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Harmful substances in recycled plastics



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Requester

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1 Background

Nordic Ecolabelling aims to update requirements for post-consumer recycled (PCR) plastic content in Swan-labelled products to support a circular economy while ensuring consumer safety. Nordic Ecolabelling is now assessing their requirements for recycled rigid plastics in the following products: Floor coverings, furniture, outdoor furniture, playground equipment, office supplies, packaging for liquid detergents (laundry detergents, hand dishwashing detergents, dishwasher detergents, cleaning products). The Danish Technological Institute (DTI) conducted this study to:

- a) list potentially harmful substances in household-collected recycled high-density polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET);
- b) recommend chemical testing methods; and
- c) propose a quality assurance procedure.

Deliverables include: a list of relevant hazardous compounds, suggested analytical tests, and quality assurance guidelines. This report synthesizes DTI's findings and provides considerations on the relation between plastic type, material source, recycling process, application, safety testing, and economic barriers.

2 Conclusion

Post-consumer recycled HDPE, PP, and PET can contain diverse hazardous chemicals from prior product use and processing. PE and PP present broader, more unpredictable contamination profiles due to their apolar nature, readily absorbing organic contaminants and volatile compounds. PET demonstrates lower overall contamination risk due to its lower diffusion coefficient and widespread feedstock availability from controlled bottle-collection systems.

Nine priority substance groups are highlighted due to their proven presence in recycled plastics and toxicological profiles, namely: phthalates, heavy metals, primary aromatic amines (PAAs), polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), phenolic compounds, flame retardants, allergens (particularly fragrance compounds), and per- and polyfluoroalkyl substances (PFAS). Among these, substances classified as carcinogenic, mutagenic, reproductive toxicants (CMR), or endocrine-disrupting merit highest priority for control and monitoring.

Recommendation for Nordic Ecolabelling is to adopt a tiered, risk-based testing strategy that allocates analytical resources proportionally to exposure risk and feedstock traceability: well-characterized closed-loop recycling systems (e.g., bottle-grade PET) warrant periodic verification testing, while mixed household waste streams

require more comprehensive chemical screening and migration assessment. Potential quality testing is suggested to contain broad screening (GC-MS, LC-MS, ICP-MS) to characterize contamination profiles, followed by targeted quantification of priority substance groups. Detected substances should be compared with existing EU regulatory limits (REACH Annex XVII, Toy Safety Directive 2009/48/EC, EU Cosmetics Regulation) where applicable; and related to the specific exposure scenario in the given case. Often no regulatory limit exists, in which case, margin-of-safety calculations using conservative toxicological parameters can provide defensible safety thresholds.

Lastly, continuous quality assurance can be accomplished by combining routine monitoring with event-driven testing. Here it is encouraged to retest the quality of the recycled plastic whenever material sources, suppliers, or recycling processes change significantly. The overall challenge is to find the extremely fine balance between consumer protection through testing and economic viability of low-value recycled materials. By considering the combination of plastic type, material source, recycling operation and final application, the optimal test-program can be selected, but this should ideally be done on a case-to-case basis.

3 Quality and application

The quality and safety of post-consumer recycled (PCR) plastics are dependent on a complex combination of polymer chemistry, contamination source, end-use exposure pathway, and recycling process control. Unlike virgin plastics, whose chemical composition is explicitly defined through manufacturing specifications and regulatory declarations, recycled plastics emerge from heterogeneous waste streams characterized by incomplete knowledge of prior use history, variable processing conditions, and the inevitable accumulation of contaminants from multiple product categories, lifecycles, and user environments.

The hierarchy of quality requirements for plastic applications (Figure 1) reflects both exposure pathways and process parameters. Technical applications—such as outdoor furniture where direct skin contact is limited—present the lowest exposure risk and generally also have lower requirements for polymer purity and mechanical properties. The quality requirements increase for cleaning and cosmetics product packaging as both skin exposure scenarios increase as well as requirements for processability and user perception. Packaging and products for food and medical use have highest requirements as the applications include risk of internal exposure to the product.

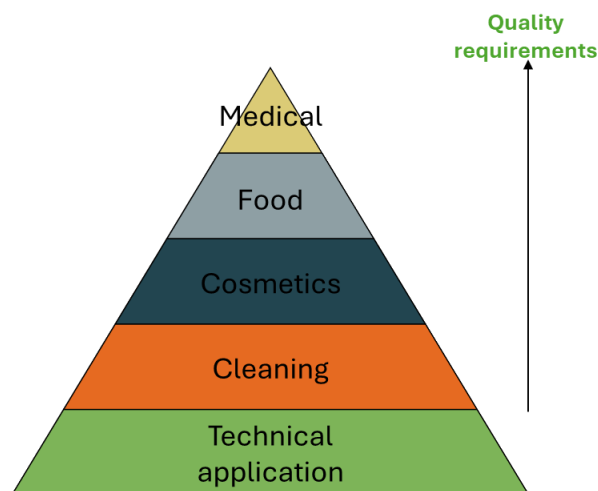


Figure 1 Hierarchy of quality requirements of different application areas.¹

3.1 Segmentation of applications

Nordic ecolabelling is assessing the requirements for recycled rigid plastics in the following products:

- Packaging for liquid detergents (laundry detergents, hand dishwashing detergents, dishwasher detergents, cleaning products)
- Floor coverings
- Furniture
- Outdoor furniture
- Playground equipment
- Office supplies

These applications occupy the lowest-risk tier of the quality hierarchy for plastic use, positioned below food-contact materials and cosmetic products in terms of allowable chemical contamination thresholds. The applications are scored in Table 1 according to their exposure risk (low, medium, high). However, the “high exposure”-category is here reserved for cosmetic applications and above in the quality hierarchy. The assignments of exposure risk in this report are based on reflections of possible use and should not be interpreted as absolute risk levels, but rather as relative differentiation within a constrained, lower-exposure product category.

When assessing quality requirements for products containing recycled plastic, the level of consumer exposure is a critical factor in determining acceptable contamination

¹ Udvikling af plastemballager i en cirkulær økonomi - et MUDP projekt (slutrapport)

profiles.² Exposure intensity is fundamentally shaped by application type, user population age category, contact duration, contact frequency, and exposure pathway characteristics.³ Adult users and young children (ages 0-3 years) exhibit markedly different exposure patterns for identical product types, with children demonstrating substantially higher risk through multiple mechanisms: (1) developmental incompleteness of hepatic and renal detoxification systems; (2) proportionally larger body surface area relative to body weight; (3) high-frequency mouthing and hand-to-mouth transfer behaviors; and (4) extended contact duration during play and developmental exploration. Therefore, the risk of exposure is estimated both for adults and for children (0-3 years) respectively.

Table 1 Estimated exposure risk for adults and children for different product applications.

Risk of exposure			
Application	Adult	Child	Exposure rationale
Floor coverings	Low	Medium	Children crawl, sit, and place objects in mouth. Adults mostly shoe-mediated contact.
Playground equipment	Low	Medium	Primary child use; prolonged skin contact; mouthing of surfaces possible; outdoor environments may accelerate degradation and migration.
Indoor furniture	Low	Medium	Frequent skin contact for all users; children climb and may mouth edges; exposure duration moderate.
Outdoor furniture	Medium	Medium	Regular skin contact; higher usage by children in play; weather aging may increase migration potential.
Office supplies	Medium	Low	Frequent handling by adults; hand-to-mouth contact possible; children are less frequent users but still have some exposure.
Packaging for liquid detergents	Low	Low	Intended adult use; potential incidental contact for children (handling bottles, mouthing caps); contents washed off prior to use.

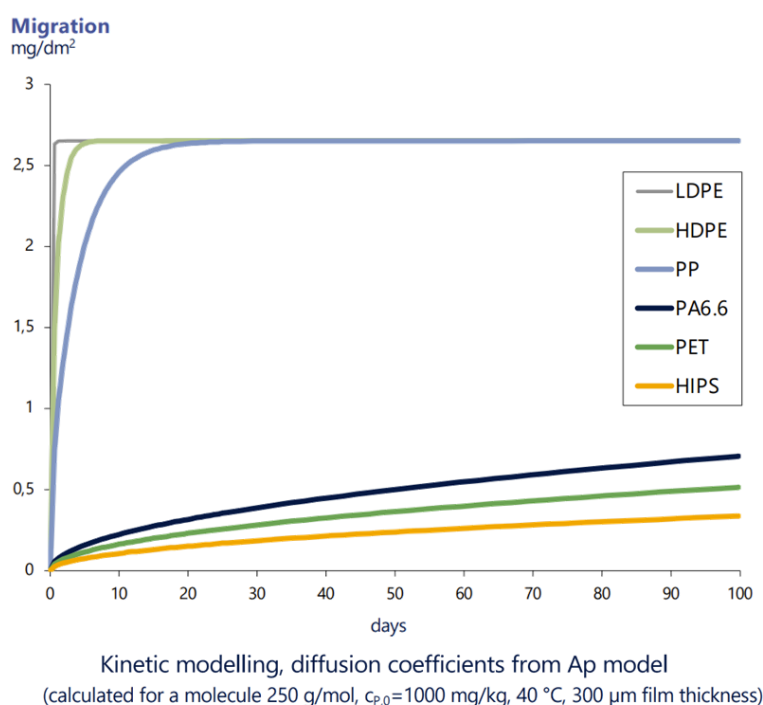
² euric.org

³ a) pmc.ncbi.nlm.nih.gov, b) one.oecd.org, c) one.oecd.org



4 Polymer types (HDPE/PP vs PET)

Many harmful substances belong to the group of *apolar organic compounds* and thus plastics' ability to absorb such compounds directly impacts the contamination risk. Apolar compounds diffuse (migrate) into apolar polymers (like PE and PP) much faster than into more polar polymers (PET). As depicted in Figure 2 the PE and PP can be categorized as *high-diffusion polymers* whereas PET has a lower diffusion coefficient, for is much lower. This means hazardous substances are more likely to migrate into PE and PP causing contamination of the material. Therefore, PE and PP will be categorized equally in the following evaluation while PET is in its own *lower risk* category.



Source: A Störmer Fraunhofer IVV 7/2/23

Figure 2 Diffusion coefficient of different polymer types.

4.1 PE and PP

PE and PP are non-polar plastics that readily absorb oils and organic substances. During use and recycling, PE/PP can accumulate residues from detergents, cleaning agents, and personal care products (fragrances, dyes, surfactants). Their relatively low melting points mean volatile contaminants (e.g. some solvents and aroma compounds) may survive processing. As a result, recycled PE/PP tend to have a broad and unpredictable contaminant profile. One distinguishment, however, is that PE is often the material of choice for e.g. packaging for different chemicals (such as cleaning

agents), whereas the majority of PP in the mixed household waste originates from food contact materials, which generally can lead to a less severe contamination profile. PE and PP are still considered together here, due to the risk of cross-contamination between plastics.

4.2 PET

In contrast, PET is more polar and primarily recycled through well-controlled bottle collection systems. The chemical characteristic makes PET less prone to absorb hydrophobic contaminants, and the higher processing temperatures used in its recycling process help to reduce volatile impurities. However, PET has its own specific risks, including potential migration of acetaldehyde (a degradation product) and residual antimony (from its use as a catalyst during polymerization). Thus, PET's structure and recycling chain result in a cleaner but more narrowly defined hazard profile.

5 Hazardous substance groups

The main challenge in ensuring safe use of recycled PE, PP, and PET is the high variability in chemical composition and contamination. Potential risks stem from substances such as phthalate plasticizers, heavy metals, primary aromatic amines (PAAs) from dyes and adhesives, polycyclic aromatic hydrocarbons (PAH), volatile organic compounds (VOC), flame retardants, and allergens. Many of these substances are not intentionally added in the original plastic application, but can enter PCR plastics through mixed waste streams, misuse of products, or be formed via chemical degradation pathways *e.g.* caused by UV light or high temperatures in the recycling process itself. Based on previous studies and available literature, the main substance groups of concern in recycled HDPE/PP/PET are listed in the following paragraphs.

5.1 Plasticizers (Phthalates, etc.)

Plasticizers are organic compounds (mainly phthalates) added to soften rigid plastics and improve flexibility. Phthalates are typically used in PVC but since they are not chemically bound in the plastic, they can migrate/leach into other plastics like HDPE and PP (cross-contamination) when they are in physical contact through the waste handling system. Many common plasticizers are under regulatory scrutiny due to possible adverse health effects. For instance, bis(2-ethylhexyl) phthalate (DEHP), which is the most common member of the class of phthalates, constitutes a well-established endocrine disruptor and is linked to reproductive toxicity, developmental effects in

children, and liver and kidney impacts at higher exposures.⁴ Due to these concerns, DEHP is now restricted in many regions and product types, particularly those for children and food contact, but is still a widely used in some applications.

5.2 Heavy metals

Metals such as lead, cadmium, chromium, nickel, and tin can be introduced as pigments, stabilizers or catalysts in polymer production. Antimony, for example, is used as a catalyst in PET production. Metals may persist in recycled plastics, particularly when sourced from mixed or poorly sorted waste streams.

5.3 Primary Aromatic Amines

PAAs are nitrogen-containing organic compounds, often formed by breakdown of azo dyes or polyurethanes. They are not intentionally added to plastics, but can occur as contaminants, especially in recycled PE and PP, as a result of colorant or adhesive residues. PAAs are considered carcinogenic and are therefore subject to special restrictions

5.4 Polycyclic aromatic hydrocarbons (PAH)

PAHs are a class of organic pollutants with multiple aromatic rings. They originate from incomplete combustion, carbon black pigments or thermal degradation, and are mainly found in black or dark-colored plastics, especially recycled ones. PAHs are considered carcinogenic when in contact with skin.

5.5 Phenols

Phenolic compounds include antioxidants and stabilizers (e.g. BHT) and their degradation products, as well as bisphenols like BPA and BPS. They are used to prevent polymer degradation during processing but can migrate into products, being especially relevant in recycled PE and PP.

5.6 Volatile organic compounds (VOC)

VOCs are small, volatile organic molecules which can be absorbed into plastics. VOCs can have many different origins such as processing residues, degradation products, and often components of different products or formulations (e.g. fragrances in cosmetics). In mixed household plastic waste VOC contaminants can also include organic solvents like turpentine, gasoline etc. Since the compounds are volatile, the

⁴ <https://pmc.ncbi.nlm.nih.gov/articles/PMC5842715/pdf/BMRI2018-1750368.pdf>

content of VOCs in recycled plastics can often be effectively reduced by including high-temperature and/or vacuum treatments in the recycling process to evaporate the compounds.

5.7 PFAS (per- and polyfluoroalkyl substances)

PFAS (e.g. PFOS, PFOA) are generally not used in PE/PP/PET but may migrate from PFAS-treated textiles, paper for food packaging, and other plastics. The perfluorinated substances are considered relevant in this context because some PFAS can exhibit a wide range of reprotoxic, immunotoxic, persistent, and neurotoxic effects.^{5,6} Previous studies conducted by Technological Institute indicate that PFAS levels in recycled PE/PP are generally low (non-detectable) and do not pose the largest health risk in the plastics.⁷

5.8 Flame retardants

Flame retardants such as brominated or phosphorus compounds are used to decrease the flammability of materials. They are most found in electronics housings (often ABS, HIPS) but may contaminate recycled PP and PE through cross-contamination. If the recycled plastic (e.g. PP) originates from electronic waste material streams (often black plastics), it is highly recommendable to examine the content of especially brominated flame retardants such as polybrominated diphenyl ethers (PBDEs), tetrabromobisphenol A (TBBPA), hexabromocyclododecane (HBCD), and polybrominated biphenyls (PBBs)

5.9 Allergens

Allergens in plastics are predominantly organic substances including antioxidants, UV stabilizers, and fragrance compounds from previous cosmetic/detergent use. Of particular concern are fragrance allergens—recently expanded from 26 to 82 regulated compounds in the EU Cosmetics Regulation—which are lipophilic (oil-based) substances readily absorbed and retained by polyolefins like PE and PP (e.g., limonene, linalool, citronellol). These compounds provoke allergic contact dermatitis and respiratory sensitization, posing heightened risks in products intended for children and sensitive populations. Allergenic contamination is disproportionately reported in flexible materials and recycled content due to incomplete removal during mechanical recycling.

⁵ <https://www.sciencedirect.com/science/article/pii/S001393512400389X>

⁶ <https://www.sciencedirect.com/science/article/abs/pii/S2468748023000267?via%3Dihub>

⁷ <https://www2.mst.dk/Udgiv/publications/2021/07/978-87-7038-330-1.pdf>

Regional contamination patterns vary by application sector: In Denmark, PE is predominantly used for household cleaning product packaging and flexible films, making recycled PE particularly prone to high fragrance allergen loads. Conversely, PP and PET are dominated by food packaging applications where fragrance use is minimal, resulting in lower baseline contamination—though cross-contamination during mixed-stream collection remains a risk.

5.10 Virgin plastic

Even virgin plastics contain residuals (monomers, solvents, additives like UV stabilizers). For example, benzophenone (a UV filter) can migrate from new material. Hence, recycled plastic limits should not be set stricter than those for virgin plastic of the same type.

6 List of harmful substances

When evaluating the safety of recycled plastics, it is key to prioritize the most hazardous chemical groups, as these pose the greatest potential for long-term or irreversible health effects even at low concentrations. Substances classified as CMR (carcinogenic, mutagenic, or toxic to reproduction) are particularly critical because they can initiate or promote cancer, alter genetic material, or impair reproductive development—effects that typically lack a safe exposure threshold. Detecting and controlling such compounds early in the assessment is therefore essential to ensure consumer safety.

In recycled PE, PP, and PET, the priority CMR-related risks include phthalates (*e.g.*, DEHP), heavy metals (cadmium, lead), polycyclic aromatic hydrocarbons (PAHs), benzene derivatives, and brominated flame retardants (*e.g.*, PBDEs). These chemicals are toxicologically significant because they can bioaccumulate, persist through several recycling cycles, and migrate into new products where users may be exposed via skin contact, inhalation, or ingestion.

Chemicals with endocrine-disrupting (ED) properties, such as bisphenol A (BPA), DEHP, DBP, and certain organophosphate flame retardants, also merit high priority. These compounds can interfere with hormonal regulation even at trace levels, influencing reproductive health, metabolism, and developmental processes.

Finally, allergenic substances—including nickel and chromium (from pigments and stabilizers), isocyanates/amines (e.g. from polyurethane adhesives), and degradation products of certain phenolic antioxidants—should be closely monitored. These can provoke skin sensitization or allergic reactions after repeated or prolonged contact, posing particular concern for consumer products handled frequently or intended for children.

The substance group of particular concern are collected in Table 2 below.

Table 2 Overview of hazardous substance groups, relevant chemicals, and the risk of occurring in PE/PP or PET.

Group	Chemical	PE and PP	PET
Plasticizers/phthalates	DEHP, DBP, BBP	High risk due to cross-contamination from flexible PVC packaging in mixed waste streams	Lower risk as PET bottles rarely contain phthalates, but contamination possible from mixed recycling
Metals (heavy metals)	Lead (Pb), Cadmium (Cd), Mercury (Hg), Hexavalent chromium (Cr VI), Arsenic (As), Barium (Ba)	Moderate to high risk from printing inks, colorants, and industrial applications	Lower risk due to more controlled collection systems, but antimony catalyst residues might occur
PAHs (Polycyclic Aromatic Hydrocarbons)	Various polycyclic aromatic compounds from combustion processes	Moderate risk especially from black pigments and from diverse use at consumer	Lower risk due to bottle collection systems, but possible from mixed waste
Primary Aromatic Amines (PAAs)	Compounds from azo dye breakdown and other degradation processes	Moderate-high risk from colorants and printing inks	Lower risk, but possible from colored bottle contamination and label adhesives
Phenolic byproducts	Degradation products from phenolic antioxidants and stabilizers	High risk as these polymers commonly contains phenolic antioxidants that can degrade	Moderate risk from cross-contamination with polycarbonate materials

	Bisphenol compounds (BPA, BPS)		
PFAS (Per- and polyfluoroalkyl substances)	Persistent fluorinated compounds from various applications	Low-moderate risk from food packaging and industrial applications	Lower risk, but growing concern as PFAS use expands in barrier coatings Additional substances from general PCR contamination
Volatile Organic Compounds (VOCs)	<i>E.g</i> formaldehyde and acetaldehyde from degradation. Fragrances from previous use.	High risk in (especially PE) from previous cosmetics/detergent use	Moderate-high risk - acetaldehyde is a primary migration concern in PET
Flame Retardants	Brominated compounds (BDEs, TBBPA)	Higher risk from electronics and textile applications	Lower risk due to limited use in bottle applications

In previous projects conducted by Technological Institute, the following substances are examples of CMR and allergenic substances that have been detected in recycled plastics and where a safety evaluation were recommended.^{8 9}

Intentionally added stabilizers/antioxidants:

- 2,4-Di-tert-butylphenol
- Benzophenone
- 2,6-bis(1,1-dimethyl)-4-methylphenol (BHT)
- Tris-(2,4-di-t-butylphenyl)phosphit

Phthalates:

- Di-butyl phthalate (DBP)
- Butyl-benzyl-phthalate (BBP)
- Bis(2-ethylhexyl) phthalate (DEHP)

⁸Udvikling af plastemballager i en cirkulær økonomi - et MUDP projekt (slutrapport)

<https://www2.mst.dk/Udgiv/publikationer/2024/01/978-87-7038-576-3.pdf>

⁹ Miljøprojekt nr. 2174: Indledende sikkerhedsvurdering af genanvendt plast til emballering af kosmetiske produkter

Metals:

- aluminium

Fragrances:

- Limonene
- α -Hexylcinnamaldehyde

PAAs:

- 4,4'-Diaminodiphenylmethan
- *p*-Cresidine
- *o*-Toluidin

It should be stated that the selected substances do not constitute an exhaustive list of substances in connection with a safety assessment of PCR plastic materials, but the list contains examples of specific relevant substances to analyze for and evaluate.

7 Test methods

Evaluating the safety of recycled plastics relies on assessing the migration potential of harmful substances from the material into its surrounding environment during realistic use. Migration testing provides a measure of actual user exposure rather than total content, offering a more accurate picture of consumer risk.

Because recycled PE, PP, and PET can contain both known additives and unknown contaminants (NIAS), testing typically follows a two-tiered approach:

1. **Broad chemical screening** (e.g., GC-MS/LC-MS and ICP-MS) to identify all extractable or migratable compounds, including non-intentionally added substances.
2. **Targeted quantitative analysis** of selected priority groups (such as phthalates, PAHs, heavy metals, and PAAs) to confirm concentrations and evaluate toxicological relevance using limit values or margin-of-safety calculations.

Migration media should simulate realistic exposure routes, such as sweat, saliva, or skin-contact emollients, depending on product use and target group (child vs. adult). This ensures that testing results are directly relevant to consumer exposure and ecolabelling safety assessments.



7.1 Sample preparation

To create a representative sample for analysis, both the material and its intended application must be considered. The surface-to-volume ratio of the test sample is a key factor in the evaluation of hazardous substances. Materials with a high surface-to-volume ratio, such as granulate/pellets will release greater amounts of substances during extraction compared to samples like sheets or intact bottles, which have a lower ratio.

Most potential hazardous substances in recycled material do not migrate through air and are thus not harmful until contact is established between user and product. Thus, a migration medium is required for the hazardous substances to migrate from the material to the user *e.g.* sweat or lotion. Depending on the migration medium different substances might migrate from the product to the user. Therefore, the choice of migration solvent for an analysis depends on the most probable application of the material but is often chosen from a worst-case scenario mindset. If the recycled plastic is used for an application exposed to children, the migration solvent should include simulated media for sweat and spit as children are prone to oral exposure. If the application is used by adults the exposure would mainly include skin contact where a migration medium simulating sweat or lotion might be appropriate. Hence, both hydrophilic and hydrophobic migration media can be relevant based on the case.

7.2 Relevant quality tests of recycled plastics

The following list of relevant analytical tests is based upon established information on potentially harmful substances in recycled plastic, and serves as a recommendation for how to obtain the data foundation that allows for a full safety evaluation of a specific recycled plastic:^{10 11}

- 1. Overall migration level (total migration).** To give an overall picture of the amount of leaching compounds from the specific recycled plastic (overall quality).
- 2. Targeted GC-MS analysis with internal standards (quantitative)**
 - a. Phthalates (*e.g.* 95% ethanol)
 - b. PAAs (*e.g.* 3% acetic acid)
 - c. PAHs (*e.g.* isooctane)

¹⁰ <https://mst.dk/publikationer/2021/august/indledende-sikkerhedsvurdering-af-genanvendt-plast-til-emballering-af-kosmetiske-produkter>

¹¹ <https://mst.dk/publikationer/2024/januar/udvikling-af-plastemballage-i-en-cirkulaer-oekonomi-mudp>

- d. Phenols
- e. PFAS

The targeted tests will measure the actual quantitative amount of specific compounds within a group of harmful substances, which allows for toxicological safety evaluation. To keep testing cost down, a suggestion is to screen for first phthalates as a representative for apolar contaminants and PAAs as examples of more polar contaminants. If detection of the compounds are very low, perhaps further tests can be excluded from lower exposure products.

3. ICP-MS for heavy metals (acetic acid 3%)

- a. Cr, Co, Ni, Hg (allergenic metals)
- b. Cd, As, Pb (CMR hazard)

Often cheap, standard methods for detecting heavy metals.

4. NIAS screening: GC-MS screening for non-intentionally added substances (NIAS) (semi-quantitative)

This test is non-standard and can be more or less extensive (and expensive), however, it provides important knowledge of the contaminant profile of a specific waste stream.

5. GC-MS of 82 fragrances on the EU list

The recently updated list of perfume substances subject to declaration can provide an indication of how efficient the decontamination process has been through the recycling process.

The acceptable limit of any detected compound will depend on a toxicological evaluation considering the exposure scenarios for the relevant users *e.g.* adults and children. Additionally, risk-assessment of chemical substances requires continues updating as many chemicals are still not evaluated for their long-term effects.

For comparison, Figure 3 is a suggested test-program for evaluating the safety of recycled HDPE to a contact-sensitive application (rinse-off and leave-of cosmetic products).

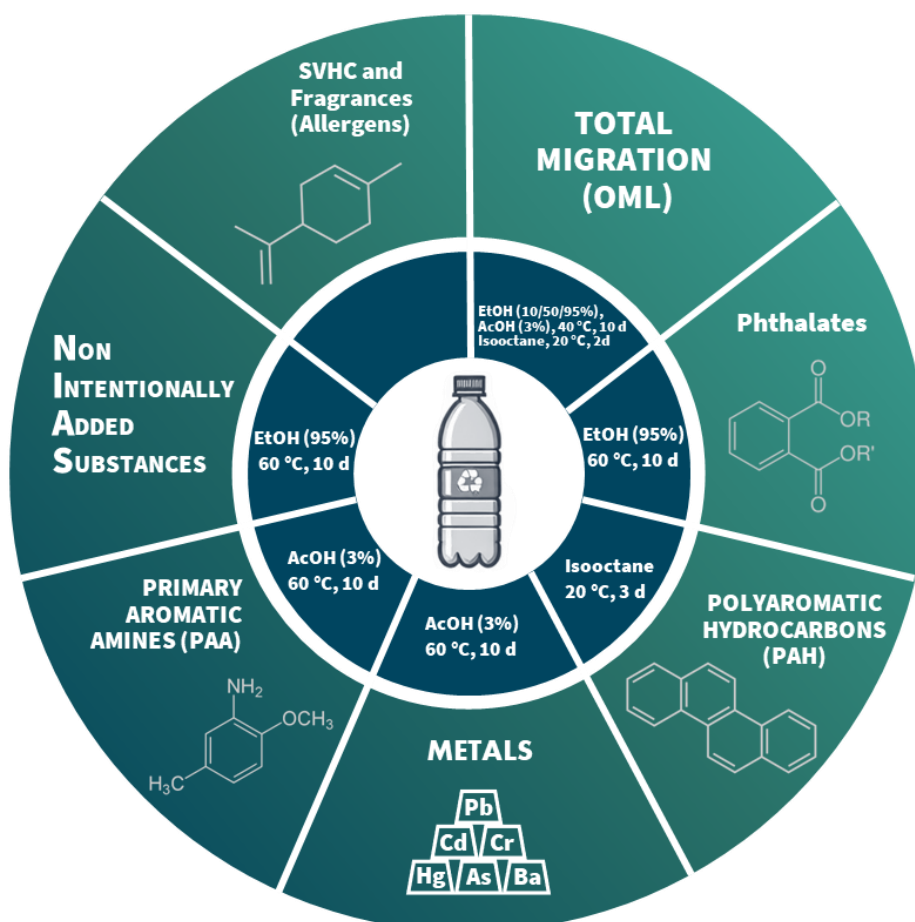


Figure 3 Suggested test-program for quality evaluation of recycled HDPE for cosmetic packaging.

7.3 Balancing safety ambitions and practical feasibility

From a safety standpoint, the ideal approach would be to perform comprehensive and repeated analytical testing of every recycled plastic batch and product. In practice, this is seldom feasible. Recycled plastics are low-value materials, and exhaustive test programs for each production run would impose costs that could easily exceed the material's market value. Therefore, the challenge is to maintain a high level of consumer protection while applying a strategic, risk-based testing framework that remains economically viable.

A clever testing strategy combines toxicological priorities with practical considerations:

- **Risk-based focus:** Select tests according to exposure potential and product use scenario. High-exposure items or products intended for children require broader and more frequent testing than low-exposure items.

- **Source-driven differentiation:** The cleaner and more traceable the feedstock, the less frequent testing is required. For example, closed-loop bottle-grade PET recycling may rely on periodic verification, while mixed household PE/PP waste demands more intensive analysis.
- **Indicator substances:** One can consider establishing a set of representative marker compounds, such as DEHP (for plasticizers), benzo[a]pyrene (for PAHs), and nickel (for metals), to serve as early-warning indicators of contamination trends. Elevated levels of these markers can trigger expanded testing of related substance groups.
- **Tiered testing frequency:** Conduct a comprehensive test program at initial qualification of a recycled plastic source, followed by routine monitoring (*e.g.*, annually or upon process changes).
- **Alignment with regulation and exposure risk:** Prioritize substances with the highest toxicological potency (CMR, endocrine-disrupting, or sensitizing compounds) as defined in REACH Annex XVII, the Toy Safety Directive, or other relevant legislation.

This pragmatic framework can allow producers and recyclers to allocate resources where they have the greatest impact on risk reduction, maintaining scientific integrity and regulatory compliance while supporting the circular economy.

7.4 Flow chart

The flow chart below (Figure 4) outlines a decision framework for selecting the appropriate level of chemical testing for recycled PE, PP, and PET materials. Because contamination risks vary greatly depending on the origin, composition, and traceability of the recycled feedstock, applying a single, uniform test program to all materials is neither practical nor scientifically justified.

The purpose of this flow chart is therefore to help Ecolabelling and producers differentiate between high-, medium-, and low-risk feedstocks and tailor the testing scope accordingly.

In general:

- **Well-characterized, closed-loop feedstocks** (*e.g.*, bottle-to-bottle PET) require limited verification testing.
- **Mixed or poorly documented post-consumer waste streams** demand broader chemical screening and migration studies. Special attention should be

given to black plastics and material streams stemming from Asia, due to risk of electronic waste origin.

- **Intermediate cases**, such as single-polymer household collections with known sources, can apply an adaptive testing program using indicator substances to confirm cleanliness and stability.

This approach allows resources to be focused where they have the greatest impact on risk reduction—on the feedstocks most likely to carry hazardous legacy chemicals or unknown contaminants.

The flow chart provides guidance for prioritizing test efforts based on feedstock characteristics and is not a prescriptive testing standard.

Users should note that:

- The chart assumes that all recycled materials already comply with relevant legal limits for substances of very high concern (SVHCs) under REACH and other applicable regulations.
- The suggested testing intensity represents minimum best-practice guidance; additional analyses may be required for products with high consumer exposure or intended for sensitive user groups (e.g., children). On the other hand, practical and economic considerations might pose a barrier for the suggested tests to be realistic in every case.
- The framework should be reviewed and updated as new analytical data, regulatory developments, or scientific evidence on contaminants in recycled plastics become available.

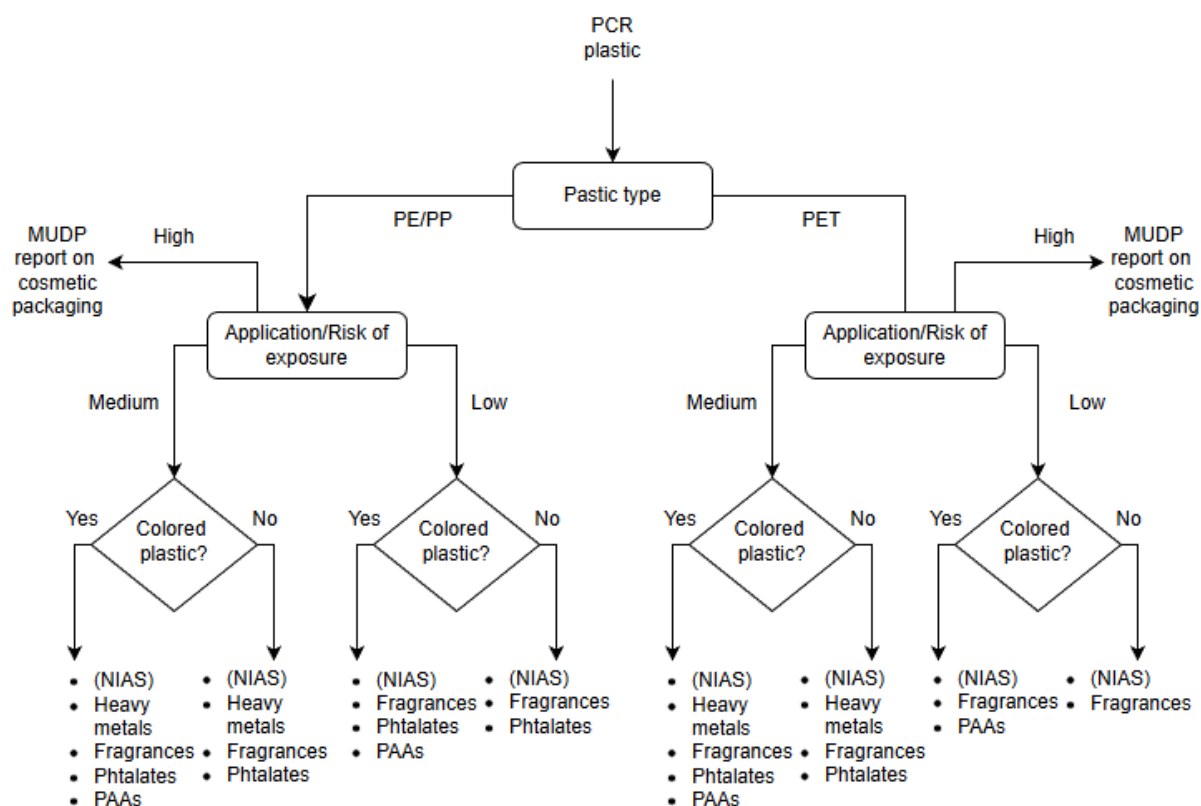


Figure 4 Suggestive flowchart for test-program decision.

If a true safety evaluation is to be completed, the recycled plastic should be analysed for NIAS. Standard NIAS-screening procedures exists for assessing plastics for food contact. This method, based on GC-MS, can give an indication of what compound groups that are present, and thus highlight the need for targeted test of these. The compound groups (metals, fragrances, phthalates, PAAs) are mentioned where the risk of detecting the substances is assessed to be highest.



8 Limit value of harmful substances

Some available limit values for specific harmful substances are given in Table 3.

Table 3 Limit value for specific compounds set in different regulatory contexts.

Substance (CAS)	Limit	Source
2,4-Di-tert-butylphenol (96-76-4)	-	
Benzophenone (119-61-9)	Tolerable daily intake (TDI) 0,03 mg/kg bw/day	EFSA Toxicological evaluation of benzophenone ¹²
di-butyl phthalate (DBP) (84-74-2)	≤0.1% w/w (in toys/childcare)	REACH Annex XVII (Entry 51) ¹³ ; Toy Safety Directive 2009/48/EC
butyl-benzyl-phthalate (BBP) (85-68-7)	≤0.1% w/w (in toys/childcare)	REACH Annex XVII (Entry 51) ¹¹ ; Toy Safety Directive 2009/48/EC
bis(2-ethylhexyl) phthalate (DEHP) 1117-81-7)	≤0.1% w/w (in toys/childcare)	REACH Annex XVII (Entry 51) ⁷ ; Toy Safety Directive 2009/48/EC
Aluminium (7429-90-5)	5,625 mg/kg (toy) 70 mg/kg (cosmetic product)	Toy Safety Directive 2009/48/EC; Environmental project nr. 2174 ¹⁴
Heavy metals (Pd, Cd, Hg, Cr IV)	A sum of 100 ppm	Packaging Waste Directive (Directive 94/62/EC) ¹⁵
d-Limonene (5989-27-5)	0.01% in cosmetic rinse-off products	REACH Annex III to Regulation (EC) No 1223/2009 ¹⁶
4,4'-diaminodiphenylmethane (MDA) (101-77-9)	0,1% (w/w)	REACH Annex XVII (entry 56) ¹⁷
PAHs	1 mg/kg (general use) and 0,5 mg/kg (toys and child product); 10 mg/kg (tyres)	The Danish Environmental Protection Agency 2025 ¹⁸ REACH Annex XVII to Regulation (EC) No 1907/2006 ¹⁹

¹² <https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2009.1104>

¹³ <https://echa.europa.eu/documents/10162/aaa92146-a005-1dc2-debe-93c80b57c5ee>

¹⁴ <https://mst.dk/publikationer/2021/august/indledende-sikkerhedsvurdering-af-genanvendt-plast-til-emballering-af-kosmetiske-produkter>

¹⁵ https://echa.europa.eu/da/heavy-metals-packaging-waste?p_p_id=eucleflegislationlist_WAR_euclefportlet&p_p_lifecycle=0

¹⁶ <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32023R1545>

¹⁷ <https://echa.europa.eu/documents/10162/a3af0497-4775-1a05-7037-80d653a39272>

¹⁸ <https://mst.dk/publikationer/2025/september/kortlaegning-af-kemikalier-i-forbrugerprodukter-med-genanvendt-plast>

¹⁹ https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202500660

While evaluating the toxicological effect of the harmful substances, it should be assessed if multiple substances are found in the same product and accumulative effect might occur.

8.1 Estimating limit value by calculation

If a limit value is not defined, limit values can be estimated by calculation. A margin of safety (MoS) accounts for differences in absorption between chemicals and helps ensure a substance is safe for its intended use by ensuring the exposure dose is well below the level that causes adverse effects. The MoS is calculation that determines the risk of a chemical substance by dividing a No Observed Adverse Effect Level (NOAEL) or other derived reference dose by the estimated human exposure dose. This ratio is calculated as:

$$MoS = \frac{NOAEL}{SED}$$

SED, the systematic exposure dose, depends on the dermal absorption fraction (P), and the dermal exposure, E_{dermal} , and is calculated as:

$$SED = \left(\frac{conc.}{100}\right) \cdot P \cdot E_{dermal}$$

Derived No Effect Level (DNEL), total daily intake (TDI) or acceptable daily intake (ADI) can be used instead of NOAEL. MoS of at least 100 is normally accepted when using NOAEL, but when using DNEL (or TDI or ADI) we only need a MoS of 10 to account for the 10% allocation of DNEL to e.g. cosmetic products, to allow for exposure to the same chemical substance from other sources, such as drinking water and food. For substances where data on dermal penetration are not available, a P-value of 1 is used, corresponding to 100% of the substance penetrating the skin. This is a conservative assumption that is used by default until specific data becomes available.

Based on the list of detected substances, the selection of substances for safety assessment can be made by screening according to their tolerable daily intake (TDI) values and their ability to penetrate the skin (P). A worst-case scenario could be if the PCR plastic material is intended for use in baby body lotion (leave-on), the following criteria can be established:

- For substances that readily penetrate the skin (P=1) and have a TDI value of 1 mg/kg bw/d, the measured concentration must not exceed 300 mg/kg (as this results in a Margin of Safety (MoS) of 10).

- For substances that readily penetrate the skin ($P=1$) and have a TDI value of 10 mg/kg bw/d, the measured concentration must not exceed 3,000 mg/kg (as this results in a MoS of 10).
- For substances that only partially penetrate the skin ($P=0.1$) and have a TDI value of 10 mg/kg bw/d, the measured concentration must not exceed 30,000 mg/kg (as this results in a MoS of 10).

9 Quality assurance procedure

Ongoing quality assurance is crucial to ensure consistent safety and performance of recycled materials throughout the product lifecycle. Again, the suggestion and recommendation to an effective and realistic quality assurance procedure heavily depends on a combination of plastic feedstock, plastic type, recycling procedure, and product application.

In general, a recommendation is to combine routine monitoring with event-driven quality checks. For instance, for a specific recycled HDPE, it might be decided to conduct a specific migration analysis program every third month after initial quality approval for a given application. However, in addition to the routine monitoring, it is also recommended to perform a quality check whenever one of the following events occurs:

- Changes in the source of PCR material (e.g. from Swedish waste to Asian waste)
- Changes in provider of PCR material (e.g. change of recycler)
- Changes in the recycling process (e.g. new washing process, sorting method etc.)

Since these events can impact the quality of the recycled material significantly.

What the quality check consists of in terms of specific analysis-program may also vary with feedstock, plastic type, recycling procedure and application, but it is suggested to include:

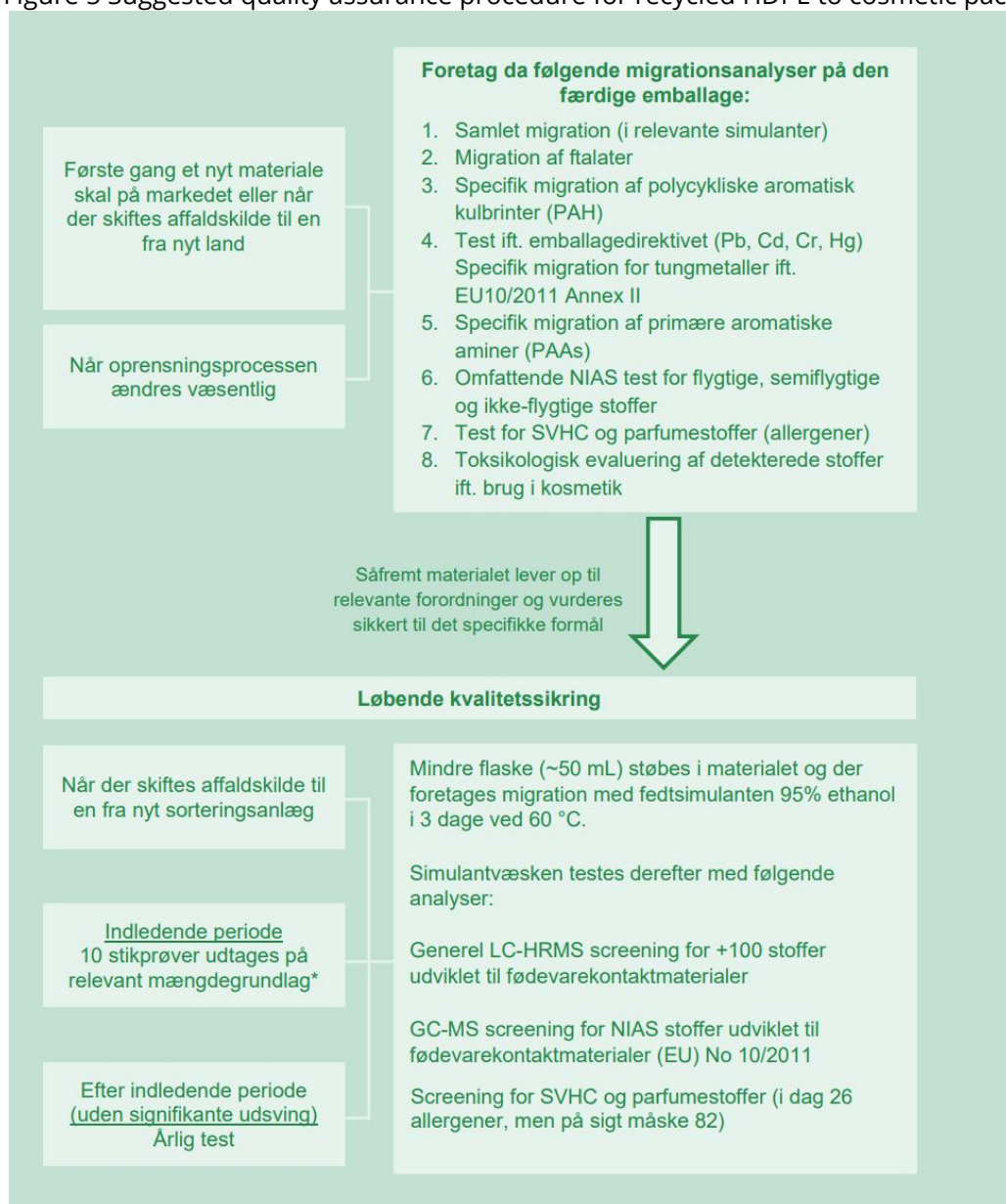
- Migration from plastic product (item, bottle or granulates) in suitable migration media then;
- Test of the migration media
 - GC-MS screening for NIAS substances
 - Relate the detected compound quantities to the exposure scenario
 - Screening for SVHC and allergenic substances

Specific considerations should be given if the recycled plastic is colored (especially dark grey or black), in which case regular tests for PAA content are advisable, as they can originate from degradation of the original mixed colors. Another focus can be to

continuously monitor the presence of phthalates and if increasing content of these substances is observed further investigation and evaluation are recommended.

Figure 5 presents (in Danish) a recommended quality assurance procedure used to evaluate recycled HDPE for cosmetic products. While this case qualifies as a contact-sensitive application, the build-up of the analysis frequencies can serve as inspiration for future development of quality assurance procedures for other applications.

Figure 5 Suggested quality assurance procedure for recycled HDPE to cosmetic packaging²⁰



²⁰ <https://www2.mst.dk/Udgiv/publikationer/2024/01/978-87-7038-576-3.pdf>