Chemicals in a circular economy

Using human biomonitoring to understand potential new exposures

HBM4EU

science and policy
for a healthy future

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Executive summary

Implementing circularity potentially creates new pathways through which humans can be exposed to hazardous chemicals in contaminated material flows.

Human biomonitoring measures concentrations of chemicals or their metabolites in human biological samples and provides a tool for understanding human exposures to chemicals as Europe shifts towards a Circular Economy.

In the short term, human biomonitoring can inform understanding of potential new human exposures resulting from the recycling of new material flows.

Monitoring the exposure of workers involved in:

- sorting and de-contaminate waste streams to separate out stream for recycling;
- recycling processes;
- production processes using recycled feedstock.

Evaluating consumer exposure to hazardous substances in products containing recycled materials, and in particular consumer exposure to legacy substances, as a means of tracking the elimination of hazardous substances from product flows as foreseen under the Chemicals Strategy for Sustainability. The Circular Economy Action Plan identifies key product chains where human biomonitoring may be of particular benefit.

This report presents five case studies of chemicals in material flows, with a focus on how people may be exposed to chemicals as production and consumption in Europe shifts towards a circular economy. The focus is on synthetic chemicals placed on the market for inclusion in products, and not on naturally occurring toxins. For each case study, evidence of human exposure generated through human biomonitoring studies is presented, showcasing how human biomonitoring data can inform a current and future understanding of new exposure pathways that result from the implementation of circularity in material flows.

The five case studies are:

- Occupational exposure to chemicals of concern in recycling installations, with a focus on workers managing **e-waste** and their exposure to chromium, cadmium, mercury, flame retardants and phthalates.
- Consumer exposure to chemicals in **recycled paper**, with a focus on bisphenols and diethylhexyl phthalate (DEHP).
- Consumer exposure to chemicals of concern in consumer goods made from **recycled plastics**, with a focus on flame retardants (polybrominated diphenyl ethers), phthalates and bisphenols.
- Dietary exposure to a range of emerging substances used in cosmetics, medicinal products and cleaning products resulting from the **reuse of sewage sludge and waste water** on agricultural lands.
- Exposure to polycyclic aromatic hydrocarbons (PAHs) found in granules and mulches used in **synthetic turf pitches and playgrounds**.

Human biomonitoring data can inform our current and future understanding of exposure and health impacts and serve as a useful tool to further enhance the evidence base, allowing timely and targeted policy interventions and risk management.

HBM4EU is a Horizon 2020 project that used human biomonitoring-based research to generate knowledge to inform the safe management of chemicals and protect human health in Europe. A major hurdle to reliable risk assessment and management of chemicals is the lack of harmonised information at European level concerning the exposure of citizens, including workers, to chemicals and subsequent impacts on health.

Under HBM4EU, human biomonitoring studies were used to produce robust, coherent evidence on human exposure to HBM4EU Priority Substances and Substance Groups across Europe, and to understand resulting health impacts. Human biomonitoring assesses internal exposure to chemicals by measuring either the substances themselves, their metabolites or markers of subsequent health effects in body fluids or tissues. Information on human exposure is then linked to data on sources and epidemiological surveys, to understand exposure-response relationships in humans.

HBM4EU bridges science and policy, producing new knowledge to support risk assessors and risk managers in delivering chemical safety. Human biomonitoring can help to build an understanding of human exposure to chemicals in the transition to a circular economy, where the shift to circularity may exacerbate existing and/or create new routes of human exposure.

The Context

01

WHAT IS A CIRCULAR ECONOMY?

A **circular economy** represents a fundamental alternative to the linear take-make-consume-dispose economic model that currently predominates. The linear model assumes that natural resources are available, abundant, easy to source and cheap to dispose of. In contrast, the circular model is restorative, maintaining the utility of products, components and materials and extracting the maximum possible value from them (Ellen Macarthur Foundation, 2021).

As shown in Figure 1, a circular economy aims to minimises the need for new inputs of materials and energy upstream and reducing the environmental pressures linked to resource extraction. Materials flows should then be managed efficiently and sustainably throughout their life cycles, to reduce waste. Products should be designed to be durable, upgradeable, and repairable to extend their lifespan and prevent waste. At the end of product life, basic materials, including chemicals, should be retrieved and either reused or recycled. Material losses through landfill and incineration will thereby be reduced, although these may continue to play a role in the disposal of material flows contaminated with hazardous substances and in the recovery of energy from non-recyclable waste (EEA, 2016).

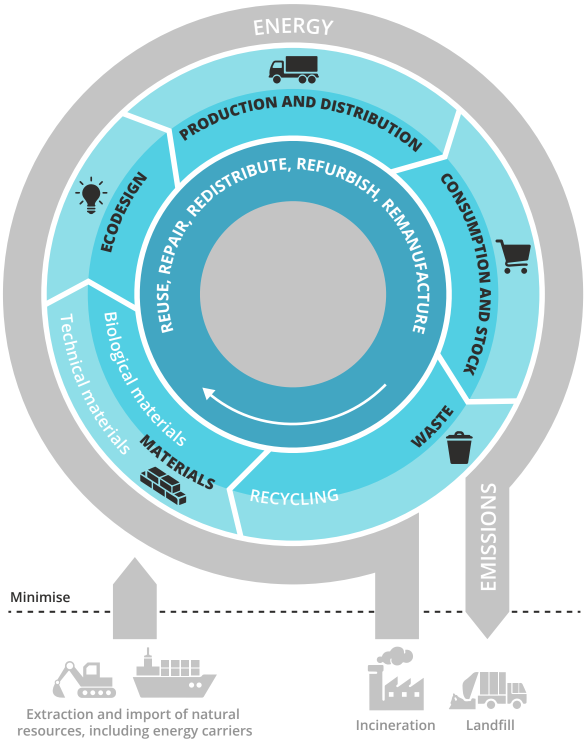

FIGURE 1 Simple model of a circular economy

SOURCE EEA, 2019

The traceability of material flows and keeping material cycles clean from hazardous substances are important enablers of circularity. Trust in material performance and safety, in addition to price, will determine whether manufacturers will be willing to use recycled materials and whether consumers will be prepared to buy products made thereof. A recent assessment of material flows and waste generation show that the circular economy is still in its early development. At macro level, only around 10 % of the materials used in the European economy are recovered and reused (EEA, 2019).

CHEMICALS IN A CIRCULAR ECONOMY

Chemicals are used in a vast array of consumer products and materials, from textiles, furniture, construction materials, electronics, and vehicles to food contact materials, medical devices, and toys. Society's reliance on chemicals as inputs to production processes continue to grow at global level. Between 2000 and 2017, the production capacity of the global chemical industry increased from 1.2 to 2.3 billion tonnes (UNEP, 2019).

In terms of the diversity of chemicals on the market in the European Union (EU), in August 2021 over 23 370 chemicals were registered under the Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (ECHA, 2021). The European Chemicals Agency (ECHA) has identified over 200 substances of very high concern. As an indication of the toxicity of chemicals consumed in the EU, in 2019 75% by volume of chemicals consumer were hazardous to human health (Eurostat, 2021a). However, chemical consumption data does not inform us about human exposure to chemicals. Actual exposure is determined by emissions during the chemical's life cycle, including production, use and waste phases and recycling and/or reuse, and not by the tonnage consumed (EEA, 2020).

The presence of chemicals in material flows poses challenges for achieving circularity in the economy and concerns have been raised regarding possible risks to public health (WHO, 2018, WHO, 2019). Managing chemical risks to public health in the context of the shift towards circularity requires an understanding of the use of hazardous chemicals in products, and of the potential for human exposure as products move off the production line and shift into the use phase, and end up as recycled, re-used and/or disposed of as waste. The current state of knowledge is weak, in particularly given the large number of chemicals on the market, the complexity of material flows and the lack of available data on the presence of chemicals in products. The novelty of the shift towards a circular economy also presents uncertainties regarding possible future risks.

The recycling of products that contain hazardous chemicals is likely to contaminate flows of recycled materials, in a context where it is more difficult to control the quality of recycled feedstock than virgin materials due to the cost of detecting and removing chemicals (WHO, 2018). Limited research suggests that products made from recycled materials, such as recycled paper and construction materials, contain both higher concentrations of chemicals and a more diverse range of chemicals (Lowe et al., 2021). The recycling of long-lasting products can contaminate material flows with hazardous chemicals that are now banned in Europe, known as “legacy chemicals”. This can be particularly problematic for banned substances that previously had wide-ranging applications in products with a long service life.

The complexity of global supply chains in the context of international trade also poses challenges to keeping material flows clean. Hazardous chemicals whose use in manufacturing is restricted in the EU may enter the EU through imported articles. In addition, supply chains using flows of material from outside the EU imply that material flows may be contaminated with hazardous substances banned in the EU.

These mechanisms can potentially create new pathways through which humans can be exposed to hazardous chemicals in contaminated material flows. Workers may be exposed in the occupational setting when recycling waste materials that contain hazardous substances. Consumers may be exposed in the use phase of secondary products containing recycled materials contaminated with hazardous substances. As an example, food safety issues have been raised in connection with hazardous chemicals present in recycled materials used in food packaging and kitchen items (WHO, 2019). The recycling of older products containing legacy chemicals, now restricted, and the re-introduction of those chemicals into secondary products is of particular concern.

Certain materials flows have received attention from researchers and policy makers due to concerns regarding chemical contamination of secondary materials. Regarding plastics, a lack of information regarding the possible presence of hazardous chemicals is impacting on recycling rates. The improved traceability of chemicals and in particular the identification of legacy substances in end-of-life plastics is a first step towards their removal during recycling, although technical feasibility is also a barrier.

Another example is the re-use of sewage sludge and treated wastewaters from urban wastewater treatment plants on agricultural land providing an effective use of waste materials, supporting soil structure and reducing water use. At the same time, it has the potential to disperse micropollutants from consumer products washed down the drain, such as cosmetics, cleaning products and pharmaceuticals, potentially exposing people to substances not removed by current wastewater treatment processes via food and drinking water.

The challenge in relation to chemicals and the circular economy is to increase recycling and reuse, while ensuring that consumers and workers are not at increased risk from exposure to substances of concern in recycled products. Moving forward effective management of chemicals in the circular economy will involve:

- Eliminating substances of concern from materials and products through upstream substitution with alternatives that are safe and sustainable by design.
- Ensuring that information about the presence of substances of concern in products is accessible to actors along the products life cycle.
- Improving the management of end-of-life products in waste streams to systematically remove hazardous substances from material flows channelled for recycling, through effective sampling and testing of waste streams followed by sorting to remove contaminated materials. This involves finding solutions to technical and financial challenges.

CHALLENGES TO THE MANAGEMENT OF CHEMICALS IN WASTE STREAMS

Operators of recycling installations face both technical and financial barriers to the identification of hazardous chemicals in mixed waste streams.

Systematically and reliably monitoring mixed material flows for large numbers of hazardous chemicals is resource intensive and expensive. While for metals, x-ray fluorescence equipment can be used to test for toxic metals in material flows on site, analysis to identify organic chemicals is done off-site entailing significant cost. Operators also face difficulties in reliable sampling large volumes of mixed waste of heterogeneous composition.

Where hazardous substances are identified and removal of contaminate materials is necessary, operators need to put in place processes to extract those contaminated materials as well as risk management measures to protect workers.

In a case where the diversity of materials flows channelled for recycling increase, operators may risk accepting materials containing hazardous substances that are not covered by site permits and licenses and indeed by risk management procedures in place to protect workers.

Operators may also face a loss of income if secondary materials become contaminated with hazardous substances and downstream customers reject the materials as feedstock to their production processes due to quality concerns.

THE POLICY CONTEXT IN THE EUROPEAN UNION

The Circular Economy Action Plan, published in March 2020 by the European Commission, foresees a shift to 'safe-by-design chemicals' through the progressive substitution of hazardous substances to better protect citizens and the environment. It recognises that the safety of secondary raw materials can be compromised if banned substances persist in recycled feedstock.

Proposed actions to increase confidence in the use of secondary materials include:

- Developing solutions for high-quality sorting and removing contaminants from waste
- Advancing methodologies to minimise the presence of hazardous substances in recycled materials and secondary products
- Co-operating with industry to progressively develop harmonised systems to track and manage information on substances of concern
- Improving the classification and management of hazardous waste to maintain clean recycling streams

The Commission gives priority to addressing circularity in the following key products values chains:

- Electronics and Information and Communication Technology
- Batteries and vehicles
- Packaging
- Plastics
- Textiles
- Construction and building materials
- Food, water, and nutrients

REACH is the Regulation on registration, evaluation, authorisation and restriction of chemicals and is the key piece of horizontal legislation that aims to protect human health and the environment. The REACH Regulation obliges companies to provide information on the properties and hazards of chemicals they manufacture and market in the EU and to manage the associated risks. The regulation also calls for the progressive substitution of the most hazardous chemicals when economically and functional alternatives have been identified. This is done by restrictions on their uses, or by authorising the chemical uses for defined purposes.

The Regulation on the Classification, Labelling and Packaging of Substances and Mixtures (**CLP Regulation**) aims to protect human health and the environment by regulating chemical management in the supply chain. It ensures that information about the hazards of chemicals and mixtures of chemicals are communicated down the supply chain, alerting workers to the presence of a hazard and the need for risk management.

The Commission's Chemicals Strategy for Sustainability recognises the need to move towards toxic-free material flows to boost the production and uptake of secondary materials. This requires a combination of actions upstream, to ensure that products are safe and sustainable-by-design, and downstream, to increase safety of and trust in recycled materials and products. Progress on this path requires the proactive substitution of chemicals which can cause damage to human health and the environment with safer alternatives. The strategy aims to promote the EU industry as a global frontrunner in the production and use of safe and sustainable chemicals.

"As a principle, the same limit value for hazardous substances should apply for virgin and recycled material. However, there may be exceptional circumstances where a derogation to this principle may be necessary. This would be under the condition that the use of the recycled material is limited to clearly defined applications where there is no negative impact on consumer health and the environment, and where the use of recycled material compared to virgin material is justified on the basis of a case-by-case analysis."

Chemicals Strategy for Sustainability

Occupational exposure to hazardous chemicals in e-waste facilities

02

KEY MESSAGES

- The EU market for electrical and electronic equipment grew in recent years to reach 8.7 million tonnes and continues to expand, making waste electrical and electronic equipment, or e-waste, one of the fastest growing waste streams in Europe. The volume of e-waste channelled to recycling is also expected to increase, together with the number of workers involved in managing and recycling e-waste.
- E-waste contains hazardous substances, such as flame retardants, phthalates, and heavy metals. Legacy substances, now banned in the EU, have also been found in e-waste in Europe.
- Workers at e-waste facilities may be exposed to hazardous substances by breathing in vapours, dust and fibres suspended in air, by accidentally swallowing dusts or liquids, and through the skin, with certain tasks such as shredding and crushing e-waste associated with higher exposure levels.
- Studies have demonstrated workers' exposure to heavy metals in installations recycling cathode tubes in Sweden, France, and the US, and to flame retardants in e-waste dismantling facilities in Sweden, Finland, and Canada.
- Human biomonitoring can be used to identify those tasks in the recycling process where workers are most exposed, to assess the effectiveness of risk management measures in reducing exposure and to identify those hazardous substances to which workers are exposed.

CHEMICALS IN E-WASTE

Waste electrical and electronic equipment (WEEE) is an overarching term describing the waste from a range of end-of-life electrical and electronic equipment, including computers, TVs, fridges and mobile phones.

In the period from 2011 to 2018, the EU[1] market for electrical and electronic equipment expanded by 14 % to reach 8.7 million tonnes and is predicted to continue to grow (Eurostat, 2021b). At the same time, the lifespan of such products has tended to shorten and as such WEEE is one of the fastest growing waste streams in Europe. The EU sets targets for the collection and recovery of WEEE, implying that the volume of e-waste channelled to recycling is also expected to increase.

In 2018, 4 million tonnes of WEEE were collected in the EU, representing a collection rate of 47 %. The volume of WEEE treated was 3.9 million tonnes and of WEEE recovered, including both recycling and energy recovery, was 3.6 million tonnes. The volume of WEEE recycled and prepared for reuse was 3.2 million tonnes (Eurostat, 2021b).

In terms of export, in 2018 EU Member States exported 157,252 tonnes of WEEE containing hazardous substances and 14,549 tonnes of non-hazardous WEEE. These waste types include transformers, capacitors and other discarded equipment containing polychlorinated biphenyl (PCB), discarded equipment containing chlorofluorocarbons (CFCs, HCFCs), discarded equipment containing free asbestos and other discarded electrical and electronic equipment containing hazardous components, hazardous and non-hazardous components removed from discarded equipment, discarded equipment and discarded electrical and electronic equipment other than hazardous, fluorescent tubes and other mercury-containing waste (Eurostat, 2021c).

WEEE, also known as e-waste, is a complex mixture of materials and components that can present risks to health. Materials may include glass, metals, plastics, ceramics, and various composites such as circuit boards, cathode ray tubes, flat screen monitors, batteries, connectors and transformers and cables. E-waste streams contain a broad range of hazardous substances, including metals such as cadmium, lead and mercury, polybrominated diphenyl ether (PBDE) and organophosphate ester flame retardants, phthalates, hexabromocyclododecane (HBCD), polychlorinated dibenzo-p-dioxins (PCDD), polybrominated dibenzo-p-dioxins (PBDD) and polychlorinated dibenzofurans (PCDF). While some of these substances are now banned, their use was legal at the time of manufacture of the equipment (Grant et al., 2013). For example, concentrations of pentabromodiphenyl ether (pentaBDE), octabromodiphenyl ether (octaBDE) and decabromodiphenyl ether (decaBDE) were detected in mixed electronic waste at WEEE recycling plants in Switzerland (Morf et al., 2005) and in the Czech Republic (Vojta et al., 2017). This section focuses on workers managing e-waste and presents available evidence of workers' exposure to the HBM4EU priority substance chromium, cadmium, mercury, flame retardants and phthalates from human biomonitoring studies.

[1] Data is presented for the 27 member States of the EU.

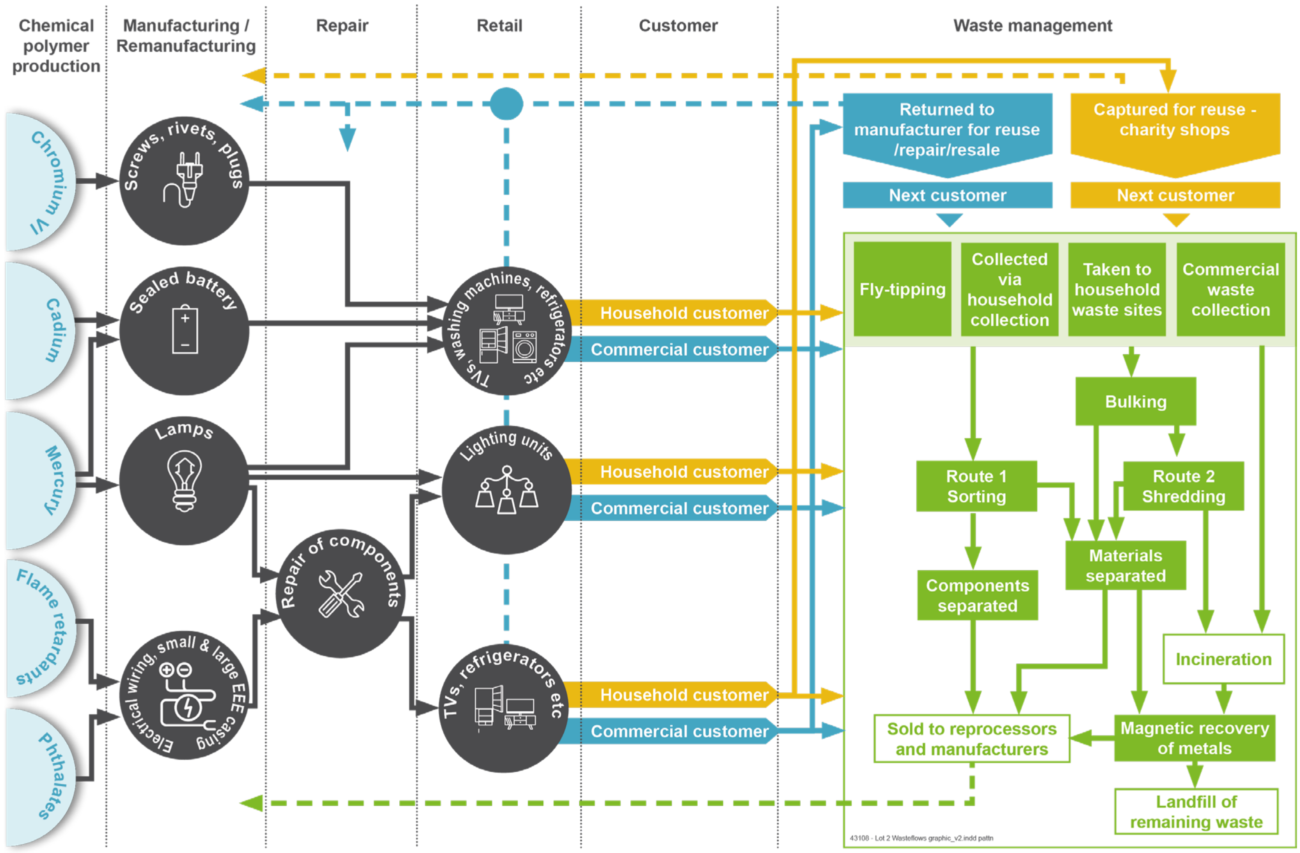

FIGURE 2 Flow of selected chemicals through electrical and electronic equipment to e-waste

SOURCE Wood Ltd.

An overview of material flows with respect to chemicals in electrical and electronic equipment is shown in figure 2. The EU benefits from a well-developed formal e-waste management infrastructure to collect e-waste in shops and municipal recycling centres, as well as formal facilities to recover recyclable components and dispose of residual waste.

Workers at formal recycling installations may be exposed to chemicals at different steps in the chain of waste recycling, including collection, sorting, dismantling, shredding and/or grinding and further pre-processing and purification of recycled material flows. Facilities might use automated large-scale shredding or grinding machinery, they may manually recover materials, or combine both methods. Many e-waste recycling facilities distribute material flows to downstream parties that specialise in the recovery of plastics, glass, or metals (Ceballos and Dong, 2016). Examples of processing and/or purification methods to recover materials include melting metals, and processing polymers to a granulated product that can be re-used in recycled plastics. Some non-recyclable material is lost to waste at each stage, and must be separated out, stored and ultimately transported for incineration or landfill.

Substance	Components of electrical and electronic equipment in which the substance may be found
Chromium VI	Anticorrosion agent on electronics components
Cadmium	Ni-Cd batteries, circuit boards, computer batteries, cathode ray tubes
Lead	Printed wiring boards, lead acid batteries, cathode ray tubes, TVs
Mercury	Batteries, thermostats, sensors, monitors, cells, printed circuit boards, cold cathode fluores-cent lamps
Flame retardants	Electrical wiring, cables, equipment casings, refrigerators, washing machines, dryers, vacu-ums, TVs
Phthalates	Electrical wiring, cables, wires, connectors and medical equipment

TABLE 1 Chromium VI, cadmium, mercury, flame retardants and phthalates in electrical and electronic equipment

SOURCE Ministry of the Environment and Food, Norway, ECHA, National Institute of Environmental Health Services, and Intertek

Significant volumes of e-waste are still managed outside of formal recycling sectors, through export for reuse or recycling as metal scrap (Forti et al., 2020). Small electronics can end up in municipal solid waste streams, resulting in a loss of materials. It is estimated that in EU countries, 0.6 Mt of e-waste ends up in waste bins (Rotter et al. 2016). Workers collecting e-waste from kerbsides, bring banks, recycling centres, as well as illicit dumping of e-waste, may be exposed to any leaking or crushed products. In addition, used electrical and electronic equipment may be passed on for reuse via charity shops, flea markets and directly from consumer-to-consumer using online platforms, entailing a potential risk of exposure in cases where equipment may be damaged.

Although individual electronic devices contain very small volumes of hazardous substances, chronic exposure in the workplace may have the potential to impact human health. Regarding the presence of HBM4EU Priority Substances in e-waste, the types of components that may contain chromium VI, cadmium, mercury, flame retardants and phthalates, including legacy chemicals, are shown in table 1.

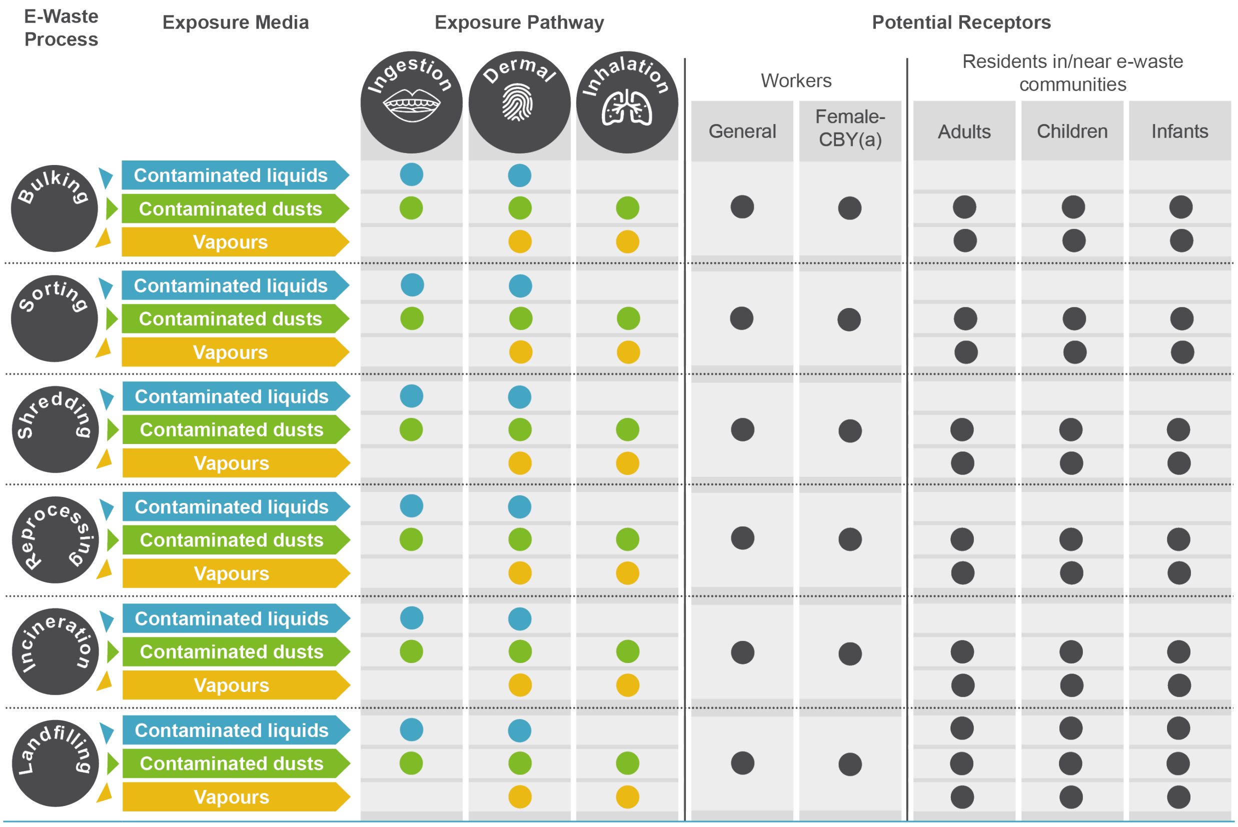

FIGURE 3 Exposure pathways to chemicals in e-waste

SOURCE Wood Ltd.

RISK OF OCCUPATIONAL EXPOSURE TO CHEMICALS IN E-WASTE RECYCLING FACILITIES

Those most at risk of exposure are workers in e-waste recycling installations who are involved in the bulking, shredding, separation, and reprocessing of materials where fluids, dusts and other respirable fragments may become airborne and result in human exposures.

The potential pathways for exposure to hazardous chemicals for workers in general and for female workers in their child-bearing years are shown in figure 3. Three exposure pathways are identified:

- inhalation of vapours and dust and fibres suspended in air,
- incidental ingestion of dusts or liquids, such as wiping the mouth with contaminated hands, and
- dermal exposure, whereby dust or liquid are deposited on the skin and absorbed into the bloodstream, which can occur directly or indirectly and, in limited cases via contact with an open wound.

Secondary exposure may occur through deposition of particulates on clothing which can then be incidentally ingested or inhaled (Caravanos et al., 2013). Legislation is in place to protect workers from chemicals exposure in the EU, as described in the boxes below.

A limited number of human biomonitoring studies have explored exposure to chemicals amongst workers managing e-waste in Sweden and Germany. Studies from Sweden, Finland, France and Canada exploring exposure via air are also presented as useful evidence of the potential risk of chemical exposure in e-waste facilities.

The bulk of the literature on human exposure to chemicals in e-waste focuses on recycling facilities, both formal and informal, in southeast China. This evidence is not considered relevant to the European context due to significant differences in the legislative framework on chemicals in electrical and electronic equipment and on occupational health and safety and is not reviewed here.

A Swedish study investigated workers' exposure to metals in three e-waste recycling plants, using biomarkers of exposure in urine and blood samples in combination with monitoring of personal air exposure (Julander et al., 2014). Workers involved in recycling activities, including dismantling activities, indoor work and outdoor work, were exposed to airborne concentrations of **metals** (chromium, cobalt, indium, lead, and mercury) 10 to 30 times higher than office workers. Concentrations of antimony, indium, lead, mercury, and vanadium showed strong associations between concentration in personal air and in blood, plasma, or urine. Significantly higher concentrations of chromium, cobalt, indium, lead, and mercury were found in the blood, urine, and/or plasma of the recycling workers, compared with the office workers.

Blood levels of **lead** in workers were twice that of office workers at the same recycling facility. This is of particular concern for female workers, given the know impacts of prenatal exposure to lead on the developing child. There is no threshold for the adverse effects of lead on the central nervous system, such as impaired cognitive and motor skills (EFSA, 2010). Lead is predominantly found in the glass of cathode ray tubes and in solders used in electronics (Frazzoli et al., 2010) and may be released if the equipment is ground up for recycling. The amount of lead in one cathode ray tubes screen can be up to 3 kg, depending on the size of the television set (Chen et al., 2011). At the Swedish plants, cathode ray tubes were crushed or ground and the highest concentrations of lead in blood originated from workers engaged in such tasks. Ground material was often transported on conveyor belts and stored in open containers or piles outdoors awaiting ongoing transportation, potentially dispersing lead dust into the environment. The study found no difference in lead concentrations in personal air samples for the outdoor workers compared to dismantling workers, supporting this hypothesis (Julander et al., 2014).

Recycling of old equipment containing **mercury** (now banned in electrical and electronic equipment) may release mercury in its elemental gaseous form leading to inhalation by e-waste workers, especially if e-waste is heated. A German study from 2001 found two cases of potential kidney damage (membranous nephropathy) resulting from occupational exposure to mercury vapour in the fluorescent-tube-recycling industry (Aymaz et al., 2001), although the age of this study creates uncertainties regarding the relevance of the study today.

A study in a dismantling plant for electronics in Sweden found average concentrations of **polybrominated diphenyl ethers** (PBDEs) in air to be 4-10 times higher by a plastic shredder than in other areas of the plant. The blood serum levels of plant

[2] The concentration ranges were 157.6–208.6; 13.9–16.7; and 2.8–3.3 ng/m3 for inhalable, total and respirable fractions, respectively.

workers were approximately five times higher than those of control and office workers (Sjödin et al., 1999). A later study compared blood serum concentrations of workers at a single Swedish e-waste recycling plant from 1997 and from 2000 following improvements in risk management procedures. Even though the amount of waste processed had doubled by 2000, there was a significant decrease in the serum levels of two higher brominated diphenyl ethers (BDEs), namely BDE-183 and BDE-209. In contrast, concentrations of BDE-47 did not significantly change, whereas for BDE-153 a significant increase was seen (Thuresson et al., 2006).

Several relevant studies have explored exposure to hazardous chemicals at e-waste recycling facilities by monitoring air. For example, a study in a Swedish e-waste recycling facility investigated PBDEs concentrations in inhalable, total, and respirable dust fractions and found the highest concentration of PBDE in the samples from the inhalable dust fraction, which was 10 times higher than for the total dust fraction[2] (Julander et al., 2005). A Finnish study investigated inhalation exposure to **brominated flame retardants** at four e-waste recycling facilities. Seven brominated flame retardants and one chlorinated flame retardant were detected in personal air samples at all recycling sites. PBDEs were found to be the most abundant, including deca-BDE, TBBP-A, and DBDPE, substances for which there are no Occupational Exposure Limit Values (OELs) at European level. The study demonstrated how adequate control measures and good occupational hygiene practice at recycling sites effectively reduced workers' exposure (Rosenberg et al., 2011).

A 2015 study assessed the risk of chemical exposure via air at nine formal recycling facilities processing cathode ray tube screens in France and documented worker exposures to **barium, cadmium, lead, and yttrium**. Processing steps including dismantling, tube preparation, and cathode ray tube glass processing (including splitting of glass and shredding) were identified as the exposure source (Lecler et al., 2015). In addition, an exposure assessment in five French recycling facilities reported exposure to **mercury** vapours and to dust containing **lead and yttrium** during the recycling of fluorescent lamps in France (Zimmermann et al., 2014).

Two recent studies from Canada also looked at exposure to emissions of **flame retardants** from e-waste dismantling facilities. The first assessed exposure of workers to flame retardants at a Canadian e-waste dismantling facility, measuring concentrations in air and dust samples collected at a central location and at four workbenches. Dust concentrations at the workbenches were higher than those measured at the central location, consistent with the release of contaminated dust during dismantling. BDE-209 had the highest concentrations in both dust and air, followed by triphenyl phosphate. The authors estimated that dust ingestion accounted for 63% of total exposure, while inhalation and dermal absorption contributed 35 and 2%, respectively (Nguyen, 2019).

The second study detected 79 **flame retardants and plasticizers** in air and dust samples from a dismantling facility in Ontario processing a range of e-waste, including monitors, computers, printers, phones, and toys. Dust and air concentrations were dominated by three compounds: BDE-209, DBDPE, and TPhP. Levels of PBDEs, NBFRs, and dechloranes were close to two orders-of-magnitude higher in dust from the dismantling facility than in residential homes, while organophosphate esters were one order-of-magnitude higher. E-waste dismantling facilities represent a source of emissions for a wide range of flame retardants at relatively high concentrations to both workers and the immediate environment (Stubbings et al., 2019).

A US study assessed exposure to metals at three e-waste recycling facilities and found elevated level of **lead** in blood, as well as metals on the skin and clothing of workers before they left work in all the facilities (Ceballos et al., 2017). An additional US study identified elevated blood lead levels in two children, due to dust brought home on the work clothes of a parent working at a US formal e-recycling facility processing cathode ray tubes (Newman et al., 2015).

EU POLICIES TO REGULATE E-WASTE

The Directive on waste electrical and electronic equipment (WEEE Directive) aims to prevent the creation of WEEE, contribute to the efficient use of resources and the retrieval of secondary raw materials through re-use, recycling and other forms of recovery and improve environmental performance along the life cycle of electrical and electronic equipment. Under the WEEE Directive, Member States establish collection schemes where consumers return their used e-waste free of charge.

The WEEE Directive set collection, recycling, reuse, and recovery targets. From 2016 to end of 2018, the minimum collection rate to be achieved annually by a Member State was 45 % of the average weight of electrical and electronic equipment placed on the market in the three preceding years. From 2019, this increased to 65 %, or alternatively 85 % of e-waste generated within a Member State. Where e-waste is sent for treatment in another Member State or exported for treatment in a third country, the exporting Member State counts it towards their recovery targets.

Member States must ensure that collected WEEE undergoes proper treatment, including the removal of all fluids, certain substances, mixtures and components and selective treatment for certain components. In terms of recovery targets, the WEEE Directive sets minimum targets for six categories of WEEE defined in the directive, with 75-85 % to be recovered, and 55-80 % to be prepared for re-use and recycling (with the exact percentage varying by category of WEEE) by weight of the volume of WEEE collected.

The Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) sets maximum concentration levels for lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP) and diisobutyl phthalate (DiBP) and requires them to be substituted by safer alternatives. By reducing the presence of hazardous materials in electrical and electronic equipment, the RoHS Directive promotes recyclability.

The Directive 2013/56/EU on batteries and accumulators and waste batteries and accumulators prohibits the marketing of batteries and accumulators containing hazardous substances and further regulates the collection, treatment, recycling and disposal of waste batteries and accumulators to avoid incineration and landfilling.

Under the Regulation on mercury, mercury-containing batteries were banned. WMercury is also no longer allowed in most switches and relays found in electronic equipment. Energy-efficient lamps using mercury technology are only permitted on the market with a reduced mercury content.

EU POLICIES TO PROTECT WORKERS FROM CHEMICAL EXPOSURE

In the EU, the risk of workers' exposure is minimised through occupational safety measures required under EU legislation to protect workers from exposure to chemicals. Measures include closed systems in production facilities, ventilation and exhaust systems to remove gases and dust, and the use of respiratory and dermal personal protective equipment (PPE).

Directive 98/24/EC - risks related to chemical agents at work lays down minimum requirements for the protection of workers from risks to their safety and health arising, or likely to arise, from the effects of chemical agents that are present at the workplace or as a result of any work activity involving chemical agents.

The directive sets binding occupational exposure limit values for inorganic lead and its compounds and biological limit values for lead and its ionic compounds, as well as requiring medical surveillance if exposure to a concentration of lead in air is greater than 0,075 mg/m3, calculated as a time-weighted average over 40 hours per week, or — a blood-lead level greater than 40 µg Pb/100 ml blood is measured in individual workers.

Indicative occupational exposure limit values (IOELV) are health-based, non-binding values, derived from the most recent scientific data and considering the availability of reliable measurement techniques. For any chemical agent for which an IOELV has been set at European Union level, Member States are required to establish a national occupational exposure limit value. IOELVs have been set out in the following EU directives:

- Directive 2019/1831
- Directive 2017/164/EU
- Directive 2009/161/EU
- Commission Directive 2000/39/EC
- Commission Directive 2006/15/EC
- Commission Directive 91/322/EEC

Directive 2004/37/EC - carcinogens or mutagens at work covers the protection of workers from health and safety risks from exposure to carcinogens or mutagens at work. Employer shall assess and manage the risk of exposure to carcinogens or mutagens. This process shall be renewed regularly, and data shall be supplied to the authorities upon request. Special attention should be paid to investigate and take account of all possible ways of exposure (including all skin-related possibilities), and to persons at particular risk. Workers' exposure must be prevented. If replacement is not possible, the employer shall use a closed technological system. The employer shall reduce the use of carcinogens or mutagens by replacing them with a substance that is not dangerous or less dangerous. Where a closed system is not technically possible, the employer shall reduce exposure to the minimum. Exposure shall not exceed the limit value of a carcinogen, as set out in Annex III (EU-OSHA, 2021).

The pregnant workers Directive protects the health and safety of women in the workplace when pregnant or after they have recently given birth and women who are breastfeeding. A set of guidelines detail the assessment of the chemical, physical and biological agents and industrial processes considered dangerous for the health and safety of pregnant women or women who have just given birth and are breast feeding. Pregnant and breastfeeding workers may under no circumstances be obliged to perform duties for which the assessment has revealed a risk of exposure to agents, which would jeopardize their safety or health.

USING HUMAN BIOMONITORING IN THE OCCUPATIONAL SETTING

Occupational exposure to chemicals, in many instances, may be several times higher than environmental exposures experienced by the general population. Human biomonitoring provides a valuable tool for understanding exposure to chemicals in the workplace and ensuring safety at work. Monitoring workers' internal exposure to chemicals support the development of safe risk management measures in e-waste management facilities.

A typical challenge in undertaking occupational biomonitoring studies is the low number of workers that can be recruited in national studies. In addition, the studies are usually performed by different research groups in individual countries and consequently these are usually not aligned with respect to sampling, data collection or analytical methodologies. This hampers the comparison of the findings and the use of the data in regulatory risk assessment throughout Europe. HBM4EU researchers combined results from national surveys across Europe that have used harmonized study designs and methodologies to deliver added value.

HBM4EU has implemented three occupational studies. A study on chemical exposure in e-waste management and recycling facilities is ongoing and described in box 1. A study on hexavalent chromium exposure is presented in box 2. The final occupational studies, focus on exposure to diisocyanates is ongoing.

Box 1: HBM4EU study on occupational exposure to chemicals in e-waste recycling

HBM4EU's collaboration with the recycling industry will benefit of workers' health and contribute to ensuring good practices in e-waste processing facilities in Europe. We aim to raise awareness of potential hazards and stimulate good work practices that will improve workers' protection from the risk of exposure to toxic components, including combined exposures.

The study is assessing exposure to several HBM4EU priority compounds, including metals (lead, inorganic mercury, cadmium, chromium), phthalates, and flame retardants. The study involves Portugal, Poland, Germany, Latvia, The Netherlands and in Luxembourg and probably also in Belgium, Finland and UK.

The specific objectives are to:

- Identify the most relevant compounds in the e-waste processing and use of available knowledge developed and available in HBM4EU to support an exposure study.
- Collaborate with employers and employees of parties in the public and private sectors to collect the biological specimen for HBM.
- Develop a study protocol, information materials and informed consent forms and documentation for ethics approval in each of the collaborating member states.
- Re-use and revise existing SOP, already available from the chromium study and develop new SOPs if needed.
- Set up a collaboration with those labs that could support the analysis of the most relevant biomarkers in matrices that can be obtained.

Implement the HBM study with sufficient supportive measurements and contextual data to be able to identify opportunities for further improvements of occupational hygiene practice and herewith address questions and concerns that employers and employees might have.

Further details on the study design can be found at HBM4EU, 2020, Detailed research plan for the occupational diisocyanate and e-waste study, HBM4EU, 2020.

In the context of increased flows of e-waste and higher volumes being processed within Europe, a research framework is needed to systematically assess workers' exposures and impacts on health (Ceballos and Dong, 2016). Human bimonitoring offers a number of opportunities.

- Large-scale, long-term biomonitoring of occupational exposure in the European e-waste recycling sector is needed to better understand potential risks.
- Human biomonitoring can be used to identify those tasks in the recycling process where workers are most exposed, by sampling and comparing the internal exposure of workers engaged in different tasks.
- Follow up sampling can be used to assess the effectiveness of risk management measures in reducing internal exposure.
- Biomonitoring can be used to identify substances of concern to which workers are exposed in e-waste recycling facilities, to feedback to upstream controls of the use of hazardous materials electronic and electrical equipment. Biomonitoring should assess exposure to both well-known substances and explore unknows through non-targeted screening.

Box 2: HBM4EU study on occupational exposure to chromium

The H**BM4EU chromate study** assessed occupational exposure to hexavalent chromium (Cr(VI)) in surface treatment activities and welding in eight European countries. This study included approximately 40 companies and almost 580 workers and control subjects (not occupationally exposed to hexavalent chromium) from across eight countries.

Preliminary results

• The study found higher chromium (Cr) levels in urinary samples of workers when compared to the control subjects.

• Workers in the chrome plating sector had the highest levels of Cr in urine, red blood cells and exhaled breath condensate.

• Chrome platers had the highest exposure and the welders the lowest. All exposed groups showed significantly higher exposure than the control group.

• In areas where welding and chrome plating took place, air measurements showed the 90th percentile (P90) of inhalable Cr(VI) levels below the binding occupational exposure limit value (BOELV) of 5 10 µg/m3. In areas where workers engaged in other types of surface treatment, the P90 was above the BOELV of 10 µg/m3.

• Human biomonitoring data, together with air and dermal monitoring data, helped to identify the contribution of different exposure routes to total exposure to Cr(VI) in these occupational settings.

• Information provided by different (bio)markers complement assessments of occupational exposure.

• This multicentre study using human biomonitoring to assess occupational exposure and associated health risks provides a model that can greatly improve risk assessment.

Further information on the hexavalent chromium study can be found at:

• Santonen et al (2019) Setting up a collaborative European human biological monitoring study on occupational exposure to hexavalent chromium. Environ Res., Jul 10;177:108583.

• HBM4EU, 2021, Research brief on occupational exposure to Cr(VI), HBM4EU

Flame retardants in recycled plastic products

03

KEY MESSAGES

- Plastics contain large numbers of chemical additives, and increased rates of plastic recycling has raised concerns regarding the presence of chemicals in recycled plastic goods purchased on the European market.
- Flame retardants have been detected in plastic goods purchased on the European market.
- The EU recently tightened legislation on the presence of flame retardants in recycled plastic products.

CHEMICALS IN RECYCLED PLASTIC

Plastics are composed of polymers produced from crude oil, combined with chemical additives that deliver a diverse range of specific functionalities but that may also be hazardous. Around 25.8 million tonnes of plastic waste are generated in Europe every year, with less than 30% currently collected for recycling (EEA, 2020).

The EU's plastics strategy sets the target that 10 million tonnes of recycled plastics are used to make products in the EU by 2025, compared to less than 4 million tonnes used in 2016. To reach this target, the strategy called on stakeholders to make voluntary pledges to use or produce more recycled plastics.

The EU-28 represents the largest source of export of plastic waste, accounting for around one third of all exports of plastic waste from 1988 to 2016 (Brooks et al., 2018). Most of this waste was previously exported to China. However, following a Chinese ban on the import of non-industrial plastic waste, overall exports, with the remaining volume re-routed to other countries in South East Asia. Going forward, the export of plastic waste from the EU is likely to fall, creating the need for increased reuse and recycling within the EU (EEA, 2020).

In the plastic recycling process, plastics are sorted by polymer type and colour and are then re-melted and converted to produce recycled plastic goods. A barrier to closing the loop is the presence of additives in plastic products. Additives can potentially migrate and lead to human exposure when present in products produced from recycled plastic. A lack of information regarding the presence of chemicals of concern in virgin plastic materials creates a significant obstacle to achieving higher recycling rates. It is a challenge to trace chemicals in recycled material flow, with the removal of hazardous substances during recycling processes being technically very complicated. Avoiding the upstream introduction of hazardous substances to plastics is a preferable approach to ensuring safety.

In terms of risk to health, focus has fallen on the presence of flame retardants in recycled plastic goods purchased on the European market. The plastic used to manufacture these consumer products is assumed to have originated from electronic waste, containing polybrominated diphenyl ethers (PBDEs) frame retardants, such as octabromodiphenyl ether (OctaBDE), decabromodiphenyl ether (DecaBDE) and hexabromocyclododecane (HBCD).

HUMAN EXPOSURE TO FLAME RETARDANTS IN RECYCLED PLASTICS

Studies have found brominated flame retardants in plastic consumer products that may be put to daily use, such as toys and kitchen utensils. Human exposure may occur if children put contaminated toys in their mouths, or if chemicals migrate from kitchen utensils into food.

Brominated flame retardants have been found in children's' toys (Fatunsin et al., 2020, Guzzonato et al., 2017) and in black plastic kitchen utensils in the UK (Kuang et al., 2018), as well as in black thermo cups and selected kitchen utensils purchased on the European market (Samsonek et al., 2016). A study found hexabromocyclododecane (HBCDD) to be present in 90% of Irish and UK polystyrene packaging samples (Abdallah et al., 2018).

NGOs have also been active in leading studies in this area. A survey of recycled plastic children's products from 26 countries found that 90% of samples contained OctaBDE or DecaBDE, while nearly half contained HBCD (DiGandgi et al., 2017). A second study tested 430 plastic items, including toys, hair accessories, kitchen utensils and other consumer products, purchased in EU Member States and found that 25% were contaminated with flame retardants, including pentabromodiphenyl ether (PentaBDE) and OctaBDE (Straková et al. 2018). Another NGO study found significant levels of brominated dioxins accompanying brominated flame retardants in nine samples of consumer products made from recycled plastics (Petrlik et al., 2018).

GLOBAL AND EU POLICIES ON CHEMICALS IN PLASTICS

EU policies to manage hazardous substances in waste electrical and electronic equipment are described in section 2 above.

The value chain for products made of recycled plastic is global and therefore influenced by international policies, in particular the Stockholm Convention on persistent organic pollutants (POPs). Due to their toxicity and persistence, several families of brominated flame retardants have been listed as persistent organic pollutants (POPs) in the Stockholm Convention. This treaty mandates that parties take actions to prevent the environmental impacts that POPs pose, both within their jurisdictions and in the global environment. For some chemical substances, specific exemptions are defined by the Convention for certain parties. Penta- and Octa-BDE can be present in waste materials for recycling until 2030 (Sharkey et al., 2020). The EU had registered for this exemption, to allow for the recycling of articles containing these substances. This exemption was withdrawn in 2020, with the recycling of materials containing these flame retardants no longer permitted in the EU.

Flame retardant is the term given to any compound or mixture added to a consumer product or building material to reduce the flammability and thus improve product safety. Since the 1970s, the primary FR compounds used were the polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCDD).

However, due to concerns regarding their persistence, toxicity and bioaccumulative potential, these compounds have been added to the Stockholm Convention on Persistent Organic Pollutants, including the most recent addition of deca-BDE in 2017. Nevertheless, the need for flame retardants has not decreased and this has led to a broadening of the market, with a wide range of replacement compounds used globally.

PBDEs and HBCDDs have been identified to have a range of adverse health effects, including potential neurotoxic, endocrine, and carcinogenic effects (Chevrier, 2010, Herbstman, 2010). Tetrabromobisphenol A (TBBPA) has been identified to have a range of potential hazardous properties (IHCP, 2006, Lai, 2015, Birnbaum, 2003). Early evidence suggests that a number of the replacement flame retardants may have similar health concerns (Dishaw, 2011; Patisaul, 2013; Springer, 2012).

For more information see the HBM4EU webpage on flame retardants.

HBM4EU publication on flame retardants:

Bajard, L., Negi, C.K., Mustieles, V., Melymuk, L., Jomini, S., Barthelemy-Berneron, J., Fernandez, M.F. and Blaha, L., 2021. Endocrine disrupting potential of replacement flame retardants–review of current knowledge for nuclear receptors associated with reproductive outcomes. Environment International, 153, p.106550.

Dvorakova, D., Pulkrabova, J., Gramblicka, T., Polachova, A., Buresova, M., López, M.E., Castaño, A., Nübler, S., Haji-Abbas-Zarrabi, K., Klausner, N. and Göen, T., 2021. Interlaboratory comparison investigations (ICIs) and external quality assurance schemes (EQUASs) for flame retardant analysis in biological matrices: Results from the HBM4EU project. Environmental Research, 202, p.111705.

Bajard, L., Melymuk, L. and Blaha, L., 2019. Prioritization of hazards of novel flame retardants using the mechanistic toxicology information from ToxCast and Adverse Outcome Pathways. Environmental Sciences Europe, 31(1), pp.1-19.

Hajeb, P., Castaño, A., Cequier, E., Covaci, A., López, M.E., Antuña, A.G., Haug, L.S., Henríquez-Hernández, L.A., Melymuk, L., Luzardo, O.P. and Thomsen, C., 2021. Critical review of analytical methods for the determination of flame retardants in human matrices. Analytica Chimica Acta, p.338828.

USING HUMAN BIOMONITORING TO EXPLORE EXPOSURE TO CHEMICALS IN RECYCLED CONSUMER PRODUCTS

Human biomonitoring can be used to evaluate consumer exposure to hazardous substances in products containing recycled materials, and in particular consumer exposure to legacy substances, as a means of tracking the elimination of hazardous substances from product flows as foreseen under the Chemicals Strategy for Sustainability. Targeted analysis would be required to focus on groups using recycled plastic products, such as kitchen utensils, and a control group, to allow for a comparison in exposure across time.

Bisphenols and phthalates in recycled paper used for food packaging

04

KEY MESSAGES

- In Europe, paper and cardboard is recycled at a rate of 74% - making paper one of the materials with the highest recycling rates. A range of chemicals are used on paper and cardboard and are not easily removed during the recycling process, and occur in recycled paper products
- When recycled paper and cardboard are used for food packaging, as chemical residues may migrate into foods. Hundreds of chemicals have been measured in food packaging made from recycled paper and cardboard, as well as in the packaged food.
- A limited number of studies have detected phthalates and bisphenols in food contact materials and in food.
- The European Food Safety Authority (EFSA) sets safe levels for five phthalates and has concluded that current exposure to these five phthalates from food is not a concern for public health.
- EFSA is currently re-evaluating the risks to public health related to the presence of BPA in foodstuffs.
- EU legislation to control the migration of chemicals into food from food contact materials sets standards for bisphenols and phthalates in plastics but does not set standards for paper and cardboard.

CHEMICALS IN RECYCLED PAPER AND CARDBOARD

The EU Packaging Waste Directive sets the target for Member States to collect a minimum of 60% by weight of paper and cardboard based packaging waste generated. In 2016, 76 million tonnes of paper and cardboard were used in Europe, with the resulting waste recycled at a rate of 74% - making paper one of the materials with the highest recycling rates (European Paper Recycling Council, 2020). The majority, 50 million tonnes, was used for recycling by the European paper industry, with 11% bought by third countries.

Europe leads the world in paper recycling, with paper fibres used on average 3.8 times. Generally recycled fibre is used to produce paper of an equal or lower grade with packaging or newsprint often being made into new packaging or newsprint.

A range of chemicals are used on paper and cardboard to label them, and to prevent deterioration. When such materials are recycled, the chemicals may be retained in the final recycled paper or cardboard product. This case study focuses on the presence of bisphenols and phthalates in recycled paper and cardboard materials, with a particular focus on food contact materials.

Phthalates (also called phthalate esters or esters of phthalic acid), and their substitute Hexamoll® DINCH®, are a group of plasticizers with a production volume of millions of tons per year. They are widely used in the manufacture of plastics, to make them soft and flexible, and in personal care products. Phthalate-containing plastics are found in a vast range of products including construction materials, paper and cardboard products, food and product packaging materials, toys, cosmetics, electrical wiring and a range of textiles, vehicle upholstery, and medical products. Phthalates are also found in adhesives and inks. They can be found in common products such as soaps, sun tan lotion, soft plastic toys, plastic bottles, raincoats, shoes and food packaging (HBM4EU).

Due to their endocrine disrupting properties, the uses of a several phthalates are restricted in the EU. Nevertheless, restricted phthalates have been found in a high number of products imported into the EU (ECHA, 2018). Banned phthalates may be present in consumer products purchased before restrictions entered into force.

Plasticizers can be taken up by ingestion, inhalation and dermal contact. For high molecular weight phthalates, the main source of exposure is through ingestion of food contaminated via food contact materials (Wittassek et al., 2011), especially for Bis(2-ethylhexyl) phthalate (DEHP) and DiNP. Inhalation of indoor air, exposure via ingestion of house dust by children and dermal contact with articles and dust can also be sources of exposure (Fromme et al., 2013). In addition, medical treatment can lead to high exposure towards certain phthalates.

DEHP is a widely used phthalate, classified as toxic to reproduction and an endocrine disruptor and a substance of very high concern under REACH (ECHA), with some uses restricted.

For more information on phthalates see the HBM4EU webpage on phthalates and Hexamoll® DINCH.

Bisphenols are commonly used in the manufacture of polycarbonate plastics and as a stabiliser in primarily polyvinylchloride (PVC). Currently, bisphenol A (BPA) is the substance in the bisphenol group that is produced and used in the highest volumes. There is wide use of polycarbonate, with it being used in the manufacture of modern optical media, such as DVDs and CDs, sports equipment, medical and dental devices, building and construction materials, automotive parts and domestic appliances, as well as food containers, such as reusable beverage bottles and some manufacturing equipment. BPA is also used in epoxy resins, such as those used to line food and beverage cans. Small amounts of the BPA contained in these food contact materials migrate into food and beverages stored in materials containing the substance, resulting in human exposure. The most common exposure route for BPA is through ingestion via the diet, whereby bisphenols migrate from food packaging into the food and are ingested by the consumer. There is solid evidence that a large majority of the human population is exposed to BPA (HBM4EU).

BPA has also been commonly used in thermal receipt papers as a colour developer and is in sales receipts, public transport and parking tickets. This raised concerns regarding the dermal exposure of cashiers in frequent contact with receipts, whereby BPA is transferred from thermal paper products to the finger pads upon handling it, leading to dermal penetration of BPA (Björnsdotter et al., 2017). This resulted in a restriction on the use of BPA in thermal paper in the EU.

BPA is classified under the CLP Regulation as a substance that may damage fertility, may cause serious eye damage, may cause skin allergies and respiratory irritation. It has also been identified as an endocrine disruptor for human health and for the environment. Due to its properties as toxic for reproduction, BPA was listed as a substance of very high concern (SVHC) on the Candidate List under Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).

Bisphenol S (BPS) was developed as a substitute for BPA, and has been used in the manufacturing of plastics, thermal papers and is authorised for use as a food contact material in the EU under the Regulation on plastic materials and articles intended to come into contact with food. BPS is replacing BPA in thermal papers across Europe (ECHA, 2020). A study investigating the presence of BPA and BPS in till receipts from 2018-2019 from 39 countries found BPA to be the most common compound used around the world, found in 69% samples, with BPS found in 20% of samples (Frankowski et al., 2020). Two hundred tonnes of BPS are estimated to be present in the European paper cycle, with this volume predicted to increase more than fivefold over 60 years. In that period, more than 90 tonnes of BPA would still be circulated in European paper products (Pivnenko et al., 2018).

For more information on bisphenols see the HBM4EU webpage on bisphenols.

Paper is made up of layers of cellulose fibres derived from wood, cotton, rice, papyrus, which can be recycled six to seven times. Commercial papers incorporate chemicals, with around 15% of the weight of paper made up of fillers. Other chemicals are added to deliver properties such as opacity, brightness, or glossiness, including resins, wet strength agents, optical brightening agents, sizing agents, dyestuffs, coatings, retention agents, anti-foaming agents, cleaning agents, or biocides. Chemical residues from the production process remain in the paper product (JRC, 2011). An overview of the material flow process with respect to recycled paper is shown in the diagram below.

Printing inks used on packaging materials are chemicals mixtures including colorants (5–30%), binders (15–60%), solvents (20–70%) and additives such as plasticizers (1–10%), added to paper and packaging to deliver specific functionalities (DTU, 2021). Bisphenols are used as a developer in thermal paper during manufacture, as well as in inks and glues (Pivnenko et al., 2016). Phthalates are used in inks, lacquers and adhesives (Fierens et al., 2012).

In the recycling process, wastepaper and board are combined with up to 100 times their weight of water and mixed mechanically to form a slurry. Chemicals are then added to adjust the pH and the pulp is filtered and screened to remove water-based inks, fillers, coating particles, and glues. For heavily printed waste papers, the ink is removed through a flotation process where air is blown into the pulp. The ink adheres to the bubbles and rises to the surface, where it is skimmed off. The pulp is then made into paper, and depending on the grade of paper being produced, virgin pulp may be added. Some papers, such as newsprint and corrugated materials, can be made from 100% recycled paper. The pulp is pressed and dried, after which it is rolled into large thin sheets of recycled paper. The rolls are cut for use in newspaper, books, writing paper, tissue and packaging (JRC, 2019).

Chemical substances of various origins are present in wastepaper. These chemicals are not easily removed during the recycling process, and occur in recycled paper products (JRC, 2011).

Regarding bisphenols in paper recycling, contamination of recycled pulp with BPA and or BPS can occur when thermal paper is included in the feedstock to the recycling process (Geens et al., 2012). Other sources of BPA in the recycling stream are ink and glue added to paper products (Pivnenko et al., 2016c). Numerous studies have found bisphenols in waste paper and/or recycled paper and cardboard (BMELV, 2012; Gehring et al., 2004; Liao and Kannan, 2011; Pérez-Palacios et al., 2012; Suciu et al., 2013). An analysis of 15 types of paper from different fractions of household waste detected BPA and BPS in 100% and 73% of samples respectively (Pivnenko et al., 2015).

A Spanish study investigated the presence of bisphenols in food-contact materials made of recycled paper. All the materials tested contained BPA, with a paper tablecloth, pizza carton and packaging box found to have the highest concentrations. BPF was only detected in a popcorn bag and paper tablecloth, with concentrations below the limit of quantification (Pérez-Palacios et al., 2012). A US study found BPA and BPS in recycled paper goods such as flyers, magazines, tickets, mailing envelopes, newspapers, food contact papers, food cartons, airplane boarding passes, luggage tags, printing papers, business cards, napkins, paper towels, and toilet paper and identified contamination during the paper recycling process as a source of BPA (Liao et al., 2011).

Phthalates have also commonly been measured in food packaging made from recycled paper and cardboard (Geueke et al., 2018), with sources including inks, lacquers and adhesives (Fierens et al., 2012). Amongst others, DEHP, DBP, DiBP, BBP, and diethyl phthalate (DEP) have regularly been identified in waste paper (Pivnenko et al., 2016) as well as recycled paper and cardboard (Suciu et al., 2013, Vápenka et al., 2016). A study testing for phthalates in infant food packed in recycled paperboard containers found the highest levels of phthalates (mainly diisobutyl phthalate, DiBP) in foods packed in inner bags made of paper (Gärtner et al., 2009).

An Italian study investigating the presence of contaminants in food packaging, found higher levels in food packaging made by recycled materials. Seventeen commercial samples were analyzed for the presence of BPA, DEHP, nonylphenol monoethoxylate (NMP) and nonylphenol di-ethoxilate (NDP). BPA was the only substance present in all the samples (Suciu et al., 2013).

A Czech study tested for chemicals in 132 samples of paper-based food packaging from the Czech market. The levels of 10 typical contaminants, including BPA, and a number of phthalates (DBP, DEHP, diisodecyl phthalate (DiDP), DiNP, and two diisopropylnaphthalene isomers) were compared in papers with recycled fibre content below 10% and above 90% and found concentrations to be significantly higher in samples containing more than 90% recycled (Vápenka et al., 2016).

CHEMICALS IN FOOD CONTACT MATERIALS MADE FROM RECYCLED PAPER AND CARDBOARD

The use of recycled paper and cardboard for food packaging is of particular concern, as it increases both the possible sources of contamination and the diversity and levels of chemicals that can migrate from the packaging into foods, thereby potentially affecting human health (Gueueke et al., 2018, BMELV, 2012, Muncke et al., 2017, Pivnenko et al., 2016, Vápenka et al., 2016). More than 9,000 different substances are used in printed paper and cardboard and may be carried over into recycled material, hinting at the range of different chemicals that may be found in recycled paper and cardboard and subsequently migrate into packaged foods (Pivnenko et al., 2015, Van Bossuyt et al., 2016). Hundreds of chemicals have been measured in food packaging made from recycled paper and cardboard and/or in the packaged food, with one study identifying more than 250 substances in recycled paperboard used for food packaging (Biedermann and Grob, 2013).

Chemicals can reach higher levels in recycled food packaging, for several reasons (Gueueke et al., 2018):

- materials intended for recycling may contain inks, additives and their degradation products,
- the material may be degraded during use and/or recycling,
- chemicals may accumulate when materials are recycled multiple times,
- previous use and/or waste management may introduce contaminants, and
- non-food grade materials may enter the recycling stream.

RISK OF HUMAN EXPOSURE TO BISPHENOLS AND PHTHALATES IN RECYCLED PAPER AND CARDBOARD

Human exposure to bisphenols and phthalates in recycled paper and cardboard may occur through consuming food packaged in food contact materials made of paper or cardboard with a recycled content, whereby chemicals migrate from the packaging into the food (Borchers et al., 2010, Geueke et al., 2018).

EFSA recently set a new safe level – a group Tolerable Daily Intake (TDI) – for four phthalates (di-butylphthalate (DBP); butyl-benzyl-phthalate (BBP); bis(2-ethylhexyl)phthalate (DEHP); di-isononylphthalate (DINP); di-isodecylphthalate) of 50 micrograms per kilogram of body weight (μg/kg bw) per day. The TDI is an estimate of the amount of a substance that people can ingest daily during their whole life without any appreciable risk to health. For di-isodecyl phthalate (DIDP), EFSA set a separate TDI of 150 μg/kg bw per day based on its effects on the liver. EFSA set these TDIs on a temporary basis due to uncertainties about effects other than the reproductive ones and about the contribution of plastic food contact materials to overall consumer exposure of phthalates. EFSA concluded that current exposure to these five phthalates from food is not a concern for public health. Dietary exposure to the group of DBP, BBP, DEHP and DINP for average consumers is seven times below the safe level, while for high consumers it is four times lower. For DIDP, the dietary exposure for highly exposed consumers is 1,500 times below the safe level (EFSA, 2019).

In 2015, EFSA set a TDI of 4 μg/kg bw for BPA. EFSA is currently working on the re-evaluation of the risks to public health related to the presence of BPA in foodstuffs plans to finalise the updated assessment by 2022. In a draft opinion published in 2021, EFSA proposed to considerably lower the tolerable daily intake to 0.04 ng/kg bw per day.

EU POLICIES TO MANAGE THE QUALITY OF PAPER AND CARDBOARD

The Waste Framework Directive sets the basic concepts and definitions related to waste management, including definitions of waste, recycling and recovery. Preventing waste is the preferred option, with landfill as the last resort. The directive lays down some basic waste management principles. It requires that waste be managed without endangering human health and harming the environment. The EU Packaging Waste Directive sets the target for Member States to collect a minimum of 60% by weight of paper and cardboard based packaging waste generated.

Regulation (EC) No 1935/2004 on materials and articles intended to come into contact with food sets out the general principles of safety and inertness for all **food contact materials**, including paper and cardboard. It requires that materials do not release their constituents into food at levels harmful to human health or change food composition, taste and odour in an unacceptable way. The regulation recognises that the use of recycled materials and articles should be favoured in the Community for environmental reasons, provided that strict requirements are established to ensure food safety and consumer protection. Specific measures may be put in place for materials, including recycled materials, such specific limits on the migration of constituents into or on to food.

In a follow up, Commission regulation (EU) 2018/213 limits the use of bisphenol A in varnishes and coatings intended to come into contact with food and amending Regulation (EU) No 10/2011 as regards the use of that substance in plastic food contact materials. It sets a 'specific migration limit' (SML) for BPA, meaning the maximum permitted amount of a given substance released from a material or article into food or food simulants. The migration of BPA from **plastic materials and articles** shall not exceed a specific migration limit of 0.05 mg of BPA per kg of food (mg/kg). However, the regulation does not address recycled paper and cardboard food contact materials.

Regulation (EC)10/2011 covers plastic materials and articles intended to come into contact with food. It allows the use of several phthalates that are generally considered dangerous for human health, for some categories of product. Specific migration limits for phthalates are as follows:

- DEHP: Migration limit set to a maximum of 1.5 mg/kg
- DBP: Migration limit set to a maximum of 0.3 mg/kg
- BBP: Migration limit set to a maximum of 30 mg/kg
- DAP: Migration limit set to a maximum of 0.01 mg/kg
- DIDP + DINP: Migration limit set to a maximum of 9 mg/kg

In 2019, the Commission adopted a recommendation to establish a coordinated control plan to assess the prevalence of certain substances, including bisphenols and phthalates, migrating from food contact materials. Member States should implement the coordinated control plan for materials and articles intended to come into contact with food. While it does cover paper and cardboard, they are not to be tested for the presence of bisphenols and phthalates. Rather, polycarbonate plastic and polyethersulfone plastic and coated metal packaging, such as cans, are to be tested for bisphenols, while plastic materials and articles are to be tested for phthalates. Recycled materials are not mentioned.

In 2019, EFSA updated its risk assessment of the use of five phthalates authorised for use in plastic food contact materials, namely DBP, BBP, DEHP, DINP and DIDP. There was insufficient information to draw conclusions on how much migration from plastic food contact materials contributes to dietary exposure to phthalates. While the assessment acknowledges the potential for exposure to phthalates via recycled paper and cardboard, the risk posed by this exposure route was not assessed.

Effective from 2020, the European Commission restricted the use of BPA in thermal paper, including consumer receipts, transport tickets, etc, requiring manufacturers and printers to source alternative dye products. This will serve to reduce the introduction of BPA into the paper and board production cycle, with the inclusion of thermal papers in recycling feedstock identified as a key source. Despite this, one study suggests that BPA will continue to circulate in the paper cycle and the substitution of BPA with BPS will see increased volumes of BPS circulating (Pivnenko et al., 2018).

The EU Ecolabel is awarded to products and services meeting high environmental standards throughout their life-cycle and sets criteria for a range of paper products.

USING HUMAN BIOMONITORING TO EXPLORE EXPOSURE TO CHEMICALS IN RECYCLED PAPER

Human biomonitoring cannot discriminate between exposures via different sources, and as such a targeted approach would be required. Studies might focus on vulnerable groups, both occupational and consumers, which may be at higher levels of risk from exposure to chemicals in recycled paper, such as children and women of child-bearing age. Studies could involve groups exclusively using recycled papers for two weeks to get more specific information as compared to a control group that have no contact with recycled paper for that period. This type of study design could provide valuable insights into the scale of exposure linked to recycled paper compared to other uses of bisphenols and phthalates.

Polycyclic aromatic hydrocarbons in synthetic turf pitches and playgrounds

05

KEY MESSAGES

- The use of rubber granules produced from waste tyres in artificial turf fields is increasing, with an estimated 90,000 pitches in the EU.
- Polycyclic aromatic hydrocarbons (PAH) are released into the environment from the rubber infill of synthetic turf pitches, raising concerns regarding potential human exposure, principally via inhalation and skin contacts.
- Based on current evidence, there is no reason to advise people against playing sports on such pitches.
- In 2020, the EU restricted the concentration of PAHs in granules or mulches used as infill material in synthetic turf pitches or in loose form on playgrounds or sport applications to 20 mg/kg for eight PAHs.

CHEMICALS IN SYNTHETIC TURF PITCHES

Over one billion waste tyres are generated annually worldwide. Disposal of waste tyres is challenging, with tyres being highly resistant to biodegradation, photochemical decomposition, chemical reagents, and microorganisms. This has driven efforts to develop secondary applications to utilise tyres when they reach the end of their life cycle. A growing secondary use of tyres is grinding it into rubber granules used in artificial turf fields (Sibeko et al., 2020).

A 2017 ECHA report estimated that by 2020, 21,000 full size pitches and about 72,000 mini pitches using recycled rubber granules would be found in the EU, with the annual use of end-of-life tyre infill projected to grow 160% from 2016 to 2028. The EU is a net exporter of rubber granules and is home to around 140 rubber granule formulators (ECHA, 2017).

Concerns have been raised regarding hazardous chemicals in tyres that ultimately end up in synthetic turf pitches and to which players may be exposed, such as polycyclic aromatic hydrocarbons (PAHs), metals, plasticisers (phthalates) and bisphenol A (BPA) (Schneider et al., 2020, Pronk et al., 2020, Pronk et al., 2018, Peterson et al., 2018, ECHA, 2017, RIVM, 2017). Concentration of PAHs were identified to be of highest concern. PAHs occur naturally in fossil fuels, and as such chemical products derived from fossil fuels, such as the synthetic rubber used to produce tyres, contain PAHs. For PAHs, benzo(a)pyrene, dibenz(a) and (h)anthracene and related chemicals have been of greatest concern.

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous environmental pollutants, produced by the incomplete combustion of organic materials, such as coal, oil, petrol, and wood. Some PAHs in the environment originate from natural sources, such as open burning, seepage from petroleum or coal deposits, and volcanic activities. Many PAHs are known or suspected carcinogenic and mutagenic compounds. Currently eight PAHs are classified as known carcinogens under the CLP Regulation, namely Benzo[a]pyrene (BaP), benzo[e]pyrene (BeP), benzo[a]antracene (BaA), chrysene (CHR), benzo[b]fluoranthene, (BbF), benzo[j]fluoranthene (BjF), benzo[k]fluoranthene (BkF), and dibenzo[a,h] antracene (DBAhA).

For more information see the HBM4EU webpage on PAHs.

Under HBM4EU, human biomonitoring was used to assess the exposure of mothers and their newborns to PAHS in two localities of the Czech Republic — Most and Ceske Budejovice — in 2016 and 2017. Urbancova, K., Dvorakova, D., Gramblicka, T., Sram, R.J., Hajslova, J. and Pulkrabova, J., 2020. Comparison of polycyclic aromatic hydrocarbon metabolite concentrations in urine of mothers and their newborns. Science of The Total Environment, 723, p.138116.

RISK OF HUMAN EXPOSURE TO PAHs IN SYNTHETIC TURFS

PAHs are released into the environment from synthetic turf predominantly through rubber dust particles. Abrasion from physical wear and tear breaks the rubber granules down into fine dust-like matter with synthetic turf sports pitches estimated to release 16,000 tonnes of microplastics to the environment annually (ECHA, 2020), with a proportion expected to contain PAHs. People playing on synthetic pitches may inhale airborne particles containing PAH into the lungs. Another possible exposure route is through direct skin contact with the synthetic turf, a risk enhanced if people have injuries that graze or cut the skin so damaging the skin barrier and enabling direct PAH entry to the body. A less common exposure pathway is oral, which exists as people have been reported to accidentally swallow dust particles. This route of exposure is considered unlikely, with estimates that 0.05 g and 0.01 g of rubber infill may be consumed by children and adults respectively during a game of football. Workers producing rubber granules, manufacturing, installing and maintaining synthetic pitches, and removing pitches at the end-of-use stage may be exposed (ECHA, 2017).

In 2017, ECHA published a health risk assessment on recycled tyre granulate infill following an investigation of the risks to children playing football and other sports on synthetic sports fields, adults playing professional sports and workers installing or maintaining the fields. The evaluation found no risk to health, but did highlight uncertainties and knowledge gaps with regard to data coverage, the range of substances considered and their concentrations in the rubber matrix (ECHA, 2017). Concentrations of PAHs in recycled rubber granules were well below the limit values set in the REACH restriction relevant for such mixtures.

A risk assessment produced by the Dutch authority RIVM also found no health risks and concluded that playing on synthetic turfs with rubber granulate infill was safe (RIVM, 2017). Nevertheless, the report noted that while PAH concentrations were below maximum levels for mixtures set under REACH, they slightly exceeded the limit value for consumer products. They recommended adjusting the concentrations for rubber granulate to come closer to consumer standards.

Several follow up studies agreed with the assessment that there is no elevated health risk from playing sports on synthetic turf pitches with recycled rubber granulate (Pronk et al., 2020, Pronk et al., 2018, Peterson et al., 2018).

OVERVIEW OF CURRENT EU POLICY

Rubber granules are considered as 'mixtures' under REACH, as they contain a number of substances, including low levels of PAHs. ECHA considers the level of concern from exposure to substances in the granules as very low, however, there is some concern about the concentration of PAHs. Specifically, if concentrations of PAHs are as high as the generic concentration limits under REACH Annex XVII, then the risks would not be low (ECHA, 2017). In their 2017 report, ECHA recommended changes to the REACH Regulation to ensure that rubber granules are only supplied with very low concentrations of PAHs and other relevant hazardous substances.

In 2020, with the aim of protecting human health the EU restricted the concentration of PAHs in granules or mulches used as infill material in synthetic turf pitches or in loose form on playgrounds or sport applications to 20 mg/kg for eight PAHs, namely:

- benzo[a]anthracene (B[a]A),
- chrysene (CHY),
- benzo[b]fluoranthene (B[b]F),
- benzo[j]fluoranthene (B[j]F),
- benzo[k]fluoranthene (B[k]F),
- benzo[a]pyrene (B[a]P),
- benzo[e]pyrene (B[e]P) and
- dibenzo[a,h]anthracene (D[ah]A) (ECHA, 2019).

A recent study tested 91 infill football field samples from 17 countries on 4 continents and found only one sample in the EU (from Sweden) to be in exceedance of this limit, as well as several samples from outside of the EU (Armada, et al., 2021).

In follow up to their 2017 report, ECHA examined available data on substances of concern to human health or the environment in plastic and rubber granulates used as infill in synthetic turf pitches and concluded that cobalt and zinc may pose risks to human health in infill and that these substances should therefore be considered for risk management (ECHA, 2021). In parallel, ECHA proposed a restriction on intentionally added microplastics, that includes within its scope infill used on synthetic turf pitches (ECHA, 2019). The decision by the Commission and the Member States on the implementation of the proposed microplastics restriction will affect the need for risk management for the substances in infill, potentially making any further risk management unnecessary. In the event that microplastic infill is banned, ECHA notes that non-microplastic uses of recycled end-of-life tyres, such as mulches, may still require further risk management.

USING HUMAN BIOMONITORING TO EXPLORE EXPOSURE TO CHEMICALS IN SYNTHETIC TURF

Targeted human biomonitoring studies could be employed to explore the exposure of players who regularly play on synthetic turf fields, compared with the exposure of a control group. This would allow an assessment of whether regular exposure to synthetic turfs increased levels above the general population, since synthetic turfs are not the only source of exposure to PAHs, and other contaminants.

Dietary exposure to chemicals from the reuse of sewage sludge and wastewater in agriculture

06

KEY MESSAGES

- The Circular Economic Action Plan aims to facilitate waste reuse and recover nutrient, including sewage.
- While only 2.4 % of treated wastewater is currently reused in the EU, about half the sewage sludge produced by EU Member States is spread on agricultural land as fertiliser.
- Both sewage sludge and wastewater contain chemicals, including medicines, cosmetics and personal care products and cleaning products.
- Limited evidence suggests that food grown on land on which sludge and wastewater have been applied may be contaminated through the uptake of chemicals through plants root pathway or absorbed by leaves.
- There is currently no evidence of human exposure to chemicals in food resulting from the reuse of wastewaters and/or sewage on agricultural land.
- EU legislation is in place to manage discharges of urban wastewater and to regulate the application of sewage sludge to agricultural land. From 2023, water quality requirements for the safe reuse of treated urban wastewaters in agricultural irrigation will apply.

REUSING SEWAGE SLUDGE AND WASTEWATER

The Circular Economic Action Plan aims to facilitate waste reuse to combat water scarcity, in a context where drought events are becoming more severe and more frequent due to climate change. New EU legislation on water reuse aims to stimulate and facilitate water reuse in the EU, recognising that Europe could reuse six times as much water by 2025. While the reuse of treated wastewater on agricultural land, is an accepted practice in several EU countries experiencing water scarcity issues, including Spain, Italy, Cyprus, France, Greece, Malta and Portugal, only 2.4 % of treated wastewater is currently reused in the EU. This represents less than 0.5 % of annual freshwater withdrawals (Amec, 2016). The Commission is also foreseen to develop an Integrated Nutrient Management Plan, with a view to ensure more sustainable application of nutrients and stimulating the markets for recovered nutrients, including sewage.

At the same time, chemicals in a range of consumer products, such as medicines, cosmetics and personal care products and cleaning products, end up being washed down the drain and enter wastewater treatment plants. Even the most advance wastewater treatment techniques, known as tertiary treatment, are only partially effective at removing chemicals, with many chemicals being partitioned from treated effluent into sewage sludge. In 2017, 69% of the EU population was connected to tertiary wastewater treatment facilities (EEA, 2020). Different disposal routes exist for sludge, depending on national regulatory frameworks and sludge quality. Approximately half the sewage sludge produced by EU Member States is spread on agricultural land as fertiliser and a quarter is incinerated. Sludge can contain high concentrations of metals, pathogens and traces of persistent organic pollutants, so its use on land is restricted in some Member States to protect the environment (EEA, 2021). This raises the question of whether pollutants present in sludges and treated wastewater applied to soils may be absorbed by plants and enter the human food chain leading to dietary exposure.

This case study focusses on three product types: cosmetics, medicines, and cleaning products. The use of these products will lead to their constituent substances being washed down the drain. Medicines are consumed and ultimately excreted in urine, cleaning products are deliberately washed down the drain and cosmetics are washed off the body during showering. Figure 4 presents the flow by which substances in these products may end up released onto agricultural land, potentially leading to human exposure.

The proportion of a chemical that ends up in either sludge or wastewater depends on the properties of that substance and the removal efficiency of wastewater treatment processes. Common processes for wastewater treatment in the EU include:

- Primary treatment – wastewater is left to 'settle' so that solid contaminants separate out from the liquid which is then extracted.
- Secondary treatment – biological methods are used to remove dissolved organic matter from the wastewater.
- Tertiary treatment – additional filters are used to remove chemical contaminants a well as nutrients and pathogens.
- Advanced / quaternary treatment – filters and chemical technologies are used to remove chemical contaminants present in very low concentrations, resulting in high effluent quality.

Wastewater treatment is the first step, after which the sludge is recovered and subsequently treated before being applied to agricultural land, where allowed. Common process for sludge treatment in the EU includes:

- Drying - thermal energy is used to evaporate water, reducing volume, and facilitating storage and transportation.
- Lime treatment - adding a controlled dose of hydrated lime or quicklime to sewage sludge.
- Heating for pasteurisation – heating the sludge to kill pathogens.
- Composting – a biological process that uses naturally occurring microorganisms to convert biodegradable organic matter into a humus-like product via anaerobic digestion.

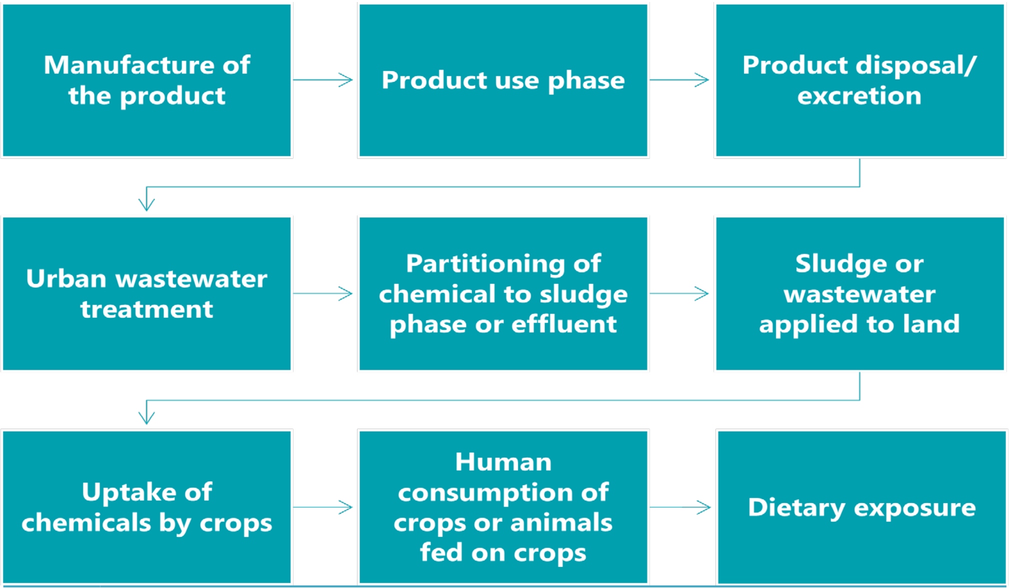

FIGURE 4 The flow of products leading to dietary exposure

SOURCE Wood Ltd.

RISK OF DIETARY EXPOSURE VIA CONTAMINATED FOOD

Limited evidence suggests that food grown on land on which sludge and wastewater have been applied may be contaminated through the uptake of chemicals through plants root pathways or absorbed by leaves. Possible pathways by which humans may then be exposed include:

- Uptake by plant roots, transfer to edible portions of plants, and human consumption
- Human consumption of plants that have been sprayed with wastewater
- Uptake into plants used a feed for animals, subsequently consumed by humans

Overall, evidence of the presence of chemicals in sludges and waste waters applied to agricultural land is very scarce with further research required to determine whether this is an exposure pathway of potential concern.

Phthalates can remain dissolved in wastewater, or they may adsorb to suspended particles and be separated into the sludge phase during treatment. A French study found high removal efficiencies for various phthalates in wastewater treatment, ranging from 78-96 % (Dargnat et al., 2008). A limited number of studies have looked at phthalates in wastewaters. In Spain, four phthalates were detected in wastewater (González-Mariño et al., 2017). In a Germany study, high concentrations of BPA and phthalates were found in waste dump water and compost water, as well as in manure (Fromme et al., 2002). While several studies comment on the potential for phthalates to be taken up by crops from contaminated soil, evidence is very weak (Giuliani et al., 2020). One study documented the uptake of phthalates by lettuce, strawberry and carrot plants (Sun et al., 2015).

While **BPA** is no longer used in cosmetics in the EU, it may be present in cosmetic packaging. The substitutes **Bisphenol F** (BPF) and **Bisphenol S** (BPS) may be found in cosmetic products. In terms of their removal due to sewage treatment, efficiency varies widely, from 1% to 77%, with a considerable fraction partitioned into sludge (Yu et al., 2015). Bisphenols have been detected in sewage sludge in Germany (Bolz et al., 2001 and Fromme et al., 2002) and Greece (Stasinakis et al., 2008), as well as in the US, Canada, China and South Korea (Yu et al., 2015). In terms of the fate and behaviour of bisphenols in soils, BPA is expected to degrade within three days and it is therefore considered unlikely to contaminate crops (Fent et al., 2003).

Regarding aniline and aprotic solvents, evidence of their behaviour in wastewater treatment plants and their fate and behaviour in the environment is lacking. Anilines have low solubilities and therefore are more likely to settle in the sludge phase than the water phase. One study showed anaerobic sewage treatment plants failed to remove four aniline derivatives, but successfully removed four other derivatives (Zhou et al., 2020).

There is currently no evidence of human exposure to micropollutants resulting from the use of wastewaters and/or sludges on agricultural land.

EU POLICIES ON URBAN WASTEWATER TREATMENT, SEWAGE SLUDGE AND WASTEWATER

The Urban waste water treatment directive (UWWTD) protects the aquatic environment from the adverse effects of discharges of urban wastewater and from certain industrial discharges. The current directive stems from 1991 and is currently under revision, a process foreseen to address the pollution of water bodies.

The Sewage sludge directive regulates the application of sewage sludge to agricultural land to prevent harmful effects on soil, vegetation, animals and people. EU rules on sewage sludge consider the nutrient needs of plants and ensure that the quality of soil, the surface and ground water is not impaired. It covers

- how farmers use sewage sludge as a fertiliser
- the sampling and analysis of sludge and soils
- procedures for recording volumes of sludge produced and its use in agriculture
- the type of treatment and sites where sludge is used
- sludge composition and properties.

At national level, practices and rules on the use of sludge on agricultural lands vary. Generally, sludge is treated to reduce its fermentability and the health risks resulting from its use. In some EU countries, untreated sludge can be used in farming if it is injected or worked into the soil, while in other countries cases, sludge cannot be used at all.

The new Regulation on minimum requirements for water reuse will apply from 2023 and aims to stimulate and facilitate water reuse in the EU. The regulation sets out harmonised minimum water quality requirements for the safe reuse of treated urban wastewaters in agricultural irrigation.

USING HUMAN BIOMONITORING TO EXPLORE DIETARY EXPOSURE TO CHEMICALS

Human biomonitoring could be used to complement environmental monitoring of micropollutants in wastewaters and sludges, soils, plants and food, to better understand whether substances are being passed up the food chain leading to human exposure. This could entail targeted studies of populations known to be consuming vegetables grown in soils watered with wastewaters and/or fertilised with sewage sludge.