DiBP dicyclohexyl phthalate, diisobutly phthalate and DEHP. The authors do not necessarily suggest the chemical was present due to the recycling of textiles, but since 95% of textile waste in Netherlands is reused, they speculate that the chemicals present in textiles are likely to last throughout the garments lifetime and multiple owners.

Xie et al. (2016) analysed mass content of plasticisers and phthalates in 6 children's backpacks and 7 toys to find out their mass transfer from product surfaces to cotton wipes. The study concluded DEHT the most common plasticiser in 4 backpacks. The authors discovered a strong correlation between average mass transfer of DEHT to wet wipes and to its average mass content in the product, "These results suggest that the mass transfer of plasticizers from products to clothing or human skin is strongly associated with their mass content". The authors did not comment further on recycling.

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3.2.8 Heavy metals

Filella et al. (2020) reviews other research on the presence of antimony in clothing textiles. The results show items of polyester clothing as one of the product groups in which antimony is found in most abundance. Antimony has been found in polyester-based products of any colour, at concentrations < 1000 mg/kg [<1,000 ppm] and in the absence of detectable Br as a catalytic residue. The paper highlights that Sb is both an additive and a possible contaminant from recycling of e-waste, particularly at lower concentrations.

Kolarik et al. (2019) examined 94 leather samples from 74 products for chromium VI and cobalt. The results showed chromium VI concentration below detection in 74/94 (79%) of the leather samples analysed. In 10 samples, the chromium VI content was higher than the limit of 3 mg/kg [3 ppm] dry matter with highs of 28 mg/kg [28 ppm], 16 mg/kg [16 ppm], 11 mg/kg [11 ppm] found in handbags. The concentration of total-chromium is high in most samples, however, there is no correlation between total-chromium and chromium VI in most samples. Cobalt was found in all product categories with the highest concentrations in purses, watch straps, handbags, bracelets, from <1 mg/kg to 153 mg/kg [<1 – 153 ppm]. The authors comment "it is estimated from these results that there are no risks for initiation of cobalt allergy from the use of the brands of ladies' boots and bracelets investigated here … further the risk for induction of symptoms when cobalt allergenics are wearing these goods is considered to be low". The authors mention that the 3 mg/kg [3 ppm] dry matter limit does not apply to recycled materials in terminal use in the Union before 1 May 2015 but does not speculate on if recycled content was the origin of these higher values.

Matoso (2012) paper analysed polyamide raw materials and textiles used in sports t shirts, as well as 11 samples of sportswear from 3 brands for heavy metals including Sb, As, Pb, Cd, Cr, Co, Cu, Ni and Hg. The results showed chromium in black fabric was the major inorganic contaminant found, some 2 orders of magnitude higher than any other element. In their black samples the chromium was found at values around 900 mg/kg [900 ppm], contrasting to in white t shirts at 2 mg/kg [2 ppm], and other elements like Ni around 2 -3 mg/kg [2-3 ppm] across all colours. Despite high concentration of Cr, the migration test for the Cr with synthetic sweat solutions showed chromium transfer of 0.3% maximum when using basic solution - this was lower than the limits values suggested by Oeko-Tex Standard 100. The authors do not discuss recycling.

Negev et al. (2018) analysed 87 parts of 22 pieces of children's jewellery bought in Israel, testing for trace metals. The results showed the tested jewellery had most trace metals including: Chromium detected in 16%, Copper 80%, Arsenic 10%, Selenium 6%, Cadmium 25%, Antimony 16%, Mercury 1%, Lead 39%, Barium 17%, Nickel 23%. 20% of cadmium exceeded limits from the ASTM F2923 standard for children’s jewellery (300 PPM). 15 parts had >10,000 ppm cadmium, 9 had >300,000 ppm cadmium (some 100x the US standard for migration tests), 23% lead exceeded ASTM limits. Twelve items were identified as having above 300 ppm lead, of which four items had about 1000 ppm. There is no discussion of recycling as the source of analytes. Nguyen (2016) analysed 120 samples of women's underwear bought in Houston, Texas. Inductive coupled plasma mass spectrometry was used to determine concentrations of trace elements from 63 cotton, 44 nylon and 13 polyester samples manufactured in 14 different countries. In general, the analysis found cotton to be rich in Al, Fe and Zn and Nylon contained high levels of Cr, Cu and Al. Polyester had the highest Ni and Fe in comparison to cotton or Nylon. Cotton had the highest relative concentration of heavy metals, followed by nylon, then polyesters. Generally, darker colours had higher levels of heavy metals than lighter colours. The results found that China, Egypt and India had highest concentrations of metals in all fabrics. Black coloured garments had high Fe, blue contained high Cu, brown contained high Fe and Cu, green contained high Cu and Fe, pink contained high Al, purple contained Al and Cu and red colour contained Cr, Zn and Al. The results showed chromium exceeded Oeko-Tex limits in 35% of samples, Pb and Ni exceeded Oeko-Tex in 14% and 5% respectively. The Chromium is mostly from Bangladesh, China and Sri Lanka, whereas Lead is mostly from Egypt. The authors do not explicitly discuss recycling, suggesting purposeful addition.

Rezic (2007) analysed 16 different textile samples from the Croatian textile industry to extract metals from materials with artificial acidic sweat solution according to Oeko-Tex standard for materials coming into direct contact with skin. This was determined by means of inductively coupled plasma-optical emission spectrometry. The results depicted Zn and Cd found in cotton and polyester, Cr detected in flax, silk, and polyester; Cu found in silk and polyester. The concentrations did not exceed permissible values according to different standards, "the textile materials investigated do not represent a health hazard to consumers". The authors do not discuss recycling.

A second Rezic study (2011) looked at both pure cellulose and textile materials including cotton, flax, hemp and wool for heavy metals presence though coupled plasma optical emission spectrometry after microwave digestion of samples. The results showed the following heavy metals in different textiles[3]: cotton: potassium (K) concentration was highest (1170.2 µg/g [1170 ppm]); then Magnesium (Mg) (397.3 µg/g [397 ppm]); then Ca (230 µg/g [230 ppm]); then Tin (Sn) (17.4 µg/g [17 ppm]); then Fe (14.4 µg/g [14 ppm]); then Zn (14.2 µg/g [14 ppm]); then Al (13.9 µg/g [14 ppm]); then Cr (4.2 µg/g [4 ppm]); then Ni (3.0 µg/g [3 ppm]); then Be (0.4 µg/g [0.4 ppm]). In Flax textiles notable levels of Ca and Mg were detected, in Hemp notable levels of Na and Ca and in Wool, notable levels of Ca. The authors do not discuss recycling, suggesting these were rather functional additives.

Rovira (2015) sampled 31 products bought in Spain, across 4 kinds of stores to analyse a variety of clothing articles, including branded/non-branded and coloured/not coloured, for heavy metals. The results showed the most notable levels were Cr in polyamide dark clothes: 605 mg/kg [605 ppm]; Sb in polyester clothes: 141 mg/kg [141 ppm] and Cu and in some green cotton fabrics: 280 mg/kg [280 ppm]. There were lower concentration of Al and Sr found in 'eco' clothes and no significant differences were found between branded and unbranded clothing. The risks identified are associated with dermal contact. The non-carcinogenic risks due to exposure to elements through skin-contact clothes were considered limit, as hazard quotients[4] fell below the safety limit (HQ < 1). For Sb, the non-carcinogenic risk above 10% of the safety limit for dermal contact (HQ >0.1). The authors do not discuss recycling as a possible route for any of the analytes entering clothing, suggesting purposeful addition.

Rovira et al. (2016) analysed 37 mixed types of clothing articles purchased in Spain for heavy metals. The results found notable high levels of zinc concentrations in zinc pyrithione labelled t shirts (186 - 5749 mg/kg [186-5749 ppm]). High levels of Sb in polyester fabrics and high levels of Cr in black polyamide fabrics. All samples fulfilled parameters of Oeko-Tex standards. However, 4 polyester samples exceeded extractable Sb limit of TOX-Proof standard (1.0 mg/kg [1 ppm]). All fabrics exclusively or partially polyester showed high levels of Sb. Sb was found in 100% of PE clothes (only one of which known to have recycled content) ranging from 57.7 to 152 mg/kg [57.7-152 ppm] with antimony levels in clothes of other materials ranging between 0.1 and 4.1 mg/kg [0.1=4.1 ppm]. For polyester clothes, mean hazard quotients (HQs) for Sb were 0.44, 0.40, 0.12 for adult males, adult females and children <1 year old respectively. One polyester t-shirt reached HQ value of 1.2 (it is unclear if this was the one with 50% recycled PE). One of the prominent routes for Sb exposure is identified from polyester socks, for other elements and samples, non-carcinogenic and carcinogenic risks were considered safe and acceptable. The authors do not discuss recycling.

A following study by Rovira et al. (2017) investigated 78 textile items bought in Spanish stores and online including 31 bedclothes, 22 pyjamas and 25 towels for heavy metals. The results depict As, Be, Cd, Scandium (Sc), Se, Samarium (Sm) and Thallium (Tl) concentrations are below respective LODs in all the samples, with Hg, Molybdenum and Vanadium only in 2-4 items. The highest mean concentrations were: Mg (142 mg/kg [142 ppm]); Cu (32.8 mg/kg [32.8 ppm]); Sb (26.9 mg/kg [26.9 ppm]); Al (14.7 mg/kg [14.7 ppm]); Fe (12.9 mg/kg [12.9 ppm]) and Ti (10.9 mg/kg

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[3] *Note that Table 5 claims that the results are presented in mg/g. However, this seems inconsistent with the results, as it would suggest that K, detected at 1170.2 mg/g made up more than 100% weight of cotton. Given other values in the paper are presented as µg/g (e.g. Table 4), we have assumed that this is the accurate metric.*

[4] *Hazard quotient is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. A HQ less than or equal to 1 indicates that adverse health effects are not considered likely to occur.*

[10.9 ppm]). The highest concentrations corresponding to Cu in a black (100% cotton) sample and Manganese in brown (50% lyocell-50% cotton) sample, 1065 and 889 mg/kg [1065 and 889 ppm] respectively. The results concluded high levels of Sb in polyester, Ti concentrations increased in synthetic fibre and high levels of Cr in polyamide black fibres. The maximum HQ for almost all trace elements was well below 0.01, with Sb being the only exception. The HQs for dermal exposure tp Sb due to use of bedclothes/pyjamas and towels were 0.4 and >1 respectively. The most relevant daily activity leading to dermal exposure was towel to-hand-to-mouth actions. The authors do not explicitly discuss recycling; however, it is recognised that polyester and synthetic fibres are often recycled.

Turner (2018b) examined 71 items of clothing and accessories, two of which contained PVC, with an XRF scanner for Br. As the focus of the study is on black plastics, items in this category include things such as: buttons; sunglasses; beads and necklaces; bracelets and watch straps; protective clothing; shoes; hair bands; hair brushes; belts and wallets. The sample was analysed both for frequency and concentration. In clothing and accessories, Cd was detected within 6/71 (8%) at concentrations spanning 77-35,500 ppm; Cr in 15/71 (21%) at concentrations 19.1-1,800 ppm; Hg in 4/71 (6%) at concentrations 4.8-43.4 ppm; Pb in 25/71 (35%) at concentrations 5.2-4670 ppm and Sb in 15/71 (21%) at concentrations 29.5-48,600 ppm. The author concludes that widespread detection of the elements, particularly Pb and coupling with Br in the samples suggest that the products include recycled WEEE plastic.

Turner and Filella. (2017a) analysed 76 samples of clothing-upholstery, testing for Sb concentrations. The results show Sb concentrations in 14/76 (18%) clothing-upholstery samples of which 8 (57%) were alongside detectable Br concentrations. The highest Sb encountered in combination with similar or higher corresponding concentration of Br and Chlorine (Cl) in were in the samples of futon cover and cushioning from a garden chair, dressing table stool, safety jacket, raincoat, sport shirts etc. The authors suggest the role of recycling in transfer of Sb from e-waste: "when electronic plastic waste is recycled, there is no consideration of the subsequent use and fate of Sb dissipated within the polymeric matrix".

Turner and Filella (2017b) analysed 78 clothing-accessories samples for Br concentrations. This included items such as raincoats, jewellery, rucksacks, shoes, spectacles etc. Sb was found in 14/78 (18%) of samples. In 5/14 (36%) Sb positive samples, Br was also detected. Pb was also found in 14/78 (18%) of samples, of which 4/14 (29%) were also Br-positive. The authors suggest that the presence of these chemicals and the association with Br is evidence of recycling of e-waste into new black plastic products.

Tuzen et al. (2008) analysed various textile samples from textile plants in Turkey for Cu, Cd, Zn, Mn, Fe and Ni by flame and/or graphite furnace atomic absorption spectrometry. The values the authors detected are as follows: Cu: 0.76 - 341 µg/g [0.76-341 ppm]; Cd: 0.1 - 0.25 µg/g [0.1-0.25 ppm]; Zn: 0.63 - 4.84 µg/g [0.63-4.84 ppm]; Mn: 1.02 - 2.50 µg/g [1.02-2.5 ppm]; Fe: 3.55 - 34.3 [3.55-34.3 ppm] µg/g; Ni: 1.20 - 4.69 µg/g [1.2-4.69 ppm]. This is generally higher than found in the literature. The copper and cadmium contents in the samples are higher than the limit values by Oeko-Tex. The authors do not suggest that recycling played a role, rather functional addition.

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3.2.9 Other

Assmuth et al. (2011) conducted a literature review looking at the life cycle stages of textiles from the manufactured fabric, including pre-treatment, colouring, use, waste and recycling. The analysis identified any chemicals harmful to the environment including Nonylphenol ethoxylate (NPEs), heavy metals, phthalates, PFCs, flame retardants and anti mould agents. The study concluded that most products containing hazardous chemicals are used in dyeing and printing, with estimation that auxiliary substances such as softeners and dyes can be assumed to stay in the product as residue through life (and recycling). The study also indicates that textiles could be a significant source of DEHP in Finland, with evidence of Nonylphenol ethoxylates used in surfactants in washing process of textiles, traces of NPEs in finished products and residue of dioxins and other persistent bioaccumulative toxic chlorinated substances. A number of hazardous substances used in dyes include heavy metals such as Cu, Ni, Pb, Hg, Cd, Cr, Zn and As. This study focuses on environmental impacts of textile production and treatment but not consumer safety risks final products. However, it is expected that hazardous additives like heavy metals that are added to textiles during production, these are likely to be present in the textile over its cycle, including recycling.

Li and Kannan (2018) analysed 74 tights samples from 6 countries in order to determine the concentration and profiles of 23 endocrine-disrupting chemicals through complete dissolution and ultrasonic extraction. The study also looked at benzophenones (BP1, 2, 3, 8 and 4-OH-BP and Triclocarban (TCC) and pentachlorophenol (PCP) concentration. The results show all 5 benzophenones are found in tights samples with benzophenone-3 (BP3) the most abundant, median 12 ng/g [0.012 ppm]. The overall estimated median dermal exposure from all 23 analytes were 60, 175 and 348 pg/kg-bw/day for ankle, knee and full-length tights respectively. Bisphenols were judged to contribute to exposure the most compared to parabens and benzophenones. There is no comment on recycling playing a role in chemical presence, suggesting their addition is as functional additives.

Wassenaar et al. (2017) conducted a literature review on a range of 368 substances, prioritised in accordance with presence and concentration as well as concern for human health. The analysis is based on the Swedish Chemical Agency report. It focuses on Dutch classification ZZS which has a strong overlap with the SVHC substances under REACH. From the Swedish Chemical Agency report, this paper identifies 368 substances of potential concern, 54 ZZS substances. They cite work which found 71 substances on the ZZS list in textiles. They suggest that of 2,400 textile-related substances identified using multiple sources, 10% pose a potential risk for human health and 5% present a potential risk to the environment. The authors do not necessarily suggest the chemical was present due to the recycling of textiles, but since 95% of textile waste in Netherlands is reused, they speculate that the chemicals present in textiles are likely to last throughout the garment lifetime and multiple owners.

Xue et al. (2017) analysed 77 textiles and infant clothing pieces for Benzophenones and novolac glycidyl ethers (NOGE) from a variety of production locations including Asia and Latin America. The study revealed the presence of BP3 in 70% samples, with a mean concentration of 11.3 ng/g [0.01 ppm]. There was no significant difference in BP3 concentrations between cotton or synthetic fibres. The authors do not comment on recycling.

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3.3 Cosmetics

3.3.1 Bisphenols

Li and Suh (2019) conducted a review looking at 342 articles that covered 202 unique chemicals, examining functional uses, product application, exposure routes, pathways, toxicity endpoints and combinations of chemicals. They found bisphenol A in the literature to be mainly related to the uses in polymers/monomers. The 3 product categories in which bisphenols were identified the most often include: food contact (32 reports), other (such as receipt paper, 8 reports) and personal care products (6 reports). As part of the review they make vague speculations referring to recycling, including the creation of chemical combinations “which might have completely different properties in retaining chemicals and different exposure to humans”. However, they do not explicitly link recycling to bisphenol’s presence in personal care products.

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3.3.2 Flame Retardants

No datapoints were identified. Return to Heat Matrix.

3.3.3 Formaldehydes

No datapoints were identified. Return to Heat Matrix.

3.3.4 Parabens

Eriksson et al. (2008) researched parabens in household products, cosmetics and the flow of parabens in Denmark and their possible accumulation. The research highlights cosmetic/personal care products are the most notable products for parabens. The suggestion is that this is present in the personal care product rather than the packaging. However, they do briefly mention that personal care products and packaging are not commonly recycled (or were not so at the time of publication) and are not commonly washed out, leaving behind residues and chemicals that can cause contamination. Some inferences can be made about possible persistence of residues were they to be recycled.

Melo and Queiroz (2010) presented a methodological paper demonstrating a test for parabens in cosmetics, identifying maximum value of 1.65 x 10^6 ng/g methyl paraben in body cream. There were no comments on recycling or any suggestion that it contributed to paraben presence.

Msagati et al. (2008) also presented a methodological paper for quantification of parabens identified skincare products as the category of cosmetics with highest paraben concentration. This research does not comment on recycling or suggest it contributed to paraben presence.

Wang et al. (2017) presented a methodological research paper on how to test for parabens in cosmetics bought in Hangzhou, China from Walmart. The results depicted parabens in cosmetics in order of mg/L. The author does not comment on recycling or suggest it had any role in paraben presence.

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3.3.5 Perfluorinated Chemicals

No datapoints were identified. Return to Heat Matrix.

3.3.6 Other Persistent Organic Pollutants

No datapoints were identified. Return to Heat Matrix.

3.3.7 Phthalates

Chen et al. (2005) looked at phthalates present in solid, cream and liquid cosmetics as a methodological demonstration. The results include phthalate esters DEP and DBP detected in body moisture gel and nail gloss samples between 1.2 and 6.9% [12,000 and 69,000 ppm] and concentrations of triphenylphosphate detected at levels of 1.68% [16,800 ppm] by weight in nail polish. The authors do not comment on recycling or suggest it had any role to play in phthalate presence.

Li and Suh (2019) produced a review paper looking at 342 articles that covered 202 unique chemicals, examining functional uses, product application, exposure routes, pathways, toxicity endpoints and combinations of chemicals. The research found 73 papers relating to phthalates, in all cases identified, the functional use of phthalates was as a plasticiser. It was most identified in personal care (39 reports) and cosmetics (30 reports). The review identifies 42 reports specifically about plasticisers in personal care products that have exposure pathways of direct contact with phthalates, Diethylhydroxylamine (DEHA) and DEHP. The paper demonstrates the published literature on health risks of chemicals in consumer products, largely focused on a handful of high-profile chemicals including phthalates, BPA, BPDE, lead and several combinations. The papers reviewed in this article were not necessarily about chemicals present in products which had been recycled, and they do not make specific claims that any phthalate presence was related to recycling. However, the authors do note that additives in products could persevere through recycling, which “could also lead to the occurrence of chemicals in recycled products, which might have completely different properties in retaining chemicals and different exposure patterns to human”. This comment was more general about all product categories and analytes they considered, rather than cosmetics and phthalates directly. They do not test the extent of recycling-based contamination nor its risks.

Llompart et al. (2013) studied personal care and cosmetic products for 18 plasticisers. The study discovered 25/30 target compounds found, with diethyl phthalate as the most frequent phthalate (concentrations 0.7 to 357 µg/g [0.7-357 ppm]). The authors do not comment on recycling.

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3.3.8 Heavy metals

Li and Suh (2019) conducted a review analysing 202 unique chemicals, examining functional uses, product applications, exposure routes, pathways, toxicity endpoints and combinations of chemicals. The authors identified 8 reports about Pb use as a colorant in cosmetics through which dermal contact was the exposure pathway. They do not suggest necessarily that lead in cosmetics was a result of recycling, but more generally do point out that recycling could lead to “occurrence of chemicals in recycled products which might have a completely different properties in retaining chemicals and different exposure patterns to humans”.

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3.3.9 Other

Capela et al. (2016) analysed 123 cosmetics and health care products for Organosiloxanes. The study detected volatile methylsiloxanes in almost all selected products. There is no comment on recycling.

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Llompart et al. (2013) studied personal care and cosmetic products for 12 musks. The study discovered 25/30 target compounds, including the most frequent musks, galxolide and tonalide. The authors do not comment on recycling.

Lu et al. (2011) researched 158 personal care products marketed in China for linear siloxanes. The results show siloxanes were detected in 88% of the samples, with a maximum concentration of 52.6×10^6 ng/g [52,600 ppm] in makeup products. There is no comment on recycling.

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3.4 Electrical appliances and equipment

3.4.1 Bisphenols

No datapoints were identified. Return to Heat Matrix.

3.4.2 Flame Retardants

Chen et al. (2010) sampled 32 electronics from Guangzhou City and 11 raw materials used for electronics from Foshan City. PBDEs were found in all television casings. In computer monitors, PBDE concentrations were generally low except from one sample. High concentrations of PBDEs were observed in computer components compared to casings, particularly decaBDE derived PBDEs. In all electronics, the PBDE concentrations were below the threshold limit of 1000 ppm required by RoHS and the WEEE directives, except one computer component with a total PBDE concentration of 1,607,010 ng/g [1607 ppm]. It was also noted that relatively high concentrations of PBDEs from discontinued penta and octaBDE mixtures were found in the recycled materials. It was therefore concluded that recycling old electronics and their reuse may be “a potential important pathway of these low brominated BDEs re-entering into the environment”.

Choi et al. (2009) analysed and tested plastic mouldings of TV for the presence of BFRs and their leaching characteristics. The results showed PBDE content about 3% of the total sample weight [30,000 ppm], of which DecaBDE the most abundant homologue. The authors performed some tests of BFR solubility in DHM solution, finding hydrophobic BFRs can leech out to great extent in presence of DHM (dissolved humic matter). There is no discussion related to recycling.

Drage et al. (2018) sampled 239 WEEE components from household waste centres in Ireland to construct an inventory of PBDEs and HBCDD associated with waste polymers. The authors identify WEEE as 13% of all Irish waste which exceeds POP-BFR limits based on their analysis of product streams and mass of waste. HBCDD was detected in 25/237 (11%) samples, with median concentration <0.0003 mg/kg [<0.0003 ppm]. One sample exceeded LPCL, and other samples from the same item had HBCDD. "This suggests that whilst a small proportion of HBCDD has been used to treat electronic items, it has not been widely used for this purpose”. However, the authors suggest contamination may occur through the use of recycled plastics: “This is consistent with the literature that only a minor proportion (<1%) of the globally produced HBCDD was used in the treatment of High impact polystyrene (HIPS) for electronic items". They identified PBDEs in 110/237 samples (46%), with median concentration <0.003 mg/kg [<0.003 ppm]. The LPCL was exceeded only in one sample, a CRT TV front panel. BDE-209 was found in 151/237 samples (64%), with median concentration of 0.43 mg/kg [0.43 ppm], exceeding theoretical LPCL in 8 samples.

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English et al. (2016) reviewed literature on BDE-209 in Australian TV housings, finding that its use is commonplace, but the average concentration is almost always less than 1% of total weight of polymer [10,000 ppm], but frequently greater than 0.1% [1000 ppm]. There were no trends in terms of the age or specific type of TV that were associated with higher or lower levels of BDE-209. The authors commented that concentrations are "greatest for components associated with heat production, indicating that it may be possible to recycle some plastics from small household appliances, if BDE-209 containing components could be identified and removed".

Evangelopoulos et al. (2019) studied Br content in Swedish modem wi-fi plastics and PCBs using scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS) No figures were given for content found, but the authors comment that "BFRs are present in most of the WEEE fractions worldwide and will continue to be present for the coming years".

Gallistl et al. (2018) studied the fat obtained by wipe tests on the inner surface of 21 baking ovens, which was then analysed for halogenated FRs as an indication of FR content in the material and how much was leaching out. Detection of halogenated FRs in residues from all 21 baking ovens analysed in the study confirmed the presence and release in every tested household. PBDEs were detected in 82% of the samples with widely ranging concentrations (6.9–246,000 ng/g fat [0.0069-246 ppm]). The authors concluded that PBDE sources were variable and originated most likely from external sources rather than the surfaces themselves.

Ionas et al. (2016) collected 28 back panels from electronic products including computer monitors (16), television sets (4), computer mice (4), keyboards (2) and others (2) and analysed for Br content as well as PBDEs and other FRs. Br was detected at levels of 0-2200 ppm. None of the traditional BFRs typically used in plastics, such as PBDEs, HBCDDs and TBBPA were detected so the source of the Br detected by XRF is likely non-traditional BFRs. Two samples contained BDP (Bisphenol A bis(Diphenyl Phosphate), a PFR used as a replacement for BDE-209). This suggests purposeful addition rather than contamination.

Jandric et al. (2020) studied Br concentrations in 882 Austrian WEEE plastic samples including power supply units, personal computers, keyboards, computer mice, electric toothbrushes and vacuum cleaners. The XRF analyses showed that 312 out of 882 components exceeded the LOD of 10 ppm and 42 components the RoHS limit – this corresponds to 35% and 5%, respectively, of all samples. In detail, 18% of the analysed power supply units, 10% computer casings, 4% of keyboards, and 1% of vacuum cleaners exceeded the RoHS limit, while none of the computer mice and toothbrush samples exceeded the limit value. Keyboards, vacuum cleaners, and electric toothbrushes showed the lowest Br contents. The authors suggest that "WEEE recyclers could exclude certain equipment or plastic components (e.g. power supplies or computer housings) directly on-site prior to WEEE recycling and shredding in order to produce high-quality recycled products and avoid cross contamination”.

Kajiwara et al. (2011) analysed Japanese TVs, laptops, computer boards, rice cookers and computer mice for flame retardants. Total PBDEs found in composite samples of computer boards ranged from 22,000-24,000 ng/g [22-24 ppm]. For rice cookers, the average total PBDE content ranged from 10,000-96,000 ng/g [10-96 ppm]. In computer mice the total PBDE content was 7300-7900 ng/g [7.3-7.9 ppm]. The total Br content found in various parts of a liquid crystal display (LCD) TV ranged from <18,000 – 140,000,000 ng/g [18-140,000 ppm] and for a laptop the total Br content ranged from <2000-95,000,000 ng/g [2-950,000 ppm]. All consumer products

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tested contained ‘traditional’ BFRs in amounts inadequate to impart flame retardancy, which the authors concluded that this implied the incorporation of recycled plastic materials.

Keeley et al. (2020) analysed over 2,000 WEEE items from waste and recycling centres around England and Wales, scanning for Br by XRF, then a selection also sent for GC-MS. The results looked at those items where POP-PBDE concentration exceeded the 1,000 mg/kg [1000 ppm] limit and classified that waste stream as being POPs waste, including: PCBs, Cables, CRT, flat-panel display (FPD) and small mixed WEEE. The only appliances that did not were fridges and large domestic appliances (white goods). In both cases, some plastic components were above the 1000 mg/kg [1000 ppm] limit, but as entire units they did not exceed the maximum concentration limit (MCL). With intentional pop-PBDEs as high as 20% weight of component [200,000 ppm], levels of legacy POPs from use of recycled plastics will likely be lower but can still exceed the MCL. All other studies they look at which assess PBDE concentrations in WEEE have shown these chemicals can be present in the plastics at concentrations above 1,000 mg/kg [1000 ppm] limit.

Keet et al. (2011) studied Br content to estimate the percentage weight of BDE in a number of electrical items from New Zealand. The samples ranged from 0.012% [120 ppm] in a toaster to 2.578% [25,780 ppm] in a TV. One TV back contained a Br level of 84,367 mg/kg Br [84,367 ppm]. Recycling was not explicitly discussed as a reason for analyte presence.

Kemmlein et al. (2003) sampled consumer products, including 5 electricals (computer, tv housing, pc housing, printed circuit boards (PCB) and housing) to look at emissions of brominated flame retardants. The main finding was that computers, with increased temperature (i.e. under operational conditions), had increased emission rates of organophosphates and PBDEs at 10-85 and 0.6-14.2 ng/unit/hour respectively. But in their model room, the organophosphate concentrations from PCB and polycarbonate (PC) (82 and 14 ng/m^3 respectively) were smaller than a possible limit, based on which "the investigated samples would be classified as harmless materials". The authors do not discuss recycling.

Kousaiti et al. (2020) analysed 36 plastic housings from a WEEE recycling company in Austria, including 9 microwave ovens, 7 irons, 16 vacuum cleaners and 4 DVD/CD players. The mean TBBPA concentrations found were: 1146 µg/kg [1.146 ppm] in DVD/CD players, 754 µg/kg [0.754 ppm] in vacuum cleaners, 677 µg/kg [0.677 ppm] in irons and 350 µg/kg [0.35 ppm] in microwave ovens. TBBPA concentration also depended on the main polymer group within the product type, with ABS having the highest mean concentration (1225 µg/kg [1.225 ppm]) and PC and PC blends with ABS not having detectable TBBPA levels. The risk of flame retardant contamination from goods such as these during recycling is noted to rely on how diligently the waste is filtered.

Lassen et al. (2014) summarised the risks associated with brominated flame retardants, the regulatory framework and a summary of information on environmental and health effects. The majority of WEEE exported from Denmark for processing is in the EU, but in some cases, there is dismantling in Denmark with disposal to WEEE incinerators. However, the authors highlight there is "no overview of the final destination of BFR-containing plastic parts after dismantling abroad". Similarly, they highlight that "some WEEE is illegally exported to countries outside the EU. The final disposal of BFR-containing parts is not known...no data on the actual recycling of BFR-containing waste in Denmark or the EU have been identified".

Li and Suh (2019) conducted a review paper analysing 202 unique chemicals, examining functional uses, product applications, exposure routes, pathways, toxicity endpoints and combinations of chemicals. The authors identified 31 reports about flame retardant electronics which have dust exposure through dermal absorption PBDEs, with 31 reports on about unintentional ingestion of dust and 28 reports about inhalation. They do not directly suggest FR presence in electronics was a result of recycling, but do note that the possibility of recycling leading to “occurrence of chemicals in recycled products which might have a completely different properties in retaining chemicals and different exposure patterns to humans”.

Li et al. (2020) collected 19 samples of e-waste and recycled plastic from two recycling facilities in China. PBDE concentration in e-waste housings ranged from 1.15 - 50.89 mg/kg [1.15-50.89 ppm], with an average value of 11.82 mg/kg [11.82 ppm]. Generally, PBDE content was higher in TVs than other e-waste, with the authors speculating that obsolete TVs are the major source of PBDEs entering into the recycled materials flow. High recycling rates in China means contamination could spread extensively and cumulatively. The paper states that "therefore, even though PBDEs have been banned, their release is still significant and can be expected to continue in the coming years, not only from electrical appliances but also from remanufactured PBDE-containing products.” It also highlights that “the recycling flow of PBDE-containing materials returning back to remanufactured products prolongs their lifetime, resulting in potential continued contamination and human-health risk."

Miller et al. (2016) sampled US electronics including 41 mobile phones, 23 holiday lights and 23 tech accessories for Br content. Nearly 100% of new mobile phones and tablets had greater than 100 ppm flame retardant, and more than half had a part with at least 10,000 ppm. Nearly 80% of holiday lights contained Br, most of which were above 10,000 ppm. This indicated purposeful use of flame retardants in electronic goods, which was expected.

Park et al. (2014) sampled television sets and refrigerators taken from two recycling centres in Korea for PBDE content. It was found that there was a significant change in PBDE concentration before and after 2005, driven by regulation. Average PBDE concentration in TV rear covers before 2000 was 145,027 mg/kg [145,027 ppm], whereas for TV rear covers after 2000 the average PBDE concentration was 14,079 mg/kg [14,079 ppm]. TV fronts generally had much lower average PBDE content than rear covers. Refrigerator samples had PBDE concentrations ranging from not detected to 445 mg/kg [445 ppm]. There was no discussion of recycling contaminants into new products but there was some discussion on safety in the context of atmospheric emissions from the recycling process.

Peeters et al. (2015) analysed a series of electronics after manual disassembly in order to investigate the types of plastics. This included looking at 252 FPD TVs, 60 CRT TVs, 45 FPD monitors and 101 CRT monitors. The results showed that for CRT TVs and monitors: octaBDE was used with ABS; decaBDE and HBCD used with HIPS; TBBPA used with ABS. The FPD TV and monitors use PFRs mainly. The transition from CRT to FPD technology and the implementation of legislation on fire-safe housings for TVs resulted in changes in the type of plastics and additives applied in electronic display housings. The plastic and FR types used for housings of the four electronic displays analysed strongly differ, whereas CRT TVs and monitors or FPD TVs and monitors "are often perceived as similar products and are consequently jointly treated at EoL". The authors forecasted share of FR plastics "is forecasted to further reduce from 8% to 1% in 2025". They highlight that only some of these BFR plastics are not allowed to be recycled in Europe, but recycling separation processes into different types of BFR is not technically possible. The study concludes that the decreasing numbers of CRT TVs and relatively small quantity of FPD monitor back covers in the forecast collection will lead to the complexity of plastic waste from housings of electronic displays to significantly increase. However, not possible to sort and recycle the FR plastics with high efficiency - FR plastics in FPD TVs have wide spread of density and "as a result, it will become increasingly difficult for recycling companies to achieve the material recovery rates put forward in the European WEEE directive".

Singh et al. (2020) collected 20 waste mobile phones from an e-waste recycling company in Shenzhen, China and analysed them for PBBs and PBDEs. PBBs, PBDEs and HBCDD were not detected except for two samples, which had an average concentration of 234.5 µg/kg [0.2345 ppm] for nonaBDE and decaBDE. The total Br content varied from 0-471 mg/kg [0-471 ppm] (average of 87.9 mg/kg [87.9 ppm]) and TBBPA had an average concentration of 214.3 µg/kg [0.2143 ppm]. The study found that cellular phones had higher average Br and TBBPA concentrations than smart phones, but all samples were below the RoHS Directive limits in China and Europe.

Takigami et al. (2008) took apart 5 waste Japanese TV sets and tested them for levels of PBDEs, TBBPA, PBDD/DFs, polychlorinated dibenzodioxins (PCDD/DFs), HCBDs and Cl-PCBs. Interior dust was also collected. Concentrations of PBDEs, TBBPAs and PBDFs were highest in the rear cabinets at 48,000 µg/g [48,000 ppm], 19,000 µg/g [19,000 ppm] and 9,600 µg/g [9,600 ppm] respectively. The total PBDD concentrations were detected highest in the circuit boards at a mean of 460 ng/g [0.46 ppm]. The respective ΣPBDE and ΣPBDF concentrations in the dust samples were 67–500 µg/g [67-500 ppm] (mean 300 µg/g [300 ppm]) and 180–650 ng/g [0.18-0.65 ppm] (mean 410 ng/g [0.41 ppm]). The study recommends that TV interior dust should be removed before separating components to reduce the environmental emissions and exposure to workers at TV recycling plants.

Turner (2018b) analysed 133 black UK EEE items, of which 88 (66%) contained Br. EEE had higher bromine content than other groups analysed, however this was expected due to its use as a flame retardant at approximately 3-5% by weight [30,000-50,000 ppm] required for flame retardancy. EEE in this study is divided into pre-RoHS and post-RoHS where possible. 4 out of 32 (13%) of pre-RoHS black EEE products were sufficiently flame retardant in bromination terms. Another 4 had high Cl content, so likely retardant from chlorination. In the remaining 22 "the presence of Br over a wide range of concentrations (4-4000 ppm) that are too low to provide retardancy, coupled with a co-association with Sb, raises possibilities about material recycling". Br and Sb had similar distribution in the post-RoHS samples, with 2 out of 90 with sufficient Br content for flame retardancy. Thirty-two contained no measurable Br but were probably flame retardant through other non-brominated compounds. For the remaining 56 samples, Br was detected in a wide range of concentrations (2-10,000 ppm) which were “too low for retardancy but that were often co-associated with Sb, consistent with the material recycling assertion".

Turner and Filella (2017a) study analysed 194 electronics from Plymouth testing for Br. The results show presence of Br in 75/194 (39%) electronic samples. The highest concentrations of Br encountered in white electronic casings (plug adaptor, telephone-modem connector, fans and thermostats) and consistent with the use of antimony oxides such as synergistic flame retardants. They suggest that the recycling of e-waste could lead to persistence of antimony in new plastic products.

Go to Heat Matrix

Turner & Filella (2017b) sampled 267 UK electronic items for Br content and had 113 (42%) Br-positive results with concentrations varying from 1.8-171,000 µg/g [1.8-171,000 ppm]. The highest concentration was amongst relatively small appliances, many of which dated to pre-2005, and was usually found in association with Sb. Concentrations over 100,000 µg/g [100,000 ppm] were found in the plastic casings of 7 items: 2 plugs, 2 chargers, a fan heater, DVD cover of workstation and a DSL filter. Only one of these items was manufactured post-WEEE directive, however. Amongst electronic goods, a decreasing Br concentration is accompanied by a distinctive shift in the colouration of plastic casing towards black. The authors state that "these observations, coupled with the presence of Br at concentrations below those required for flame-retardancy in a wider range of electronic and non-electronic items, are consistent with the widespread recycling of electronic plastic waste. That most Br-contaminated items were black suggests the current and recent demand for black plastics in particular is met, at least partially, through this route".

Vojta et al. (2017) sampled 19 electronics and electrical items from Czechia for PBDEs, HBCDDs and novel flame retardants (NFRs). The sampled items included a vacuum cleaner, coffee maker, keyboard, screen and printed wiring plastic parts. PentaBDE was found, as well as similar concentrations of octaBDEs. The presence of octaBDE in EEE is expected, as it is used for flame retarding thermoplastics like ABS resins. The authors noted that the presence of penta- and octaBDEs in recycled materials is more likely to be from the original materials due to the use of these substances being in decline since the early 2000s. There was some detection of BDE-209. BTBPE was detected at a maximum concentration of 317 µg/kg [0.317 ppm] which corresponds to the use of BTBPE as a replacement for octaBDE in ABS and other thermoplastics. HBCDD was detected in lower quantities in electronic goods than in floor coverings or textiles. BDE-209 and HBCD are more likely to be found in primary use, suggesting the presence of these does not originate from recycling contamination.

Yang et al. (2019) conducted a study whereby surface wipes of electronic devices were taken of the exterior surfaces that would be in contact with hands, including cell phones (n=31), home phones (11), tablets (32), laptops (36), desktops (14), televisions (68) and stereos (7) testing for TCEP, Tris(2,6-dimethoxyphenyl)phosphine (TDMPP), TDCPP, Triphenyl phosphate (TPHP), Ethylhexyl diphenyl phosphate (EHDPP), Tris(2-butoxyethyl) (TBOEP), Tris(2-ethylhexyl) phosphate (TEHP), IsodecylPP. Alongside the electronic devices, urine, air and dust were also analysed. The results showed the compounds found in >80% of electronic device wipes were generally TBOEP>TPHP>ΣTCPPs > TCEP > TDMPP > TDCPP > EHDPP. TEHP, IsodecylPP and ΣTCPPs were detected in 0-73% of wipes of handheld devices (cell phones, home phones, tablets and laptop computers). Wipe concentrations were generally highest in cell phones, followed by home phones, tablets, laptops and lowest in desktop computers, televisions and stereos. For all compounds, levels of OPEs were significantly higher in handheld devices over non-handheld devices. TBOEP was the most abundant OPE in handheld devices (Geometric Means (GM) 1800-7700 pg/cm^2), followed by TPHP (GM 5,602,950 pg/cm^2) and ΣTCPPs (GM 180-540 pg/cm^2). The order of abundance differed in non-handheld devices, with larger devices such as desktop computers, televisions and stereos having TCEP (GM 170-380 pg/cm^2) and ΣTCPPs (GM 180-540 pg/cm^2) as the dominant compound followed by TPHP (GM 50-320 pg/cm^2). OPEs in cell phone wipes were correlated with each other at $p < 0.05$, namely TCEP, ∑TCPPs, TDMPP, TDCPP, TPHP , EHDPP, TBOEP and isodecylPP. The paper also studies urine metabolite levels but does not draw conclusions about what this means for consumer safety. The authors suggest several reasons for the detection of multiple OPEs at low levels, including "the cases were made of recycled plastic containing flame retardants from previous use", noting the high number of different flame retardants present is not likely to have been to comply with flammability standards as the concentration of individual flame retardants is 6 orders of magnitude lower than that required to confer flame retardancy.

Return to Heat Matrix.

3.4.3 Formaldehydes

No datapoints were identified. Return to Heat Matrix.

3.4.4 Parabens

No datapoints were identified. Return to Heat Matrix.

3.4.5 Perfluorinated Chemicals

Bečanová et al. (2016) analysed a total of 126 samples of new and used items for PFAAs (PFSAs and PFCAs) by high-performance liquid chromatography/electrospray ionization tandem mass spectrometry (HPLC-ESI-MS/MS) in electrical appliances. They examined both household appliances and WEEE, finding concentrations of Σ15PFAA from <LOD - 11.7 µg.kg [<LOD-0.0117 ppm] and between 0.046 - 2.20 µg/kg [0.000046-0.0022 ppm] respectively in the two product groups. The authors highlight the toxicity and possible impact to consumers and although there is no direct mention of recycling as the source of contamination, the conclusion states "the concentrations of PFAAs in the majority of studied materials suggested that the presence of these compounds was not caused by the intentional addition of PFAAs or their precursors to the materials during the manufacturing, as the levels were typically low and product groups contained multiple assorted and unrelated PFAAs."

Giovanoulis et al. (2019) analysed dust in 20 preschools which were a part of a larger study of 100 preschools (2018 vs 2015) to compare change in ambient toxicity level of PFAs based on product substitution of old electrical equipment. These preschools had all followed the Swedish "chemical smart" guidance and removed old articles and materials with high risk of hazardous content. The study has not been able to allocate specific concentrations or causation to specific items. PFAs were not sampled in the 2015 readings and therefore were not directly compared to the 2018, post-intervention amounts. However, the 2018 concentrations were compared to other dust samples from dust studies in Sweden and other countries. The results showed that "perflourinated carboxylic and sulfonic levels in this study were similar or lower than the previous studies in Sweden and other countries". No comments are made about recycling, with the suggestion being that the age of the product is of more relevance.

Herzke et al. (2012) performed a spot check of 30 products in Norway and Sweden including 3 PCBs. All 3 were found to have very low PFAS levels and PFOs were found in trace amounts in all 3. The paper highlights that treating consumer products with PFAS tends to increase durability, offering a longer service life compared to similar, non-treated products. This will likely prolong emissions of PFAS to households and possible human or environmental exposure. It was not suggested that recycling contributed to the presence of analytes.

Return to Heat Matrix.

Go to Heat Matrix

3.4.6 Other Persistent Organic Pollutants

No datapoints were identified. Return to Heat Matrix.

3.4.7 Phthalates

No datapoints were identified. Return to Heat Matrix.

3.4.8 Heavy metals

Bodar et al. (2018) looked at waste from CRT televisions and other electrical appliances (tv monitors, computers etc) and the Pb content specifically. The authors looked at the presence of recycled granulate that is applied in concrete, concluding "while (theoretically) safe during use, there is a problem when this concrete is turned into waste", thus making concrete waste hazardous. "As a consequence, when CRT glass is re-used in concrete cements, up to three times larger volume of hazardous waste will be created in the future, with no current recovery operations available". Therefore, the study summarises that concrete waste with CRT aggregates must be processed separately from other concrete waste.

Filella et al. (2020) reviewed research on presence of antimony in electrical appliances and equipment. The results show concentrations above 5000 mg/kg [5000 ppm] in both old and new electrical equipment as a synergist, usually in the presence of Br at similar/greater concentrations. In PVC electrical, Sb concentrations encountered of >5000 mg/kg [>5000 ppm] but without detectable Br, where Cl as component of polymer is acting as flame retardant. They suggest that recycling of e-waste plastics can lead to presence of antimony in other products.

Keeley et al. (2020) analysed over 2,000 WEEE items from waste and recycling centres around England and Wales, scanning for Br by XRF, then a selection also sent for GC-MS to assess levels of antimony. The results showed the following appliances had antimony levels above the limit: PCBs, cables, CRTs, FPDs, fridges, small mixed WEEE as collection stream, notably Cats 1 – 7, dual use office equipment (i.e. home / office equipment) and large domestic appliances (white goods etc.). If not treated as hazardous waste, there may be a risk of recycling-based contamination.

Singh et al. (2020) collected 20 waste mobile phones from an e-waste recycling company in Shenzhen, China and analysed them for heavy metals after manual separation. The mean and range of the results are:

- 2207.7 µg/kg [2.2 ppm] (503.9–11569.9 µg/kg [0.5-11.57 ppm]) for Pb;
- 91.6 µg/kg [0.09 ppm] (8.8–464.4 µg/kg [0.008-0.46 ppm]) for Cd;
- 13.7 µg/kg [0.01] (1.6–58.9 µg/kg [0.0016-0.06 ppm]) for Be;
- 7203.3 µg/kg [7.2 ppm] (117–69813 µg/kg [0.117-69.81ppm]) for Sb;
- 471.3 µg/kg [0.47ppm] (143.4–2351.3 µg/kg [0.14-2.35 ppm]) for As;
- 1.5 mg/kg [0.0015 ppm] (2.1–12.5 mg/kg [0.0021-0.0125]) for Hg; and
- 523.7 mg/kg [0.5237] (27.1–3859 mg/kg [0.027-3.859 ppm]) for Cr.

The authors discuss the potential toxicity of each heavy metal but conclude overall that the toxic substances found are below the limit values of substances regulated in the RoHS Directive in China and Europe.

Turner (2018b) analysed 133 black plastic EEE items from the UK and found that 51 of them (38%) contained Sb with concentrations spanning 3 orders of magnitude. Cd, Cr, Hg and Pb were also measured for the samples, with positive identification in 8 (6%), 20 (15%), 1 (1%) and 31 (23%) of the samples respectively. The paper suggests that presence of such metals in non-PVC plastics implies that such products may have been manufactured from mixed recyclate. Cd and Pb are always associated with Cl in EEE samples, suggesting traces of PVC may have been recycled into new products due to imperfect sorting of WEEE materials.

Turner and Filella (2017a) analysed 750 samples and analysed 194 samples of electronics in Plymouth, testing for Sb concentrations. The results show Sb presence in 47/194 (24%) samples, of these 47, 34 (72%) also detected alongside Br. The highest concentrations encountered in white electronic casings and consistent with the use of antimony oxides as synergistic flame retardants. The authors consider the possibility of Sb transfer through recycling, "when electronic plastic waste is recycled, there is no consideration of the subsequent use and fate of Sb dissipated within the polymeric matrix".

Van Oyen et al. (2015) analysed heavy metal content in ex-electronic ABS. Br was found at 1985 mg/kg [1985 ppm], Cl at 357 mg/kg [357 ppm], Sb at 1356 mg/kg [1356 ppm], Ba at 209 mg/kg [209 ppm], S at 660 mg/kg [660 ppm] (120 mg/kg [120 ppm] for virgin ABS), and Cd at 257 mg/kg [257 ppm]. The authors conclude that this ABS material would not be suitable for physical/thermal recycling due to metal content.

Wäger et al. (2012) also studied heavy metal content in their samples from European WEEE recyclers. Heavy metals were found in the following concentrations: Pb 61.9-7,800 mg/kg, Ca 2.35-159 mg/kg, Cr 20.3-1290 mg/kg and Hg 0.01-5.21 mg/kg (Wäger et al., 2012 SI Table S3). Small household appliances contained high average concentrations of cadmium. ICT equipment and consumer equipment both contained high average levels of lead. Flat screen monitors had the lowest number and average concentration of analytes, and CRT monitors and TVs had the highest. The authors conclude that no mixed plastics fraction from WEEE is completely free from substances regulated by the RoHS Directive as all investigated mixed plastic fractions contained at least one regulated substance in measurable amounts.

Return to Heat Matrix.

3.4.9 Other

No datapoints were identified. Return to Heat Matrix.

3.5 Toys

3.5.1 Bisphenols

Negev et al. (2018) analysed 26 parts of 14 soft non-PVC toys bought in Israel for heavy metals. The results showed BPA was found in 22% of samples, and 17% of test results exceeded the EU standard. Of those above LOD, mean ppm was 1.03 (EU standard is 0.1). Highest BPA level 9.9 ppm in PVC bath toy from low-cost online retailer. Two diaper changing mats were found to have a notably high concentration, 2.6 ppm and 1.32 ppm. All other items above EU standard had concentrations below 0.5 ppm, still 4x higher than limit. The authors did not comment on recycling or suggest it had a role in the analyte presence.

Return to Heat Matrix.

3.5.2 Formaldehydes

No datapoints were identified. Return to Heat Matrix.

3.5.3 Flame Retardants

Chen et al. (2009) represents an important starting point for research into toys and FRs and is regularly cited across the literature. In this study, 69 toy samples were collected from Guangzhou market. Guangdong province is the site of about 70% of China's toy manufacturing, and China accounts for some 70% of the world's toys, meaning toys manufactured in this area account for approximately 50% of the globe's toys. They were tested for BFRs including PBDEs, DBDPE, BTBPE and PBBs. All hard plastic toys had PBDEs detected within them. The concentration of these chemicals was also highest in hard plastic toys, with average concentrations of 53,000 ng/g [53 ppm]; 5,540 ng/g [5.54 ppm]; 101 ng/g [0.101 ppm] and 28 ng/g [0.028 ppm] for PBDEs, DBDPE, BTBPE and PBBs respectively. They found PBDEs in all foam toys, but at lower concentrations (average 1,012 ng/g [1.012 ppm]). All the stuffed toy samples had PBDEs, with DBDPE (Decabromodiphenyl ethane) detected in half of them. In rubber / soft plastic toys, BFR detection was very low. The authors also calculated risk associated by modelling inhalation, mouthing, dermal contact and oral ingestion. They found the daily total PBDE exposures associated with toys to range from 82.6 - 8992 pg/kg bw-day. Toys constitute a small proportion of daily indoor-associated PBDE inhalation. Mouthing was identified as a possibly harmful avenue, particularly mouthing hard plastic toys by infants and toddlers due to their low body weight. Overall, however, the authors indicate that BFR exposure via toys is likely to constitute a small proportion of their daily BFR exposure, with a HQ for noncancer risk evaluation far below a one value. The study mentions in passing the possibility of recycling as the source of BFRs. In particular, this is due to the presence of PBBs, which was unexpected: it has been banned in the US since the 1970s and was likely never produced in China. For the authors, "a plausible explanation is that some toys were manufactured using recycled plastic materials that contained PBBs".

DiGangi et al. (2017) screened consumer products bought from 26 countries using an XRF for Br, before further analysing positive samples by GC-MS for particular flame retardants. It is unclear what the size of the original sample is and therefore the rate of Br-positive tests, however of 95 Rubik's-style cubes and 16 other items (toys, cup, hair clip etc.) which were Br positive, some 90% contained octBDE at concentrations from 1 – 1174 ppm, one sample exceeded 1,000 ppm. Some 91% Br-positive samples contained decaBDE at concentrations from 1-672 ppm, HBCD was identified in 43% of the Br-positive sample at concentrations ranging 1 - 1586 ppm. These results "indicate that toxic flame retardant chemicals found in -e-waste are widely present in children's toys made of recycled plastic". The authors use the study to argue that strict LPCLs for POPs contained in e-waste and other POPs should be applied, as the current Stockholm Convention recycling exemption is eroding "the credibility of recycling".

English et al. (2016) refer to an unpublished study of toys on the Australian market. 109 toys were tested for Br, which was typically detected in very low levels (<0.1% by weight [<1000 ppm]). As the reference was unpublished, it was unable to get more information than this. They also say that in the same study, two toys were tested in some detail. Neither had BDE-209, which was the focus analyte, but one 'slot car race track' had TBBPA contributing 14.4% of the weight [144,000 ppm] of plastic used. They do not discuss the role of recycling in any of these samples.

Fatunsin et al. (2020) looked at 23 samples from 20 toys purchased, mainly second hand, in the UK, all previously shown to have BFR in them. These were analysed in more detail: PBDEs were found in all samples, particularly BDE-209, with a maximum concentration of 2500 mg/kg [2500 ppm]. HBCDD was detected in 14/23 (61%) of samples, at concentrations above EU legal limits in four of those. TBBPA was detected in 11/23 (48%), at a maximum concentration of 3100 mg/kg [3100 ppm]. Novel BFRs were found at very low concentrations. Overall, they found concentrations and patterns which was consistent with other studies such as those referenced in this review. Of the eight samples which exceeded current or impeding limit values for restricted BFRs, the items were second hand and manufactured before 2016, which the authors suggest points to possibly successful measures to eliminate damaging substances. This was complemented by a calculation of risk. The authors are critical of Chen et al. (2009) and Ionas et al. (2014) for using the same exposure assessment algorithms, both relying on emission factors from TV sets which may not be appropriate for toys. They contribute to the safety literature by evaluating exposure to BFRs measured in plastic children's toys using the Toy Safety Directive's assumption of 8 mg/day oral ingestion, focusing on infants between 3 and 18 months old. They calculate that "accidental ingestion of plastic from toys is orders of magnitude greater" as an exposure pathway than dermal exposure and "can make a very substantial contribution to overall exposure of young children" to BFRs. In a 'typical' scenario, when ingesting plastic at the mean concentration in the study, ingestion contributes 31.8% of overall exposure to SPBDEs and 58% overall exposure to SHBCDD. More reassuringly, when comparing this to reference doses, the exposures arising from toys alone or in combined pathways are "well below" respective values. It is only in the case of BDE-99 that typical exposure is close to the Netherlands' health-based limit, and this limit is exceeded in the maximum exposure scenario. The authors conclude that the results "reinforce existing evidence that the recycling of BFR-treated electronic plastics has led to the unintentional BFR contamination of articles not required to be flame-retarded", but this is speculation based on the correlation of certain chemicals and being at levels below those used for flame retardancy purposes.

Ionas et al. (2014) looked at 106 toy samples in Belgium from a mixture of sources: flea markets; donated; bought from shops. They found an overall low concentration of flame retardants. Phosphate flame retardants were detected in up to 50% of samples. 99% of total PBDE amounts detected was accounted by BDE209, with foam and textile toys the most abundant BDE209 sources. The highest BDE209 was in a toy containing foam inner core and textile cover, but this remained below the REACH threshold. In all cases, the flame retardant content was insufficient for imparting flame retardancy. Most of the analysed toys were made in China, but a number were unspecified. They found China-manufactured toys to have typically higher level of all analytes, apart from TDCPP. They also compare concentrations over time: most analyte levels were lower in toys made after 2007, with BDE-209, -153 and –99 having levels 2-10x lower after 2007. The authors offer some discussion of the risk and transmission pathways of toys, using the same assumptions as Chen et al. (2009), but mainly focus on the context of the REACH regulations. Overall, they find low concentrations of flame retardants and low exposure potential for children using the toys, below REACH regulations. They conclude that the flame retardant presence is insufficient to impart flame retardancy. These low levels "indicate that this contamination may arise during the recycling process of raw materials used to manufacture toys".

Keet et al. (2011) combined literature review, industry engagement and XRF scanning of over 800 parts across seven retail stores in New Zealand. They estimated from their research the percentage BDE present in imported consumer goods: for toys, they estimated 0.007% [70 ppm]. Their comparison of XRF Br detection and laboratory analysis suggested that approximately half of the Br value obtained by the XRF was detected as BDEs in the lab analysis, which they round to 0.003% [30 ppm]. They make no suggestion that recycling has contributed to the BDE content.

Go to Heat Matrix

Leslie et al. (2016) considered eight plastic toys made from recycled parts sourced in the Netherlands. A quarter of these samples contained POP-BDEs up to a concentration of 44 µg/g [44 ppm] and BDE209 up to 800 µg/g [800 ppm], as well as TBBPA and other flame retardants. Though sourced in the Netherlands, the recycled products were produced abroad, suggesting BDEs exported in plastics "are returned in the new products made from them". This study differs from some others cited here in that the toys they analyse are described with more certainty as being made from recycled plastic. It is not clear how this is known. Their results lead them to conclude that "a substantial percentage of toxic BDEs in waste plastic still find their way into new products made from recyclates".

Miller et al. (2016) tested 87 toys on the US market. Just under 40% of their sample had Br detected at significant levels, but most of these were under 100 ppm. Toys were therefore considered of relatively low concern when compared to both the detection frequency and occurrence of bromine in other product categories (Miller et al., 2016, fig. 1).

Negev et al. (2018) analysed 26 parts of 14 soft non-PVC toys bought in Israel for heavy metals. The toys and other childcare products analysed are not disaggregated. The authors screened items for bromine, finding Br in 36% of samples, at a mean of 5.01 ppm. 28 samples were selected for further analysis. All flame retardant analyses were negative. The possible reasons the authors outline for the negative tests include: they did not test for DecaBDE; the type of tests, size of sample or LOD insufficient; and manufacturers not adding FR to products without FR requirements as it would add cost, so FRs would not be expected. They do not discuss recycling.

Pettersson et al. (2018) analysed items used in preschools in Stockholm, Sweden. FRs were tested in a sample of nine (six toys, five 'interior items'). No BFRs were detected in any of the samples, but OFRs were found in four toys and all five 'interior items'. In those samples where OFRs were detected, it was common for multiple substances in the group to be detected. They found all new products to be within relevant legal limits for chemical content. They do not discuss the role of recycling in product contamination. They attribute the presence of toxic chemicals to legislation at the time of production, by showing how introduced regulation – including municipality-approved product procurement as part of Stockholm's 'Chemical Smart Schools'[5] – has successfully reduced the detection of target substances.

Straková et al. (2017) analysed Rubik's-style cubes and other plastic toys for Br, before further analysing Br-positive samples for HBCD in a laboratory. It is unclear how many were sampled in total, but the sample of Br-positive items further tested was 88 Rubik's-style cubes and 16 additional samples from 24 countries (note: this sample overlaps with the sample reported in Straková & Petrlík (2017)). Of these, 43% contained HBCD at concentrations ranging from 1 – 1,586 ppm. Seven items (7%) had HBCD above 100 PPM, and two exceeded 1,000 ppm. They cite this as evidence of the recycling of e-waste plastic into toys.

Straková et al. (2018) sampled 50 toys as part of a larger sample of 430 plastic items bought across European countries (both EU and non-EU), which were screened by XRF analyser for Br content. Across toys, the ΣPBDEs ranged from <LOD – 3,318 ppm, with mean and median of 421 and 166 ppm respectively. The ΣBFRs ranged from 1 – 1,211 ppm. They state that their findings demonstrate that "hazardous e-

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[5] *https://leverantor.stockholm/fristaende-forskola-skola/forskola-pedagogisk-omsorg/kemikaliesmart-forskola/*

waste is finding its way across state boundaries via recycling workshops back into recycled products”.

Straková & Petrlík (2017) analysed by XRF the black parts of 47 toy and beauty items. Of these, 15 had significant Br levels and were then further analysed for levels of specific PBDEs and HBCD. Seven toys were subject to further analysis due to their Br content: two Transformer figurines, a car, a shoe toy, two Rubik’s cube and one cube with a depiction of a mole. OctaBDE was found between 3.94 – 380.15 ppm; DecaBDE between 7.03 – 2234.12 ppm; HBCD between <0.01 – 91.07 ppm. Four of the seven toys had OctaBDE above 10 ppm, therefore exceeding the POP regulation limit. One toy (the cube with a depiction of a small mole) exceeded 1,000 ppm DecaBDE, meaning it exceeded REACH regulatory limits. On explaining the presence of flame retardants in these products, the authors suggest that that "the composition and concentrations of BFRs in the samples shows the fact that the products were manufactured from recycled plastics obtained from electronic waste. In order to ensure non-flammability of the material, higher concentrations of the chemicals would have to be used".

Turner (2018a) study sourced approximately 200 second-hand plastic toys and scanned by XRF for hazardous elements, both Br and heavy metals. Frequent occurrence of Br at maximum concentrations about 16000 µg/g [1600 ppm], with the biggest safety concern Br: detected in 48 samples, 5 exceeded migration limit (1000 µg/g [1000 ppm]). The results showed mean 1050 µg/g [1050 ppm], median 32.1 µg/g [32 ppm], max 15900 [15900 ppm]. Turner concludes that ""the widespread detection of these elements, and in particular Pb, across a broader range of materials, coupled with the extensive occurrence of Br among the samples tested that require no flame retardancy (and at concentrations insufficient to provide retardancy), calls for an alternative explanation". This leads to the conclusion that “polymers of this colour are often sourced for new consumer goods from end of life WEEE”.

In Turner (2018b), 86 ‘toys and hobbies’ items were sourced in the UK. 49 of these (57%) had Br detected in them. All of the items were black plastic. The author highlights that countries such as India, Pakistan, Nigeria and China import significant quantities of WEEE from Europe, North America and Japan, leading to “stockpiles that include older WEEE and restricted BFRs [that] may be processed by inexperienced operatives without suitable screening technology at informal or unregulated facilities”, which then could be returning in new products.

Turner and Filella (2017a) analysed 162 samples of toys from Plymouth testing for Br concentrations. The results show Br detected in 14/162 (9%) toy-hobby samples. Br was often detected in the presence of Sb and Pb. They speculate that recycling was the origin of this Br: “that most Br-contaminated items were black suggests the current and recent demand for black plastics in particular is met, at least partially, through [recycling of e-waste]”.

Turner and Filella (2017b) tested 291 samples of ‘leisure’ products from the UK for Br, as a surrogate for BFR content. 45 (15%) of the samples were Br-positive results. A child’s puzzle from this category was amongst the highest levels detected (more than 10,000 ng/g [10,000 ppm], or 1% weight), but the average concentration of Br in the ‘leisure’ category was just 75 µg/g [75 ppm]. Across all product categories considered in the paper, most Br-contaminated products were black in colour. They summarise their findings across all product categories, including toys or ‘leisure’, as being “consistent with the widespread recycling of electronic plastic waste”. These conclusions are driven by the low Br content, below functional levels, and most Br-contaminated items being black, suggesting demand for black plastics is met through recycling, likely related to the relative difficulty of associating other black plastics and limited availability of recycled black plastic “but a desire and demand for the production and use of black-coloured items”.

Return to Heat Matrix.

3.5.4 Formaldehydes

No datapoints were identified. Return to Heat Matrix.

3.5.5 Parabens

Eriksson et al. (2008) reviewed evidence of parabens in household products and the flow of parabens in Denmark and their possible accumulation. The research identified one study which tested 18 slimy toys and identified the presence of parabens methylparaben and propylparaben in 17% of them. Included within the ‘toy’ category, artificial blood and finger paint samples had MP as a binding agent, and finger paint samples (n=19) had methylparaben, propylparaben, butylparaben and ethylparaben detected in fewer than half of them. The authors do not comment on recycling or suggest it had any role in the presence of the analyte.

Return to Heat Matrix.

3.5.6 Perfluorinated Chemicals

No datapoints were identified. Return to Heat Matrix.

3.5.7 Other Persistent Organic Pollutants

Petrlík et al. (2018) provides evidence of ‘dioxin-like’ activity in toys. Dioxins are considered POPs. However, the authors speculate that the source of the ‘dioxin-like activity’ is due to e-waste treated with DecaBDE, a flame retardant, so information from this study may also be relevant as evidence for flame retardants. They studied nine samples, eight of which were toys (and one hairclip) all made from black recycled plastic. All nine samples had previously been used in studies published by the same organisations (Arnika and the International Pollutants Elimination Network [IPEN]) and had previously been shown to have PBDE higher than 500 ppm and DecaBDE about 250 ppm. It is therefore a pre-screened sample for toxic chemicals. The samples were taken from across the world: Nigeria; India; Argentina; Czechia; France; Germany; Portugal. They found levels of 17 toxic PBDD/F congeners ranging from 5-600 – 386,000 pg/g [0.0005-6 – 0.386 ppm]. They document that some of these levels were higher than PBDD/F levels measured in waste incineration bottom ash from Taiwan. The pattern of PBDD/Fs congeners in samples resembled the pattern found as impurities in commercial DecaBDE mixture, the authors therefore conclude it likely that “the PBDD/Fs observed in consumer products in this study are due to the impurities in the original e-waste plastic treated with DecaBDE. This indicates that allowing the recycling of plastics containing DecaBDE also allows significant amounts of PBDD/Fs to be recycled into new products as well”.

Pettersson et al. (2018) analysed items used in preschools in Stockholm, Sweden. Eleven new toys and eight new creative materials and 52 old plastic toys were analysed. They were tested for chlorinated paraffins. Of new items, just one item (magnetic tape for arts and crafts) contained 0.12% SCCP [1,200 ppm], putting it just above the REACH limit. In old items, 3/52 items had chlorinated paraffins. Detected SCCP at levels between <0.1%-0.7% [<1,000 – 7,000 ppm] and MCCP between <0.1%-2.9% [<1,000 – 29,000]. They do not discuss the role of recycling in product contamination. They attribute the presence of toxic chemicals to legislation at the time of production, by showing how introduced regulation – including municipality-approved product procurement as part of Stockholm's 'Chemical Smart Schools'[6] – has successfully reduced the detection of target substances.

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3.5.8 Phthalates

Ashworth et al. (2018) analysed the concentration of 7 phthalates in 49 children's toys purchased in Christchurch, New Zealand, where there is not regulatory control of maximum allowable phthalate concentration in toys. The results showed that out of the 49 toys, 65% contained at least one phthalate at concentration of >0.1% by mass [1000 ppm]; 35% contained multiple phthalates at individual concentrations of >0.1% [1000 ppm]. From these finding, the risk assessment calculations indicate that using realistic exposure scenarios, worst-case combined exposure to phthalates is associated with developmental toxicity exceeding HQ of 1, so may cause adverse developmental effects. But the HI for hepatotoxic phthalates fell below 1, so in isolation it would not be considered to represent a risk of harm. The authors conclude that "these exposures represent only one source amongst a host of other, largely better recognized and significant exposure sources". There is no suggestion that recycling was a cause for analyte presence.

Ionas et al. (2014) sampled 106 toys in Belgium from a range of first- and second-hand sources. The phthalate esters DEHP, DBP and BBP were detected in 98%, 94% and 68% of the samples, respectively. DnOP was found only in one sample. DEHP was not in foam and textile toys, but was in all hard and soft plastic toys. Five of these samples had more than 0.1% [1000 ppm] phthalate content, of which only one was produced after 2007. In most cases, the phthalate content was below what would be required to improve the properties of the material, suggesting that "recycled materials are an important source of these additives in toys". The authors suggest that "they have not been added with a specific purpose to the materials, but instead they are originating from the use of recycled plastics or cross-contamination during the manufacturing process of raw materials used".

Negev et al. (2018) analysed 26 parts of 14 soft non-PVC toys purchased in Israel for phthalates. The results concluded all of the non-PVC toys tested complied with EU phthalate standard, however, previous studies have detected phthalates predominantly in PVC toys. The authors did not comment on recycling.

Oteef and Elhassan (2020) analysed 27 products from the Saudi Arabian street market for regulated phthalates. Of these, 11 (41%) were made of PVC. The 16 non-PVC items were all compliant with regulations. Amongst the 11 PVC items, five (45%) were noncompliant with regulations. DEHP was detected in all 11 PVC products with maximum values of 32.2% weight [322,000 ppm]. In 36% of the PVC products, DEHP levels exceeded regulatory levels. DBP and DINP were also detected in PVC products with upper detection rates of 0.275% [2750 ppm] and 14.2% weight [142,000] respectively. They also found non-regulated plasticisers such as DINCH (1,2-Cyclohexane dicarboxylic acid diisononyl ester) and ATBC (Acetyltributylcitrate) in the products. There was no suggestion that recycling was the cause of analyte content. They identify that PVC products were a common source of childhood exposure to phthalates, and their results suggest "low-cost children's toys

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[6] *https://leverantor.stockholm/fristaende-forskola-skola/forskola-pedagogisk-omsorg/kemikaliesmart-forskola/*

from street sellers or from discount stores are less compliant with regulatory standards, and may pose more health risks to children".

Pettersson et al. (2018) analysed items used in preschools in Stockholm, Sweden. Eleven new toys and eight new creative materials and 52 old plastic toys were analysed. They found all new products to be within relevant legal limits for chemical content, with phthalate content below 0.1% [1000 ppm]. They found a higher use of alternative plasticisers in new products, but there were not restricted or classified products. In the old toys, phthalates were identified in 39/52 (75%) of samples. In 14 of those, the levels were 'very high', up to 40% [400,000 ppm] of the toy material (Pettersson et al., 2018, fig. 5), up to 400x the relevant legislated level for that type of material. DEHP, Diisononyl phthalate (DINP), DBP were the most commonly detected phthalates. It was not suggested that recycling played a role in the phthalate content. They attribute the presence of toxic chemicals to legislation at the time of production, by showing how introduced regulation – including municipality-approved product procurement as part of Stockholm's 'Chemical Smart Schools'[7] – has successfully reduced the detection of target substances.

Strandesen et al. (2015) analysed 34 toys and 35 'other products for children' including bike handlebars, phone cases, watch straps for phthalates. The results displayed 9 out of the 34 toys had phthalates in concentrations above 0.05% [500 ppm]. 10 out of 35 'other products' contained phthalates with concentrations above 0.05% [500 ppm]. Of the toys which had concentration above 0.05% [500 ppm], most failed to comply with phthalate legislation. DEHP the primary reason for non-compliance, followed by DIBP, DINP, DNOP of other products: 10 had more than 1% [1000 ppm], including 2 bicycle handles, 6 mobile covers, 2 wrist watches. DEHP and DINP the primary identified phthalates. Migration analysis was carried out for the 10 'other' products with concentration above 1% [1000 ppm]. From this, only 3 had notable migration. In a realistic worst-case scenario, calculated health assessment HQ was well below 1, suggesting they did not have risk of causing antiandrogen effects for 6-year-old children. The low risk was due to low migration of phthalates and limited skin absorption. The authors do not discuss recycling.

Xie et al. (2016) analysed mass content of plasticisers in 6 children's backpacks and 7 toys, and their mass transfer from product surfaces to cotton wipes. The results showed Dioctyl terephthalate (DEHT) the most common plasticiser in 6 toys, revealing a strong correlation between average mass transfer of DEHT to wet wipes and to its average mass content in the product. The authors conclude "these results suggest that the mass transfer of plasticizers from products to clothing or human skin is strongly associated with their mass content". There is no comment on recycling.

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3.5.9 Heavy metals

Filella et al. (2020) brought together other research on presence of antimony in children's toys. The review concludes that "as a pigment, flame retardant synergist or residue from recycling, Sb may occur in a variety of plastic toys" and therefore recycling is hard to isolate as the reason, but recycling of e-waste was considered one possible avenue.

Guney et al. (2020) reviewed evidence of 'potentially toxic elements' in children's toys and jewellery by analysing concentration, bioavailability, exposure and

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[7] *https://leverantor.stockholm/fristaende-forskola-skola/forskola-pedagogisk-omsorg/kemikaliesmart-forskola/*

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bioaccessibility of heavy metals such as Pb, Cd and Cr. The results from a review of various studies concludes that toys purchased in 1970s, 80s and some more recent toys tested using XRF revealed 34% of non-vinyl tested toys would violate Pb limits in US and Denmark as of 2015, and 13% would violate Cd limit as of 2015 (Miller and Harris, cited in Guney et al.). Another study indicated out of 535 toys from ten daycares in Las Vegas analysed, 29 toy samples had elevated total Pb concentration, all of those contained PVC (Greenway and Gertensberger, cited in Guney et al). Compared to soluble limits in Brazil, 51 polymeric plastic toys more than half had concentrations of Cd, Cr and Pb exceeding soluble limits (Godoi et al, cited in Guney et al.). In another cited study, 30 plastic toys from Lebanon were analysed and concluded presence of Pb in 10% of plastic samples and 5% of tested plastic samples have concentrations above EU migratable limitations (Korfali et al, cited in Guney et al.). The total Pb content of plastic toy samples purchased in Chinese market showed 27/72 samples exceed US allowable limit of 100 mg/kg. The authors do not explicitly comment on recycling causing contamination, however, there is a suggestion that heavy metals would continue to transfer through recycling and re-use. A concern is raised regarding second-hand toys produced prior to regulations limiting harmful additives. However they also stress that approaches which consider bioaccessibility instead of total concentrations are more important to consider.

An unpublished ISO study (ISO, 2019) undertook an XRF-based analysis for plastic toys on the Sri Lankan market, looking at 145 new and 27 used toys. This analysis found Pb, Cd, Hg, Cr, As and Br in 20/145 (14%) of new toy samples. In new toys, Pb concentrations were found at a maximum of 4,465 ppm, well above the 1,000ppm limit in the RoHS Directive. All other metals had maximum levels well below RoHS limits. For used toys, the analytes were detected in 10/27 (37%) samples. Cd was detected at a maximum of 147.94ppm, above the RoHS limit of 100. The authors claim that “it is obvious that these imported toys have made from recycled plastics without proper treatment/purifications. Especially plastic waste obtained from electronic and electric equipment".

Negev et al. (2018) analysed 26 parts of 14 soft non-PVC toys bought in Israel for heavy metals. The results concluded all 26 parts analysed complied with Israeli toy standard, which is equivalent to the EU toy standard. The authors did not comment on recycling.

Straková et al. (2018) sampled 50 toys as part of a larger sample of 430 plastic items bought across European countries (both EU and non-EU), which were screened by XRF analyser for Sb content alongside Br. Across toys, the antimony ranged from 111 – 6,620 ppm, with mean and median values of 1,264 and 722 ppm respectively. They state that their findings demonstrate that “hazardous e-waste is finding its way across state boundaries via recycling workshops back into recycled products”.

Turner (2018a) sourced approximately 200 second-hand plastic toys and scanned by XRF for hazardous elements, both Br and metals (As, Ba, Cd, Cr, Hg, Pb, Sb, Se). The results showed every element was detected in > 20 toys except As, Hg and Se. Frequent occurrence of Cd and Pb at maximum concentrations about 2000 and 5000 μg/g [2000 and 5000 ppm] respectively. The authors simulated migration of 34 components from 26 toys under stomach conditions. In 8 cases, Cd or Pb exceeded migration limited under current EU Toy Safety Directive. The Cd released from yellow and red LEGO bricks (from the 1970s) exceeded the limit by an order of magnitude. Correlation between total and migratable concentrations significant only for Cd and Pb, this "suggests that total concentration is not, necessarily, a good proxy for exposure through ingestion". The authors do not further discuss recycling, however, the focus on reuse is important to note, as this may lead to risks from items manufactured before limits were put in place, with legal uses at the time. Pb appears to have been employed in compounds, as stabilisers in PVC or in association with Cr as yellow pigment. Cadmium generally encountered in bright coloured plastics, such as the yellow LEGO bricks though these are now restricted, and modern bricks no longer have detectable Cd. The authors conclude "the results of the present study reveal high concentrations of many elements listed by the Toy Safety Directive in products that remain in circulation, being handed-down by parents, recycled via charity shops, and donated to nurseries, hospitals and schools".

Turner (2018b) used an XRF analyser to assess 86 items in the ‘toys and hobbies’ category, part of a larger paper in which over 600 consumer products were considered, all of which were black plastic items. Four of these toys had PVC in them. In this study Cd, Cr, Hg and Pb were analysed, as well as Sb due to its association with electronic waste. Cd was detected in 4 samples (5%); Cr in 11 (13%), Hg in 0 (0%); Pb in 29 (34%) and Sb in 22 (23%). The metals were found in the following concentrations: Cd average 317 ppm; Cr average 38.5 ppm; Hg not detected; Pb average 76.3 ppm; Sb average 447 ppm. The author concludes by arguing that the “widespread detection of these elements, and in particular Pb, across a broader range of materials” alongside Br levels insufficient for flame retardancy suggests that black plastic is “often sourced for new consumer goods from end of life WEEE”, leading to a “quasi-circular economy for WEEE plastics that results in significant and widespread contamination of black consumer goods”. This is happening “unaware to the consumer and, in many cases, the manufacturer and retailer”. One compelling evidence for this role of recycling is the inconsistency in levels, which would indicate blending of a mixture of plastics, leading to “identical looking products from different suppliers sometimes containing relatively high concentrations of these elements and sometimes Br- and Pb- free"

Turner and Filella (2017a) analysed 162 samples of toys-hobbies, testing for Sb concentrations. The results show Sb presence in 24/162 (15%) toy-hobby samples of which 7 (29%) are alongside Br presence. All the toys considered would fall into the 'scraped off materials' category which includes paints and plastics. The concentrations exceeded 560 µg/g [560 ppm], the European standard EN71-3 in 13 samples, however, the potential for the migration of Sb was not determined in these samples. The authors consider the possibility of Sb transfer through recycling, "when electronic plastic waste is recycled, there is no consideration of the subsequent use and fate of Sb dissipated within the polymeric matrix".

Turner and Filella (2017b) examined 291 items in the ‘leisure’ category, which included toys. Their analysis primarily targeted flame retardants through the presence of Br, but this was also tested against presence of Sb and Pb for their use as additives related to flame retardants. Of these, 35 (12%) were Sb positive, and 32 (11%) were Pb positive. Of the Sb positive sample, 54% were detected alongside Br, for Pb it was 56% alongside Br. For non-electronic items, the relationships between Sb and Br were not found to be significant overall nor on a colour basis (Turner & Filella, 2017b, fig. 1).

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3.5.10 Other

Pettersson et al. (2018) analysed items used in preschools in Stockholm, Sweden. Both new and old products were tested. Amongst new toys, formamide was detected in 4/6 samples but all below legislated content levels from the Toy Safety Directive (0.3% [3,000 ppm]), as well as below the level where emission tests need to be undertaken (0.02% [200 ppm]). Amongst old products, formamide was found in all seven samples, though at relatively low levels. In one sample it exceeded the limit at 0.42% [4,200 ppm]. There was no suggestion recycling contributed to chemical presence, rather the age of product was highlighted.

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3.6 Furniture

3.6.1 Bisphenols

No datapoints were identified. Return to Heat Matrix.

3.6.2 Flame Retardants

A study by Andersen et al. (2014) analysed 15 furniture products using XRF for flame retardants (broken into layers/subsamples). The results showed only a few subsamples had enough phosphorus/chlorine to indicate FR (TCPP, TDCPP, TCEP). 13 subsamples tested under GC-MS. TCPP and TDCPP was found in 4/13 samples. TDCPP was found in very small concentrations in a single subsample. From the XRF results, about half of the layers had bromine, but in such small levels that "it is hardly due to the content of brominated flame retardants". Levels were approximately 0.04% [400 ppm]. The GC-MS found no signs of components such as BFRs. If agreed that the Br was not due to BFR addition, the authors do not then discuss or speculate on the of the Br. A risk assessment was completed for TCPP and TDCPP of total dermal, inhalation and dust exposure. They present total exposure, where sources of observed quantities do not necessarily come from home interiors but could be from other sources. The largest exposure was dermal exposure, but total HQ of less than 1 for both substances for children and adults, suggests substances "do not pose an unacceptable risk of harmful effects in the use scenarios" - no immediate risk. The authors do not speculate recycling could be involved.

Chen et al. (2010) analysed 7 samples of sofa, mattress, pillow and carpet padding from China for PBDEs, but did not find evidence of any PBDE content in these materials. This was attributed to the lax furniture flammability standards in China at the time of the study.

DiGangi & Strakova (2011) analysed recycled foam underlay for carpets collected from Canada, Hungary, USA, Nepal, Kyrgyzstan and Thailand. Of 26 samples, 23 had at least one PBDE listed in the Stockholm Convention. The highest level was for PentaBDE (77% contained, of which 50% > 50 ppm), followed by OctaBDE (65% contained, of which 27% > 50 ppm) and DecaBDE (89% contained, of which 23% > 50 ppm) respectively, which "indicates predominant contamination of pentaBDE as a result of recycling". In a number of cases, BDEs were found above the EU's low POPs content level (10ppm), this was the case for Tetrabromodiphenyl ether (tetraBDE) (50% of samples), pentaBDE (50% samples) and hexaBDE (46% samples).

Drage et al. (2018) sampled 122 soft furnishings to construct an inventory of PBDEs and HBCDD associated with waste polymers in Ireland. The study results show waste furniture as 41% of the Irish waste which exceeds POP-BFR limits. Of the samples, HBCDD was found in 32/122 (26%). 11 samples exceeded the LPCL (6 upholstery, 5 furniture foam). In cases where detection is below LPCL range, the authors reason it to be “likely due to migration out of other treated products during contact and/or the result of using recycled products during the manufacturing process that have previously been treated with HBCDD". No mattresses, carpets or curtains had HBCDDs above LPCLs. PBDEs were detected in 93/122 (76%) samples, median concentration of 0.058 mg/kg. None exceeded current LPCLs. BDE-209: 75/122 (61%), median 5.4 mg/kg [5.4 ppm]. 10 exceeded theoretical LPCL: 6/22 furniture fabrics, 3/20 furniture foam, 1/31 carpet samples. Four of the highest BDE-209 concentrations were in fabric covers. This suggests migration of BDE-209 from back-coated fabric to underlying foam via direct contact. However, no curtains, mattress foams or mattress upholstery samples exceeded the theoretical LPCL for BDE-209. The authors directly suggest some of the analyte presence comes from use of recycled textiles.

English et al. (2016) reviewed the use of flame retardants, specifically BDE-209, in Australian soft furnishings, but concluded that it is unlikely BDE-209 is widespread in these applications, especially in the domestic environment. The authors highlight that recycling materials containing BDE-209 could prolong the lifespan of BDE-209 in the environment but provide no evidence that their samples had been recycled.

Ionas (2016) collected 47 curtain and 14 carpet samples from Antwerp, Belgium. Time-of-flight high resolution mass spectrometry and GC-MS were used to analyse them. Of the samples, BDE-209 was the main BFR detected, present in 4/61 (7%) samples at maximum concentrations of 560,000 ng/g [560 ppm]. Amongst PFRs, triphenyl phosphate was the most often detected, found in 14/61 (23%) of samples at maximum concentrations of 95,000 ng/g [95 ppm]. There was no suggestion that recycling was the cause of FR presence.

Kajiwara et al. (2009) collected 10 different types of flame-retardant upholstery fabrics (mostly curtains) and analysed bromine content of each sample using handheld XRF. Identification and quantification of HCBD diastereomers were carried out using liquid chromatography-mass spectrometry. PBDEs and DeBDethane were analysed for 6 of the textile samples. The results show HBCDs were detected in all the samples analysed, with concentrations ranging from 22,000-43,000 mg/kg [22000-43000 ppm]. The percent proportions of α-, β- and γ-diastereomers in the textiles were found to be 13-46%, 2.0-17% and 38-84%, respectively. None of the samples contained DeBDethane (<50 ng/g [0.05 ppm]), but PBDEs with concentrations ranging from 0.011 to 120,000 mg/kg [0.011-120,000 ppm] were observed, as well as high HBCD concentrations in 9/10 polyester curtains. No comments are made on the role of recycling.

Kajiwara et al. (2011) analysed Japanese curtains for flame retardant content, with PBDEs found at concentrations of 7.4-9.1 ng/g [0.0074-0.0091 ppm]. A total HBCD concentration of 130,000-210,000 ng/g [130-210 ppm] was also observed. The authors suggested that the as all samples in the study contained traditional BFRs in amounts inadequate to impart flame retardancy, this “implies the incorporation of recycled plastic materials containing BFRs”.

Kajiwara et al. (2013) analysed 2 curtain textiles treated with HBCD and one treated with DecaBDE, exposed to sunlight for over 300 days to test photolytic transformation. The results showed different photolytic transformation profiles, those curtains treated with HBCD showed no substantial loss of HBCD diastereomers during exposure period, i.e. they are resistant to sunlight. But the textile treated with technical DecaBDE resulted in the formation of PBDFs as a product of photodecomposition. PBDF concentration reached maximum of 27000 ng/g, approximately 10x the initial concentration. The authors comment "although the concentrations of PBDFs in the textiles were 4–5 orders of magnitude lower than the concentrations of polybrominated diphenyl ethers, it is important to note that PBDFs were formed as a result of sunlight exposure during normal use of products treated with technical DecaBDE". Regarding the role of recycling, the authors conclude that "for assessing the risks associated with normal use, disposal, and recycling of consumer products, close attention should be paid to the fact that PBDFs are produced by sunlight exposure of products flame-retarded with PBDEs".

Keet et al. (2011) analysed curtains, drapes and flooring from New Zealand for Br content to indicate PBDE content. It was expected to find BDE in furniture, but there was less than 0.5% [5000 ppm] bromine found in more than 85% of their samples. This was attributed to the absence of legislation in New Zealand for the compulsory use of flame retardants in consumer goods. Recycling was not explicitly discussed as the reason for contamination.

Kemmlein et al. (2003) sampled consumer products including 3 furniture pieces testing for flame retardants. The study tested emissions to the air from the product. The upholstered stool sample showed TCPP levels in air increasing slowly, reached steady state of 41 µg/m^3. Emissions of HBCD and decaBDE were not detected over 170 day test period. Upholstery foam had a much sharper increase, with earlier and higher TCPP concentration. This suggests emissions from upholstery stool is influenced by diffusion through covering material, which has sink effect. All suggested to be treated materials, none possibly recycled.

Li and Suh (2019) reviewed 202 unique chemicals, examining functional uses, product applications, exposure routes, pathways, toxicity endpoints and combinations of chemicals. The authors identified 47 reports about flame retardants in furniture which have dust exposure through unintentional ingestion, 41 reports on flame retardants in furniture which have dust exposure through inhalation and 26 reports of unintentional ingestion. They do not comment specifically on furniture recycling but do speculate that recycling could lead to "occurrence of chemicals in recycled products which might have a completely different properties in retaining chemicals and different exposure patterns to humans".

Shin and Baek (2012) analysed the amount of BFRs in 3 curtain textile samples using GC-MS, TD-GC/MS and high resolution gas chromatography / High resolution mass spectrometry (HRGC/HRMS). Some samples had recently been treated with flame retardants and some had been treated 10 years previously. The results showed PBDEs in curtains high of 2612 ng/g [2.612 ppm] (sum PBDEs), the majority of this was BDE-209. In curtains, total PBDEs were found at levels of 1194 to 2659 ng/g [1.194-2.659 ppm], with BDE-209 contributing 1172 to 2612 ng/g [1.172-2.612 ppm] to that. The authors conclude "although FRs is [sic] used in large quantities during manufacturing and processing, the amount of these compounds in fiber material can be changed by exposure to light and time-dependent degradation. This could mean that decaBDE is processed after the factory line, which supports the idea that degradation can readily occur in the environment." They suggest that they did not detect decaBDE because of limitations on its use worldwide. There is no further comment on recycling.

Stapleton et al. (2012) tested FRs in 102 samples of PUF from residential couches purchased in the US to see how FR makeup has changed in relation to California's furniture flammability standard. The results showed chemical FRs detected in 85% of sofas. Prior to 2005 (n=41), PBDEs associated with PentaBDE the most common FR (39%) then TDCPP (24%). Post-2005 (n=61), the most common FRs were TDCPP (52%), and components associated with Firemaster550 mixture (18%). Since 2005 the phase out of PentaBDE created significant increase in use of TDCPP, and

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mixture of nonhalogenated organophosphate FRs. The authors do not discuss recycling.

Another Stapleton et al. (2009) study analysed 26 pieces of furniture purchased in US 2003 to 2009 and analysed using GC-MS. The results showed 15 foam samples containing TDCPP, 1-5% by weight [10,000-50,000 ppm] - this was the most abundant FR. Four samples contained TCPP, 0.5%-2.2% by weight [5,000-22,000], the next most abundant. The authors do not discuss recycling further.

Vojta et al. (2017) 2017 analysed 13 floor coverings from Czechia and found low concentrations of pentaBDE, but no octaBDE or decaBDEs were detected. HBCDs were higher in 3 carpet samples with a maximum concentration of 1140 µg/kg [1.14 ppm]. The authors comment that items such as the ones studied frequently consist of recycled plastic materials, but do not provide direct evidence of recycling for the specific items sampled.

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3.6.3 Formaldehydes

No datapoints were identified. Return to Heat Matrix.

3.6.4 Parabens

No datapoints were identified. Return to Heat Matrix.

3.6.5 Perfluorinated Chemicals

Bečanová et al. (2016) analysed a total of 126 samples of new and used items for PFAAs (PFSAs and PFCAs) by HPLC-ESI-MS/MS in carpets. The results show the levels of PFOS in carpets (16–44 µg/m^2 Σ15PFAA and 4.8–13.2 µg/m^2 PFOS) exceeded the PFOS limit (1 µg/m^2) by the EU directive by more than 5 times. The authors highlight the toxicity and possible impact to consumers and although there is no direct mention of recycling in this category, the conclusion states "the concentrations of PFAAs in the majority of studied materials suggested that the presence of these compounds was not caused by the intentional addition of PFAAs or their precursors to the materials during the manufacturing, as the levels were typically low and product groups contained multiple assorted and unrelated PFAAs."

Guo et al. (2009) analysed 116 consumer products in total, all expected to or labelled as having fluorine. This included 9 pre-treated carpets and 14 treated home textile and upholstery. The results showed pre-treated carpeting contained 48.4 ng/cm^2 TPFCA, treated home textile and upholstery contained 336 ng/g [0.336 ppm] TPFCA. The maximum carpet fluorine concentration was 292 ng/g [0.292 ppm] fibre carpets and 427 ng/g [427 ng/g] max in home textile and upholstery. The authors concluded that within a home, carpets and textiles classified as among the main sources of PFCAs, including floor waxes and sealants / treating materials. There is no comment on recycling, rather the expectation that these analytes were purposeful additives.

Herzke et al. (2012) performed a spot check of eight samples of coated fabric purchased in Norway and Sweden for PFAS. Of the sub-samples: food contact samples were free of PFAS; office furniture textile and Teflon treated table cloth were both free of PFOS, but several PFCAs could be detected in the table cloth. Telomeric 6:2, 8:2 and 10:2 FTOHs detected in both samples, comprising more than 90% the total PFAS concentration in those products. In two leather samples, PFOS detected at 28-31 µg/m^2, above regulatory limit of 1 µg/m^2. The authors suggest stain and waterproofing as the reason for the high concentration. Lastly, carpets were sampled: the Teflon treated carpet had PFOS at a concentration 1.05 µg/m^2, whereas the non-treated carpet fell slightly below the limit at 0.7 µg/m^2. Both treated and untreated contained 6:2, 8:2 and 10:2 FTOH, but these were at a ten times greater magnitude higher in the treated carpets. This suggests that purposeful addition through treatment was the main driver of chemical present, but the authors do state that the "amount remaining on the carpet at the end of life-time is assumed to be disposed of with the carpet, to landfill or to incineration" – or, we assume, to recycling if that is the route by which it is disposed.

A Liu et al. (2014) study continues the analysis in Guo et al. (2009) until 2011 by purchasing like-for-like, or similar, replacements. Results are grouped into 95 samples from 35 products as a whole, identifying a trend over time that shows PFCA in many products decreasing. PFOA (C8) was still detected in many products, and a reduction of PFCAs both in short-chain and long-chain was observed over the study period. An increase in PFBS as alternative to PFOS was observed in the samples. They present strong evidence that TPFCAs have been reduced in a majority of the products in recent years. No comment was made regarding recycling, the change over time was attributed to manufacturing changes.

Pettersson et al. (2018) analysed items used in preschools in Stockholm, Sweden. This sample did include some mattresses/furniture. Approximately 11 of the new items were furniture textiles and office furniture. On all three types of mattress cover, all three preschool furniture textiles and an acrylic-surface tablecloth, 8:2 and 10:2 FTOH were detected. This is likely due to the "good stain repellent properties" provided by these substances. Four of the analysed furniture textiles from the office assortment did not contain any detectable levels of highly fluorinated substances. Amongst old products, one textile carpet was analysed, and 6:2, 8:2 and 10:2 FTOH were all detected. There is no suggestion that recycling has played a role in the chemical presence, rather purposeful addition for stain-repellent properties.

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3.6.6 Other Persistent Organic Pollutants

Pettersson et al. (2018) analysed items used in preschools in Stockholm, Sweden. This sample did include some mattresses/furniture. Approximately 11 of the new items were furniture textiles and office furniture. One new mattress contained SCCP at a concentration of 0.7% weight [7,000 ppm], above the REACH regulation of 0.15% [1,500 ppm]. This mattress also exceeded DEHP limit. One old item, a slip-proof mat, contained 0.4% SCCP [4,000 ppm] and 7% MCCP [70,000 ppm]. There was no suggestion that recycling contributed to chlorinated paraffin content.

Return to Heat Matrix.

3.6.7 Phthalates

Pettersson et al. (2018) analysed items used in Swedish preschools, including mattresses and various rugs and mats, for phthalate content. One new mattress cover contained 0.3% [3000 ppm] DEHP as well as 0.7% [7000 ppm] SCCP, making it illegal to sell under phthalate and SCCP regulations. One mattress for snow play contained 0.4% [4000 ppm] DINP in the cover. Of the 'other toy types and interior items' group, including cloths, rugs and pillows, 5/31 (16%) of the new items contained phthalates. For old products, phthalates were found in all 'other toy type and interior items', most commonly DINP and DEHP.DEHP and DINP were found at levels slightly above 0.1% [1000 ppm], but DIDP and DIBP were found in lower levels in some rugs and mats. One slip-proof mat contained 25% [250,000 ppm] DINP and 4.4% [44,000 ppm] DEHP. The authors state that contents below 0.1% [1000 ppm] "is considered unintentional contamination during production" but do not elaborate on if recycled content plays a role.

Return to Heat Matrix.

3.6.8 Heavy metals

Andersen et al. (2014) analysed 15 furniture products using XRF for heavy metals (broken into layers/subsamples). A further 13 subsamples were studied by GC-MS. The results showed all aluminium subsamples, up to 1.8% concentration [18,000 ppm], but the authors suggested that it was filler rather than related to FR. Few samples contained titanium, likely due to colorant rather than FR. Zirconium was found in 5 subsamples above detection limit, but concentrations were very small. Antimony was also found in small concentrations (maximum 88 ppm), in correlation to bromine concentration. The authors do not discuss recycling.

Ionas (2016) collected 47 curtain and 14 carpet samples from Antwerp, Belgium. Time-of-flight high resolution mass spectrometry and GC-MS were used to analyse them. The detection of Al and Sb in amounts high enough to impart flame retardancy suggest "it is very likely that halogen-free FR treatments/solutions are preferred for the textiles on the Belgian market". Al and Sb were detected at concentrations around 1.5-3.5% weight [15,00-35,000 ppm]. Na and Ca were found at similar levels, but the author suggests they may have been used as fillers. There was no suggestion that recycling contributed to the presence of the chemical. Of the samples, BDE-209 was the main BFR detected, present in 4/61 (7%) samples at maximum concentrations of 560,000 ng/g [560 ppm]. Amongst PFRs, triphenyl phosphate was the most often detected, found in 14/61 (23%) of samples at maximum concentrations of 95,000 ng/g [95 ppm]. There was no suggestion that recycling was the cause of FR presence.

Return to Heat Matrix.

3.6.9 Other

No datapoints were identified. Return to Heat Matrix.

3.7 Motor vehicles

3.7.1 Bisphenols

No datapoints were identified. Return to Heat Matrix.

3.7.2 Flame Retardants

Chen et al. (2010) studied 55 samples for PBDE flame retardants, including 5 samples of car plastic interiors, seat PUF and textile coating from China. PBDEs were identified in 4 out of 5 car plastic interiors with a mean value of 87,505 ng/g [87.5 ppm]. The highest concentration was found in seat textiles where a decaBDE mixture is often used. The paper noted that relatively high concentrations of PBDEs from discontinued penta- and octaBDE mixtures were found in the recycled materials. Thus, recycling old electronic products might be a potential important pathway to these low brominated BDEs re-entering the supply chain.

Drage et al. (2018) sampled 135 ELV fabrics and PUF, all from one vehicle scrap site in Ireland to construct an inventory of PBDEs and HBCDD. The authors identify HBCDD, PBDEs and BDe-209 found in all ELV samples. HBCD was found in 36/119 (30%) samples, with a median of <0.0003 mg/kg [0.0003 ppm]; PBDEs 98/119 (82%) with a median of 0.09 mg/kg [0.09 ppm] and BDE-209 in 105/119 (88%) with a median of 1.6 mg/kg [1.6 ppm]. All evidence of exceedances were found in upholstery: roof trim, seat covers, floor mats rather than PUF. The authors highlight that 4/5 were manufactured in Asia and the vehicle with highest BDE-209 was registered in 2012, "demonstrating that products containing DecaBDE were still entering the European market, several years after the introduction of restrictions on its use in 2008". This report does not directly mentioned recycling for ELV, however.

English et al. (2016) reviewed the standards pertaining to flame retardancy and prevalence of BDE-209 in Australian car carpets and upholstery, in preparation for c-decaBDE, of which BDE-209 is a major component, being added to Stockholm Convention POP. Only 2 out of 47 carpets analysed contained bromine at a maximum concentration of 2.7% [27,000 ppm], and only one sample of a back seat lining contained BDE-209 at a concentration of less than 0.0001% [1 ppm]. The review does not discuss the possible source of BDE-209, but does state that the recycling of materials containing BDE-209 could prolong the lifespan of BDE-209 in the environment unless efficient removal technologies are employed.

Gearhart and Posselt (2006) study analysed 15 samples (13 windshield films and 2 dust) from random privately owned vehicles, from 2000-2005 car models from 11 manufacturers looking 11 PDBE congeners concentrations. The results showed the highest PBDE μg/m^2 from windshield concentrations in Mercedes (1.772 μg/m^2); Chrysler (1.021 μg/m^2) and Toyota (0.936 μg/m^2). The mean concentration was 0.365 μg/m^2. The highest concentration of PDBE congeners in dust samples was deca-DBE followed by penta-DBE, tetra-DBE and hexa-DBE. Results were based on an average of 6-10 randomly selected vehicles sampled for each company. The authors note that 7 out of 8 vehicles sampled were cars for resale on a used dealership lot and speculate that recycling based contamination could happen as cars are reused and recycled for parts.

Keet et al. (2011) studied Br levels in over 800 products including seat foam and car seats. Using the assumption that BDE content accounts for 50% of Br found, auto interior parts were found to contain 0.034% BDE [340 ppm] and auto parts contain 0.006% [60 ppm]. Recycling was not directly discussed in this study.

Shin and Baek (2012) looked at the amount of BFRs in vehicle textile samples using GC-MS, TD-GC/MS and HRGC/HRMS. Some samples had recently been treated with flame retardants and some had been treated 10 years previously. This study sampled 3 car interior foams and 2 car interior materials. The results showed car interior foam high of 601361 ng/g [601.361 ppm] and car interior material high of 13292 ng/g [13.292 ppm]. In car interior foam, total PBDEs were found at levels of 1858 to 654,959 ng/g [1.858-654.959 ppm], of which BDE-209 contributed 1757 to 601,361 ng/g [1.757-601.361 ppm]. In car interior materials, total PBDEs were found at levels of 10,413 to 13,876 ng/g [10.413 to 13.876 ppm], of which BDE-209 contributed 9,651 to 13,292 ng/g [9.651-12.292 ppm]. The authors concluded "although FRs is [sic] used in large quantities during manufacturing and processing, the amount of these compounds in fibre material can be changed by exposure to light and time-dependent degradation. This could mean that decaBDE is processed after the factory line, which supports the idea that degradation can readily occur in the environment." They suggest that they did not detect decaBDE because of limitations on its use worldwide (e.g. through the RoHS). The authors do not discuss recycling.

Turner and Filella (2017a) analysed 750 samples and analysed 38 samples of vehicle interiors from 3 private vehicles, testing for Br. The results show Br presence in 9/38 samples (24%) of vehicle samples. They speculate on the role of e-waste recycling in leading to Br content in plastics at low levels.

Vojta et al. (2017) analysed 137 motor vehicle samples from Czechia including plastics, textiles and upholstery for PBDEs, HBCDs and NFRs. In the samples tested, no BDE-209 was found and only low levels of HBCD were observed. There was frequent detection and relatively higher levels of NFRs and other PBDEs, but car parts had relatively low amounts of target FRs compared to household equipment. Penta- and OctaBDE congeners were frequently detected, despite the decline in their use. They suggest this is due to recycling: “household equipment, car interior materials and WEEE frequently consisted of recycled plastic materials containing a wide variety of FRs”.

Return to Heat Matrix.

3.7.3 Formaldehydes

A Larsen et al (2017) review looked at the car internal environment, identifying substances of highest concern in car interior, and formulated 2 risk scenarios. Formaldehyde and other volatile aldehydes with 2-4 carbon atoms were grouped. The results show formaldehyde concentrations varying between 24.3 - 82.4 µg/m^3 in all studies apart from one global study which suggested 250 - 350 µg/m^3. The study considered two exposure scenarios: 1) a short stay in hot car ; 2) daily commuting. In the former, substances that may cause acute effects are critical, they depend on actual concentration in air rather than exposure over time. In latter, evaporation of aldehyde considered critical. This study makes no particular reference to specific products within the car, so no association to recycling could be inferred.

Return to Heat Matrix.

3.7.4 Parabens

No datapoints were identified. Return to Heat Matrix.

3.7.5 Perfluorinated Chemicals

No datapoints were identified. Return to Heat Matrix.

3.7.6 Other Persistent Organic Pollutants

No datapoints were identified. Return to Heat Matrix.

3.7.7 Phthalates

Gearhart and Posselt (2006) analysed 15 samples (13 windshield films and 2 dust) from random privately owned vehicles, from 2000-2005 car models from 11 manufacturers. The results showed that of the 5 phthalates found in automobile dust (DPB, DIPB, BBP, DEHP, DOP), the most prominent in samples was DEHP (78%) at a concentration of 49 ppm. The three companies considered with highest total phthalates and DEHP concentrations on windshield films include Hyundai (24 µg/m^2), Ford (10 µg/m^2) and Honda (7 µg/m^2). Results were based on an average of 6-10 randomly selected vehicles sampled for each company. The authors note that 7 out of 8 vehicles sampled were cars for resale on a used dealership lot and speculate that recycling based contamination could happen as cars are reused and recycled for parts.

Larsen et al. (2017) conducted a literature review of evidence on motor vehicle internal environments and used these to identify substances of highest concern in car interiors before formulating two risk scenarios. They found that emissions of phthalates DBP and DEHP appear to change with temperature. However, it is not possible to tie their analysis to specific products in the car interior, nor is there the suggestion that recycling contributed to analyte content.

Return to Heat Matrix.

3.7.8 Heavy metals

Turner and Filella (2017a) analysed 750 samples and analysed 38 samples of vehicle interiors from 3 private vehicles, testing for Sb concentrations. The results show Sb presence in 14/38 vehicle samples (37%) of which 4 (29%) were alongside Br presence. The concentrations ranged orders of magnitude with the highest (>1000 μg/g [>1000 ppm]) in panels, armrests and seats that were non-PVC based. The authors consider the possibility of Sb transfer through recycling, "when electronic plastic waste is recycled, there is no consideration of the subsequent use and fate of Sb dissipated within the polymeric matrix".

Van Oyen et al. (2015) used energy dispersive x-ray fluorescence (EDX-RF) to analyse Pb content in ex-automotive plastics. It was found at 1,124 ppm, above the 1,000 ppm limit. It was not suggested that recycling caused this contamination, but this material if recycled could contaminate further products.

Return to Heat Matrix.

3.7.9 Other

Bodar et al. (2018) looked at PAH content in end of life tyres. Results concluded PAHs concentrations in rubber granulate derived from tyres could be up to 19.8 mg/kg [19.8 ppm] dry matter, compared to a limit of 1,000 mg/kg [1,000 ppm], excluding benzo(a)pyrene and dibens(a,h)anthracene for which a limit value of 100 mg/kg [100 ppm] dry matter applies. The amount of PAHs in rubber granulate satisfies this concentration limit. The paper concludes that from a safety perspective, “PAHs and other chemicals in rubber granulate pose no risk to human health”. The amount of PAHs in rubber granulate is slightly higher than the concentration limit for consumer products and toys of 1 mg/kg [1 ppm] per dry matter and 0.5 mg/kg [0.5 ppm] dry matter listed PAH, respectively. Currently, a REACH restriction proposal is being drafted in order to determine a suitable concentration limit for rubber granulate.

Larsen et al. (2017) conducted a literature review of evidence on motor vehicle internal environments and used these to identify substances of highest concern in car interiors before formulating two risk scenarios. They found that the substances of highest concern in the vehicle interior were outside of the priority list in this study: Benzene; Naphthalene; Acrolein; Crotonaldehyde; Phenol.

Return to Heat Matrix.

3.8 Mixed product groups

3.8.1 Bisphenols

Giovanoulis et al. (2019) analysed dust in 20 preschools which were a part of a larger study of 100 preschools (2018 vs 2015) to compare change in ambient toxicity level of bisphenols based on product substitution and the removal of old electronic equipment. These preschools had all followed the Swedish “chemical smart” guidance and removed old articles and materials with high risk of hazardous content. The study has not been able to allocate specific concentrations or causation to specific items. However, the results have depicted a significant decline in median BPA (49%) and BPF (78%) as well as TBBPA reduction to half of its 2015 concentration. Whereas BPS has demonstrated significant increase by 93%. No comments are made on recycling, rather the suggestion is that the removal of older items reduced the chemical risk.

Go to Heat Matrix

Wassenaar et al. (2017) paper looks at a mixture of literature using RIVM reports, expert interviews from RIVM and Rijkswaterstaat and additional literature data. The paper focuses on the presence of ZZS in waste streams for plastics. Based on studies from Danish EPA and Swedish Chemical Agency, they identify 59 ZZS substances which could potentially be present in plastics. This includes Bisphenol A. The authors present current applications of recycled plastics, a mixture of which are in our scope and not: insulation, carpet padding, office and kitchen products,a variety of other products like clothes and footwear, outdoor elements, furniture and design, automotive, agriculture, bags and complements, packaging, construction material. The authors conclude by stressing uncertainty, “actual data on ZZS presence in waste streams are often lacking, because there is no coherent analytical monitoring program for ZZS in waste". As a result, this paper indicates the possibility of a BPA presence in waste and recycling streams but does not tie it to specific products or their recycling.

Return to Heat Matrix.

3.8.2 Flame Retardants

Cook et al. (2020) conducted a review of other studies referring to BFRs in secondary plastics. In most cases cited, products tested did not contain BFRs exceeding the RoHS Directive threshold of 1,000 µg/g plastic [1,000 ppm].

Giovanoulis et al. (2019) analysed dust in 20 preschools which were a part of a larger study of 100 preschools (2018 vs 2015) to compare change in ambient toxicity level of PBDEs based on product substitution of old electrical equipment. These preschools had all followed the Swedish “chemical smart” guidance and removed old articles and materials with high risk of hazardous content. The study has not been able to allocate specific concentrations or causation to specific items. The median concentration of most PBDEs (PBDE 28, PBDE 85, PBDE 100 and PBDE 153 were all below LOD. Other PBDEs saw concentrations decrease by 20-30%. Notably, PDE-99 decreased from 8.2 µg/g [8.2 ppm] to 6.7 µg/g [6.7 ppm]. TCPP (commonly used in PUF in consumer products, home insulation and electronics) significantly reduced by 44%. This decrease is suggested to have occurred due to the recommended actions in the guidance to “remove old electronic equipment from playrooms and not to play with old electronics”. No comments are made on recycling, rather product age is presented as the determining factor.

Kumari et al (2014) analysed 6 samples of mixed products, screening for BFRs. Three of these samples detected PBDE presence: foam from upholstery, a motherboard from a computer and window blind. None was detected in PVC flooring or electrical wire. BDE-209 had was found at high concentrations in all three: in upholstery at a concentration of 7.023 mg/kg [7.023 ppm]; the motherboard from a computer at 11,583.8 mg/kg [11583.8 ppm] and in the window blind at 4,798.72 mg/kg [4798.72 ppm]. In the motherboard, BDE-47 (1.173 mg/kg [1.173 ppm]) and BDE-153 (0.259 mg/kg [0.259 ppm]) were also detected, but not in other products. The authors conclude "the results of this preliminary investigation indicate that PBDEs are still present in the old consumer products which can be an important additional source of exposure to the population". There is no further comment on recycling as a source of contamination, rather product age is presented as the determining factor.

Leslie et al. (2016) considered some mixed product types including four samples of office and kitchen products and three samples of insulation and carpet cladding taken from the Netherlands. Both product groups were noted as being products manufactured from recycled plastic. The POP-BDE content of office and kitchen products was <0.005 µg/g [<0.05 ppm] and for insulation/carpet padding <0.001-0.04 µg/g [<0.001-0.04 ppm]. The BDE-209 detected across the groups was <0.03 µg/g [<0.03 ppm] and 0.01-0.08 µg/g [0.01-0.08 ppm] respectively. The authors suggest that state-of-the-art separation techniques do not eliminate all POP-BDEs from the recycling stream, and BDEs are being imported in recycled products produced abroad. As a result, “a substantial percentage of toxic BDEs in waste plastic still find their way into new products made from recyclates”.

Miller et al. (2016) analysed consumer products by XRF for Br content. For mixed PVC, non-electric items, a correlation between Br and other elements (Sb, Cd, Cu, Au, Fe, Pb, Mn, Sn, Zn, Rubidium) was often found. Non-electronic products were likely to contain between 5-100 ppm bromine, levels sufficiently low to suggest unintentional contamination in these products, which could have come from recycling. 57% of the 1439 non-electronic products contained more than 5 ppm bromine.

Okonski et al. (2018) analysed 137 samples of different types of consumer products for flame retardant content HBCD and its isomers. They also tested air, soil and sediment samples. HBCDs were quantified via isotope dilution by liquid chromatography system. The results showed HBCD isomers were detected in 83% of investigated products (115/137 samples). Among 15 classes of consumer products, the highest average concentrations were found in building materials, e.g., glass fibre foam from a heating, ventilation and air conditioning unit (191 µg/g [191 ppm]), decorative polystyrene, (217 µg/g [217 ppm]), and insulation, which includes mineral wool and spray foam insulation (352 µg/g [352 ppm]). The sample with the highest concentration of HBCD was an insulation foam (5.31 mg/g [5.31 ppm]), while the lowest concentrations of HBCDs were found in automobile parts, children’s toys and craft materials, and furniture and household appliances (range of 0.81–276 ng/g [0.81-2.76 ppm]). The authors note "understanding the isomer-specific environmental distributions and processes remains important for risk assessment and toxicology, considering the continued use of HBCD and the isomer-specific differences in uptake, metabolism, and toxicity". The potential risk from HBCD exposure varies at each point during transport from source to sink because of the changing isomer profile and exposure. They do not discuss the role of recycling in HBCD persistence.

Pettersson tested new and old mixed preschool-appropriate products, some of which are detailed under furniture and toys. Overall, 11 new and 11 old samples were taken and tested for BFRs. No BFRs were identified in either the old or the new items. There was no suggestion any of the items were made from recycled materials.

Van Bergen and Stone (2014) looked at 385 components from 169 products purchased from 30 retailers in Washington State, scanning with XRF to look at flame retardants. A total of 163 components from 125 products were then sent to laboratory for analysis. From this, a subsample of 67 components from 61 products was sent to a second lab to affirm results but also check for 3 additional analytes. The results showed out of 385 XRF scanned components for Br: 207 non-detects, 110 samples at <1000 ppm, 26 samples 1000<5000 ppm, 42 sample >5000 ppm. Of 54 samples sent to first lab: the majority of samples >5000ppm were plastic, with PBDE congeners PentaBDE and OctaBDE, TCEP, TDCPP, TPP particularly notable. PBDEs and Deca-BDP-ethane concentrations were above reporting limit in a number of items: highest in plastic pallet and two shredders; also above the limit in carpet padding (x3), battery charger, foot warming pad, LED TV and child's tablet. Most samples, however, did not contain PBDEs above 100 ppm reporting limit. Only 3 of

163 product components above 1000 ppm. The authors comment that "manufacturers have largely moved away from using PBDEs and their products are compliant with Washington regulations." They suggest that low concentrations could be a result of recycling: "flame retardants are typically [purposefully] used in the percent level [>10,000 ppm]. Levels near the reporting limit could be due to cross contamination during manufacture, flame retardant impurities, or flame retardants from recycled content. Concentrations lower than percent level could be part of a mixture."

Vojta et al. (2017) sampled 24 mixed textiles, including curtains, bed cover and fabric from a teddy bear toy. Both pentaBDE and HBCDs had detection frequencies over 80% in the samples. PBDEs were frequently detected in low concentrations, the median ΣPBDEs being detected at 0.616 µg/kg [0.0006 ppm]. They highlight that detection of penta- and octaBDE is likely to be a persistence from recycled materials made before their phaseout, whereas BDE-209 and HBCD are more likely to be found in primary use.

Wassenaar et al. (2017) paper looks at a mixture of literature using RIVM reports, expert interviews from RIVM and Rijkswaterstaat and additional literature data. The paper focuses on the presence of ZZS in waste streams for plastics. Based on studies from Danish EPA and Swedish Chemical Agency, they identify 59 ZZS substances which could potentially be present in plastics. These a wide range of flame retardants, both brominated and not (Wassenaar et al., 2017 Table 5). The authors present current applications of recycled plastics, a mixture of which are in our scope and not: insulation, carpet padding, office and kitchen products, a variety of other products like clothes and footwear, outdoor elements, furniture and design, automotive, agriculture, bags and complements, packaging, construction material. The authors conclude by stressing uncertainty, “actual data on ZZS presence in waste streams are often lacking, because there is no coherent analytical monitoring program for ZZS in waste". As a result, this paper indicates the possibility of a FR presence in waste and recycling streams but does not tie it to specific products or their recycling.

Xu et al. (2014) looked at phthalates and PBDEs which are extensively used in consumer products and examined their presence inside dust in 12 retail stores in Texas and Pennsylvania. They found PBDEs widely in the retail environment, at levels comparable to but slightly higher concentration than residential buildings. However, it was not possible to tie these to specific products, and there was no implication that they had been recycled.

Return to Heat Matrix.

3.8.3 Formaldehydes

Wassenaar et al. (2017) paper looks at a mixture of literature using RIVM reports, expert interviews from RIVM and Rijkswaterstaat and additional literature data. The paper focuses on the presence of ZZS in waste streams for plastics. Based on studies from Danish EPA and Swedish Chemical Agency, they identify 59 ZZS substances which could potentially be present in plastics. These include formaldehyde and formaldehyde oligomeric reaction products with aniline. The authors present current applications of recycled plastics, a mixture of which are in our scope and not: insulation, carpet padding, office and kitchen products, variety of other products like clothes and footwear, outdoor elements, furniture and design, automotive, agriculture, bags and complements, packaging, construction material. The authors conclude by stressing uncertainty, “actual data on ZZS presence in waste streams are often lacking, because there is no coherent analytical monitoring program for ZZS in waste". As a result, this paper indicates the possibility of a formaldehyde presence in waste and recycling streams but does not tie it to specific products or their recycling.

Return to Heat Matrix.

3.8.4 Parabens

No datapoints were identified. Return to Heat Matrix.

3.8.5 Other Persistent Organic Pollutants

Guida et al. (2020) review study of CP (chlorinated paraffin) production and industrial uses: how contamination can occur from production and application sites, CPs in consumer goods and their release and exposure during use and contamination from end of life management and data gaps. This study looked at a mixture of items including covers & packaging, cables & cords, sports equipment etc. The authors state "the Basel Convention defines what concentrations of specific POPs in a waste classify it as a POP waste. For SCCPs there are currently two provisional low POP contents of 100 mg/kg [100 ppm] and 10,000 mg/kg [10000 ppm] SCCPs, since the Conference of Parties of the Basel Convention had a split opinion on the low POP content and could not conclude yet on one limit. Only initial studies on CPs in waste or recycling fractions have been conducted including method development". The short lifespan of some CP-containing products, like textiles, consumer goods including toys, yoga mats and rubber mean CP would be expected in the waste stream. But the lack of labelling means they are unlikely to be separated at end of life (EoL). “This might become a challenge for instance in the recycling and reuse of rubber belts and rubber tracks." The authors conclude that a systematic assessment of the presence of CPs in products categories and recycling of waste categories is necessary, and that the implementation of the Stockholm Convention is a chance to address the gaps in the control of the lifecycle of CPs. Accurate measurements of CP occurrence are challenging due to the complexity of CP mixtures, and there is a lack of analytical capacity in developing countries. The authors mainly focus on amounts in non-recycled products, but comment on recycling in the context of contamination from EoL recycling.

Pettersson et al. (2018) analysed items used in preschools in Stockholm, Sweden for chlorinated paraffins. This included a mixture of toys, furniture and textiles. Of the old items, SCCP was identified in 9/79 (11%) and MCCP in 13/79 (16%) of samples. LCCP was not found in any of the 5 analysed. There was no suggestion that the chlorinated paraffin presence was related to recycling.

Wassenaar et al. (2017) paper looks at a mixture of literature using RIVM reports, expert interviews from RIVM and Rijkswaterstaat and additional literature data. The paper focuses on the presence of ZZS in waste streams for plastics. Based on studies from Danish EPA and Swedish Chemical Agency, they identify 59 ZZS substances which could potentially be present in plastics. These include short and medium chain chlorinated paraffins as a plasticiser. The authors present current applications of recycled plastics, a mixture of which are in our scope and not: insulation, carpet padding, office and kitchen products, a variety of other products like clothes and footwear, outdoor elements, furniture and design, automotive, agriculture, bags and complements, packaging, construction material. The authors conclude by stressing uncertainty, “actual data on ZZS presence in waste streams are often lacking, because there is no coherent analytical monitoring program for ZZS in waste". As a result, this paper indicates the possibility of a chlorinated paraffin presence in waste and recycling streams but does not tie it to specific products or their recycling.

Return to Heat Matrix.

3.8.6 Phthalates

Giovanoulis et al. (2019) analysed dust in 20 preschools which were a part of a larger study of 100 preschools (2018 vs 2015) to compare changes in ambient toxicity level of phthalates and plasticisers based on product substitution. These preschools had all followed the Swedish “chemical smart” guidance and removed old articles and materials with high risk of hazardous content. However, the level of all phthalates found in preschool dust in 2015 had decreased by 2% to 60% after “chemical smart” actions taken. Concentrations of some alternative plasticisers increased such as DEHA (34%) and DEHT (36%). Whereas ATBC decreased (26%) and DINCH (39%) which may be due to “discarding newer toys or mattresses with DINCH content by preschools during sorting”. Correlation between individual phthalates in preschool dust “may reflect that phthalates are derived from the same indoor sources of contamination, such as old PVC flooring, toys and mattresses as well as in recycled materials in new PVC flooring and/or other equipment”. However, as they analysed ambient dust, they could not determine specific products. No comments are made on recycling, the implication being that product age is of most relevance.

Pivnenko et al. (2016) sampled residual (RWP) and source segregated (SSWP) waste plastics from a municipality in Denmark. Samples were analysed for selected phthalates alongside recycled and virgin plastics. DBP, DiBP and DEHP had the highest frequency of detection in the samples analysed, with 360 µg/g [360 ppm], 460 µg/g [460 ppm] and 2700 µg/g [2700 ppm] as the maximum measured concentrations, respectively. Statistical analysis of the analytical results suggested that phthalates were potentially added in the later stages of plastic product manufacturing (labelling, gluing, etc.) and were not removed following recycling of household waste plastics. Furthermore, DEHP was identified as a potential indicator for phthalate contamination of plastics. Close monitoring of plastics was recommended for phthalate-sensitive applications if recycled plastics are to be used as a raw material in production.

A Wassenaar et al. (2017) paper looked at a mixture of literature using RIVM reports, expert interviews from RIVM and Rijkswaterstaat and additional literature data. The paper focuses on the presence of ZZS in waste streams for plastics. Based on studies from Danish EPA and Swedish Chemical Agency, they identify 59 ZZS substances which could potentially be present in plastics. These include a range of plasticisers (Wassenaar et al., 2017 Table 5). The authors present current applications of recycled plastics, a mixture of which are in our scope and not: insulation, carpet padding, office and kitchen products, variety of other products like clothes and footwear, outdoor elements, furniture and design, automotive, agriculture, bags and complements, packaging, construction material. The authors conclude by stressing uncertainty, “actual data on ZZS presence in waste streams are often lacking, because there is no coherent analytical monitoring program for ZZS in waste". As a result, this paper indicates the possibility of a formaldehyde presence in waste and recycling streams but does not tie it to specific products or their recycling.

Xu et al. (2014) looked at phthalates and PBDEs which are extensively used in consumer products and examined their presence inside dust in 12 retail stores in

Texas and Pennsylvania. The authors found phthalates widely within the retail environment, with levels comparable to concentrations in residential buildings. The phthalate concentration was lower in retail stores than residential buildings. However, phthalate presence is not traced to particular products or materials which had been used. There is no suggestion that recycled content was used in the retail products.

Return to Heat Matrix.

3.8.7 Heavy metals

Filella et al. (2020) analysed research on the presence of antimony in various items. The review concludes that overall across studies referenced by the authors, Sb has been detected in about 15% of several thousand consumer items analysed. It is most abundant in electrical equipment and items of polyester clothing. The authors state "Sb is found in a variety of PET- or polyester-based products of any colour at concentrations <1000 mg/kg [<1000 ppm] and in the absence of detectable Br as catalytic residue, while higher Sb concentrations are encountered in yellow, brown and green products and in the absence of Br as a pigment". In electrical equipment, both old and new, Sb may be found as a synergist at concentrations above 5000 mg/kg [>5000 ppm] and usually in the presence of Br at similar or greater concentrations. In PVC electrical (and some non-electrical products), Sb is encountered at concentrations >5000 mg/kg [>5000 ppm] but in the absence of detectable Br (where Cl as a component of the polymer acts as an inherent flame retardant). They identify typical concentration ranges of Sb encountered in different types of plastic product:

- Plastic recycled from electrical equipment typically has 50 - 3000 Sb mg/kg [50-300 ppm] and 50 - 5000 Br mg/kg [50-5000 ppm].
- As a synergist in PVC, Sb >5000 ppm without Br
- As a synergist in non-PVC electrical equipment, Sb >5000 ppm with Br >5000 ppm
- As a coloured pigment, between 500-2000 ppm without Br
- As a PET catalytic residue, between 100-800 ppm without Br.

They therefore identify recycling as a major source for “the wider contamination of products by Sb at lower concentrations".

The Wassenaar et al. (2017) paper looks at a mixture of literature using RIVM reports, expert interviews from RIVM and Rijkswaterstaat and additional literature data. The paper focuses on the presence of ZZS in waste streams for plastics. Based on studies from Danish EPA and Swedish Chemical Agency, they identify 59 ZZS substances which could potentially be present in plastics. These include heavy metals including Ca and its compounds; Cr and its compounds, Pb, Hg and its compounds, Sb. The authors present current applications of recycled plastics, a mixture of which are in and out of scope: insulation, carpet padding, office and kitchen products, variety of other products like clothes and footwear, outdoor elements, furniture and design, automotive, agriculture, bags and complements, packaging, construction material. The authors conclude by stressing uncertainty, “actual data on ZZS presence in waste streams are often lacking, because there is no coherent analytical monitoring program for ZZS in waste". As a result, this paper indicates the possibility of a heavy metal presence in waste and recycling streams but does not tie it to specific products or their recycling.

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3.8.8 Other

BfR (2010) produced a chemical analysis of consumer articles for their carcinogenic PAH content, estimation of possible exposure and the associated health impacts to consumers from estimated exposure levels. The study evaluated over 5,300 samples from 8 consumer article categories, including electrical devices, provided to BfR by German quality control, consumer protection organisations and monitoring authorities of the German Federal states. These were analysed for 16 PAHs from the EPA list (‘EPA-PAH’) and concluded no PAHs were detected in 90% of the analysed products. However, there was a notable difference between the consumer article categories, with some readings of everyday use articles by consumers and children displaying very high PAH contents.

Turner (2021) sampled 31 products bought in the EU and US with a mixture of uses, some in scope (e.g. toys, vehicle parts, EEE) and others (misc. items, food contact packaging) for rare earth elements. The results are presented in an aggregated form. They found one or more rare earth elements in 24/31 in 77% of samples, of which four samples had detectable concentrations of all rare earth elements analysed up to a total concentration of 8 mg/kg [8 ppm]. They were least abundant in new electronic plastics, and most prevalent in samples with Br in insufficient concentrations to effect flame retardancy. The lack of correlation between individual rare earth elements and Br content, alongside detection of rare earth elements in plastics without an e-waste signature (e.g. food contact) suggests an “additional or alternative more general sources of contamination” of plastic, such as in crude oil or plastic manufacturing.

Wassenaar et al. (2017) paper looks at a mixture of literature using RIVM reports, expert interviews from RIVM and Rijkswaterstaat and additional literature data. The paper focuses on the presence of ZZS in waste streams for plastics. Based on studies from Danish EPA and Swedish Chemical Agency, they identify 59 ZZS substances which could potentially be present in plastics. The authors present current applications of recycled plastics, a mixture of which are in our scope and not: insulation, carpet padding, office and kitchen products, variety of other products like clothes and footwear, outdoor elements, furniture and design, automotive, agriculture, bags and complements, packaging, construction material. The authors conclude by stressing uncertainty, “actual data on ZZS presence in waste streams are often lacking, because there is no coherent analytical monitoring program for ZZS in waste".

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4.0 Standards

A total of 2198 standards were identified through the search process, of which 114 were considered possibly relevant for more detailed evaluation. The breakdown of the two stages of searching (see section 2.2.3 of the main report) is presented in Table 3 and Table 4.

Table 3: Search results by product category

Product group	Total published standards found	Standards judged potentially relevant
Cosmetics	40	3
Childcare articles	63	2
Motor vehicles	89	8
Furniture	100	2
Toys	41	7
Clothes	33	0
Textile industry	406	22
Electrical Appliances - Household	458	1
Electrical Appliances - ICT	141	0
Communication & Media	0	0

Table 4: Search results by key words

Specific terms searched	Total published standards found	Standards judged potentially relevant
"Recycling"	108	15
"Recycled"	68	21
"Phthalate"	22	12
"Brominated flame retardant"	9	2
"Chlorinated flame retardant"	53	2
"Bisphenol"	7	2
"Formaldehyde"	70	0
"Perfluorinated"	4	2
"Persistent organic pollutant"	12	0
"Heavy metal"	187	5
"Paraben"	0	0
Specific electricals searched	287	8

The 114 potentially relevant standards are listed in Table 5.

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Table 5: All 'potentially relevant' standards

Reference	Standards Description	Category
BS EN 16521:2014	Cosmetics. Analytical methods. GC/MS method for the identification and assay of 12 phthalates in cosmetic samples ready for analytical injection	Cosmetics
BS ISO 22715:2006	Cosmetics. Packaging and labelling	Cosmetics
PD ISO/TR 17276:2014	Cosmetics. Analytical approach for screening and quantification methods for heavy metals in cosmetics	Cosmetics
BS EN 12868:2017	Child use and care articles. Method for determining the release of N-nitrosamines and N-nitrosatable substances from elastomer or rubber teats and soothers	Childcare Articles
PD CEN/TR 13387-2:2018	Child care articles. General safety guidelines. Chemical hazards	Childcare Articles
BS ISO 12219-1:2012	Indoor air of road vehicles. Whole vehicle test chamber. Specification and method for the determination of volatile organic compounds in cabin interiors	Motor Vehicles
BS ISO 12219-2:2012	Interior air of road vehicles. Screening method for the determination of the emissions of volatile organic compounds from vehicle interior parts and materials. Bag method	Motor Vehicles
BS ISO 12219-3:2012	Interior air of road vehicles. Screening method for the determination of the emissions of volatile organic compounds from vehicle interior parts and materials. Micro-scale chamber method	Motor Vehicles
BS ISO 12219-4:2013	Interior air of road vehicles. Method for the determination of the emissions of volatile organic compounds from vehicle interior parts and materials. Small chamber method	Motor Vehicles
BS ISO 12219-5:2014	Interior air of road vehicles. Screening method for the determination of the emissions of volatile organic compounds from vehicle interior parts and materials. Static chamber method	Motor Vehicles
BS ISO 12219-6:2017	Interior air of road vehicles. Method for the determination of the emissions of semi-volatile organic compounds from vehicle interior parts and materials at higher temperature. Small chamber method	Motor Vehicles
BS ISO 12219-9:2019	Interior air of road vehicles. Determination of the emissions of volatile organic compounds from vehicle interior parts. Large bag method	Motor Vehicles
BS ISO 22628:2002	Road vehicles. Recyclability and recoverability. Calculation method	Motor Vehicles
BS EN 15618:2009+A1:2012	Rubber- or plastic-coated fabrics. Upholstery fabrics. Classification and methods of test	Furniture
BS ISO 7617-1:2001	Plastics-coated fabrics for upholstery. Specification for PVC-coated knitted fabrics	Furniture
BS EN 71-10:2005	Safety of toys. Organic chemical compounds. Sample preparation and extraction	Toys

BS EN 71-11:2005	Safety of toys. Organic chemical compounds. Methods of analysis	Toys
BS EN 71-12:2016	Safety of toys. N-Nitrosamines and N-nitrosatable substances	Toys
BS EN 71-2:2020	Safety of toys. Flammability	Toys
BS EN 71-3:1995, BS 5665-3:1995	Safety of toys. Specification for migration of certain elements	Toys
BS EN 71-3:2019	Safety of toys. Migration of certain elements	Toys
BS EN 71-9:2005+A1:2007	Safety of toys. Organic chemical compounds. Requirements	Toys
AMD 15385	BS5808 : 1991 Specification for underlays for textile floor coverings	Textile industry
AMD 15538	BS6810-1 : 1987 Determination of metals in textiles -. Part 2 : Analysis by atomic absorption and colorimetric spectroscopy	Textile industry
BS 6806:2002	Textiles. Determination of formaldehyde. Method for the determination of total and free (water extraction method) formaldehyde using chromotropic acid	Textile industry
BS 6810-2:2005	Determination of metals in textiles. Analysis by atomic emission spectroscopy	Textile industry
BS EN 17130:2019	Textiles and textile products. Determination of dimethylfumarate (DMFu), method using gas chromatography	Textile industry
BS EN 17131:2019	Textiles and textile products. Determination of dimethylformamide (DMF), method using gas chromatography	Textile industry
BS EN 17132:2019	Textiles and textile products. Determination of Polycyclic Aromatic Hydrocarbons (PAH), method using gas chromatography	Textile industry
BS EN 17134:2019	Textiles and textile products. Determination of certain preservatives, method using liquid chromatography	Textile industry
BS EN 17137:2018	Textiles. Determination of the content of compounds based on chlorobenzenes and chlorotoluenes	Textile industry
BS EN ISO 14184-1:2011	Textiles. Determination of formaldehyde. Free and hydrolised formaldehyde (water extraction method)	Textile industry
BS EN ISO 14184-2:2011	Textiles. Determination of formaldehyde. Released formaldehyde (vapour absorption method)	Textile industry
BS EN ISO 14362-3:2017	Textiles. Methods for determination of certain aromatic amines derived from azo colorants. Detection of the use of certain azo colorants, which may release 4-aminoazobenzene	Textile industry
BS EN ISO 16373-2:2014	Textiles. Dyestuffs. General method for the determination of extractable dyestuffs including allergenic and carcinogenic dyestuffs (method using pyridine-water)	Textile industry

BS EN ISO 16373-3:2014	Textiles. Dyestuffs. Method for determination of certain carcinogenic dyestuffs (method using triethylamine/methanol)	Textile industry
BS EN ISO 17881-1:2016	Textiles. Determination of certain flame retardants. Brominated flame retardants	Textile industry
BS EN ISO 17881-2:2016	Textiles. Determination of certain flame retardants. Phosphorus flame retardants	Textile industry
BS EN ISO 18254-1:2016	Textiles. Method for the detection and determination of alkylphenol ethoxylates (APEO). Method using HPLC - MS	Textile industry
BS EN ISO 18254-2:2019	Textiles. Method for the detection and determination of alkylphenol ethoxylates (APEO). Method using NPLC	Textile industry
BS EN ISO 22744-1:2020	Textiles and textile products. Determination of organotin compounds. Derivatisation method using gas chromatography	Textile industry
BS EN ISO 22744-2:2020	Textiles and textile products. Determination of organotin compounds. Direct method using liquid chromatography	Textile industry
PD CEN/TR 16741:2015	Textiles and textile products. Guidance on health and environmental issues related to chemical content of textile products intended for clothing, interior textiles and upholstery	Textile industry
PD ISO/TR 17881-3:2018	Textiles. Determination of certain flame retardants. Chlorinated paraffin flame retardants	Textile industry
PD CLC/TS 50574-2:2014	Collection, logistics & treatment requirements for end-of-life household appliances containing volatile fluorocarbons or volatile hydrocarbons. Specification for de-pollution	Electricals
BS EN 17206:2020	Entertainment technology. Machinery for stages and other production areas. Safety requirements and inspections	Electricals
BS EN 60728-11:2017	Cable networks for television signals, sound signals and interactive services. Safety	Electricals
BS EN 60728-11:2017+A11:2018	Cable networks for television signals, sound signals and interactive services. Safety	Electricals
BS EN 60728-4:2008	Cable networks for television signals, sound signals and interactive services. Passive wideband equipment for coaxial cable networks	Electricals
BS EN 60728-5:2016	Cable networks for television signals, sound signals and interactive services. Headend equipment	Electricals
BS EN 60728-6:2011	Cable networks for television signals, sound signals and interactive services. Optical equipment	Electricals
BS EN 62028:2004	General methods of measurement for digital television receivers	Electricals
BS EN 62216:2011	Digital terrestrial television receivers for the DVB-T system	Electricals
111/574/NP , PNW 111-574:	General method for assessing the proportion of reused components in products	Recycling
111/610/NP , PNW 111-610 ED1	Sustainable management of waste electrical and electronic equipment (e-waste).	Recycling
88/800/NP	Decommissioning and preparation for recycling	Recycling

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BS EN 13430:2000	Packaging. Requirements for packaging recoverable by material recycling	Recycling
BS EN 13430:2004	Packaging. Requirements for packaging recoverable by material recycling	Recycling
BS EN 15343:2007	Plastics. Recycled plastics. Plastics recycling traceability and assessment of conformity and recycled content	Recycling
BS EN 17410	BS EN EN Plastics - Controlled loop recycling of post-consumer (or post-use) PVC-U windows and doors	Recycling
BS ISO 17098:2013	Packaging material recycling. Report on substances and materials which may impede recycling	Recycling
BS ISO 22451	Rare earth -- Elements recycling -- Measurement method of rare earth elements in by-products and industrial wastes	Recycling
BS ISO 7001:2007/Amd 108	PI PF 082: Recycling - Plastics	Recycling
CEN/TC 249 N 2339,	Plastics Ã,- Environmental Aspects Ã,-Vocabulary	Recycling
PD CEN/TR 13688:2008	Packaging. Material recycling. Report on requirements for substances and materials to prevent a sustained impediment to recycling	Recycling
PD CEN/TS 17045:2017	Materials obtained from end of life tyres. Quality criteria for the selection of whole tyres, for recovery and recycling processes	Recycling
PD CEN/TS 17045:2020	Materials obtained from end-of-life tyres. Quality criteria for the selection of whole tyres, for recovery and recycling processes	Recycling
PD ISO/TR 23891:2020	Plastics. Recycling and recovery. Necessity of standards	Recycling
111/610/NP , PNW 111-610 ED1	Sustainable management of waste electrical and electronic equipment (e-waste).	Recycled
BS EN 15342:2007	Plastics. Recycled plastics. Characterization of polystyrene (PS) recyclates	Recycled
BS EN 15343:2007	Plastics. Recycled plastics. Plastics recycling traceability and assessment of conformity and recycled content	Recycled
BS EN 15344	Plastics - Recycled plastics - Characterization of Polyethylene (PE) recyclates	Recycled
BS EN 15344:2007	Plastics. Recycled plastics. Characterization of polyethylene (PE) recyclates	Recycled
BS EN 15345:2007	Plastics. Recycled plastics. Characterization of polypropylene (PP) recyclates	Recycled
BS EN 15346:2007	Plastics. Recycled plastics. Characterization of poly(vinyl chloride) (PVC) recyclates	Recycled
BS EN 15346:2014	Plastics. Recycled plastics. Characterization of poly(vinyl chloride) (PVC) recyclates	Recycled
BS EN 15347:2007	Plastics. Recycled Plastics. Characterization of plastics waste	Recycled

BS EN 15348:2007	Plastics. Recycled plastics. Characterization of poly(ethylene terephthalate) (PET) recyclates	Recycled
BS EN 15348:2014	Plastics. Recycled plastics. Characterization of poly(ethylene terephthalate) (PET) recyclates	Recycled
BS EN 17410	BS EN EN Plastics - Controlled loop recycling of post-consumer (or post-use) PVC-U windows and doors	Recycled
BS ISO 5677	Testing and characterization of mechanically recycled Polypropylene (PP) and Polyethylene (PE) for intended use in different plastics processing techniques	Recycled
CEN/TC 249 N 2540, Revision of EN 15346:2014	Plastics Recycled plastics Characterization of poly(vinyl chloride) (PVC) recyclates	Recycled
CEN/TC 249 N 2734, Revision of EN 15346:2014	Plastics Â Recycled plastics Â Characterization of poly(vinyl chloride) (PVC) recyclates	Recycled
ISO/NP 5677,	Testing and characterization of mechanically recycled Polypropylene (PP) and Polyethylene (PE) for intended use in different plastics processing techniques	Recycled
PD CEN/TS 16010:2013	Plastics. Recycled plastics. Sampling procedures for testing plastics waste and recyclates	Recycled
PD CEN/TS 16010:2020	Plastics. Recycled plastics. Sampling procedures for testing plastics waste and recyclates	Recycled
PD CEN/TS 16011:2013	Plastics. Recycled plastics. Sample preparation	Recycled
PD CEN/TS 16861:2015	Plastics. Recycled plastics. Determination of selected marker compounds in food grade recycled polyethylene terephthalate (PET)	Recycled
PD CEN/TS XXX	Plastics - Recycled plastics - Determination of solid contaminants content	Recycled
BS EN 15777:2009	Textiles. Test methods for phthalates	Specific chemical searches
BS EN 62321-3-3 Ed.1.0	Determination of certain substances in electrotechnical products Part 3-3: Screening of polybrominated biphenyls, polybrominated diphenyl ethers and phthalates in polymers by pyrolysis (Py-GC-MS) or thermal desorption (TD-GC-MS) gas chromatography-mass spectrometry. .	Specific chemical searches
BS EN 62321-8:2017	Determination of certain substances in electrotechnical products. Phthalates in polymers by gas chromatography-mass spectrometry (GC-MS), gas chromatography-mass spectrometry using a pyrolyzer/thermal desorption accessory (Py/TD-GC-MS)	Specific chemical searches
BS EN IEC 62321-12	Determination of certain substances in electrotechnical products. - Part 12: Simultaneous determination â€“ Polybrominated biphenyls, polybrominated diphenyl ethers and phthalates in polymers by gas chromatography-mass spectrometry	Specific chemical searches

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BS EN IEC 62321-3-4	Determination of certain substances in electrotechnical products. - Part 3-4: Screening of Phthalates in polymers of electrotechnical products by Fourier transform infrared spectroscopy (FT-IR), high performance liquid chromatography with ultraviolet detector (HPLC-UV) and thermal desorption mass spectrometry (TD-MS)	Specific chemical searches
BS EN ISO 14389	Textiles -- Determination of the phthalate content -- Tetrahydrofuran method	Specific chemical searches
BS EN ISO 14389:2014	Textiles. Determination of the phthalate content. Tetrahydrofuran method	Specific chemical searches
BS EN ISO 16181-1	Footwear -- Critical substances potentially present in footwear and footwear components. Part 1: Determination of phthalate with solvent extraction	Specific chemical searches
BS EN ISO 16181-2	Footwear -- Critical substances potentially present in footwear and footwear components. Part 2: Determination of phthalate without solvent extraction	Specific chemical searches
BS ISO 8124-6	Safety of toys. Part 6: Certain phthalate esters in toys and children's products	Specific chemical searches
CEN/TC 351 N 912, Conversion of CEN/TS 17332	'Construction products: Assessment of release of dangerous substances - Analysis of organic substances in eluates'	Specific chemical searches
DD CEN ISO/TS 16181:2011	Footwear. Critical substances potentially present in footwear and footwear components. Determination of phthalates in footwear materials	Specific chemical searches
BS EN 16377:2013	Characterization of waste. Determination of brominated flame retardants (BFR) in solid waste	Specific chemical searches
BS EN ISO 17881-1:2016	Textiles. Determination of certain flame retardants. Brominated flame retardants	Specific chemical searches
111/563/NP , PNW 111-563:	Determination of certain substances in electrotechnical products - Part 13: Bisphenol A in plastics by liquid chromatography-diode array detection (LC-DAD), liquid...	Specific chemical searches
BS IEC 62321-13 Ed.1.0	Determination of certain substances in electrotechnical products â€“ Part 13: Bisphenol A in plastics by liquid chromatography-diode array detection (LC-DAD), liquid chromatography-mass spectrometry (LC-MS) and liquid chromatography-tandem mass spectrometry (LC-MS/MS)	Specific chemical searches
BS EN ISO 22818:2021	Textiles -- Determination of short-chain chlorinated paraffins (SCCP) and middle-chain chlorinated paraffins (MCCP) in textile products out of different matrices by use of gas chromatography negative ion chemical ionization mass spectrometry (GC-NCI-MS)	Specific chemical searches
PD ISO/TR 17881-3:2018	Textiles. Determination of certain flame retardants. Chlorinated paraffin flame retardants	Specific chemical searches

BS EN ISO 24640	Footwear -- Critical substances potentially present in footwear and footwear components -- Test method for quantitatively determine perfluorinated compounds (PFC) in footwear materials	Specific chemical searches
ISO/NP 24640 - ISO/TC 216 N 825	Footwear -- Critical substances potentially present in footwear and footwear components -- Test method for quantitatively determine perfluorinated compounds (PFC) in footwear materials	Specific chemical searches
BS EN ISO 21392	Cosmetics -- Analytical methods -- Measurement of traces of heavy metals in cosmetic finished products using ICP/MS technique	Specific chemical searches
BS ENISO 23352	Footwear -- Critical substances potentially present in footwear and footwear components -- Determination of heavy metals in footwear materials	Specific chemical searches
ISO/TC 61/SC 5 N 2097, ISO/NP 5134	Plastics - Sample Preparation for Heavy Metal determination and Digestion in Closed Pressure Vessels	Specific chemical searches
PD CEN/TR 13695-2:2019	Packaging. Requirements for measuring and verifying the four heavy metals and other dangerous substances present in packaging, and their release into the environment. Requirements for measuring and verifying dangerous substances present in packaging, and their release into the environment	Specific chemical searches
PD ISO/TR 17276:2014	Cosmetics. Analytical approach for screening and quantification methods for heavy metals in cosmetics	Specific chemical searches

5.0 Safety Gate Analysis

5.1 Detailed methodology

The Safety Gate portal documents each individual product alert and produces regular reports of product alerts. As these alerts reach the many thousands, a quantitative analysis was undertaken. This process and necessary data transformations are discussed in this section.

5.1.1 Data Extraction

The Safety Gate site does have a statistical analysis tool, however a brief exploration of this tool suggested that analysis is only possible at a high level (e.g. comparing countries reporting, or type of hazard). This was considered insufficient for our purposes. As a result, the reduced dataset was extracted into Microsoft Excel using the extraction tool on the EU Safety Gate website for further analysis. This was done with the following filters applied:

- Product category list matching the product categories set out in section 1.3 of the main report
- All reporting countries
- All countries of origin
- Chemical risk type only
- All alert types
- Consumer product user
- Reports from every year available, which cover the calendar years 2005-2021

The data was extracted in March 2021. The results from this search, by product group, are displayed in Table 6.

Table 6: Safety Gate product alerts by product category

Category	Number of alerts
Toys	2907
Clothing, textiles and fashion items	1001
Childcare articles and children's equipment	117
Electrical appliances and equipment*	32
Motor vehicles	13
Furniture	8
Cosmetics	2048
Total	6126

This shows that by some distance the product groups with the most alerts raised are toys, clothes and cosmetics.

Despite a large number of alerts, Cosmetics were not included in the final dataset. Our analysis is interested in recycled products, therefore it is the cosmetic *packaging* rather than the cosmetic *product* which is of interest: e.g. the shampoo bottle, not the shampoo liquid, as the latter is unlikely to face possible recycling-based contamination. However, chemical alerts reported by member states for cosmetics do not distinguish between the two. From a brief random sample of 20 cosmetic reports in the extracted dataset, all described chemical hazard concerns with the product itself rather than its packaging. Since none of the random sample included mention of the packaging, where recycling-based contamination would be more of a concern, it was considered prudent to exclude cosmetics from further analysis. A separate analysis of cosmetics was carried out to see the profile of chemicals in the alerts, as in some cases this could be due to migration from packaging. To avoid confusion, the analysis of cosmetics is presented separately in section 5.3. All future analysis applies only to the dataset listed in Table 6 but not containing cosmetics, in which the final number of alerts was 4,078.

5.1.2 Limitations of the Safety Gate data format

Product reports on Safety Gate are not conducive to quantitative analysis of thousands of results. Whilst some descriptive statistics such as the type of report, the country submitting the report and the origin country of the product are standardised, two key fields appear to have a very low level of standardisation:

- The ‘Product’ field
- The ‘Risk’ field

The ‘Product’ field had every unique value extracted into a single list. From analysing this list it appears that the reporting process may involve open text boxes rather than selections. To give an example in our sample, within the ‘Product’ field, the term ‘Plastic doll with accessories’ appears 58 times, ‘Plastic dolls’ 40 times and ‘Plastic doll’ 30 times. In some cases, likely due to formatting or the number of blank spaces input, the seemingly exact same term appeared on multiple occasions in the unique value extraction: ‘Doll’ alone appears at least three times in the list of unique values.

The ‘Risk’ field, similarly, appears to be the documentation of a free text box for those submitting alerts. A first significant problem is that of whether a description exists or not: only 2,190 of the 4,078 (54%) had any information input at all. It is in this field that key information regarding the toxic chemicals identified are described, as well as regulations which the product is in contravention of. As a result, for 46% of the dataset it is not clear what the risk is other than that it is a serious chemical risk. This is a substantial limitation on any conclusions drawn from the Safety Gate dataset.

For the 54% which do have information, it is highly inconsistent. Due to extracting reports from a 16 year time frame, regulations have evolved and it is likely that the method of documentation has evolved as well. This leads to often incomparable documentation. To take some examples from the toys category, some product reports use phrases such as ‘According to the REACH regulation, certain phthalates in toys are prohibited’, others use phrases such as ‘The product does not comply with the Toys Directive’, others mention an analyte which is ‘banned in toys’.

As well as an inconsistency in describing relevant regulations, there is an inconsistency in how analytes are described. For example: 5 product reports were identified which used the chemical symbol Pb but *not* the word ‘lead’. Similarly, 139 reports were identified which used the word ‘lead’ but *not* the symbol Pb. 19 reports use *both* in the ‘Risk’ field.

These inconsistencies and the very substantial data gap make meaningful quantitative analysis for the data difficult. As a result, the analysis can only be considered to give a broad indication of toxic chemical hazards and should not be considered precise, as searches may have missed alternative ways of documenting the same information – if information was documented at all.

5.1.3 Data transformation and extraction

To address issues related to data quality (see section 5.1.2), some data was transformed into more usable formats for quantitative analysis.

5.1.3.1 Product standardisation

Of the total 4,078 product alerts, 3,986 (98%) contain some detail in the 'Product' field (Figure 1).

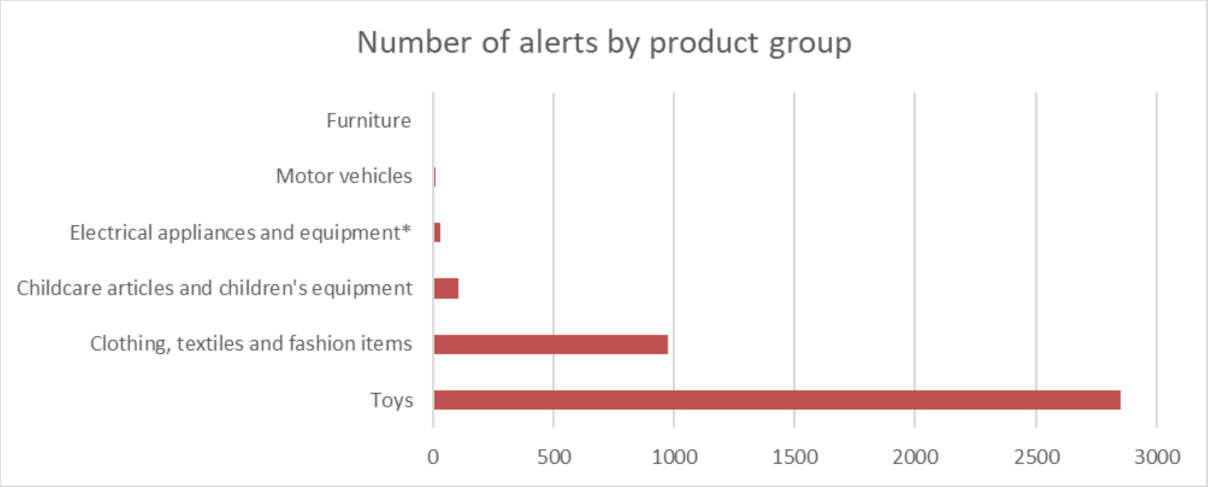

Figure 1: Safety Gate alerts with product details, by product category

This was considered sufficient coverage that analysis of the product field would be worthwhile. In order to overcome inconsistencies and similar products being written in slightly different ways, products were given an additional code which corresponds to product groups. The aim was for product groups to sit between product descriptions and product categories. For example: 'Gloves' would constitute the product description and 'Clothing, textiles and fashion items' the product category. An additional grouping of 'Accessories' would allow 'Gloves' to be grouped with other similar items: 'Children's gloves', 'Leather gloves', 'Belt' and so on.

All unique product terms were extracted into a single list (n=1,996). These were then reviewed for common product groups against which they could be coded, grouped by the overarching product category. The higher-level product categories and their associated product groups are listed Table 7. This also shows the number of alerts registered to that product group in the main database table.

Discounting the incorrectly labelled items and those alerts without product descriptions, the final sample of grouped products is 3,983.

Table 7: Safety Gate alerts, by detailed product group

Product Category	Product Groups	Alerts
Toys	Doll	1189
	Puzzle	37
	Balloon	57
	Craft	315
	Inflatable	125
	Non-figurine toy	833

	Soft toy	122
	Sports and balls	55
	Fancy Dress	98
	Other Toy	22
Childcare articles and children's equipment	Furniture	49
	Bib	29
	Soothers and bottles	15
	Textiles and clothes	9
	Other childcare	2
Electrical appliances and equipment*	Headset & Speakers	7
	Power bank & charging	7
	Other electronic	16
Furniture	Chair or sofa	8
Motor vehicles	Fabric or interior	5
	Car part	6
	Other motor	2
Clothing, textiles and fashion items	Footwear	485
	Jackets and rainwear	36
	Scarves	45
	Trousers, jeans, shorts	51
	Hats	12
	Tops	34
	Dresses and skirts	28
	Suits, tracksuits, overalls and pyjamas	18
	Bags	20
	Non-clothing textile	30
	Other clothes	7
	Underwear	21
	Accessories	188
All	Other incorrectly labelled	3

Due to the substantial variation in detail of the existing ‘Product’ field, grouping was done by the authors’ best judgement and broadly in line with the materials used and the final product’s qualities. This will be an imperfect science and there will be many different ways the products could have been grouped based on the desired level of granularity. As this analysis is intended to be a quick overview of chemical hazard issues in Safety Gate, 36 categories were considered sufficient to get a more nuanced picture within the project’s resources and timeframes.

Most of the categories should be self-explanatory, but some may benefit from additional clarification:

- In the ‘Toys’ category, the ‘Doll’ refers to any product which was described as a ‘doll’ or ‘figurine’ and are typically assumed to be made of soft or hard plastic. Some are explicitly made of wood, many more do not specify the product. Where a doll was described as a ‘rag doll’, ‘plush doll’ or similar it was grouped in ‘soft toy’, to indicate a toy more likely to be made of textile and with a soft interior.
- ‘Non-figurine toy’ refers to other, typically hard or soft plastic toys which do not depict human figurines, such as animal figurines, vehicles, buildings, implements such as guns or spades, and so on. Plastic toys for bathing such as rubber ducks were included here.
- ‘Craft’ was used for creative and artistic toys, including pens, pencils and crayons, clay and other sculpting putties, along with slime toys. Plastic string for braiding, such as scoubidou was classified here.
- ‘Inflatable’ refers primarily to inflatable balls such as swimming equipment, beach balls etc. but was considered discrete from products described as ‘balloons’ – whilst also inflatable, balloons typically differ in material from, say, swimming bands.
- In the ‘Childcare articles and children’s equipment’, the group ‘Furniture’ refers to all baby chairs, seats, strollers, changing mats and so on.
- In ‘Motor vehicles’ section, ‘Fabric or interior’ refers to optional components possibly made of plastic or textile and used inside the car: steering wheel covers, for example. References to an entire car, or its mechanical part – such as the clutch – were classified as car part.
- In ‘Clothing, textiles and fashion items’ a number of non-clothing items were recorded, such as pillowcases or bedspreads. It is likely these constitute incorrect labelling and should be elsewhere, however since still being made of the broad material of interest (textiles) they are not excluded but rather considered a product group within clothing.
- In a small number of cases, it appears as though the item has been incorrectly labelled: a child’s BMX bike in ‘childcare articles’ rather than ‘toys’, a bicycle repair kit in ‘Electrical appliances’ etc. – these have been classified as incorrectly labelled. Only 3 such errors were identified and removed from the sample.

5.1.3.1.1 **Electrical appliances and equipment**

As discussed in the main report (see section 2.3.3.2.4), electrical appliances had only a small number of alerts identified. There were few meaningful groups of products, with the three being identified as ‘headset & speakers’, ‘power bank & charging’ and ‘other electronic’.

In the ‘Power bank & charging’ six of the seven alerts relate to power banks. All six of these relate to the same product: Luxembourg made six different alerts regarding the ‘Amazon basics’ power bank due to the risk of battery overheating, exploding or leaking. This suggests one defective product, or even one defective batch, rather than a problem with power banks more generally, and is clearly related to the battery rather than the possibility of recycled chemicals in the casing.

The ‘Other electronic’ group forms the largest product group. This is because there is no other clear trend of what unites these products other than being small electric and electronic goods. Only two items (e-cigarette and alarm clock) are duplicated within the ‘Other’ products, all others appear in the Safety Gate alerts only once. A number of these products (popcorn maker, electric heater, steam iron) deal with high temperatures, but this does not necessarily constitute a trend as others (water pocket calculator; nose hair trimmer) do not explicitly deal with heat. The full list of products in the 'other' group was as follows:

- Digital multimeter
- Carbon monoxide alarm
- Digital alarm clock
- Alarm clock
- E-cigarette
- Single-use electronic cigarette
- Electric heater
- Steam iron
- Popcorn maker
- Electric nose hair trimmer
- Electric tea maker
- Water pocket calculator
- Camera

Only two of the alerted products had an EU* origin country. Both fall in the 'Other electronic' category.

5.1.3.2 **Analyte extraction**

Of the total 4,078 product alerts, 2,190 (54%) contain information in the 'Risk' field. It is in this field that chemical risks are described, in particular information pertaining to the chemical of concern, its abundance and potentially relevant regulations. It is unclear *why* such a large share (46%) of alerts do not have information submitted in the 'Risk' field: these cases only include descriptions of the product and document that it is a serious chemical concern, but no more information. This rather substantial data gap is a serious limitation of the analysis of analyte information from Safety Gate.

All alerts with no 'Risk' information were filtered out, leaving a sample of 2,190. Due to the 'Risk' field being an open text data format, it was possible that there would be many different ways of writing the same information – as evidenced by the example of whether lead is written as 'lead', 'Pb' or both (section 5.1.2). In order to analyse this variable text, searches were conducted to identify the use of certain words, whereby for each analyte group of focus, a list of keywords was identified. These are listed in full in section 5.2. Where possible, searches were conducted for common variants in ways of describing the same thing: 'TBBPA *and* 'TBBP-A' were searched separately, for example, 'Chromium' was searched as 'Chromium', 'Cr' and 'Chrome'. Note that the heavy metals Arsenic (As) and Beryllium (Be) were searched only as full names, not as chemical symbols, as search by symbol lead to a substantial number of errors where other words including As or Beryllium (Be) were identified, significantly inflating the suggested presence. In all other cases, the chemical symbol was detected less frequently than the metal's name, so these searches were retained.

New binary variables were added to the database for each search term used, indicating its presence or lack thereof in the corresponding 'Risk' field. These values were then grouped by analyte, with another new binary variable introduced for each analyte group. Each alert was assigned to these groups on the basis that *at least one* search term in that analyte category was identified in the 'Risk' text. This was done to avoid double counting. For example, the 'Risk' box could contain the phrase 'this product contains the phthalate DIDP'. Both *phthalate* and *DIDP* were search terms, which was needed to account for alerts which only used one of these phrases (e.g. 'this product contains phthalates above legal limits' or 'this product contains DIDP'). This phrase would therefore return two counts of mentions in the 'phthalates' group. If 'phthalates' = 2, because 2 > 0, this alert would be classified as having mention of phthalates.

This process was repeated for each of the focus analyte groups. Some product alerts contain mention of more than one focus analyte. To avoid double counting, a separate binary value was calculated to distinguish those alerts where *at least one* analyte group was identified and where no focus analytes were identified.

Note that that search function used returned non-exact matches, in an attempt to capture alternate uses or descriptions of certain analytes. This, and the possibility of unexpected phrases which include the acronyms used for certain chemicals, means that the analyte search process can only be considered a rough analysis. The data format is not suited for quantitative analysis at this level of detail. However, it should be sufficiently accurate to give a broad overview of analytes and products of interest.

5.2 Safety Gate search terms

The below terms were the search terms used in the 'Risk' field of Safety Gate to determine possible analytes, as described in section 5.1.3.2.

Table 8: Safety Gate analyte search terms

Analyte group	Search term
Phthalates	phthalate
	DEHP
	DMP
	DEP
	DINP
	DIBP
	DNOP
	DIDP
	DBP
	BBP
Persistent Organic Pollutants (POPs)	POPs
	aldrin
	chlordane
	dieldrin
	endrin
	heptachlor
	mirex
	toxaphene
	furan
	hexachlorobenzene
	PCB
	DDT

	dioxin
Heavy Metals	Heavy metal
	Arsenic
	Beryllium
	Cadmium
	Cd
	Chromium
	Cr
	Chrome
	Lead
	Pb
	Mercury
	Hg
	Antimony
	Sb
Perfluorinated chemicals	PFAS
	PFNA
	PFHxS
	PFHxA
	PFH
	PFDA
	PFBS
	PFOS
	PFOA
	Perfluorinated
	Perfluoro
Parabens	paraben
	banxylparaben
	butylparaben
	ethylparaben
	isobutylparaben
	isopropylparaben
	methylparaben
	propylparaben
Formaldehyde	Formaldehyde
Bisphenols	Bisphenol
	BPA
	BPF
	BPS
Flame retardants	Flame retardant
	BFR
	Bromine
	PBDE
	BDE
	PentaBDE
	Penta-BDE
	OctaBDE
	Octa-BDE

	DecaBDE
	Deca-BDE
	HBCD
	HBCDD
	TBBPA
	TBBP-A
	SCCP
	MCCP
	DBDPE
	DP
	PBDD
	TPP
	TCPP
	OPFR
Non-focus analyte	PAH
	nitrosamine
	DMF
	Azo-dye
	Azodye
	Azo dye
	Azo colours
	Azo colors
	Azo
	Benzene
	acetophenone
	barium
	copper sulphate
	ferrous sulphate
	sodium carbonate
	potassium iodide
	calcium hydroxide
	Battery
	Batteries
	batter
	Boron
	Talc
	Talcum

5.3 Safety Gate Cosmetics Analysis

A separate analysis of the Safety Gate cosmetics alerts was undertaken to identify if there were any trends regarding the products or chemicals of concern which regularly arise, which may indicate the source of contamination. In particular, the presence of contaminants which we would not expect to be related to the cosmetic product itself could suggest migration or leaching from packaging. The cosmetics analysis essentially repeated the process described in Section 5.1 but only for Safety Gate alerts with the product category 'Cosmetics'. The data was taken in the same download so the search parameters of all years and all reporting countries available were also used here.

The Cosmetics data download contained 2,048 alerts in total. These products came from 62 different countries of origin. The origin countries are particularly interesting for having a notably different distribution to other consumer products. The top ten origin countries are presented in Table 9.

Table 9: Cosmetics alert by origin country

Origin countries	Number of alerts
People's Republic of China	280
United States	266
Unknown	196
Ivory Coast	188
Pakistan	100
France	84
Italy	82
United Kingdom	78
India	68
Turkey	64

Whilst China remains the biggest source country, it is far more evenly spread than in the wider product groups of focus: some 14% of cosmetics with safety alerts came from China, comparable to the 13% from the USA. 10% had an unknown country of origin.

5.3.1 Product groups

The process outlined in section 5.1.3.1 was followed for Cosmetics to establish nine product groups within the category. The number of alerts which had information in the 'product' field was 1,960. Of the 88 which did not have 'product' information, 83 had sufficient information in another field to ascertain what the product was and manually assign it to a group. As a result, the final sample of product-group-classified alerts was 2,043.

Table 10: Cosmetics alerts by product group

Product groups	Number of alerts
Hair products	334
Skin cream/lotion/oil	926
Dental products	122
Makeup	218
Shower / bath / soap / cleanser	92
Nail polish and related	182
Fragrance	97
Wipes	48
Misc.	24

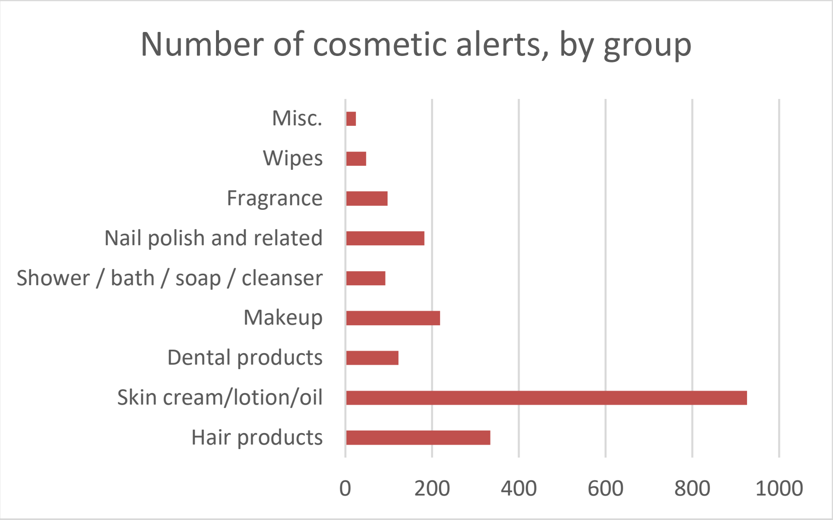

Figure 2: Distribution of cosmetic alerts by product group

By some distance, the largest product group was relating to creams, lotions, oils etc. which are applied to the skin. Whilst classifying the products, it was noticed that many of the products related to skin lightening creams. As a result, a search was undertaken for the number of alerts in the 'Skin cream/lotion/oil' category which also contained the term 'whiten', 'lighten' or 'bleach'. In this category, 578 alerts contained at least one of those three terms. This amounts to 62% of skin cream/lotion/oil alerts known to relate to skin lightening products. Otherwise expressed, skin lightening products are estimated to make up 28% of all chemical alerts in the Cosmetics category.

This is a notable finding for two reasons. Firstly, it indicates that there are systemic problems related to the production of skin lightening products, which are found to be regularly in contravention of chemical limits. This is not, however, a new finding, and many are known to be illegal and treated accordingly (Khan, 2018). Secondly, this finding points to a concerning problem worldwide. Skin lightening is expected to nearly double its value worldwide from 2017-2027 (Statista, 2020) and are most commonly used in African, Asian and Caribbean nations (World Health Organization, 2019). Safety Gate relates to alerts raised in European consumer markets. The fact that 28% of all cosmetic-related chemical alerts in Europe are related to skin-lightening would suggest that, in regions where these products are more commonly used, the scale of the risk is much larger.

5.3.2 Analytes

The process described in section 5.1.3.2 was repeated for the Cosmetics category. Of the total Category, 920 (45%) of the alerts had no information in the 'Risk' box, leaving a sample which could be analysed for information with 1,128 alerts.

were searched for in the 'Risk' box. 432 alerts (38%) had at least one of these analytes mentioned. The remaining 62% were filtered through to identify other common chemicals mentioned in 'Risk' descriptions. The additional search terms are listed in Table 11:

Table 11: Number of cosmetic alerts by search term

Search term	**Number of alerts containing term**
Methylchloroisothiazolinone	78
Methylisothiazolinone	110
Methyldibromo glutaronitrile	24
hydroquinone	172
N-nitrosodiethanolamine	54
Basic	16
Red	16
Yellow	20
Blue	12
CI	14
pigment	2
color	4
diethylene glycol	42
bimatoprost	10
bishydroxyethyl biscetyl malonamide	12
glucocorticoid	20
glucocort	24
cholecalciferol	8
p-phenylenediamine	34
mistaken	12
confused	4
food	18
acid	58
diamine	50
hexyl cinnamal	36
linalool	32
d-limonene	30
citronellol	34
geraniol	30
hydroxycitronellal	18
benzyl salicylate	24
lidocaine	4
nitromusk	4

For the most part these relate to specific chemicals, with the exception of “Basic”; “ red”; “ yellow”; “ blue”; “ CI “; “pigment” and “color” which relate to dyestuffs mentioned in different formats[8], and “mistaken”, “confused” and “food” which relate to alerts highlighting how a product may be mistakenly ingested as a foodstuff.

The search terms in section 5.2 and Table 11 account for 1026 alerts, of 91% of the alerts with information in the Risk field. The other 9% appeared to be chemicals mentioned only once so were not further analysed.

5.3.2.1 Focus analyte results

A total of 406 (36%) of alerts were identified to mention at least one focus analyte. This was distributed between the focus analyte groups as follows:

Table 12: Cosmetic alerts by focus analyte group

Analyte group	Number of alerts	Share of alerts with a focus analyte
Phthalate	98	24%
Other POPs	2	0%
Heavy metals	284	70%
Perfluorinated chemicals	0	0%
Parabens	10	2%
Formaldehyde	22	5%
Bisphenols	0	0%
Flame retardants	0	0%

Note that the sum of the number of alerts will not necessarily equal 406 as some alerts may mention multiple analytes. As a result, the shares will sum to above 100%. Some POPs are in multiple categories and may be classified in a different category. The list of categories and search terms is detailed in section 5.2.

There are both commonalities and differences between the cosmetics group and the wider product groups of focus (see section 2.3.3 of the main report). Perfluorinated chemicals and bisphenols again have no mentions, which may suggest either that they are not of concern in consumer products, there is insufficient testing for them or that there are limitations in the search terms employed here. Unlike wider consumer goods, flame retardants appear in none of the Cosmetic alerts, which would suggest either that they are not present in cosmetics or that they are not being tested for. Phthalates appear in both categories but represent a much smaller share of alerts with focus analytes than for other consumer goods. By some distance, the most

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[8] *The spaces within the quotation marks are purposeful, and were used to identify when that word had been used in isolation and avoid capturing when that sequence of letters was used in a longer word.*

represented analyte group is heavy metals, with 284 alerts, some 70% of the alerts with focus-analytes. As a share of the total chemical alert sample, 25% mention heavy metals.

Table 13: Cosmetics alerts by heavy metal search term

Search term	Number of alerts
Heavy metal	8
Arsenic	8
Beryllium	0
Cadmium	4
Cd	0
Chromium	10
Cr	92*
Chrome	0
Lead	116
Pb	4
Mercury	88
Hg	0
Antimony	8
Sb	6

*This result should be treated with some caution. In the main analysis, the number referring to ‘chromium’ or ‘chrome’ outnumbered ‘Cr’, giving some confidence that the ‘Cr’ search was not picking up terms accidentally due to being a slightly imprecise functionality. The fact that ‘chrome’ is not mentioned at all and ‘chromium’ just ten times suggests that this is identifying other uses of ‘Cr’ which do not in fact refer to chromium.

Looking in more detail at the heavy metal search terms, the most common contaminants are lead and mercury, which are present in 41% and 31% of the heavy metals references respectively. These are considered in more detail to see the product groups in which they arise.

Table 14: Lead and mercury cosmetics alerts by product group

Product group	Lead	Mercury
Hair products	10	0
Skin cream/lotion/oil	28	88
Dental products	2	0
Makeup	66	0
Shower / bath / soap / cleanser	4	0
Nail polish and related	4	0

Fragrance	2	0
Wipes	0	0
Misc.	0	0
Total	116	88

Every reference to mercury was in a skin product. This is consistent with their use in skin-lightening products, a cause for concern for the WHO (World Health Organization, 2019). 72 of the products including mercury (82%) were explicitly described as for skin-lightening purposes.

Lead is present in more product groups. However, it is predominantly observed in makeup. This is consistent with previous findings of lead being common in lipstick in particular (Campaign for Safe Cosmetics, 2021). It is also known to be found in hair products, particularly dyes (US FDA, 2020). Its appearance in some skin creams, lotions and oils is less clear however and may suggest accidental contamination.

Within the phthalates product group, 94 alerts used the term ‘phthalate’ directly, but very few referenced a specific substance. The only particular phthalate to be mentioned in more than four alerts was DBP, which was present in 36 alerts.

5.3.2.2 Non-focus analyte results

702 of the alerts (62%) had mention of at least one identified analyte which was not a focus analyte. Of the non-focus analytes identified in section 5.2, only three were identified in any alerts: nitrosamine in 18 alerts, boron in ten and barium in four. None of the others were mentioned, demonstrating a sharp difference between cosmetic and non-cosmetic product categories outside of the focus analytes. The number of alerts per search term can be viewed in Table 11.

The most commonly recurring chemicals were: hydroquinone (172 alerts); Methylisothiazolinone (110 alerts) and Methylchloroisothiazolinone (78 alerts). All others had fewer than 60 alerts related to them.

Hydroquinone is a skin-lightening agent. As a result, it is associated with skin lightening products. 154 hydroquinone alerts (90%) were associated with products in the skin cream/lotion/oil category. The remaining 18 were spread across hair products (6), makeup (4), shower / bath / soap / cleansing (4) and nail polish and related (4). 100 of hydroquinone alerts (58%) explicitly described themselves as skin-lightening products. The fact that 42% were not described as lightening but contained a lightening agent above legal limits would suggest that the share of chemical alerts related to skin lighteners may be even higher than is suggested in section 5.3.1.

Methylisothiazolinone (MI) and Methylchloroisothiazolinone (MCI) are preservatives found in liquid cosmetics, and were overwhelmingly found together: no product alerts contained MCI but not MI, but 32 contained MI and not MCI. This explains their very similar distribution across product groups: MI and MCI alerts were made up by 22%-21% hair products and 58%-62% skin cream/lotion/oil respectively.

Table 15: MCI and MI cosmetic alerts by product group

Product group	Methylchloroisothiazolinone (MCI)	Methylisothiazolinone (MI)
Hair products	16	24
Skin cream/lotion/oil	48	64

Dental products	0	0
Makeup	2	2
Shower / bath / soap / cleanser	2	6
Nail polish and related	0	2
Fragrance	0	0
Wipes	8	8
Misc.	2	4
Total	78	110

This suggests that the non-focus analytes which were most commonly reported in cosmetics are both known and expected, and are related to the cosmetic product rather than possible migration from packaging.

5.3.3 Summary

This section offers a brief overview of the Cosmetics category in Safety Gate, which was analysed separately from wider products. It was analysed both in terms of which product groups occur most regularly in Safety Gate alerts and which analytes appear in the most alerts.

2,043 product alerts with information sufficient to group the product were considered. In this group, cosmetics applied to the skin, such as creams and lotions, account for 45% of all alerts, making them by distance the largest group: next was hair products and makeup, with 16% and 11% of alerts respectively.

Within skin creams, 578 alerts (62% of the product group) were products explicitly described as for the purposes of skin lightening. 28% of all cosmetics alerts related to skin-lightening cosmetics, suggesting this is a product group of particular concern. A large number of hydroquinone alerts were identified of which only 58% explicitly described themselves as skin-lightening products, suggesting that the share of alerts which relate to products of this nature is even larger than indicated here.

1,128 product alerts (55%) had information in the Risk field, allowing analysis of the analytes present. The analytes of focus in this study were mentioned in 36% of this sample. Of these, the most commonly mentioned groups were heavy metals (284 alerts) and phthalates (94 alerts). No alerts mentioned perfluorinated chemicals, bisphenols or flame retardants. Within heavy metals, the common elements were lead and mercury, with 116 and 88 alerts respectively. All of the mercury-containing alerts were in skin creams, 82% of which were explicitly labelled as skin lightening products. This is a known problem. 57% of lead-related alerts were for makeup, which can be explained by use of lead in lipstick and some eyeliners primarily. It also appeared in hair products (10 alerts) which may be associated with dyes, and appeared in some skin products (28 alerts) with less clear pathways as to why it may be present.

62% of the sample had a non-focus identified analyte. Of these, the most common was hydroquinone (172 alerts), which is associated with skin-lightening. 90% of hydroquinone alerts were in the skin cream group. The next most common analytes were MI/MCI, which were mentioned in 110 and 78 alerts respectively, and found in the presence of one another. These are preservatives commonly used in cosmetics.

What this suggests is that the analytes identified in cosmetics, even in the analyte group of focus, are overwhelmingly analytes expected to be associated with the cosmetics themselves rather than packaging, and therefore possible use of recycled material in packaging. This does not mean that we can rule out migration into the product of chemicals from the packaging; indeed it may be the case that certain things (such as, say, flame retardants) are not being regularly tested for. However, there is little evidence presented in Safety Gate to suggest that packaging, and its possible association with recycling, is a known problem.

6.0 Surveys

Two surveys were administered, one for own brand retailers/manufacturers and one for reprocessors. These are presented separately. All surveys were completed using online tool SurveyMonkey. Table 16 presents the key for the survey questions and is applicable to both surveys.

Table 16: Survey key

*	Respondent must answer question
•	Multiple choice question
[SS]	Single selection, i.e. one answer only
[MS]	Multiple selection, i.e. can select multiple answers

6.1 Own brand retailer/manufacturer survey

* 1. Are you a manufacturer or an own brand retailer? [SS]

- Manufacturer
- Own brand retailer
- Both – Manufacturer and own brand retailer

* 2. What type of products do you manufacture/sell? [MS]

Definitions:

Children's equipment = Consumer products designed for childcare activities other than toys, e.g. mattresses, cribs, nappies nappy-changing mats, chairs.

Electronic equipment = Any electronic or electrical device.

- Clothing, textiles and fashion items
- Children's equipment (not including sports equipment)
- Cosmetics
- Electronic appliances and equipment
- Toys
- Furniture
- Other (please specify)

* 3. Where do you source most of your material from? [SS]

- The UK
- Outside of the UK

Outside of the UK

* 4. Where do you source most of your material from? [MS]

- Europe (European Continent not European Union)
- Asia
- India
- USA
- Japan
- Other (please specify)

Recycled Content

* 5. Do you use recycled content in your products? [SS]

- Yes
- No

(if no) Which of the following best describes your reasons for not using recycled content? Please tick all that apply. [MS]

- Cost issues
- Quality/physical integrity issues
- Physical appearance issues
- Availability/supply issues
- Regulatory/safety concerns
- Negative consumer preference
- Other (please specify)

(if yes) Which of the following best describes your reasons for using recycled content? Please tick all that apply. [MS]

- Cost efficiency
- Higher quality products
- In line with company recycling targets
- In line with internal environmental policy
- General environmental benefits
- Customer demand
- Government pressure/regulatory pressure
- Other (please specify)

* 7. What are the top 3 factors you look for when sourcing recycled content/material? [MS]

- Price
- Quantity/supply available
- Certification/ recycled logo
- Type and percentage composition of recycled material i.e. recycled, post consumer, pre consumer, recovered.
- Quality of material
- Assurance that the recycled material meets regulatory requirements
- Origin of recycled material i.e. recycled plastic bottles, recycled ocean plastic.
- Alignment to internal policy requirements
- Sourcing location
- Ease of recyclability for consumer
- Other (please specify)

*8. Do you perceive there to be a difference between imported and UK sourced recycled content? [SS]

- Yes
- No

(if yes) What do you perceive as the main differences between imported and UK sourced recycled content?

[Free text box]

Regulatory Requirements

Regulatory Requirements = physical and chemical safety requirements that government imposes on a business e.g. The REACH Regulation, CLP Regulation and POP Regulation.

* 9. Are you aware of the regulatory requirements that are in place for the recycled feedstock material you use? [SS]

- Yes
- No
- Other (please specify)

* 10. What, if any, physical and chemical safety constraints do you face when using recycled materials as feedstock?

[Free text box]

* 11. Please indicate if you use any of the following to identify whether the recycled material meets regulatory requirements'. Please tick all that apply. [MS]

- It will display a green label/eco label/environmental label
- It will be accompanied with independent reports from credited bodies
- Testing conducted by supplier
- Testing conducted in-house
- Don't actively look for this information
- Don't know
- Other (please specify)

* 12. Who in your supply chain do you believe to be responsible to ensure products meet regulatory standards? [MS]

- The Supplier
- The Reprocessor
- The Manufacturer
- The Retailer
- The Regulator
- Other (please specify)

* 12. Who in your supply chain holds the most responsibility to ensure products meet regulatory standards? [SS]

- The Supplier
- The Reprocessor
- The Manufacturer
- The Retailer
- The Regulator
- The Government
- The Consumer
- Other (please specify)

*13. In your view, who in your supply chain should be responsible to ensure products meet regulatory standards? [MS]

- The Supplier
- The Reprocessor
- The Manufacturer
- The Retailer

- The Regulator
- Other (please specify)

* 12. Who in your supply chain do you believe should hold the most responsibility to ensure products meet regulatory standards? [SS]

- The Supplier
- The Reprocessor
- The Manufacturer
- The Retailer
- The Regulator
- The Government
- The Consumer
- Other (please specify)

* 14. Do you blend recycled materials with virgin materials? [SS]

- Yes
- No
- Prefer not to say

Which of the following best describes your reasons for using blended recycled materials? Please tick all that apply. [MS]

- To meet regulatory requirements
- Cost reasons
- To improve aesthetics (e.g. surface finish, clarity)
- To change the colour
- To reduce the concentration of specific chemicals
- To improve durability
- Inadequate supply of recycled material
- Other (please specify)

Testing

*15. How concerned are you about the chemical safety of the material you use? [SS]

- Not at all concerned
- Slightly concerned
- Somewhat concerned
- Moderately concerned
- Extremely concerned

Please outline reasons for your level of concern

[Free text box]

* 16. Do you test the material you use for toxic chemicals/hazardous substances? [SS]

- Yes – virgin materials only
- Yes – recycled materials only
- Yes – all materials
- No

(If yes) what chemical groups do you test for? [MS]

- Bisphenols (e.g. BPA, BPF, BPS)

- Flame retardants (e.g. BFR, Bromine, PBDE, BDE)
- Formaldehydes
- Parabens (e.g. banxylparaben, butylparaben, ethylparaben)
- Perfluorinated chemicals including perfluoroalkylated substances (e.g. PFAS, PFNA, PFOA)
- Persistent organic pollutants (e.g. Adrin, Chlordane, Furin)
- Phthalates (e.g. DEHP, DEP, DMP)
- Heavy metals (e.g. Cadmium, Lead, Mercury)
- Other (please specify)

* 17. Do you test your final product/s to see if they meet physical and chemical safety regulatory requirements? [SS]

- Yes
- No
- Other (please specify)

(If yes) what do you test for?

[Free text box]

6.2 Reprocessor survey

* 1. Are you a manufacturer or an own brand retailer? [SS]

- Manufacturer
- Own brand retailer
- Both – Manufacturer and own brand retailer

* 2. What type of products do you manufacture/sell? [MS]

Definitions:

Children's equipment = Consumer products designed for childcare activities other than toys, e.g. mattresses, cribs, nappies nappy-changing mats, chairs.

Electronic equipment = Any electronic or electrical device.

- Clothing, textiles and fashion items
- Children's equipment (not including sports equipment)
- Cosmetics
- Electronic appliances and equipment
- Toys
- Furniture
- Other (please specify)

* 3. Where do you source most of your material from? [SS]

- The UK
- Outside of the UK

Outside of the UK

* 4. Where do you source most of your material from? [MS]

- Europe (European Continent not European Union)
- Asia
- India
- USA
- Japan

- Other (please specify)

Recycled Content

* 5. Do you use recycled content in your products? [SS]

- Yes
- No

(if no) Which of the following best describes your reasons for not using recycled content? Please tick all that apply. [MS]

- Cost issues
- Quality/physical integrity issues
- Physical appearance issues
- Availability/supply issues
- Regulatory/safety concerns
- Negative consumer preference
- Other (please specify)

(if yes) Which of the following best describes your reasons for using recycled content? Please tick all that apply. [MS]

- Cost efficiency
- Higher quality products
- In line with company recycling targets
- In line with internal environmental policy
- General environmental benefits
- Customer demand
- Government pressure/regulatory pressure
- Other (please specify)

* 7. What are the top 3 factors you look for when sourcing recycled content/material? [MS]

- Price
- Quantity/supply available
- Certification/ recycled logo
- Type and percentage composition of recycled material i.e. recycled, post consumer, pre consumer, recovered.
- Quality of material
- Assurance that the recycled material meets regulatory requirements
- Origin of recycled material i.e. recycled plastic bottles, recycled ocean plastic.
- Alignment to internal policy requirements
- Sourcing location
- Ease of recyclability for consumer
- Other (please specify)

*8. Do you perceive there to be a difference between imported and UK sourced recycled content? [SS]

- Yes
- No

(if yes) What do you perceive as the main differences between imported and UK sourced recycled content?

[Free text box]

Regulatory Requirements

Regulatory Requirements = physical and chemical safety requirements that government imposes on a business e.g. The REACH Regulation, CLP Regulation and POP Regulation.

* 9. Are you aware of the regulatory requirements that are in place for the recycled feedstock material you use? [SS]

- Yes
- No
- Other (please specify)

* 10. What, if any, physical and chemical safety constraints do you face when using recycled materials as feedstock?

[Free text box]

* 11. Please indicate if you use any of the following to identify whether the recycled material meets regulatory requirements'. Please tick all that apply. [MS]

- It will display a green label/eco label/environmental label
- It will be accompanied with independent reports from credited bodies
- Testing conducted by supplier
- Testing conducted in-house
- Don't actively look for this information
- Don't know
- Other (please specify)

* 12. Who in your supply chain do you believe to be responsible to ensure products meet regulatory standards? [MS]

- The Supplier
- The Reprocessor
- The Manufacturer
- The Retailer
- The Regulator
- Other (please specify)

* 12. Who in your supply chain holds the most responsibility to ensure products meet regulatory standards? [SS]

- The Supplier
- The Reprocessor
- The Manufacturer
- The Retailer
- The Regulator
- The Government
- The Consumer
- Other (please specify)

*13. In your view, who in your supply chain should be responsible to ensure products meet regulatory standards? [MS]

- The Supplier
- The Reprocessor

- The Manufacturer
- The Retailer
- The Regulator
- Other (please specify)

* 12. Who in your supply chain do you believe should hold the most responsibility to ensure products meet regulatory standards? [SS]

- The Supplier
- The Reprocessor
- The Manufacturer
- The Retailer
- The Regulator
- The Government
- The Consumer
- Other (please specify)

* 14. Do you blend recycled materials with virgin materials? [SS]

- Yes
- No
- Prefer not to say

Which of the following best describes your reasons for using blended recycled materials? Please tick all that apply. [MS]

- To meet regulatory requirements
- Cost reasons
- To improve aesthetics (e.g. surface finish, clarity)
- To change the colour
- To reduce the concentration of specific chemicals
- To improve durability
- Inadequate supply of recycled material
- Other (please specify)

Testing

*15. How concerned are you about the chemical safety of the material you use? [SS]

- Not at all concerned
- Slightly concerned
- Somewhat concerned
- Moderately concerned
- Extremely concerned

Please outline reasons for your level of concern

[Free text box]

* 16. Do you test the material you use for toxic chemicals/hazardous substances? [SS]

- Yes – virgin materials only
- Yes – recycled materials only
- Yes – all materials
- No

(If yes) what chemical groups do you test for? [MS]

- Bisphenols (e.g. BPA, BPF, BPS)
- Flame retardants (e.g. BFR, Bromine, PBDE, BDE)
- Formaldehydes
- Parabens (e.g. banxylparaben, butylparaben, ethylparaben)
- Perfluorinated chemicals including perfluoroalkylated substances (e.g. PFAS, PFNA, PFOA)
- Persistent organic pollutants (e.g. Adrin, Chlordane, Furin)
- Phthalates (e.g. DEHP, DEP, DMP)
- Heavy metals (e.g. Cadmium, Lead, Mercury)
- Other (please specify)

* 17. Do you test your final product/s to see if they meet physical and chemical safety regulatory requirements? [SS]

- Yes
- No
- Other (please specify)

(If yes) what do you test for?

[Free text box]

7.0 Telephone interview topic guides

Telephone interviews were conducted with selected participants from the on-line surveys who agreed to take part. Interviews were conducted across the sectors in question.

The interviews were structured according to the sector and industry therefore all participants were asked similar questions at the beginning and end of the interviews for consistency. Inevitably, there was repetition in questions being asked regardless of the sector. In these cases, the questions have not been duplicated. The common questions are presented in 7.1, with questions specific to particular sectors following in subsequent sections. As a semi-structured interview, these were discussion prompts only, so when respondents had a lot to say on a particular topic, this was encouraged with follow-up questions.

7.1 Questions across all sectors

7.1.1 Context

- Contact name
- Company
- Final product
- Materials handled (with grade details if applicable)
- Approximate tonnage processed/ sold annually
- Market: do you predominantly sell material to international or domestic markets?

7.1.2 Concluding questions

- What do you think are currently the biggest problems facing the reprocessing and use of recycled materials?
- What would you change if you could?
- Where are the biggest opportunities?

7.2 Reprocessors – Plastics or Waste Electronic and Electronic Equipment

7.2.1 Context

- What type of reprocessor is your business? Is the recycling process mechanical or chemical?
- What are the outputs of your recycling process / final product?

7.2.2 Feedstock

- What type of waste do you take in?
- From which industry does your feedstock come?
- Thinking about this plastic waste that you use as feedstock, is it pre or post consumer?

7.2.3 Hazardous Waste

- Is any of the waste that you receive hazardous?
- If yes to the above: Where does this waste come from? Is this a different source to non-hazardous waste that you receive?
- Do you process hazardous waste?
- If not, why?

- If so, are there any special considerations or restrictions on its use as feedstock?
- Do you have any processes in place to check that waste is (not) hazardous?
- Could you explain what these are? Could you explain how these work?
- Could you explain why you don’t have any processes in place to check whether waste is hazardous? Would you be interested in implementing these? Does someone else perform these checks for you?

7.2.4 Feedstock Sources

- Where do you source your feedstock from?
- What kind of traceability do you have over your feedstock? How certain can you be about where it comes from/what it is made from?
- Do you think there is a difference between imported and UK-sourced recycled content. What are the main differences? / Why do you see no differences? In an ideal world, which would you prefer to use? Why?

7.2.5 Rejected Waste

- How do you filter this out?
- What do you do with the rejected waste?
- Why do you deal with rejected waste in this way? Do you feel it is better than alternatives?
- If using a chemical recycling process: Because you use a chemical recycling process, chemicals in the feedstock are separated from the output materials. How do you dispose of this chemical waste? Why do you deal with it in this way? Do you feel it is better than alternatives?

7.2.6 Recycled Content

- Do you use recycled content in your products?
- Do the products from your plant contain 100% recycled materials? If not, what percentage do they contain? Why?
- Are the outputs from your plants certified by any recycling bodies or standards?
- Do you communicate to customers what the recycled content of the final product is. Why not?
- How do you communicate recycled content of the final products to customers?
- Do your customers ask about recycled content?
- Do customers require certification from you, in terms of recycled content?
- Do customers know which certifications they should be asking for when sourcing recycled materials, either from yourself or other companies?

7.2.7 Regulatory Requirements

- What regulatory requirements must the recycled material that you reprocess comply with? Can you explain why?

7.2.8 Testing for Hazardous Substances

- Do you test the feedstock material you use for toxic chemicals or hazardous substances?
- Why not? Could it be important to do so?
- What chemical groups do you test for?
- Why do you test for these specific chemical groups?

- Which common toxic chemicals or hazardous substances do you test for? Why?
- Do you test your final product(s) to see if they meet regulatory requirements?
- What do you test for?
- Why (not)?
- What do you think are currently the biggest problems facing the reprocessing and use of recycled materials? What would you change if you could?

7.3 Reprocessors – Soft Furnishings Textiles

7.3.1 Context

- Which country are you based in?
- How many reprocessing sites do you have?
- How do your sites differ? Are there any major differences?
- Do you source your recycling feedstock from inside or outside the UK?
- What type of reprocessor is your business? Is the recycling process mechanical or chemical? What are the benefits of this, in terms of the quality of your product(s)? What are the drawbacks of this?
- What are the outputs of your recycling process / final product?
- In general, who are your main customers? Where are these outputs being passed on to?
- Are your customers main end markets for their products in the UK or outside the UK?

7.3.2 Feedstock

- What type of waste do you take in as feedstock for your recycling process? Is it from the textile industry or another industry?
- Is it post consumer textile waste, commercial textile waste, waste from other industries?
- What are your feedstock sources?
- What kind of traceability do you have over your feedstock? How certain can you be about where it comes from/what it is made from?
- In what format do you receive your feedstock?
- What processes do you use to prepare the feedstock for recycling?
- Do you perceive there to be a difference between imported and UK sourced feedstock?
- Do you ever have to reject feedstock? Why?
- What are the most common contaminants that would require you to reject feedstock?

7.3.3 Hazardous Waste

- Is any of the waste that you receive hazardous?
- Where does this waste come from? Is this a different source to non-hazardous waste that you receive?
- Do you process hazardous waste?
  - If not, why?
  - If so, are there any special considerations or restrictions on its use as feedstock?
- Do you have any processes in place to check that waste is (not) hazardous?
  - Could you explain what these are? Could you explain how these work?

    - Could you explain why you don’t have any processes in place to check whether waste is hazardous? Would you be interested in implementing these? Does someone else perform these checks for you?

7.3.4 Rejected Waste

- How do you filter out rejected waste?
- What do you do with the rejected waste? Does it go to residual disposal? Is it sold on to another company for reprocessing.
- Why do you deal with rejected waste in this way? Do you feel it is better than alternatives?
- If using a chemical recycling process, chemicals in the feedstock are separated from the output materials. How do you dispose of this chemical waste? Why do you deal with it in this way? Do you feel it is better than alternatives?

7.3.5 Recycled Content

- Do the output products from your plant contain 100% recycled materials? If not, what percentage do they contain? Why?
    - If they are not 100% recycled: What other materials are in your products?
- Are the outputs from your plants certified by any certification bodies or standards?
- Do you communicate to customers what the recycled content of the final product is. Why not?
- How do you communicate recycled content of the final products to customers?
- Do your customers ask about recycled content? Are customers coming to you purely for recycled content?
- Do customers require certification from you, in terms of recycled content?
- Do customers know which certifications they should be asking for when sourcing recycled materials, either from yourself or other companies?

7.3.6 Regulatory Requirements

- Does the feedstock you use have to meet any regulatory requirements? What are these? And how do you know the feedstock meets the requirements?
- What regulatory requirements must the output of your recycling process comply with? Is this different depending on which country the end product will be sold in? Can you explain why?

7.3.7 Testing for Hazardous Substances

- Do you test the feedstock material you use for toxic chemicals or hazardous substances?
    - If not, why not? Could it be important to do so?
    - If yes why? (regulatory requirements, certification requirements?)
    - What chemical groups do you test for?
    - Why do you test for these specific chemical groups?
- Do you test your final product(s)/outputs to see if they meet regulatory requirements?
    - What chemical groups do you test for?
    - Why not?
    - If yes to regulatory requirements: which ones?
- Who is responsible for testing your products?

- Do your customers require you to test if your outputs meet regulatory requirements? & how do you provide them with assurance they meet requirements?
- Do your facilities follow any voluntary chemical management guidelines? Why (not)?
- Do your customers require you to meet any voluntary chemical management guidelines?

7.4 Own Brand Retailers/Manufacturers – Toys, Waste Electronic and Electronic Equipment, Soft Furnishings and Textiles.

7.4.1 Context

- Can you confirm that you are a manufacturer/own brand retailer/both?
- Do you sell other branded products, that are not your own brand?
- Approximately what percentage of your products are ‘own brand’?
- If a manufacturer, do you source most of your material from the UK or abroad? Could you estimate roughly which percentage of materials are sourced in the UK, vs. abroad? Can you explain why?
- If any materials are sourced from outside the UK, where do you source most of your raw material from? Could you narrow it down to specific countries?
- Could you explain the relevant regulations in this country(s) i.e. the UK?
- Are there any chemical or regulatory considerations you have to think about when purchasing and using primary materials in the manufacturing of your product?
- If more than one country, how do regulations differ between these two countries?
- What impact does this have on your business? Do these regulations influence decision-making, when choosing where to source raw materials from?
- If not a manufacturer where do you source your products from? Could you estimate roughly which percentage of products are sourced in the UK, vs. abroad? Can you explain why?
- Do you know where your suppliers source most of their materials from?
- Do you know how you might find out? How easy or difficult might this be?
- If any products are sourced from outside the UK: Where do you source most of your products from? Could you narrow it down to specific countries?
- Do you know anything about manufacturing regulations in these countries? Does this influence decision-making, when choosing where to source products from?

7.4.2 Recycled Content

- Do you use recycled content in your products?
- Do you know roughly the percentage of recycled materials your products contain?
- Are there any particular product categories where you use recycled content the most? Why these categories?
- If yes, are you looking to increase the amount of recycled content you are using in your products in the future? Why (not)?
- Why do you/ don’t you use recycled content? What are the benefits?
- If not, would you look to incorporate recycled materials into your products in the future? Why (not)?

- If unsure, are you confident in the claims made by your suppliers about recycled content in products? Why (not)? Does this differ by supplier or product group?
- If recycled content is used, do you know whether the recycled content used in your materials and/or products is the result of a chemical or mechanical recycling process?
- If recycled content is used, what are the most important factors you look for when sourcing recycled content/materials?
- Which certification(s) do you require when using recycled content? Why these specifically? *If none:* Do you feel that you can confidently claim your [products and/or materials] contain recycled content without any certification? Why (not)?
- Do you know the origin of the recycled content in your [product and/or materials]? For example, might it have been pre- or post-consumer waste from the toy industry, or pre- or post-consumer waste from another industry?
- What processes do you follow to make sure recycled content meets regulatory requirements? Can you explain why (not)?
- Do you know where the feedstock that is used for your [materials and/or products] comes from? Could you be specific to a country? Why (not)? How easy or difficult might it be to find out?
- You said in the online survey that you [think / do not think] there is a difference between imported and UK-sourced recycled content. Why? What are the main differences? In an ideal world, which would you prefer to use? Why?

7.4.3 Regulatory Requirements

- Are you aware of the regulatory requirements that are in place for the recycled feedstock material you use? What are they?
- Are you confident that your [materials and/or products] meet these requirements? Why (not)? How do you check if they meet these requirements?
- Do you face any physical and/or chemical safety constraints when using recycled material as feedstock? Could you explain these? Why do they (not) arise? How might these be overcome?
- How do you identify if [materials and/or products] meet regulatory requirements?
- If does not identify if materials/products meet regulatory requirements: Why? How easy or difficult would it be to find this information?
- Who in your supply chain is currently responsible for ensuring products meet regulatory standards? Do you think this responsibility sits with the appropriate group/company in the supply chain? Where would you rather see the responsibility lie? Can you explain why?
- Do you know whether your suppliers follow any voluntary chemical management guidelines? Why (not)?
- Do you require your suppliers follow any voluntary chemical management guidelines? Why (not)?
- Do [you/your suppliers] blend recycled materials with virgin materials? Why (not)?
- Can you be confident that virgin materials are not being mixed with potentially hazardous recycled materials that have come from the recycled content? How confident are you of this?

- How can you safeguard against the possibility that virgin materials might be mixed with potentially hazardous recycled content?

7.4.4 Testing for Hazardous Substances

- I would like you to think now about the potential for hazardous substances within recycled materials, and how we go about testing these.
- Are you concerned at all about the chemical safety of the recycled materials used in the products you [manufacture and/or purchase]? Why (not)?
- Do you test the materials used in [manufacturing and/or products you sell] for toxic or hazardous substances?
  - Why not? Could it be important to do so?
  - What tests do you carry out? Why?
  - What chemical groups do you test for?
  - Why do you test for these specific chemical groups?
- Are you aware of any different testing requirements that apply to recycled content, compared to virgin raw materials?
- Do you test your final product(s) to ensure that they meet physical and chemical safety requirements?
- Is there a certification chain to ensure that all components of a finished product meet regulations? Do retailers request this from manufacturers? Why (not)?
- Does your final product go straight to the end user or on to the next part of the manufacturing chain? If so, who is responsible for testing it? Who pays for testing?
- Who is responsible for testing products? Who pays for this? Do retailers foot the bill or are the costs passed back to manufacturers?
- For the products you sell that are not own-brand (i.e., they are branded), who is responsible for testing for the presence of hazardous chemicals? Is this different for own brand vs. branded? Can you explain why?

Contact us if you have any enquiries about this publication, including requests for alternative formats, at: OPSS.enquiries@beis.gov.uk

Office for Product Safety and Standards

Department for Business, Energy and Industrial Strategy
4th Floor, Cannon House, 18 The Priory Queensway, Birmingham B4 6BS
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