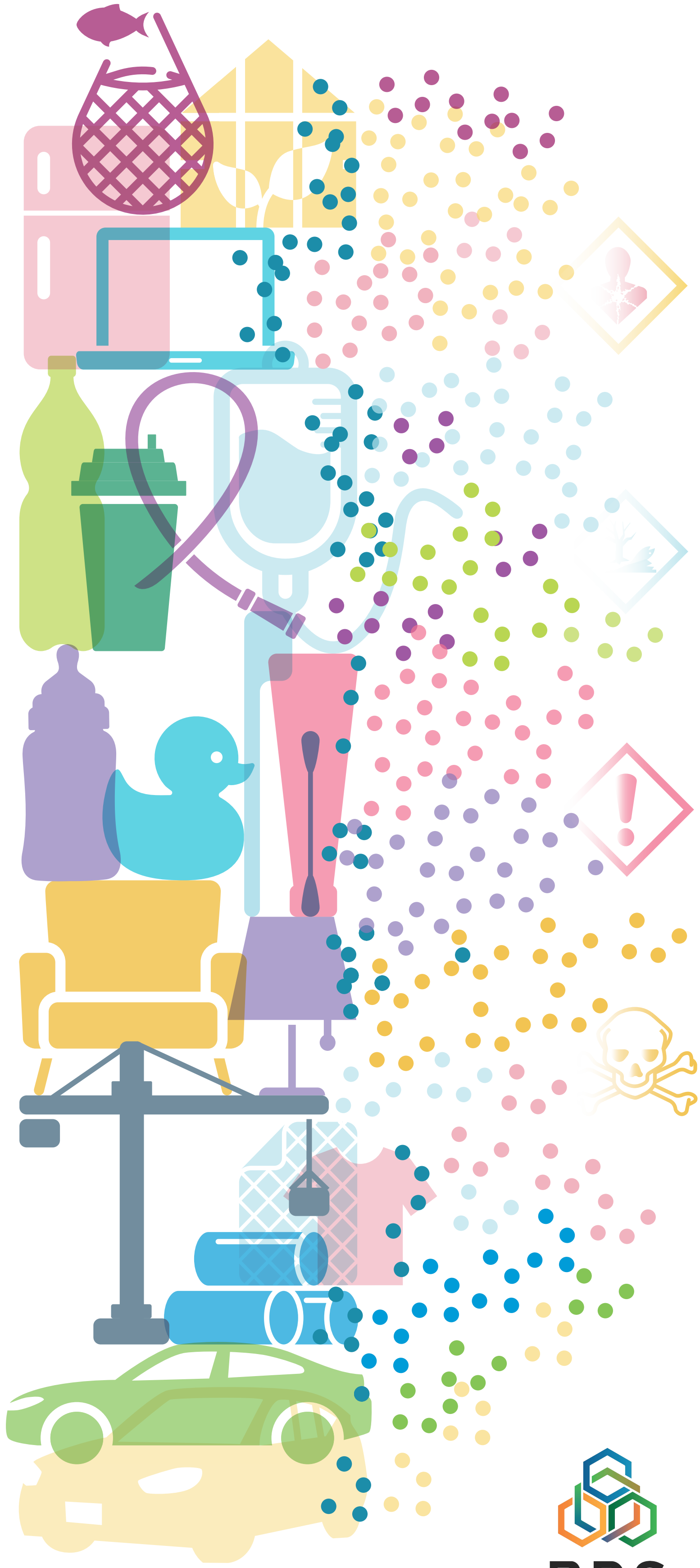
UN environment programme

CHEMICALS IN PLASTICS

A SUMMARY AND KEY FINDINGS



BRS CONVENTIONS

This is a Summary and Key Findings of the"Chemicals in plastics: a technical report" (2023) by the United Nations Environment Programme and Secretariat of the Basel, Rotterdam and Stockholm Conventions (ISBN No: 978-92-807-4026-4 -JOB NUMBER: DTI/2524/PA). UNEP does not accept responsibility for the accuracy or completeness of the contents of this Summary and Key Findings and shall not be liable for any loss or damage that may be occasioned directly or indirectly through the use of, or reliance on, the contents of this Summary and Key Findings. In case of inconsistencies, the full version will prevail.

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CHEMICALS IN PLASTICS : A SUMMARY AND KEY FINDINGS

About the present document

"Chemicals in Plastics: A Summary and Key Findings" has been prepared on the basis of the "Chemicals in Plastics: A Technical Report"[1].developed by UNEP in cooperation with the Secretariat of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, and the Stockholm Convention on Persistent Organic Pollutants, with lead authors from the International Panel on Chemical Pollution.

Key findings

The United Nations Environment Assembly of UNEP adopted a historical resolution in March 2022 calling for the development of an international legally binding instrument on plastic pollution based on a comprehensive approach that addresses the full life cycle of plastics[2].

1. **Chemicals are an integral part of plastics.** Over 13,000 substances have so far been associated with plastics, either known for use in plastic production or detected in plastic materials.

2. In addition to certain monomers, **ten groups of chemicals** (based on chemistry, uses, or sources) **are identified as being of major concern** due to their high toxicity and potential to migrate / be released from plastics, including specific flame retardants, certain UV stabilizers, per- and polyfluoroalkyl substances (PFASs), phthalates, bisphenols, alkylphenols and alkylphenol ethoxylates, biocides, certain metals and metalloids, polycyclic aromatic hydrocarbons, and many other non-intentionally added substances (NIAS).

3. **Chemicals of concern have been found in plastics across a wide range of sectors and products value chains**, including toys and other children's products, packaging (including food contact materials), electrical and electronic equipment, vehicles, synthetic textiles and related materials, furniture, building materials, medical devices, personal care and household products, and agriculture, aquaculture and fisheries.

4. **Chemicals of concern in plastics can impact our health and our environment**: Extensive scientific data on the potential adverse impacts of about 7,000 substances associated with plastics show that more than 3,200 of them have one or more hazardous properties of concern. These include chemicals that are persistent and mobile in the environment, accumulate in the body, can mimic, block or alter the actions of hormones, reduce fertility, damage the nervous system, and/or cause cancer.

[1] UNEP (2023). "Chemicals in plastics: A Technical Report", available on the UNEP website at https://www.unep.org/resources/report/chemicals-plastics-technical-report. Accessed 9 May 2023.
2 UNEA Resolution 5/14 entitled "End plastic pollution: Towards an international legally binding instrument"

5. **Women and children are particularly susceptible to these toxic chemicals.** Exposures can have severe or long-lasting adverse effects on several key period of a women's life and may impact the next generations. Exposures during fetal development and in children can cause, for example, neurodevelopmental / neurobehavioural related disorders. **Men are not spared either**, with latest research documenting substantial detrimental effects on male fertility due to current combined exposures to hazardous chemicals, many of which are associated with plastics.

6. **Chemicals of concern can be released from plastic along its entire life cycle**, during not only the extraction of raw materials, production of polymers and manufacture of plastic products, but also the use of plastic products and at the end of their life, particularly when waste is not properly managed, finding their way to the air, water and soils. Some chemicals can pose significant challenges to technological solutions to plastics recycling and material circularity (e.g., through contamination of new products made from recycled plastics).

7. **Existing evidence calls for urgent action to address chemicals in plastics as part of the global action on plastic pollution**, to protect human health and the environment, and transition to a toxic-free and sustainable circular economy. Key levers include:
    - Preventing and minimizing the use of chemicals of concern in plastics
    - Ensuring access to information and raising awareness on chemicals in plastics along the value chains
    - Enhancing availability and accessibility of safer and more sustainable alternatives to plastic products and chemicals in plastics
    - Building capacities and partnerships to address chemicals of concern in plastics
    - Strengthening research and monitoring of chemicals in plastics, in particular information on chemical hazards and mixtures of chemicals in plastics

Introduction: Chemicals in plastics matter

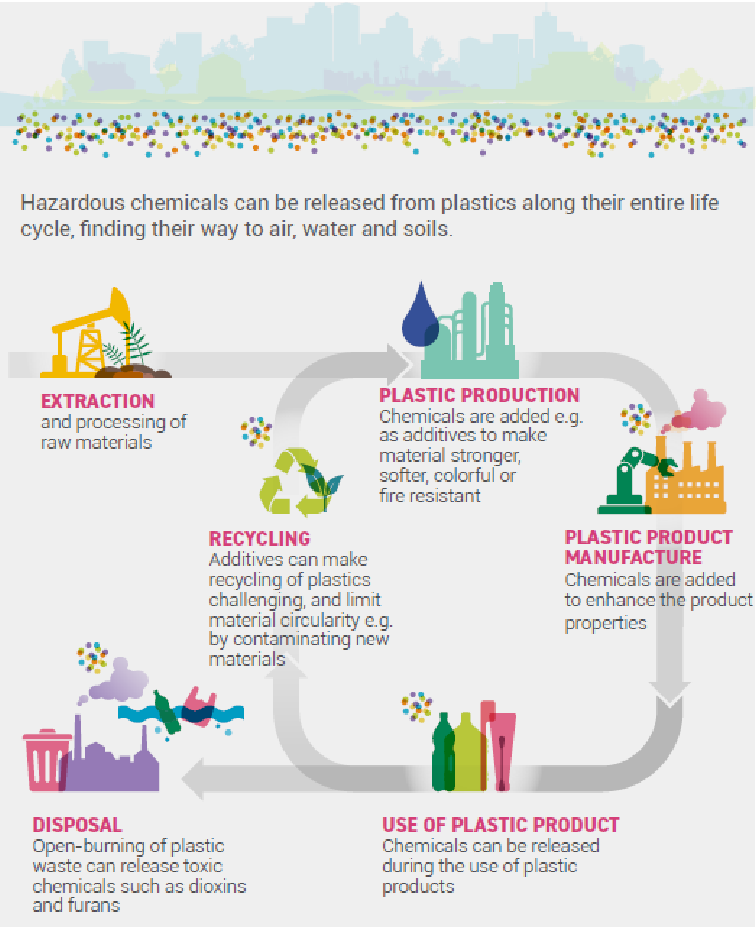
All plastics are made of chemicals, including polymers, additives to make products stronger, softer, colourful or fire resistant, and non-intentionally added substances such as impurities from manufacturing, use (e.g., leftover cleaning agents) and recycling.

Plastics have become ubiquitous in our modern life because of their light weight, low cost and versatility. As a result, global plastic production has increased exponentially since the 1950s, reaching about 460 million tonnes in 2019. The continuing growth of the global annual production of primary plastic is currently on course to possibly reaching 1.1 billion tonnes in 2050. Meanwhile, the world has seen a tremendous increase in plastic waste in the environment and many associated adverse impacts on human health and ecosystems.

Concerned by the devastating impacts of plastic pollution, the United Nations Environment Assembly (UNEA) adopted a historical resolution in March 2022[1], calling for the development of an international legally binding instrument by the end of 2024. The instrument is to be based on a comprehensive approach that addresses the full life cycle of plastics.

Plastic-associated chemicals are released at all stages of the plastic life cycle—from the extraction of raw materials to the production of polymers, the production and processing of plastic products to their use, recycling and disposal (Figure 1).

Figure 1. Chemicals along the plastic life cycle



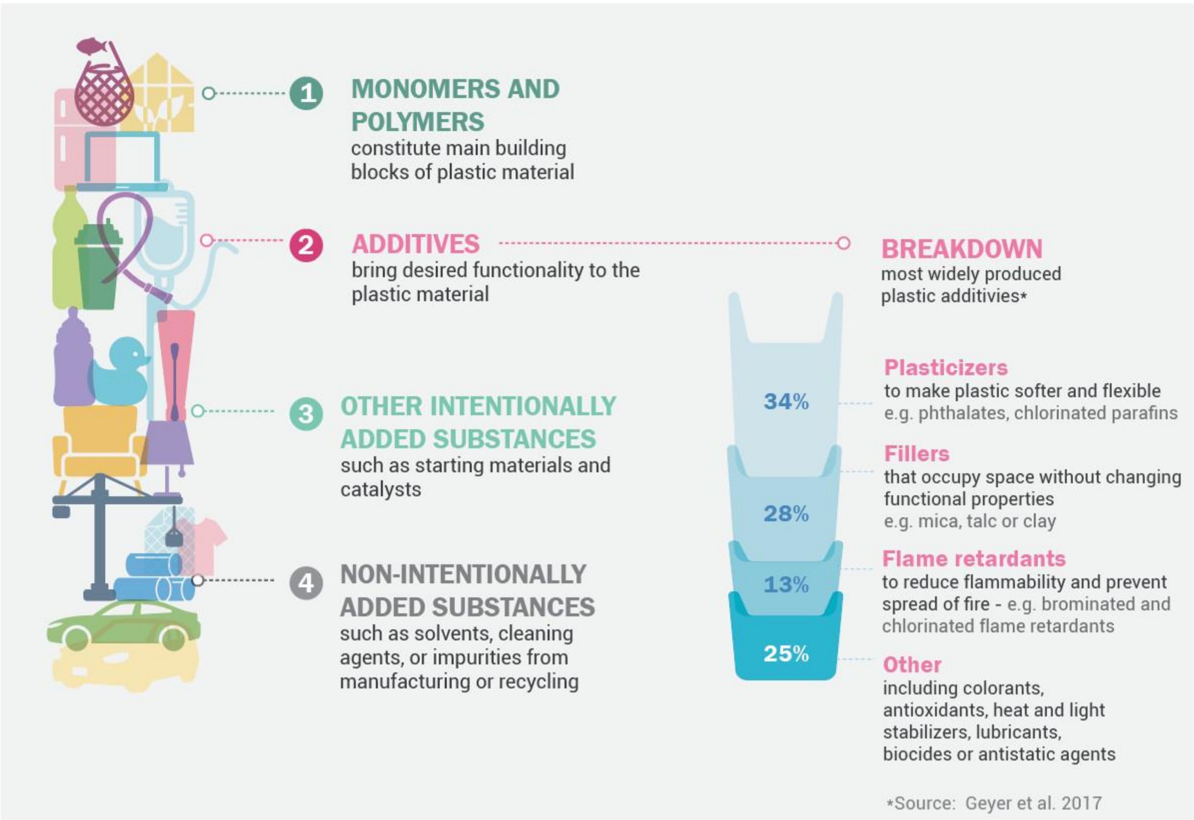
[1] UNEA Resolution 5/14

The Summary and Key Findings presented here are based on the "Chemicals in Plastics: A Technical Report" developed by UNEP in cooperation with the Secretariat of the Basel, Rotterdam and Stockholm conventions with lead authors from the International Panel on Chemical Pollution. The report aims to inform the global community about the often-overlooked chemical-related aspects of plastic pollution, particularly their adverse impacts on human health and the environment as well as on resource efficiency and circularity. Based on compelling scientific evidence, it further highlights the urgent need to act and outlines possible areas for action.

Chemicals are an integral part of plastics

Plastics are made from, and contain, a plethora of chemicals (Figures 1 and 2). The bulk component is a polymer made from repeating chemical monomer units, up to 99% sourced from fossil raw materials. The remaining 1% is sourced from biomass. Further chemicals are added as processing aids such as lubricants or as additives such as plasticizers, flame retardants, heat and light stabilizers or pigments. Recent data suggest that over 30 million tonnes of processing aids and plastic additives are used each year.

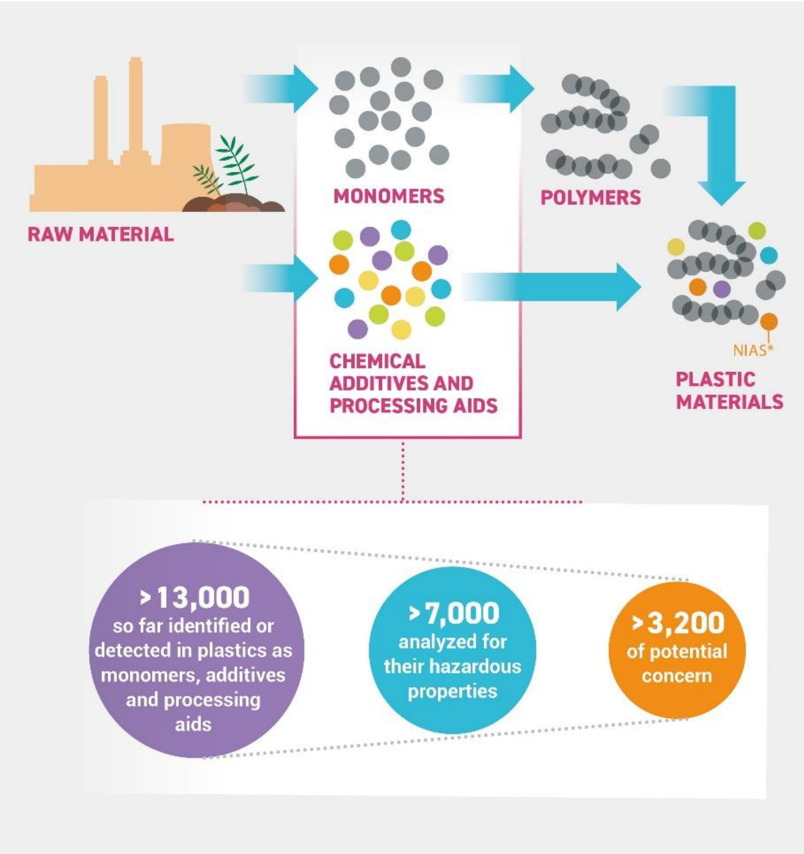
Figure 2. Anatomy of plastics – overview of key components of the plastics.



Plastics contain a wide range of chemicals that are not chemically bound to the polymer matrix, not only intentional ones such as additives, solvents, unreacted monomers and residual processing aids, but also non-intentionally added substances such as reaction by-products, breakdown products and contaminants from the raw materials and production processes.

Based on the latest studies, more than 13,000 chemical substances have been identified as associated with plastics, known for use in plastic production or detected in plastic materials (Figure 3).

Figure 3. A simplified illustration of the production of plastics from raw materials, and an overview of chemicals that may have been used in plastic production or have been detected in plastics.



*NIAS = non-intentionally added substances, including (1) break-down products of polymers, additives and other chemicals in plastics, (2) impurities, (3) contaminants from processing such as production and recycling, and (4) reaction byproducts.

Chemicals of concern in plastics are found across various sectors and products value chains

Ten groups of chemicals in plastics, grouped based on commonalities in chemistry, use or sources, are highlighted in the report as of major concern due to their known toxicity and potential to be released from plastics (Table 1). For some of these chemicals, action has been taken at the global level, such as listing under the Stockholm or Minamata Conventions, or identified as emerging policy issues and other issues of concern under the Strategic Approach to International Chemicals Management (SAICM). For some, regulations have been developed in certain countries or regions. However, developing countries generally lack comprehensive regulatory frameworks to assess and manage these chemicals. In some countries, this lack of proper control is also the case for chemicals listed as persistent organic pollutants (POPs) under the Stockholm Convention.

Table 1. Examples of chemicals of concern in plastics and their associated concerns.

Chemical class	Example substances of concern	Examples of associated concerns
Specific flame retardants (FRs)	polybrominated diphenyl ethers (PBDEs)[1], hexabromocyclododecane (HBCDD)[1], tetrabromobisphenol A (TBBPA), short-chain/ medium-chain chlorinated paraffins (SCCPs[1]/ MCCPs)[2], Dechlorane Plus[3], tris(2-chloroethyl) phosphate (TCEP), tris(1,3-dichloroisopropyl) phosphate (TDCPP), antimony (Sb), polybromobiphenyls (PBB)"	• increased toxicity of smoke by brominated FRs • adverse effects of many organic FRs themselves, including loss of IQ points, intellectual disability, carcinogenicity, endocrine disruption and reproductive toxicity
Certain per- and polyfluoroalkyl substances (PFASs)*	perfluorooctanoic acid (PFOA)[1], perfluorooctane sulfonic acid (PFOS)[1], perfluorohexane sulfonic acid (PFHxS)[1], long-chain perfluoroalkylcarboxylic acids (PFCAs)[2]	• adverse effects of many relevant PFASs, including endocrine disruption, carcinogenicity and developmental toxicity
Certain phthalates*	di-2-ethylhexyl phthalate (DEHP), dibutyl phthalate (DBP), benzyl butyl phthalate (BBP), diisobutyl phthalate (DIBP)	• significant environmental releases during plastic life cycle, and ubiquitous environmental presence, of several phthalates • adverse effects of several phthalates, including reproductive toxicity and endocrine disruption (e.g., obesity and diabetes), and significant associated societal costs
Certain bisphenols (BPs)*	BPA, BPF, BPS	• adverse effects of many BPs, such as reproductive toxicity, and endocrine disruption • migration from food containers
Certain alkylphenols	nonylphenol, nonylphenol ethoxylates	• adverse effects such as endocrine disruption in humans and aquatic organisms • migration from plastic bottles into water
Certain biocides	organotin compounds, arsenic compounds, triclosan, quaternary ammonium compounds (QACs)	• various adverse effects of many biocides, including skin/eye irritation and sensitization, genotoxicity and endocrine disruption
Certain UV stabilizers	UV-328[3] , benzophenones (BPs), benzotriazoles (BZTs), hindered amine light stabilizers (HALS)	• adverse effects of many UV stabilizers, such as causing allergies and long-lasting harm to aquatic organisms
Certain Metals and metalloids*	arsenic, antimony, cadmium, cobalt, chromium, lead, mercury, tin, zinc, etc.	• various adverse effects to humans and aquatic organisms • environmental releases of mercury and migration of cadmium from toys • occupational exposure during production and recycling
Certain polycyclic aromatic hydrocarbons (PAHs)*	benzo[a]anthracene, benzo[a]pyrene, naphthalene	• adverse effects such as carcinogenicity, mutagenicity, or reproductive toxicity • presence in direct-contact consumer goods
Other non-intentionally added substances (NIAS)	volatile organic compounds (VOCs), polychlorinated dibenzo-p-dioxins and polybrominated and dibenzo furans (PCDD/ Fs)[1] and polychlorinated biphenyls (PCB)[1], polybrominated dibenzo-p-dioxins and -furans (PBDD/Fs) etc.	• numerous sources of NIAS, e.g., PCDD/Fs and PCBs originating from chlorinated paraffin, pigments and degradation products of polymerization catalysts

* More supporting details on these substances, including current exposure as well as instruments and actions under current regulatory and policy frameworks, can also be found in the UNEP Report *An Assessment Report on Issues of Concern: Chemicals and Waste Issues Posing Risks to Human Health and the Environment* and its accompanying annexes (www.unep.org/resources/report/chemicals-and-waste-reports-unea-5);

[1] Chemicals listed under the Convention ;[2] Chemicals under review; [3] Chemical to be listed under the Stockholm Convention in 2023; For the chemicals listed under the Stockholm Convention or under review, further information can be found in risk profiles and risk management evaluation documents adopted by the POPs Review Committee (http://chm.pops.int/tabid/243)

The report further points to ten industry sectors and products value chains that need to be prioritized for action due to presence and exposure risk of hazardous chemicals.

Table 2. Priority industry sectors and products value chains for action, and examples of chemicals of concern therein

Industrial sectors	Rationale for prioritization	Examples of known chemicals of concern
TOYS AND OTHER CHILDREN'S PRODUCTS	• High prevalence of plastic toys (about 90% of the toys on the market) • Significant human exposure to chemicals through mouthing • Children being particularly vulnerable due to low bodyweight and ongoing developmental processes	certain phthalates, BPA, SCCPs, PBDEs, dioxins, toxic metals and metalloids
PACKAGING, INCLUDING FOOD CONTACT MATERIALS	• Significant human exposure to chemicals through migration into food • Major contributor to marine plastic pollution	certain monomers, toxic metals and metalloids, NIAS
ELECTRICAL AND ELECTRONIC EQUIPMENT	• Large volumes – about 10 million tonnes of plastic waste generated each year, 20% of the total e-waste	legacy POP additives (e.g., PBDEs, HBCDD)*
VEHICLES	• Increasing plastic content, e.g., in a passenger car, the average plastic content increased from 100 kg in the 1980s to 200 kg in 2014	toxic metals and metalloids VOCs, brominated and organophosphorus flame retardants, certain phthalates leading to elevated levels in interior air and dust and thus elevated human exposure
SYNTHETIC TEXTILES	• High prevalence of plastics – over 60% of textile fibres, about 65 million tonnes in 2016 • Requiring more flame retardants than natural fibres	PBDEs, HBCDD, SCCPs, PFOS and PFOA
FURNITURE	• Significant source of human exposure to chemicals of concern, particularly for children • Long service life (including reuse), resulting in prolonged exposure, including to legacy additives	brominated and organophosphorus flame retardants
BUILDING MATERIALS	• Major use of plastics, resulting in deteriorated indoor air quality and outdoor environments • Long service life of building materials, resulting in prolonged exposure and challenges to waste management	brominated and organophosphorus flame retardants SCCPs, MCCPs, certain phthalates, PCBs
MEDICAL DEVICES	• Wide use of medical devices made of plastics in hospitals and healthcare centres, with high prevalence of PVC (about 40% of all plastics in medical devices), resulting in exposure of vulnerable populations	certain phthalates (e.g., DEHP), PCDD/Fs (from burning of medical waste made of PVC)
PERSONAL CARE AND HOUSEHOLD PRODUCTS	• Direct human and ecosystem exposure to chemicals of concern that are used in ingredients at high doses • Migration of chemicals of concern from packaging into products	certain phthalates or other plasticizers, NIAS
AGRICULTURE AQUACULTURE AND FISHERIES	• Prevalent use of plastics in agriculture and aquaculture (about 12.5 million tonnes in 2018), with high release to the environment, especially mulching films, due to difficulties in collection and recycling	certain phthalates, bisphenols, PCDD/Fs (from farmland open burning, when PVC is present)

* under SAICM: hazardous substances within the life cycle of electrical and electronic equipment identified as an issue of concern

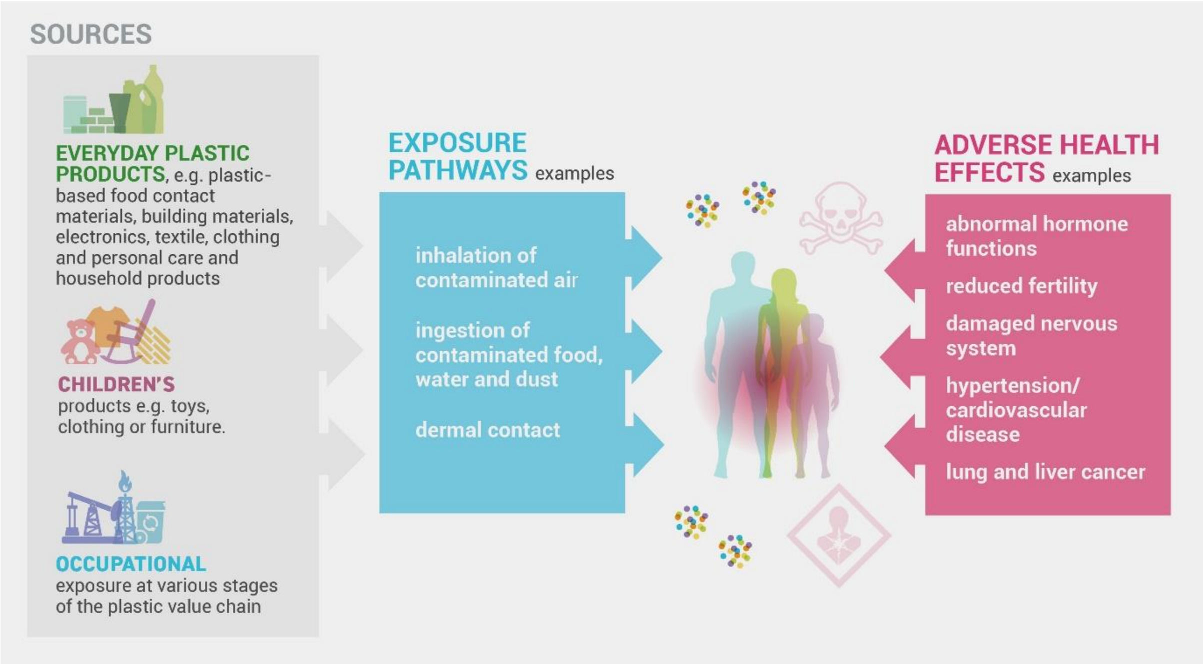
Many chemicals in plastics can exert and are exerting adverse impacts on human health and the environment

While the adverse physical impacts of plastics in the environment are generally visible, the risks associated with chemicals in plastics are less apparent[1]. Nevertheless, growing scientific evidence demonstrates that many chemicals in plastics are hazardous, with increasing exposures resulting in potential and measurable adverse impacts on human health and the environment.

Among the 13,000 chemical substances associated with plastics, 7,000 have been screened for their hazardous properties, from which more than 3,200 have one or more hazardous properties of concern, i.e., potential ability to exert significant impacts on human health and the environment (Figure 2). Some of these chemicals are persistent, bioaccumulative and toxic. Many may exert adverse health effects already at very low levels (e.g., carcinogens, mutagens, reproductive toxicants, endocrine disrupting chemicals), while many others may build up levels in the body, particularly when they bioaccumulate, eventually reaching levels that cause health harm over a period of exposure.

Susceptibility to chemicals of concern in plastics can differ by gender and age. Women and children are particularly susceptible to the hazards of chemicals. But men are also at risk, with the latest research documenting substantial detrimental effects on male fertility resulting from cumulative exposure to hazardous chemicals, many of which are associated with plastics[2].

Figure 4. *Human Exposure to chemicals in plastics*



Humans and the environment are therefore typically exposed to a wide range of chemicals of concern present in plastics from diverse sources (Figure 4). Workers may be exposed to high levels during the production of polymers, associated chemicals and plastic products, and during the management of waste, including recycling, particularly those

[1] UNEP 2021, From pollution to solution, a global assessment of marine litter and plastic pollution. Available at: https://www.unep.org/resources/pollution-solution-global-assessment-marine-litter-and-plastic-pollution

[2] Kortenkamp et al. 2022. Combined exposures to bisphenols, polychlorinated dioxins, paracetamol, and phthalates as drivers of deteriorating semen quality. Environment international, 165, 107322.

working in the informal sector in low- and middle-income countries. Consumer exposure is prevalent, particularly through plastic-based food contact materials, building materials, electronics, toys, and personal care and household products.

The general population and biota are also exposed to chemicals released from plastics through inhalation of contaminated air, dermal contact, and/or ingestion of contaminated food, water and dust, particularly when close to landfills and dumpsites. Children and animals are additionally exposed via mouthing and ingestion of plastics.

Human and ecosystem exposure is becoming increasingly ubiquitous due to the ever-intensified use and trade of chemicals, plastics, products and plastic waste, as well as the long-range environmental transport of chemicals via air and ocean currents, plastic debris, and chemicals released from plastics. At the end of life of plastics, it was estimated that approximately 70% of all plastic waste exports were originating from high-income countries, mostly to low-income countries in East Asia and the Pacific. In the receiving countries, however, only a fraction of the imported plastic waste is recycled, whereas the majority is discarded in dumpsites or littered in the environment. Open burning of plastics and thermal recovery of plastics in facilities without appropriate pollution control in these countries are additional major sources of pollution, releasing hazardous chemicals in plastics and unintentional POPs such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs).

Chemicals of concern in plastics reduces the opportunity for resource efficiency and slows down progress towards circularity

Chemicals of concern in plastics, in addition to potentially causing adverse effects on human health and the environment, can hamper the transition to circularity, as highlighted in the UNEP circularity platform[1]. The circling back of these materials may not be desired, as it would lead to renewed human and environmental exposure to hazardous chemicals. Reversing the trend and removing chemicals of concern from plastics as early as the design phase will, on the contrary, ensure a toxic-free circular economy, and allow for reuse, remanufacturing or refurbishing of plastic products and materials, and recycling of plastic waste.

The presence of chemicals of concern in plastic waste streams challenges the implementation of the waste hierarchy, in particular reuse and recycling, and requires a robust waste management scheme, a regulatory framework and related enforcement with suitable sorting processes to enable some recycling, and destruction capacity for plastics containing hazardous chemicals. Plastic waste containing POPs are hazardous waste and should be managed in line with the technical guidelines on the environmentally sound management of POPs waste under the Basel Convention (http://www.basel.int/tabid/8025). The technical guidelines on the environmentally sound management of plastic waste are also being updated under the Basel Convention.

Mechanical recycling. Currently, most efforts have focused on addressing waste or increasing the share of recycled content, with the intention of keeping plastics in value chains longer. To prevent contamination of recycled materials, thermoplastics needs to be sorted with only the non-contaminated fraction selected for mechanical recycling. However, the wide range of chemicals of concern present in existing plastic products can contaminate recycled materials, reducing their safety, technical quality and/or market acceptability (e.g., undesired colour and

[1] UNEP (2019), Circularity challenges, the current economic model towards a sustainable development (https://buildingcircularity.org/)

odours). Monitoring of consumer products has demonstrated that hazardous chemicals, including degradation products, are to some extent recycled and diluted into new products including toys and food-contact applications, resulting in human exposure to (legacy) chemicals of concern.

Chemical recycling. Chemical recycling could treat some plastic waste types not suitable for mechanical recycling like complex mixtures or thermosetting polymers. Different technologies such as pyrolysis and solvolysis are explored in full scale and pilot facilities to recover monomers and other degradation products from plastics waste as inputs to produce new polymers or other chemicals, currently contributing to <0.5% of plastic recycling. While many chemicals in plastics are destroyed to a large extent in some of these processes, many others may persist (e.g., metals) or form problematic degradation products, posing environmental and health concerns and technical challenges. For example, pyrolysis of plastics waste containing halogenated flame retardants or halogenated plastic results in degradation products such as highly toxic halogenated dioxins and furans and acidic gases, which can cause corrosion of the facilities and impact the quality of final pyrolysis product. While a lot has been learned, the fate and impacts of many other individual chemicals in plastics and their degradation products during the chemical recycling processes are largely yet to be understood.

Energy recovery. Energy from plastic waste can be recovered through co-incineration in cement kilns, in waste incinerators or other thermal processes. Only best available technique with sufficient temperature and residence time can be used for energy recovery of plastic containing very persistent chemicals like PFAS or other POPs. Plastic containing for instance halogenated flame retardants or halogen containing polymers can however yield acidic gases that cause corrosion in incinerators and other thermal facilities, and result in the emission of halogenated dioxins and other unintentional POPs, metals, as well as other air pollutants and products of thermal processes. Other factors such as operating conditions and types of materials can also impact the emissions and generation of ash. Improved air pollution control devices can reduce air pollution, but transfer the pollutants to residues such as fly ashes, which still require environmentally sound management and disposal.

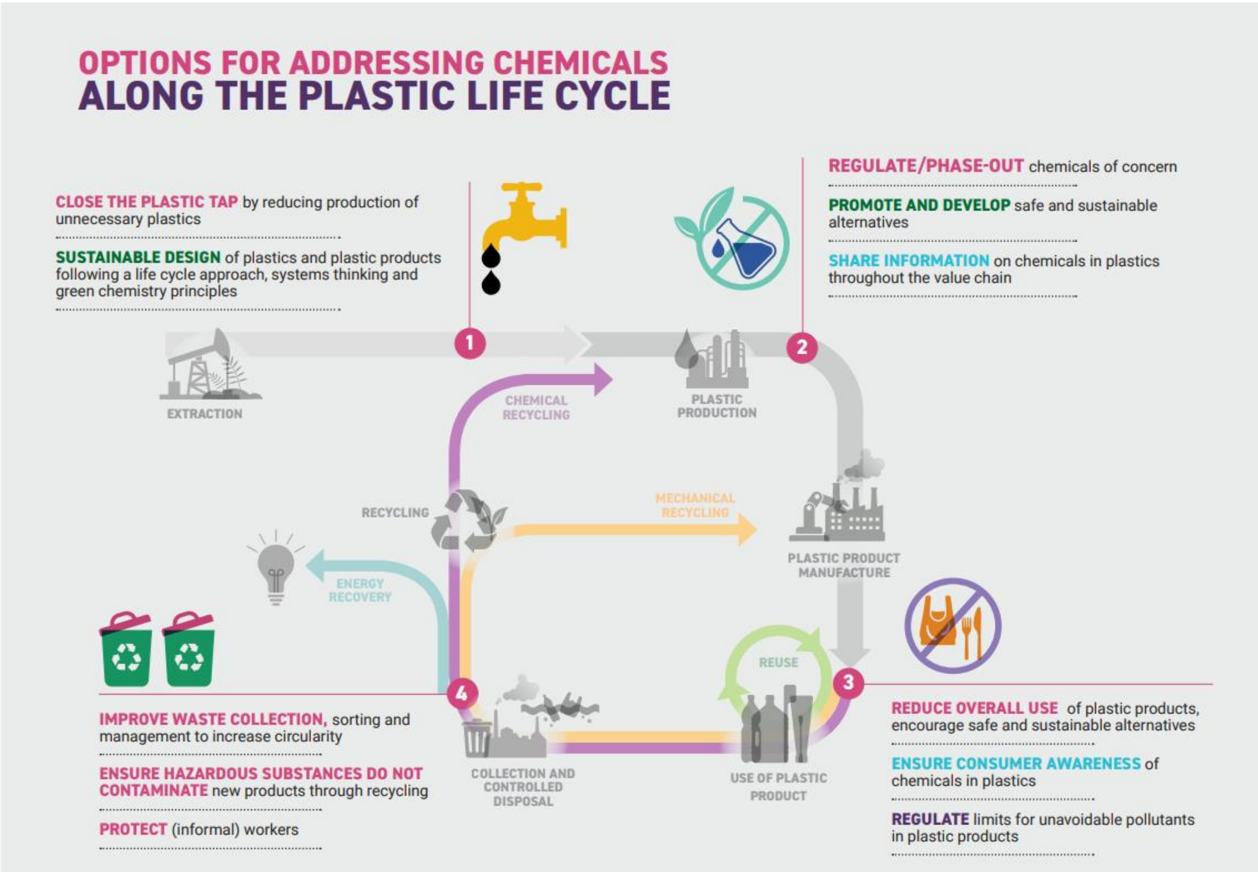
In summary, regardless of which solutions are used, the input streams of plastics waste require the pre-sorting and controlling of the presence of certain chemicals, and unusable fractions require environmentally sound disposal. Both the great variability and non-transparency of information on chemicals in plastics greatly complicates the pre-sorting. It is also important to recognize regional differences, including the general lack of capacities and financial resources for waste management in low- and middle-income countries. In particular, the prevalent informal sector in these countries typically practices open burning of non-recyclable plastics, which can lead to chemical pollution and health effects in exposed humans, in addition to incineration in facilities without appropriate pollution control.

Existing evidence of the adverse impacts of plastic-associated chemicals of concern calls for urgent action

"Business-as-usual" production and use of plastics and associated chemicals will continue to result in increasing levels of chemicals in the environment and humans globally. Therefore, action on plastics pollution is urgently needed, including at the global level, and the holistic inclusion of the chemicals aspects is required. Outlined below are potential areas for such action (Figure 5).

Preventing and minimizing the use of chemicals of concern in plastics. Preventive and precautionary approaches to minimizing chemicals of concern in plastics, starting from chemical, plastic and product (re-)design, should be at the very core of efforts to address the plastic crisis. Such efforts will also ensure a toxic-free circular economy and allow for safer and more sustainable reuse, remanufacture, refurbishment and recycling of plastic products and materials. This can be done at different levels in parallel. In addition to saving resources, such measures will also reduce the quantities and hazards of the waste generated and thus, the pressure on the overstrained waste-management systems. International action is also warranted to reduce the overall diversity and complexity of chemicals in plastics, particularly to halt the use of chemicals of concern wherever possible. Focusing on groups of chemicals rather than on individual chemicals one at a time may be one effective and efficient way to address the great number of chemicals used in plastic production.

Figure 5. Overview of options to address chemicals along the plastic life cycle.



To do so, a combination of instruments is needed. Regulatory control would be one key tool to set requirements for transparency and safety assessments of chemicals present in plastics (i.e., moving away from "no data, no harm" to "no data, no market") and to minimize chemicals of concern, including non-intentionally added substances. Chemicals restricted under different global legally binding instruments, as well as those identified as issues of concern by the Global Chemicals Outlook II (e.g., arsenic, cadmium, lead or organotins) or under SAICM (e.g., endocrine-disrupting chemicals or PFASs), could be starting points for phase-outs. Further priorities should be given to identifying and soundly managing products and chemicals with high exposure potential, particularly to vulnerable populations, taking into account multiple use cycles (if relevant). Voluntary approaches may prove useful as a complement to regulatory actions. For example, transparency requirements and action on chemicals of concern can be included in companies' voluntary phase-out schemes, in public procurement policies, and in private standards and certification such as eco-labelling. Such actions can learn from and upscale existing initiatives such as the Global Automotive Declarable Substance List[1], which is designed to facilitate information exchanges regarding the use of certain chemicals in automotive products throughout the supply chain.

The concept of "essential use", as initially integrated under the Montreal Protocol, could additionally be applied in both regulatory and voluntary actions to minimize the use of chemicals of concern. This means that chemicals of concern would, for instance, only be used within controlled material cycles if necessary for health and safety or critical for the functioning of society, and if there are no available alternatives that are technically and economically feasible or acceptable from an environmental and human health standpoint. Concepts such as "specific exemption" and "acceptable purpose" based on socio-economic analysis under the Stockholm Convention may also be considered. For unavoidable chemicals of concern, such as PAHs that are generated unintentionally, control measures should be put in place to protect humans and the environment, such as regulatory limits on their content in products, emissions/releases and exposures.

Enhancing transparency and access to information. Understanding the presence and fate of chemicals in plastics along the entire plastic life cycle is fundamental to assessing and minimizing exposure to hazardous chemicals, including non-intentionally added substances, and maximizing possibilities for reuse and recycling of plastics. Several public databases are available for such purposes, listing possible chemicals that may be used in specific industrial sectors, globally or in specific regions[2]. However, achieving a comprehensive understanding of which chemicals are present in which plastic products at which levels, how these products are used, and associated release and exposure patterns (including gender differences) is still generally impeded by limited and scattered information in the public domain. This information, however, is most often not available to value-chain actors, including downstream industrial users and waste managers, limiting their ability to manage occupational exposure and ensure the safety of their products. This lack of transparency of chemicals in plastics adds further challenges to tracing mixtures of chemicals in recycled plastics, as systematic testing of many plastic products is hardly feasible.

Raising awareness on chemicals in plastics. Providing information along the value chain, including to businesses, workers and consumers, about the presence and the risks of exposure to hazardous chemicals in plastics and regrettable substitution, can support them in taking informed decisions[3]. It can also generate much-needed public momentum towards a reduction in plastic consumption and use of chemicals of concern in plastics. In particular, development and broad implementation of common data-sharing standards will be key to tracing chemicals throughout the plastic value chain. This can build upon existing initiatives, including the European Union's SCIP database (which compiles information of Substances of Very High Concern (SVHCs) in products in the European Union). Similarly, awareness-raising may build upon existing educational materials on hazardous additives in plastics by the Stockholm Convention regional centres, and other educational materials by the many civil society organizations.

[1] https://www.gadsl.org/
[2] For example, the Pharos database (https://pharosproject.net) for building products around the world, the Food Contact Chemicals database (FCCdb) (www.foodpackagingforum.org/fccdb) for food contact chemicals (FCCs) around the world, and the High Priority Chemicals Data System (HPCDS) (hpcds.theic2.org/search) for children's products in the States of Oregon and Washington in the United States of America.
[3] For example, as requested by UNEP's Chemicals in Products (CiP) Programme www.unep.org/resources/other-evaluation-reportsdocuments/chemicals-products-cip-programme

Enhancing availability and accessibility of safe and sustainable alternatives. In many cases, chemicals of concern are to be substituted with alternatives, including non-chemical ones, bearing in mind that this should not make regrettable substitutions or create new burdens (e.g., increased resource and energy consumption, or land-use pressure). The rapidly increasing use of bio-based and biodegradable plastics, for example, needs to be carefully managed given that they have been found to contain very similar types and amounts of chemicals of concern as those used in fossil-based plastics. To ensure safe and sustainable substitutions and alternatives, decisions should be based on insights from state-of-the-art technical and scientific knowledge[4], including following the *UNEP Green and Sustainable Chemistry Framework Manual* objectives and guiding considerations[5].

Building capacities and partnerships to address chemicals of concern in plastics. Many chemicals of concern in plastics have already been restricted in some countries or regions, mostly with high incomes, whereas low- and middle-income countries generally lack capacity to identify, restrict and substitute chemicals of concern. One possible area of work could therefore focus on building capacities, including capacities for chemicals assessment and management, alternatives assessment, and phase-in of safer and more sustainable alternatives to avoid shifting the burden from one region to another and regrettable substitution. Action should build on existing knowledge, and duplication of efforts should be avoided, for example, by identifying and using regional and global synergies via partnerships. Such partnerships can also help the global community to keep up with the pace of innovation and advancement of knowledge in relation to chemicals in plastics.

Strengthening research and monitoring of chemicals in plastics, in particular information on chemical hazards and mixtures of chemicals in plastics. Of the over 13,000 chemicals found to be associated with plastics, more than 7,000 had hazard classifications readily available in the public domain. In contrast, the other over 6,000 chemical substances associated with plastics, both for intentional and non-intentionally added ones, remain poorly characterized with large data gaps in the public domain regarding their potential adverse impacts on humans and ecosystems, or even their chemical identities (Figure 1). In addition, many non-intentionally added substances remain unidentified or unknown. These problems have long been discussed, and many reasons exist for missing data, including a lack of proper testing methods and a lack of requirements/incentives for companies to disclose. Furthermore, while in reality humans and ecosystems are exposed to mixtures of chemicals, current testing primarily focuses on individual known chemicals in plastics. It calls for a better understanding of adverse effects of the complex mixtures that humans and ecosystems are exposed to.

Overall, addressing the priority areas above will contribute to the ambition of ending plastic pollution, reducing adverse impacts on human health and the environment, and supporting efforts towards resource efficiency and the transition to a non-toxic and sustainable circular economy.

[4] For example, the European Union is working on the operationalization of the safe and sustainable-by-design concept.

[5] www.unep.org/explore-topics/chemicals-waste/what-we-do/policy-and-governance/green-and-sustainable-chemistry

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