GUIDANCE ON THE IMPROVED COLLECTION AND SORTING OF PAPER-BASED PACKAGING FOR RECYCLING

VERSION 4

4ever green

Table of contents

1. List of abbreviations

AI	Artificial Intelligence
DL	Deep Learning
DRS	Deposit Return System
EPR	Extended Producer Responsibility
FBCP	Fibre-Based Composite Packaging
HORECA	Hotel, Restaurant and Café/Catering
LPB	Liquid Packaging Board
LPC	Liquid Packaging Carton
LWP	Lightweight Packaging
MSW	Municipal Solid Waste
NIR	Near Infra-red
OCC	Old Corrugated Containers
PFR	Paper for Recycling
PPE	Personal Protective Equipment
PPWR	EU Packaging and Packaging Waste Regulation
PRO	Packaging Recovery Organisation
WFD	Waste Framework Directive 2018
WSR	Waste Shipment Regulation 2024

2. Introduction

2.1. Goals and overview

4evergreen is a cross-industry alliance promoting low-carbon and circular paper-based packaging*. By bringing together the entire value chain, the different workstreams of 4evergreen aim for a comprehensive outlook on the lifecycle of paper-based packaging. To enable the recycling of paper-based packaging waste, effective collection and sorting are crucial.

This **'Guidance on the Improved Collection and Sorting of Paper-Based Packaging – Version 4'**, hereafter referred to as the Guidance, is based on input received from 47 participating companies from all relevant industry segments along the value chain. The recommendations are based on a consensus reached through discussions between workstream participants and experts.

These recommendations are written based on best practices and are intended to aid the implementation of future collection, sorting and recycling infrastructure, to meet EU legal requirements and realise 4evergreen's aspirational target of a 90% recycling rate for paper-based packaging. This Guidance affects all key actors in the paper-based packaging value chain (e.g. producers/importers, (local) authorities, waste handlers/collectors, recyclers and NGOs); and it is aimed towards policymakers, local authorities, and extended producer responsibility schemes.

This Guidance, updated in 2026, now includes additional material covering:

- Impacts of residual organic contamination on the recycling of paper-based packaging
- A deep dive on sorting technologies used for paper-based packaging
- Analysis of HORECA and on-the-go recycling systems
- Sortation challenges and opportunities, emerging technologies and need for standard sortation protocol

While summaries of this work can be found within this Guidance, more detailed information can be found in the separate annexes.

2.2. Paper-based packaging waste recycling rate targets

The European Union (EU) has adopted material-by-material packaging waste recycling rate targets for both 2025 and 2030[1]

PACKAGING WASTE RECYCLING RATE TARGETS EU

Year	All packaging waste	Plastic	Wood	Ferrous metals	Aluminium	Glass	Paper-based
2025	65%	50%	25%	70%	50%	70%	75%
2030	70%	55%	30%	80%	60%	75%	85%

Figure 1. Packaging waste recycling rate targets of the EU

Source: Regulation (EU) 2025/40

NOTE: Paper-based packaging is called "paper and cardboard" packaging in the respective regulation

* 4evergreen uses the term 'paper-based packaging' to describe all packaging and packaging materials that are predominantly made of paper, including all composite packaging in which the predominant material is paper. For 4evergreen, the term 'paper' includes cellulosic fibres processed into sheets or webs of paper or cardboard, into corrugated board, and into moulded fibre products. For illustration, 'paper-based packaging' formats include - but are not limited to - boxes, trays, cups, flexible pouches, lids, cones, wrappers, as well as liquid packaging cartons.

[1] The UK has also set packaging waste recycling targets, broadly in line with the EU.

These can be considered minimum targets, as EU Member States are free to implement more ambitious packaging waste recycling targets in their respective national legislation (e.g. Germany, Spain, and Sweden).

Therefore, 4evergreen strives for the following recycling rate sub-targets for the recycling of paper-based packaging:

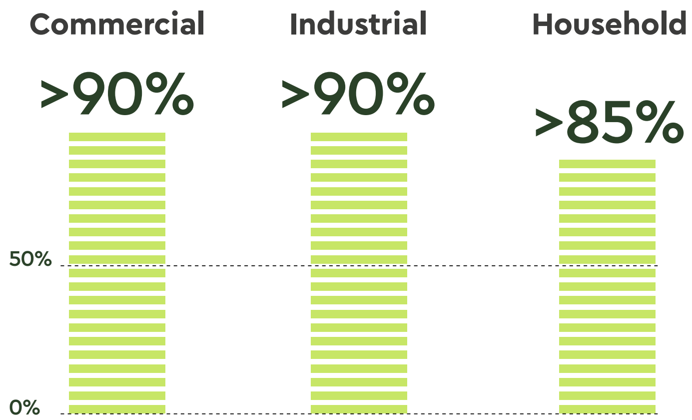


Figure 2. Recycling rate sub-targets

2.3. Collection systems today

In Europe (EU27 + NO, CH, UK), 47 million tonnes of paper-based packaging are consumed each year, of which 42 million tonnes are ultimately collected. The material collected comes from three different sources:

- Households (21% – 9 million tonnes)
- Industrial (31% – 13 million tonnes)
- Commercial (48% – 20 million tonnes)[2]

These three sources have significantly different recycling rates, with industrial and commercial at 85% and 88% respectively, while household collection is at 55%.[3]

As the current recycling rates need to be improved to reach an overall recycling rate of 90%, 4evergreen concludes that more focus needs to be put on household collection while maintaining high recycling rates for industrial and commercial collection.

2.4. Household collection

The starting point and basis for the Guidance and recommendations is a **separate collection of paper and board from households**. Here, paper-based packaging should be collected in either the paper and board stream (hereafter Stream 1 P&B) or (hereafter Stream 2 LWP).

The 4evergreen guidelines contained in this document include steps that should be taken by countries, municipalities, and other actors in the recycling value chain to make it easier for consumers to sort correctly, allowing the packaging to be collected in the correct stream and recycled into a new valuable resource. This should reduce the share of paper-based packaging in mixed municipal solid waste (MSW) and increase the recycling rate of the sorted household stream.

4evergreen recommends the **two streams for the collection of paper-based packaging** as a guide to implementing future collection, sorting and recycling infrastructure. That means one bin for paper-based packaging suitable for recycling in paper mills with conventional recycling process and a second bin for lightweight packaging (LWP), including paper-based packaging suitable for recycling in paper mills with specialised recycling processes. In every respect, 4evergreen also supports alternative streams for collection and infrastructure **capable of meeting the recycling rate (sub)targets** for composition and recyclability. The routes from collection to recycling at paper mills are also examined, followed by practical recommendations on how to optimise collection.

[2] RISI; Expert interviews; Press search; FAO; OECD; Cepi, team analysis, 2020
[3] RISI; Expert interviews; Press search; FAO; OECD; Cepi, team analysis, 2020

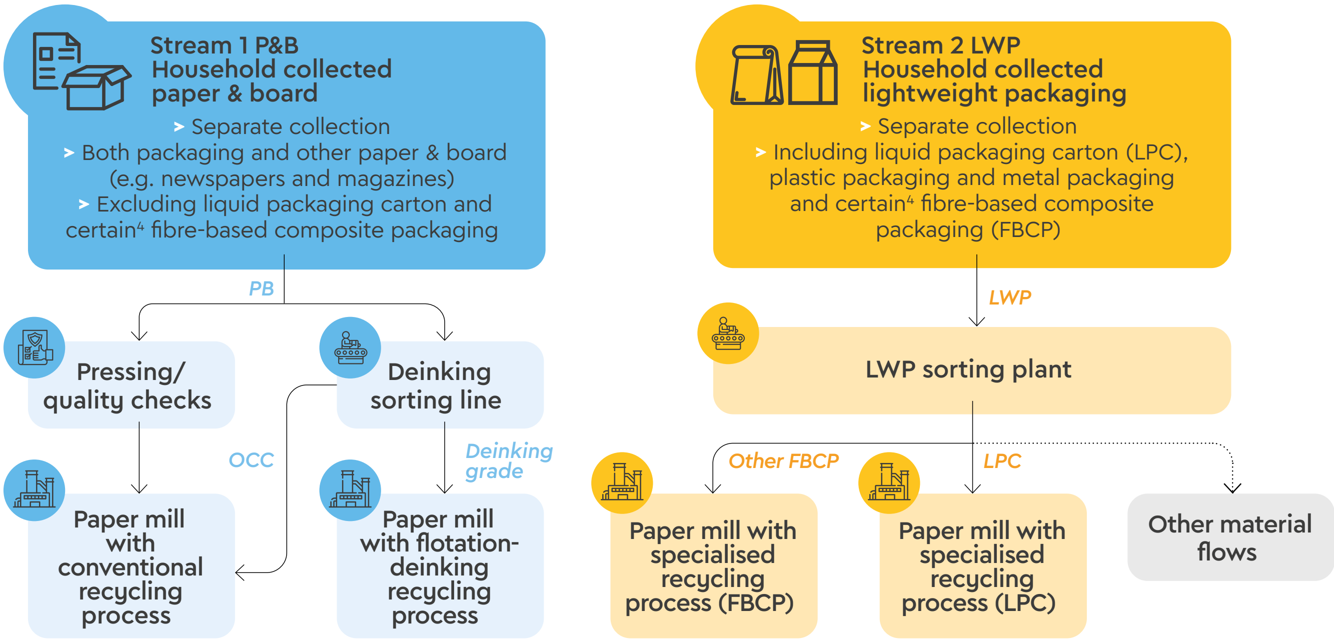


Figure 3. Two-bin system

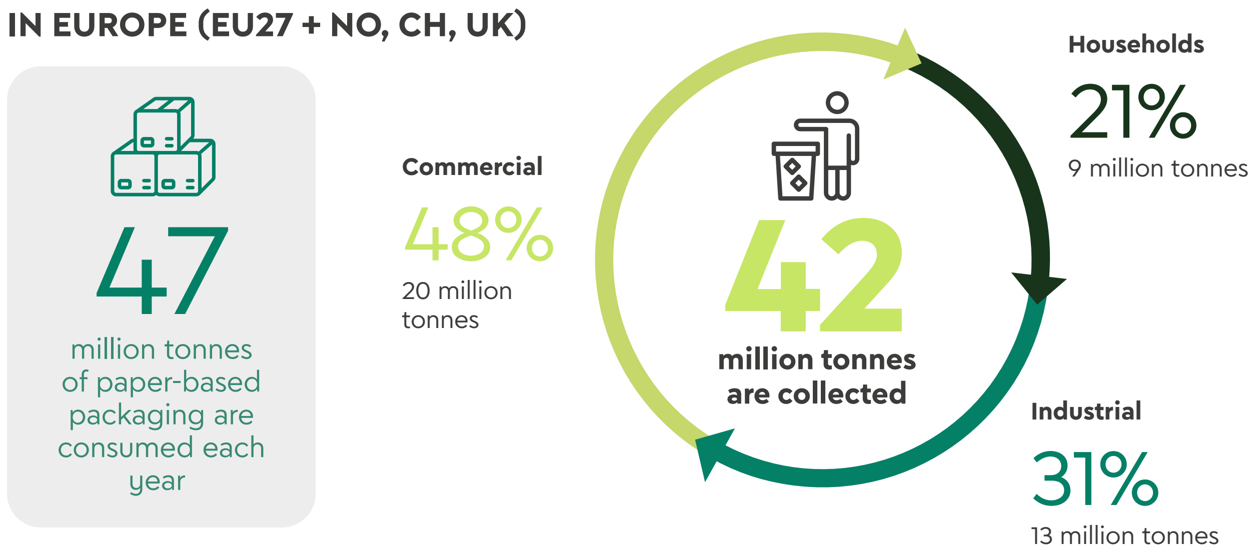


Figure 4. Collected paper-based packaging in Europe (EU27 + NO, CH, UK)

Separate collection of paper-based packaging is fundamental, as it enables better quality paper to enter recycling streams with less contamination. **4evergreen endorses collection systems where material is sorted into different streams at the source (e.g. households), laying a strong foundation for recycling at suitable paper mills.**

Household collection schemes determine suitable recycling streams for various grades of paper-based packaging and other paper products, which in turn have a fundamental impact on the efficiency of paper recycling. In essence, this concerns practical matters, such as looking at the number of recycling streams households are dealing with and what sort of instructions or information they receive on how or where to discard what packaging.

In this Guidance, a distinction is made between two dominant coexisting collection streams for paper-based packaging waste originating in households (both will be addressed in more detail in later chapters). Meanwhile, further separation at source exists in some countries whereby additional fractions being collected deliver high quality and volume for recycling.

[4] Specific information on this topic can be found in the 4evergreen Recyclability Evaluation Protocol.

It is important that the collection and sorting set-up guides the different paper grades towards the correct recycling process and end use to secure the highest quality and yield of recovered material across different types of paper mills processing different types of paper-based materials.

The highest efficiency and recycling rates will thus be obtained by ensuring that paper mills have access to paper-based material collected and sorted into different feedstock fractions, with sufficient quality to create the required recipe for their own products.

2.5. Connecting packaging and the full recycling system

There are several key elements in achieving paper-based packaging waste recycling rate targets. In principle, all paper-based packaging is recyclable, the vast majority in paper mills with conventional recycling process. However, not every paper mill can recycle all types of paper-based packaging, as their processes and equipment vary. As such, a certain packaging item for one type of paper mill could be considered recyclable, and for another paper mill it could be considered non-recyclable. Therefore, effective and efficient recycling depends upon the correct paper-based packaging reaching the correctly designated paper mills.

Consumers need to be empowered, educated and encouraged to recycle paper-based packaging and paper by separating them into the correct collection stream. This, in turn, positively affects the recycling process and avoids recyclable material being sent to incineration plants or landfill. Public awareness and education on this topic are key. Today, paper-based products collected with, and sorted from, residual waste streams are not considered suitable for recycling in paper mills, as fibres may have been heavily contaminated by organic or hazardous substances.

To achieve higher recycling rates, packaging needs to be circular by design (learn more about this on 4evergreen's Circularity by Design Guideline for Paper-based Packaging[5]).

2.6. Recycling legislation

The EU Waste Framework Directive 2008/98/EC, or WFD, named separate collection as a precondition for high-quality recycling. This rule was also confirmed in the revised EU Waste Framework Directive (EU) 2018/851. In parallel, and in accordance with the later Packaging and Packaging Waste Directive (EU) 2018/852, or PPWD, European Member States were required to establish and implement Packaging Recovery Organisations (PRO) for commercial and industrial packaging by the end of 2024[6]. This obliged affected stakeholders (e.g. municipalities, producers) to develop, among other things, the required infrastructure to collect paper-based packaging separately at source (households). Minimum requirements for such schemes have been set out in both the WFD and PPWD and now in the PPWR.

Implementation of separate collection and adequate sorting of paper-based packaging and other paper and board products is not only necessary to comply with European law, but also important to create qualities of paper for recycling that match respective paper mills, thus increasing the recycling rate and delivering the best overall environmental solution for European consumers and the planet.

4evergreen is in support of legislative initiatives that incentivise more investment and wider participation of all relevant stakeholders in separate collection and post-collection sorting actions aimed at increasing the recycling rate of paper-based packaging.

Moreover, 4evergreen supports PRO fee structures which, to the largest extent possible, reflect the real net recycling costs for each type of packaging material. An economic assessment should take into account (a) collection costs, (b) need for and cost of sorting/processing, (c) actual cost of recycling, and (d) the value of recyclates.

In addition, the EU Packaging and Packaging Waste Regulation (PPWR) goes in line with 4evergreen's paper-based packaging circular economy ambitions. It maintains the ambitious targets set by PPWD and introduces new concepts and obligations to achieve these targets. Mandatory separate collection rates, recycling at scale, high-quality recycling concepts, and the labelling of packaging and receptacles for waste collection are some examples under the new regime. Although many of these areas are already covered by this Guidance, future versions will seek to take all new legal elements into account when proposing the optimal collection and recycling systems for paper-based packaging.

[5] https://4evergreenforum.eu/wp-content/uploads/4evergreen-Circularity-by-Design3.pdf
[6] The UK has indicated that it will implement similar EPR legislation.

3. Paper mills with conventional recycling process or flotation-deinking recycling process

Recycling of paper-based packaging into new paper and board is an established technique in widespread use. In fact, paper-based packaging and paper can go through multiple cycles of production, use and recycling. The recycling processes are designed to maintain the quality of the fibres, thus allowing multiple cycles. In every cycle, the fibrous material is cleaned of non-paper components and constituents, such as staples, barrier, and adhesive applications as well as loose non-paper materials.

The basic processes to treat paper and board for recycling are similar. The raw material and the end product manufactured determine the recycling technology required and level of complexity of the processes. Common in all mills is a repulping stage which disintegrates the structure of paper and board into individual fibres, followed by cleaning and screening stages.

Mills with a conventional recycling process typically treat old corrugated containers (OCC) and/or mixed paper. They typically reject non-paper constituents and non-paper components. The output is a greyish and brownish pulp. This pulp is generally used to produce brown containerboard and inner layers of cardboard.

Paper mills with a flotation-deinking recycling process have similar cleaning and screening stages but apply additional processes to remove ink, and they typically have more sophisticated equipment to improve the cleanliness of the pulp. Inputs here are paper and board products on bleached substrates, and the output is a white or off-white pulp. This pulp can be used for graphic and for hygiene papers as well as for white top layers of liner and cardboard.

The majority of the paper and board for recycling utilised in Europe consist of corrugated, kraft and mixed grades. Most of this material is processed in paper mills with conventional recycling process to produce packaging paper and board. The remainder is largely graphic grades mainly treated using a process to remove the ink and enhance the optical properties. Both processes are well designed to handle recyclable paper and board products, which are typically non-wet-strength and limited to no more than a one-sided barrier application.

Optimum paper recycling occurs in two co-existing and interlinked material cycles. The smaller cycle is for graphic paper products, typically with deinking, and the larger one for paper-based packaging. Since deinking processes are designed to remove ink but not to bleach naturally coloured fibres, the graphic cycle is sensitive to unbleached material. The packaging cycle also receives some graphic material – directly via mixed paper and indirectly via white top layers of corrugated and solid board. Also, packaging produced on bleached, mostly virgin substrates often goes directly into packaging grades of paper for recycling. The key quality parameters sought for recycled packaging paper are properties that improve strength.

The main volume of paper and board for recycling is from post-consumer sources; industrial and commercial outlets, households, and offices. All but the households provide rather pure material, either graphic or packaging products. Collection from those sources is often well established with the help of service providers and leaves little room for augmentation.

There is definite scope for improvement in household paper recycling – the focus of this Guidance. Households provide used packaging as well as graphic products, but the collection rate is not as high as from the other three post-consumer sources.

3.1. Recommended system: separate collection

Separate collection of paper for recycling is generally accepted and supported by the paper and board industry. It is also the prevailing system in Europe. The collection system should be comprised of all used paper and products which can be utilised paper mills with conventional recycling process and in paper mills with flotation-deinking recycling process. **The key to a high recycling rate is implementation of kerbside collection systems for households.**

Drop-off systems such as 'bring banks' and recycling centres have the advantage of lower collection costs for the municipality, but they require more effort by citizens, resulting in lower collection rates.

An important aspect is the quality of the collected paper and board for recycling with respect to non-paper items and other contamination. The collected material should be as clean and dry as possible, without food residues and only with light stains, if any (see Annex 1 for examples). In general, the quantity of non-paper components and unwanted paper increases when the collection process is more anonymous. Other influencing factors are size and the shape of container openings, housing structure, the environmental consciousness of users, frequency of residential waste collection etc.

Consumers play a vital role in sorting the material at source, therefore public education is key.

The quality of the collected paper and board for recycling determines whether a subsequent sorting should take place. If part of the material is destined for a paper mill with flotation-deinking recycling process, sorting is inevitable.

3.2. Other collection systems in place

- **Selective collection of paper**
  These systems can be organised by placing separate containers, bins, or baskets at the point of collection, in recycling centres, as part of a campaign, or in participating shops, etc. Collectively, they provide rather low quantities but higher purity with less contamination, e.g. graphic paper products as well as packaging based on bleached substrates. Wherever these systems are already established, they should continue.

- **Separate collection of paper combining used liquid packaging cartons**
  Regionally, this variant of separate collection is in place. Here, subsequent sorting into conventional paper and board for recycling in paper mills with conventional recycling process and used liquid packaging cartons for recycling in paper mills with specialised recycling process (LPC) is expected.

- **Commingled collection**
  In some regions, commingled collection systems where dry recyclables (e.g. plastic, paper, metal, glass) are all collected in the same recycling stream are common. Even after sorting, the resulting paper fraction rarely meets the quality requirements of European paper mills with conventional recycling process – in terms of unwanted materials and cross-contamination.

In every respect, 4evergreen also supports alternative streams for collection and infrastructure **capable of meeting the recycling rate (sub)targets** for composition and recyclability.

The following picture shows the two main sub-routes for collected paper and board in standard grades from households to paper mills. Typically, large and heavy non-paper items and loose non-paper items are removed from the paper stream during the sorting process.

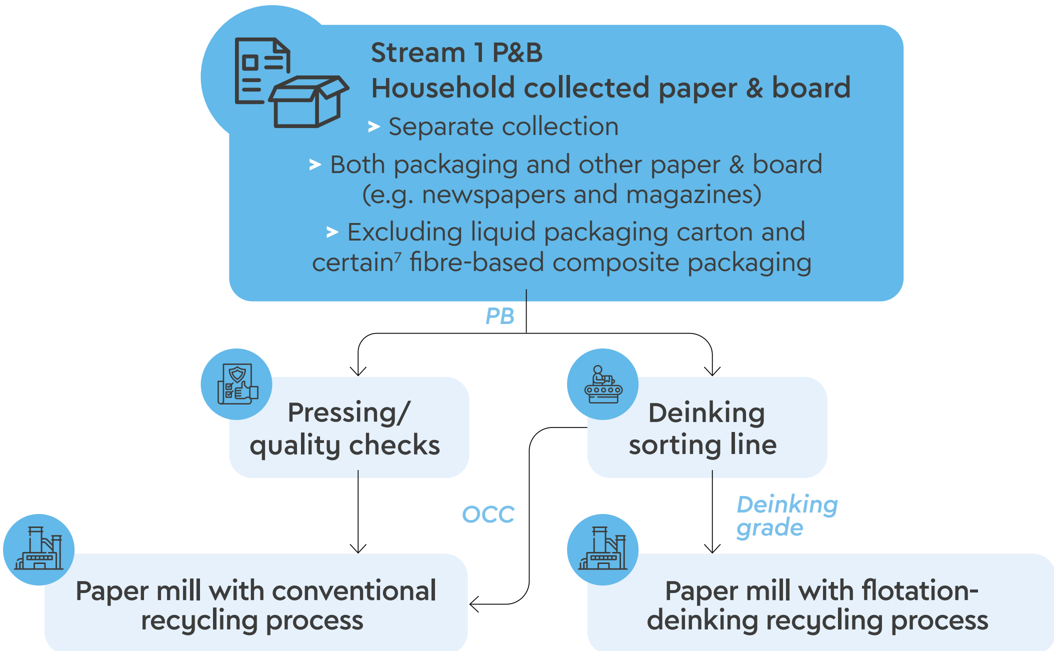


Figure 5. Paper mills with conventional recycling process or flotation-deinking recycling process

[7] Specific information on this topic can be found in the 4evergreen Recyclability Evaluation Protocol.

3.3. European standard EN 643

The European Standard EN 643, 'Paper and board – European list of standard grades of paper and board for recycling', defines general requirements for paper and board recycling and individual grades within five groups. The grades in groups 1 to 4 are suitable to be used in paper mills with conventional recycling process and/or paper mills with flotation-deinking recycling process. Grades in group 5 typically need an adapted process and thus should go to paper mills with specialised recycling processes.

The definitions and the general requirements in EN 643 are:

- **Source of the material**
  If the paper and board for recycling comes from commingled collection, it must be specifically marked. If it originates from refuse collections, it is not suitable for the paper and board industry.

- **Prohibited materials**
  Any materials considered hazardous for health, safety and the environment are forbidden, with zero tolerance.

- **Unwanted materials**
  There are two tolerance levels in each grade for non-paper components and for the total unwanted material.

- **Moisture**
  There is no limit but it is clearly stated that any moisture above 10% may be deducted from the final weight and claimed back from the supplier.

- **Form of delivery**
  Shredding should be avoided and limited to requirements for confidentiality.

- **Deinking grades**
  These grades have additional requirements in terms of their 'deinkability' and the age of the material in the case of newspapers.

The EN 643 standard lists around 100 grades by number, name, and a corresponding description of its content and two tolerance levels. One parameter is for non-paper items and loose non-paper material that can be removed by dry sorting. The second parameter is the total unwanted material; the sum of non-paper items, paper and board detrimental to production, paper and board not matching the grade definition, and (in relevant grades) paper products not suitable for deinking.

For paper collected from households and used in paper mills with conventional recycling process or paper mills with flotation-deinking recycling process, the following grades are the most relevant in terms of volume:

1.01.00, 1.02.00	mixed paper and board (after inspection and/or sorting)
1.04.00, 1.05.00 (incl. subgrades)	OCC (in different quality levels)
1.11.00	deinking grade graphic paper

For the American market, the corresponding document to EN 643 is ISRI SPECS, which is updated on an annual basis.

Paper-based packaging innovations are being developed at a rapid rate, largely in response to legislation, taxation, and restrictions on plastic packaging. Such innovations are resulting in a complex mix of fibre-based composite packaging (FBCP) products – containing non-paper integrated components – being placed on the market. It is not always clear which collection system is best suited to these new products. In this situation, 4evergreen recommends the 'Recyclability Evaluation Protocol', 'Circularity by Design Guideline' and Annex 4 of this Guidance for current and emerging sortation technologies as a reference. As a rule of thumb, material with the following characteristics should be collected via LWP: wet-strength paper, two-sided barrier application (such as liquid packaging cartons), and high percentage of non-fibre content. For such materials, a recycling route via paper mills with specialised recycling processes is recommended.

4. Paper mills with specialised recycling processes

As highlighted previously, separate collection of paper-based packaging from households lays a strong foundation for recycling different paper-based packaging in suitable paper mills, creating the highest yield and quality in the recycling process.

In the previous chapter, it was explained that clean (packaging and non-packaging) paper and board, including certain types of FBCP – ideally collected separately in order to be recycled in a paper mills with conventional recycling process. Paper and board for recycling, but which cannot be recycled efficiently in a paper mill with conventional recycling process, requires a special process. This is why used liquid packaging cartons (LPC) and certain other FBCP are to be recycled in a paper mills with specialised recycling processes.

4.1. Input qualities for paper mills with specialised recycling processes

Although paper mills with specialised recycling processes are designed to recycle specific paper grades, it does not mean they can all be recycled together. Input qualities need to be adapted to the specific process used and should consider the end products for which the fibres will be used.

Paper mills with specialised recycling process (LPC) are already well-established for the recycling of LPC. Typically, this is a two-sided laminated paper, with or without a metallised layer, which requires a specialised pulping action and a reject system handling higher quantities. The process used by these paper mills is designed to optimise paper recovery, hence providing an almost fibre-free reject quality. If the variety of products is low, such as in the treatment of LPC, additional process steps are often in place to recover and recycle the non-paper constituents as well (e.g. 'PolyAl' from LPC). Paper mills with specialised recycling processes can recycle certain types of non-standard grades of paper and board for recycling, including FBCP. They often have longer repulping times and increased screening and cleaning capacity.

Similar processes can be adapted and optimised for wet-strength products and certain other FBCP, i.e. packaging composed of two or more materials, where the predominant material is paper. Depending on product design and the type and quantity of non-paper integrated components and constituents used, part of these products could be suitable for collection via the household paper stream, and then recycled in paper mills with conventional recycling process.

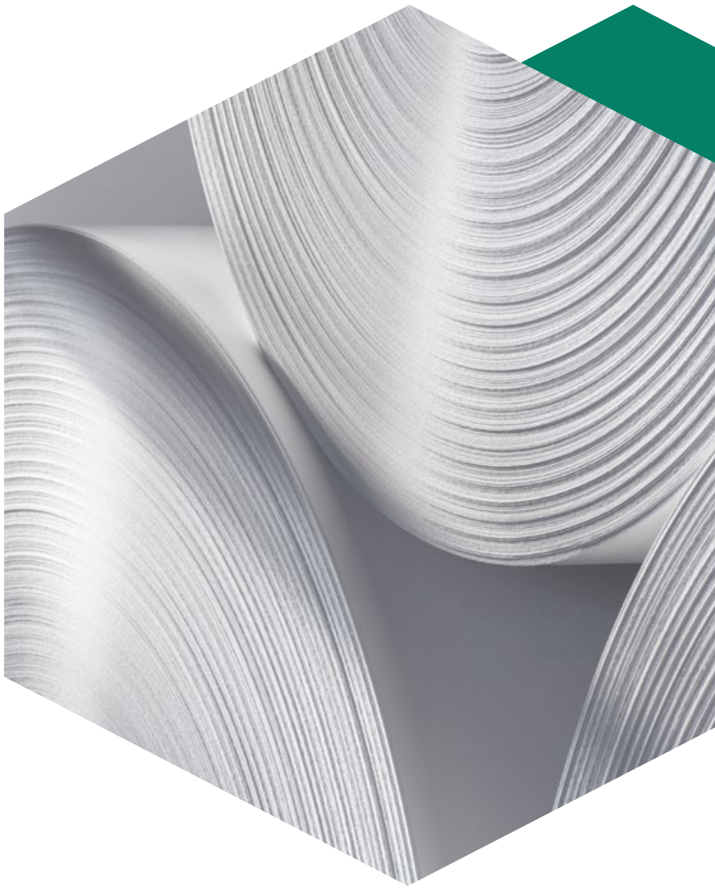
4.2. Recommended system: collection of lightweight packaging

Collection systems for lightweight packaging are well established in some countries and provide a solution to capture LPC and certain FBCP in an efficient way, as existing (and future) sorting technologies can separate qualities suitable for recycling in paper mills with specialised recycling processes. As such, it is 4evergreen's recommended collection system for this packaging. In LWP collection, targeted material may include plastic packaging, metal packaging, LPC and certain FBCP. Glass should be kept separate.

LPC is already being collected with LWP in many countries across Europe (mainly together with plastic and metal packaging), separated at source from other paper products. In some countries, such as Germany, other FBCP is also accepted in the LWP collection. Typically, LWP is sent to a dedicated sorting plant capable of separating it into different fractions ready for recycling. For paper-based packaging, two qualities need to be separated for recycling in a paper mills with specialised recycling process (LPC), i.e. LPC and paper mills with specialised recycling process (FBCP).

4.3. Industry commitments on input requirements

The EN 643 standard lists the grades of 'Paper and Board for Recycling', including barrier-coated, paper-based packaging such as liquid packaging carton or cups. As the variety of paper-based packaging is increasing, adding non-paper constituents, recycling needs to be considered for the non-paper integrated components and constituents as well.



Industry is keen to drive and increase recycling for the variety of paper-based packaging. Paper mills with specialised recycling processes are applying bilateral commitments to specific input requirements beyond EN 643, thus also acting as a benchmark for sorting plants to produce these qualities. An example from Germany can be highlighted; specification N° 512 concerns recycling in dedicated paper mills with specialised recycling process (LPC), while specification N° 550 covers paper mills with specialised recycling process (FBCP).

Sorting is a vital step in the process, as paper mills with specialised recycling processes are not necessarily capable of recycling all paper-based packaging types. A paper mill with specialised recycling process (LPC) developed to recycle LPC, or materials with a similar composition, will not automatically be able to recycle other FBCP. The technology being used in a paper mill with specialised recycling process is linked to repulping time, fibre quality and properties, additives, agents, adhesives, fillers, and non-fibre components.

Figure 6. Paper mills with specialised recycling processes

[8] Specific information on this topic can be found in the 4evergreen Recyclability Evaluation Protocol.

5. Practical recommendations for collecting and sorting paper-based packaging for recycling

4evergreen's ambitious target to exceed EU legal requirements by recycling 90% of all paper-based packaging by 2030 depends on whether a step change can be achieved in household recycling across Europe. This Guidance sets out the preferred collection and sorting processes to reach the target, but it requires the commitment of all stakeholders in the supply chain, as well as consumers and governments.

4evergreen advocates two recommended systems that can work harmoniously to deliver an effective system for collecting paper-based packaging.

5.1. Household kerbside collection; 'two-bin' system for paper-based packaging

Collection of packaging waste generated within homes is essential, with the paper-based packaging separated into two streams. The first stream, identified as the 'stream 1 P&B' should contain paper and board, paper-based packaging and certain FBCP which is suitable for recycling at paper mills with conventional recycling process (as described in Chapter 3). This makes up most of all paper-based packaging emanating from households.

The second stream identified as the 'stream 2 LWP' contains LWP, including certain paper-based packaging which is recyclable only in paper mills with specialised recycling processes. Examples of which may include LPC, and certain FBCP (as described in Chapter 4). Sorting of this packaging fraction is needed to produce the quality of feedstock required for paper mills with specialised recycling processes.

Annex 2 and 4 take an in-depth look at sorting activities and disruptor's, to identify the best available and emerging technologies and techniques to achieve the specific grades (complying with EN 643) desired by paper mills with conventional recycling process and paper mills with specialised recycling processes; even in the case of existing separate collection scenarios that differ from the standard indicated and which, if correctly applied, can contribute to achieving the target of 90% recycling of paper-based packaging.

Sorting plant layouts and main output fractions are assessed for the two main indicated recycling routes: paper mills with conventional recycling process and paper mills with specialised recycling processes. The document gives a general overview of sorting plant requirements and the main output fractions according to EN 643. In addition, typical sorting techniques for paper mills with conventional recycling process and paper mills with flotation-deinking recycling process are described. As there is a huge variety of sorting techniques the processes can vary from one sorting plant to another, therefore only the main steps and technical devices are presented in the overview.

Furthermore, the chapter provides a brief outlook in optimising emerging developments, innovations and techniques for sorting paper-based packaging.

Separation of paper-based packaging into these two streams reduces the need for unnecessary sorting for stream 1 P&B, destined for paper mills with conventional recycling process and producing higher quality paper for recycling in both paper mills with conventional recycling process and paper mills with specialised recycling processes.

While separation of materials for recycling is required to be undertaken by consumers at source, it is the most effective method of limiting cross-contamination of recyclable materials and maximises the opportunity to recycle all the packaging recovered. It should also be noted that any material collected in either the blue or stream 2 LWP should be clean, dry, and free of residue.

Organic contamination is a challenge for the collection-sorting-recycling system. Annex 1 provides more detail on how to deal with such challenges.

There are two types of residues found on paper packaging in contact with food: dry food contamination and liquids or wet/moist food contamination. The consequences of contamination will vary depending on the quantity and nature of the food contamination observed on two levels: how much contamination there is in/on each single piece of packaging; and the total amount of contaminated packaging in the stream. In addition to the nature of the food contamination (wet or dry), the local climate is another factor that can influence the impact of food contamination.

In the process of collection-sorting-recycling, the main impacts of foodstuff contamination are related to an increased probability of bad smells, pests, vermin, microbial growth, and the potential self-combustion of the material. In order to minimise these negative impacts, some solutions are proposed:

1. In the collection stage:
   a. Eco-design of products to make them easily emptied
   b. Separate collection of these paper-based packaging
   c. Public awareness and education
   d. Increased collection frequency

2. In the transportation system:
   a. Use of dedicated compactors/trucks
   b. Use of specific fleet of kerbside lorries
   c. Implement systems to clean/decontaminate lorries

3. In the sorting centres:
   a. Isolated initial and final storage of these materials
   b. Dedicated shifts to feed the sorting lines

4. In the paper mills:
   a. Isolated initial storage of the paper for recycling
   b. Use of biocides to avoid biological growth in the waters

In addition, where consumers have frequent and scheduled household kerbside collections, there is less need to take recyclables to community recycling points or 'bring banks', which typically results in higher volumes being collected for recycling.

5.2. Community and on-the-go collection points

Community and on-the-go collection points can play an important role in the required infrastructure to achieve 90% recycling rates for paper-based packaging. They can be a great complementary solution for consumers that have too much packaging to recycle through their home system, and for packaging waste generated literally 'on-the-go'. However, the Guidance discourages national and local governments from relying solely on systems that require an ever-increasing commitment from citizens. In places that rely on community waste-collection infrastructure, the relative rate of recycling is usually lower. Exceptions or special arrangements may therefore be needed for high-rise buildings and high-density areas where effective household collection can be challenging.

Examples of best practice exist in public spaces where source separation is in place, and it is 4evergreen's view that this should be expanded more widely. Annex 3 on HORECA and on-the-go collection provides greater detail.

5.3. Further considerations

The 4evergreen recommendation of two recycling bins for collection of household and on-the-go paper-based packaging is key for optimising the already well-established recycling system across Europe.

The consistency and harmonisation of collection systems is essential not only at the local level, but also the national level, and long-term aspirations for European-wide harmonisation should be considered. Properly organised, homogeneous collection and sorting systems across EU Member States will produce high-quality, paper-based recycling streams at relatively low social cost, bringing high value to the economy and reducing the carbon impact on the environment.

Other less granular collection methodologies, such as commingled collection, have proven to cause unnecessary and sometimes unacceptable levels of contamination, rendering normally recyclable material unrecyclable and undermining the overall objective of 90% recyclability for paper-based packaging.

A key responsibility in this optimised chain lies with the consumer and the need to separate paper packaging into two streams at the point of collection: either paper and board (stream 1 P&B) or LWP for sorting (stream 2 LWP). Harmonising such systems across Europe will require public engagement from consumers and must be led by public administrators. A dual-stream system is necessary to ensure that the quality of material is maintained and only material that requires sorting is economically separated through existing sorting technologies, and recycled in the correct type of paper mill.

Additional efforts can be taken to increase collection, sorting and recycling related to the HORECA and on-the-go packaging. Annex 3 shows some best practices for improving recycling of this type of packaging that primarily consist of paper-based packaging both with and without barrier coating such as polyethylene (PE) or alternative barrier coating solutions. Although it represents a small portion of the European paper and board for recycling (PfR) market (47 million tonnes[9]), it remains highly visible and should be recycled to avoid disposal in incineration or landfill. Current efforts in collecting, sorting and recycling paper-based packaging exist, but more actions are needed to reach 4evergreen's overall goal of a 90% recycling rate by 2030.

The annex further highlights that different environments (i.e. in-store, on-the-go, and at-home) present unique challenges for separate collection of paper-based packaging. Key strategies include mirroring residential recycling systems, using special bins, and exploring consumer- and employee-led sorting to improve overall recycling. Proper preparation of packaging for recycling, such as emptying food or liquids, is essential, though proper emptying of packaging can be problematic in on-the-go situations. Harmonised labelling, clear waste symbols, and frequent collection of separately sorted paper-based packaging are also crucial to improving recycling.

To be successful at scale, consistent dual-stream collection systems need to be available and accessible to the majority of the population and supported by manufacturing infrastructure capable of reprocessing the material both in sorting (see Annex 2) and in recycling capacity.

Packaging waste recycled at scale is defined in PPWR as: *"packaging waste which is collected separately, sorted and recycled in installed infrastructure, using established processes proven in an operational environment which ensure, at Union level, an annual quantity of recycled material under each packaging category listed in Table 2 of Annex II equal to or greater than 30 % for wood and 55 % for all other materials; it includes packaging waste that is exported from the Union for the purpose of waste management and which can be considered to meet the requirements of Article 53(11)".*

As recognised in PPWR, where capacity within EU Member States is insufficient, global commodity markets provide a ready outlet for high-quality materials. But the already approved revision of the Waste Shipment Regulation (WSR) lays down more rules for controlling the export of paper-based packaging waste outside the EU and, as such, consideration for increasing paper mill capacity within the EU is needed.

Further and better quality of data is needed for reporting on material collected for recycling. This should align with PPWR, and the introduction of extended producer responsibility (EPR) and eco-modulation across Member States. Necessary but simple and easy inspections should start at the point of collection and continue throughout the value chain until the point of recycling in a paper mill. Data should be made available to monitor leakage of valuable resources from within the system and highlight areas of improved efficiency which could be made.

Consumer education and information is key, with access to sorting instructions for local and national areas combined with programmes and public awareness campaigns to drive long-lasting, generational improvements. Consumers must be encouraged to understand the importance of their role in the recycling process. Together, harmonised collection system and greater transparency will boost consumer trust. Other such methods to improve engagement and enforcement include the use of penalties/incentives to drive change. As seen in some EU Member States, this can be an effective method to increase recycling rates.

For any of these recommendations to take hold, there must be clear and complete national legal and operational frameworks implemented to support these activities, including:

- The citizen's responsibility to sort their waste for recycling
- The municipality's obligation to collect and accomplish recycling targets for the material collected
- Targets to reduce municipal residual waste are issued
- Responsibility and ownership regimes for the material (e.g. EPR)
- Transparent reporting on recycling rates, and an improvement in data
- Translation of European legislation into (more ambitious) national recycling targets
- Enforcement of regulations

Throughout this process, the quality and consistency of output from the system is paramount.

4evergreen believes that to maximise our use of resources, optimise recycling systems, minimise energy and reduce carbon emissions, it is necessary to adopt a harmonised separate collection infrastructure across EU Member States, starting at local and national level.

[9] RISI; Expert interviews; Press search; FAO; OECD; Cepi, team analysis, 2020.

6. Glossary

Deinking
Process of ink removal from pulp during the recycling process.

EN 643 – European List of Standard Grades of Paper and Board for Recycling
This list gives a general description of the standard grades by defining what they are allowed and not allowed to contain.

Fibre-based composite packaging (FBCP)
Packaging composed of paper and a considerable share of non-paper integrated components and constituents that by design are not separated after use.

Paper-based packaging
A product, based on paper, suitable to pack filling goods. Design and properties of the paper-based packaging are typically specific for the respective filling goods.

Kraft paper
Paper of high mechanical strength made entirely from sulphate chemical pulp – can be either MF-paper, MG-paper or sack kraft paper.

Liquid packaging boards
Board intended for the manufacture of liquid packaging cartons.

Liquid packaging carton
A closed composite carton suitable for packing liquids or foods, other than drinking cups, for which liquid packaging board is the main component.

Paper
Range of materials in the form of a coherent sheet or web, made by deposition of pulp from a fluid suspension onto a suitable forming device. Pulp fibres are generally of vegetable origin, typically cellulose. For specialties, other origins are possible. In the generic sense, the term 'paper' may be used to describe both paper and board as well as moulded pulp products. The primary distinction between paper and board is normally based upon thickness or grammage, though in some instances the distinction will be based on the characteristics and/or end-use. Papers may be coated, impregnated or otherwise converted during or after their manufacture, without necessarily losing their identity as paper. In conventional papermaking processes, the fluid medium is water; new developments, however, include the use of air and other fluids. Sheets or laps of pulp as commonly understood for paper making or dissolving purposes are excluded.

Paper and board for recycling
Natural paper-based paper and board suitable for recycling and consisting of paper and board in any shape; products made predominately from paper and board, and may include other integrated components and constituents that cannot be removed by dry sorting, such as coatings and laminates, spiral bindings, etc.

Pulp
Fibrous material, generally of vegetable origin, obtained through various processes from raw materials in different forms and made ready for use in further manufacturing processes. Examples for raw materials are wood, wood chips, plants, paper and board for recycling, textiles, etc.

Repulping
Process for treating dry pulp, paper, board, or paper for recycling with water in order to prepare a suspension of fibres.

Recycling
The mechanical reprocessing of 'paper and board for recycling' in a paper mill as part of a production process into new products, materials, or substances.

Sorting
The dry segregation of discarded material into specified streams, either at the source or at a dedicated facility, in order to support effective and efficient recycling.

Paper mill with flotation-deinking recycling process
Paper mills with flotation-deinking recycling process have been designed for pulping, cleaning and deinking graphic paper grades, typically newspapers and magazines like grade 1.11.00 and other grades defined in EN 643 as intended for deinking. The deinking process also has the capability of processing white/bleached paper-based packaging papers if they fulfil the brightness and general

quality requirements. Flotation-deinking processes are the most commonly used worldwide. A washing step is commonly added in the deinking process, which also has to remove the minerals (e.g. for tissue papers).

Paper mill with specialised recycling process

Paper mills with specialised recycling processes treat a mix of special grades (group 5 of EN 643) and grades from other groups (1-4 from EN 643). Each paper mill determines the optimal mix and adds one or more piece of dedicated equipment, such as a horizontal high consistency drum pulper, a separate batch pulper with longer pulping time, deinking, fine cleaners, hot dispersion, special process and waste water systems. Paper mills with specialised recycling processes can treat paper-based packaging that has been coated with non-water soluble materials such as wax, plastic film or other layers such as aluminium, polyester and polyethylene entering the recycling process in homogeneous lots. Some paper mills with specialised recycling processes can also treat wet-strength grades (labels).

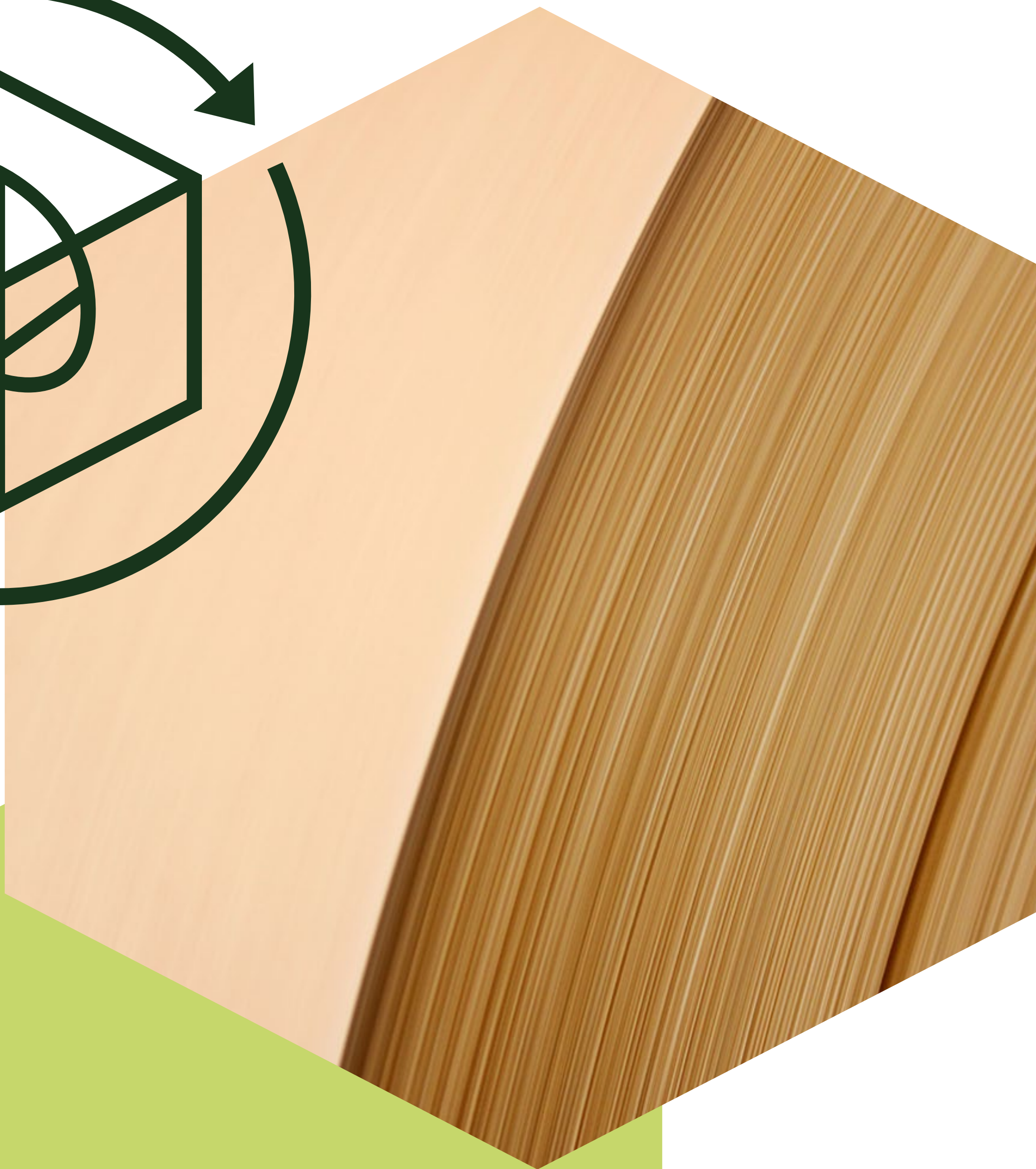
In order to optimise the recycling process, fibre-based composite packaging, which cannot be handled in paper mills with specialised recycling processes, should be delivered to paper mills with specialised recycling processes in EN 643 identified flows. As in paper mills with conventional recycling process, the result of the process is also very high quality fibrous material suspended in water ready for papermaking.

Paper mill with conventional recycling process

Paper mills with conventional recycling process typically produce high quality end-products based on EN 643 groups 1 to 4. In large paper mills, repulping is done with drum pulpers or continuous vertical pulpers. Often such processes operate deflakers to separate fibre bundles into individual fibres, as well as coarse and fine screening and cleaners. The aim is to separate the fibre from the other material. The final result is fibrous material suspended in water ready for papermaking (=recycled pulp). This process is set out in Chapter 2 of 4evergreen's Circularity by Design Guideline.

Yield

In 4evergreen the yield in paper-based packaging recycling is defined as the percentage of fibrous material recovered in the lab test procedure according to the formulas provided in the test and evaluation protocol (in parts I, II and III).



Annex 1.
Impact of residual organic contamination on the recycling of paper-based packaging

1. Introduction

Recent developments in barrier coatings and/or lamination technologies which provide special functionalities to paper (e.g. barriers for moisture, oxygen, grease, and/or liquid) have positioned paper-based packaging as an alternative for many food-contact applications. Based on a recent consumer market study[10], paper-based packaging received top rankings with consumers worldwide for its more sustainable and renewable nature compared to other packaging alternatives. As a result of this trend, more than 1 million tonnes of additional paper-based packaging is expected to be collected via municipal waste streams between 2024 and 2030. This translates into an increase of 8% compared to the current 13 million tonnes of all paper-based packaging collected.[11] Much of the new paper-based packaging being placed on the market is expected to be for food-contact applications, and thus increases the potential for food contamination to enter existing recycling systems. This presents challenges for collection, sorting, and recycling of collected paper-based packaging.

The purpose of this annex is to increase awareness of the issues associated with food-contaminated paper-based packaging, analyse the consequences, and highlight potential solutions which can help to reduce and mitigate its impact on collection, sorting and recycling systems. The potential solutions presented will help in designing optimal systems, which in turn will result in improved recycling rates and recyclate quality.

To give a clear picture of the impacts of food contamination and viable solutions, the path of packaging waste from its generation after final use – in household streams but also in hotels, restaurants and cafeterias (HORECA), see Annex 3 – to when it reaches a recycling facility is considered, noting that recycling could happen in a paper mill with conventional recycling process or paper mills with specialised recycling processes. The latter, having been built to recycle laminated paper-based packaging in high quantities, will be more prepared to deal with the challenges of food contamination described in this Annex.

2. Food contamination and paper and board for recycling (PfR) standards

Before embarking on an analysis of the impact of residual food contamination on paper collection, sorting and recycling, it is important to understand what different types of food contamination could be present and examine the views on and best practices in existing standards on how to manage them.

Residual food contamination in food-contact paper-based packaging can take two main forms:

1. Dry food contamination (e.g. dried rice/pasta, cereals): Dry food is easy to clean and if consumers empty the packaging only traces of organic contamination will be present. In this case, given the dry nature of the food contamination, the effect on collection, sorting and recycling is not as serious and can be easily managed. However, if consumers do not empty the packaging, this residual content will remain with the packaging throughout the complete recycling process creating similar issues to liquids.

2. Liquids or wet/moist food contamination (e.g. microwavable food trays, salad bowls, take-away containers): Present even if consumers fully empty the

[10] McKinsey & Company: Sustainability in packaging 2023: Inside the minds of global consumers.
[11] McKinsey report was produced in 2020 as the base case to prepare 4evergreen targets and works.

packaging, due to the nature of the wet or moisture containing contents. Wet and moist environments are fertile conditions for microbial growth and mould formation which can have a major impact on the collection, sorting and recycling of paper-based packaging.

The consequences of contamination will vary based on the quantity of food contamination, and the nature of its presence, which can impact the recycling of the item.

- **Level of contamination in individual paper-based packaging items:** Cepi advises that 'traces' or 'stains' of food contamination in paper-based packaging (e.g. stains of oil or grease in a pizza box) do not necessarily hinder the recycling of a package in the clean paper and board stream. For example, in the pizza box case the amount of contamination is so minimal that there is no need to design the packaging with a barrier against moisture. However, when the food contamination refers to a tangible 'three-dimensional' amount (e.g. pieces of unconsumed pizza left inside the box, liquids like soup, sauce or ice-cream), then this contamination creates serious challenges in the collection, sorting and recycling of paper and board.
- **Quantity of contaminated packaging in the stream 1 P&B:** Limited amounts of low-level contaminated paper-based packaging (as described above) already occur in PfR streams and, although not optimal, they are managed through existing collection, sorting and conventional recycling processes. However, if quantities increase based on the projected studies mentioned earlier, the impacts of food contamination will become more evident and additional measures to minimise/mitigate it will be required.

In addition to the nature of the food contamination (wet or dry), the local climate is another factor influencing the impact of food contamination in the recycling chain of paper-based packaging. Generally, the negative impacts of residual food contamination in recycling streams are increased in Southern European countries and Mediterranean climates with higher temperatures. More so in spring and summer, where growth of bacteria can be accelerated, and pests tend to be more prominent. As climate change is affecting temperatures in other parts of Europe, in the future this could become more of an issue for central European countries as well. Minimising the time packaging spends in the recycling system can mitigate these weather-related impacts.

EN 643 is the reference document which lists the recognised grades of PfR, and is an industry standard for both buyers and sellers (see Guidance Chapter 3). Any PfR collected and sorted will be recycled in a paper mill under one of the grades listed in EN 643, and, as such, it is essential to consider when analysing the impacts of foodstuff contamination. EN 643 considers organic waste including food residuals as prohibited foreign materials. Since 2018, CEN has been re-examining this evaluation, and in 2022 its Technical Specification (CEN/TS 17830) was published. The specification settles four conditions under which traces and stains can be tolerated:

- Food contact paper article has been emptied.
- It has been used for its purpose.
- The stains and traces cannot be treated with dry sorting.
- The paper is not fully soaked.

When arriving at a paper mill, the material is assessed applying EN 643 criteria. In terms of contaminated material, special grades of the list (group 5) are considered to be recycled in paper mills with specialised recycling processes and higher levels of contamination are tolerated (see picture in Appendix 1.6).

In addition to EN 643, legislation must be considered, especially if the PfR is destined for export from the country of origin. In some countries like the UK 'minimal' contamination is permitted for export and the practical interpretation by authorities is 'zero tolerance' for food and organic contamination.

3. Impacts and solutions in the collection system

Collection of paper-based packaging waste begins in consumers' homes, businesses, or on-the-go recycling bins, and ends in various sorting centres. Adding food contaminated paper-based packaging to a paper stream introduces organic contamination. This increases the probability of bad smells, pests, vermin and microbial growth in collection bins. If the recycling stream was previously 'clean', the conversion of this stream into a 'dirty' one results in the need for frequent cleaning and washing of the bins. The following recommendations are made to mitigate this:

- **Eco-design:** Any residual foodstuff in the packaging has an impact on every step of the process. The best way to deal with that is to prevent or minimise its presence. Therefore, such food contact packaging should be designed as 'easy to empty'.[12] 4evergreen's Circularity by Design Guideline note that paper-based packaging waste can be designed with a peelable barrier layer and clear guidance should be printed on the packaging for the consumer to remove accordingly. Using this feature, the contamination can be removed more easily by the consumer prior to disposal.

- **Public awareness and education:** Communication and education for consumers on how best to discard their paper-based packaging once used can improve collection, sorting and recycling. This should include printed/labelled instructions on how best to empty the packaging, depending on the contents (i.e. wet food packaging may need cleaning, where dry food may not).

- **Increased collection frequency:** This will result in potentially contaminated packaging waste not being stored for a prolonged period, resulting in less time or opportunity for microbial/mould growth, or pests to be attracted.

- **Certified compostable solutions – collection and disposal in organic (bio-waste) bin:** For paper-based packaging applications, where a substantial amount of food residue in the package item is unavoidable and/or emptying the packaging is impractical/impossible, using certified compostable solutions should be considered. This way, if local municipalities allow it, the food-soiled paper-based packaging can be discarded alongside the residual food though the organic waste stream and can be organically recycled.

4. Impacts and solutions in the transportation system

The impacts in sorting centres are the same as those mentioned in all other stages of the recycling process; bad smells, pests, vermin, etc. There is also the risk of contaminating equipment and other materials. If the sorting centre deals with both clean and contaminated material, then a special flow must be created to manage such material to avoid cross-contamination with the clean stream, such as:

- **Isolated initial storage** before feeding the material to conveyer belts for the sorting line. Feeding the material in specific shifts so the plant's parameters can be adjusted to manage the material.
- **Specific advanced sorting systems** are required to separate recyclable materials (see Annex 2). Such technology may be installed, but efficiency may be hampered by the presence of food contamination in the following ways:
  - ✓ Automatic sorting is commonly undertaken using near infra-red (NIR) technology. This technology recognises materials depending on the reaction of each material to its NIR waves. Contamination can disrupt this reaction creating confusion in the optical sorters.
  - ✓ Contamination can affect the ability of the systems (e.g. air jets or robotic arms) to extract the material already detected from the stream, creating inefficiencies, and negatively impacting the quality of PfR produced.
  - ✓ Faster deterioration of sorting equipment, and increased maintenance costs.
  - ✓ When manual sorting is in place, workers dealing with clean material must change their protective clothing and personal protective equipment (PPE) prior to working with dirty material. There is also the need to increase ventilation in the sorting cabin.

- **Isolated final storage** to avoid cross-contamination with the clean material. This should include system solutions to minimise the impacts of smells, pests, etc. If contaminated PfR is stored for prolonged periods, as well as creating bad odours, organic contamination can generate an auto-combustion process initiating a fire in the stock of material (see Appendix 2). This requires specific, more robust fire protection systems and a reduction in storage times to minimise these risks. An outdoor storage is highly recommended to increase ventilation and minimise damage in the event of a fire.

In addition, sorting centres dealing with clean materials can be located close to towns, which minimises the distance from the collection points. This is possible because their impact on the immediate surrounds is minimised. Sorting centres dealing with contaminated materials are typically located further away from the centre of the towns or, if they are located in the town, they take measures to reduce their impact on the surrounding neighbourhood.

[12] Some already existing recyclability protocols for plastics (e.g. RecyClass) have a scoring section on 'easy to empty' and 'easy to access' packaging where the amount of material left inside the packaging is considered in the recyclability score of the packaging. This assessment pushes designers to create better packaging, reducing the amount of organic contamination in the collection/sorting/recycling system. The effects of this reduction are especially important for the recycling process in paper mills.

5. Impacts and solutions in the paper mill

All controls and measures mentioned for the final storage in sorting centres also apply to the initial storage in paper mills. To avoid contamination problems, lower stock levels and higher rotation of the stock are required.

The main impact of food contamination for paper mills is the growth of biological content in the circulated waters used in the papermaking process. Biological growth can produce high quantities of foams that result in breaks of the sheet of paper in the paper machine. This interrupts the process and forces halting of production to clean the paper machine. This can be a lengthy and expensive process for any paper mill. To fight against this biological growth, biocides can be used. However, these biocides significantly increase the cost of recycling, and can be used only to a limited extent. This is because biological anaerobic reactors, used in effluent treatment plants (ETPs), can be adversely affected by elevated levels of biocides, again forcing a shutdown of the production process. It is therefore a continual balancing act when managing biological growth and biocide levels.

Paper mills with specialised recycling processes built to deal with laminated paper-based packaging in high quantities are better prepared to deal with these challenges linked to food contamination. They may have separate stockyards for this material with increased fire protection equipment and intensive anti-pest measures.

6. Conclusion

Having analysed the effect of residual food contamination on collection, sorting and recycling of the paper stream, one of the main conclusions is that not all types of food contamination cause significant issues in the recycling process. While dry food (e.g. dried rice/pasta, cereals), lightly stained or trace contamination from grease or oil (e.g. empty pizza box) are manageable within existing recycling systems, wet/moist food contamination (e.g. microwavable food trays, salad bowls with sauce residue, etc.) can be a serious issue due to the creation of bad smells, microbial growth, and the attraction of pests/vermin. It also greatly increases the cost of collecting, sorting, transporting and recycling the packaging, and the PfR in which it is collected. Increased environmental, health and safety, and fire risks are also associated with such food-contaminated packaging.

A small amount of food-stained paper-based packaging is already present in PfR streams and if volumes remain low, these can be managed by existing recycling systems and paper mills. However, with the expected growth of food-contact packaging solutions on the market, this could become a more significant issue, especially if the nature of contamination (e.g. physical or 3D food particles, wet food contamination) also increases alongside the volume growth.

In summary, the below recommendations are given to minimise the impact of food contamination on collecting, sorting and recycling systems:

- **Eco-design** of packaging built and labelled to be 'easy to empty' for consumers or to have the food contaminated layer designed and labelled as peelable.
- **Separate collection and sorting operations** maximising fibre recycling in paper mills with conventional recycling process (mainly non- laminated paper and board) and paper mills with specialised recycling processes (primarily laminated and LPC).
- Where food residues are unavoidable and/or emptying or cleaning the packaging is not possible, and the likelihood of organic contamination is high, such packaging should be **designed to be certified as compostable**, where the paper-based packaging may be diverted to organic waste collection.

Appendix 1. Pictures of material

1. Example of acceptable material with stains or traces:

Figure 7. Example of acceptable material with stains or traces

2. Example of material which is not tolerated due to 3D food residue:

Figure 8. Example of material which is not tolerated due to 3D food residue

3. Examples of acceptable PfR bales with light staining to packaging within:

Figure 9. Example of acceptable PfR bales with light staining to packaging within

Figure 10. Example of acceptable PfR bales with light staining to packaging within

Figure 11. Example of acceptable PfR bales with light staining to packaging within

Figure 12. Example of acceptable PfR bales with light staining to packaging within

4. Examples of PfR with stained material within; the limit of not being accepted:

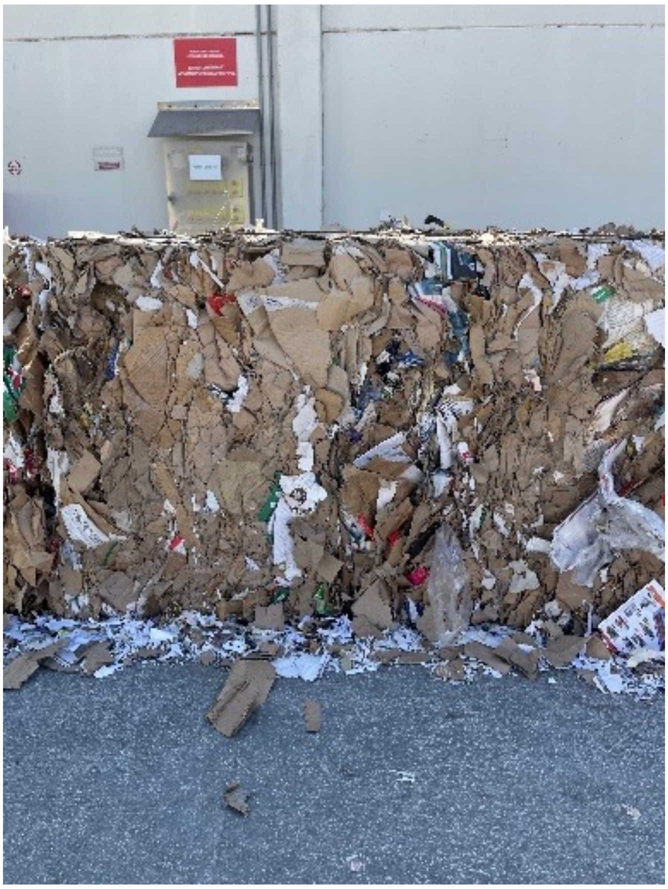


Figure 13. Examples of PfR with stained material within the limit of not being accepted

Figure 14. Examples of PfR with stained material within the limit of not being accepted

Figure 15. Examples of PfR with stained material within the limit of not being accepted

Figure 16. Examples of PfR with stained material within the limit of not being accepted

5. Examples of PfR with heavily stained/contaminated material that would be refused by paper mills with conventional recycling process:

Figure 17. Example of PfR with heavily stained/contaminated material that would be refused by paper mills with conventional recycling process

Figure 18. Example of PfR with heavily stained/contaminated material that would be refused by paper mills with conventional recycling process

Figure 19. Example of PfR with heavily stained/contaminated material that would be refused by paper mills with conventional recycling process

6. Example of paper cups collected for recycling, introducing liquid organic contamination:

Figure 20. Example of paper cups collected for recycling, introducing liquid organic contamination

7. EN 643 grade 5.03 pictures of liquid packaging cartons (with or without aluminium content), containing a minimum of 50% by weight of fibres, and the balance being aluminium or coated:

Figure 21. EN 643 grade 5.03 picture of liquid packaging cartons (with or without aluminium content) containing a minimum of 50% by weight of fibres, and the balance being aluminium or coated

Appendix 2. **Self-combustion**

Readers can find references to this phenomenon on the following platforms: www.sciencedirect.com and www.researchgate.net.

Self-combustion, also known as spontaneous combustion, is a phenomenon in which a substance ignites without the direct application of an external ignition source, such as a flame or spark. This process occurs due to the gradual accumulation of heat generated internally by chemical or biological reactions within the substance itself and driven by external factors and conditions such as compaction and ventilation.

Auto-ignition temperatures:

- Paper: 218-2460C
- Board: 258-2850C

Possible causes of self-combustion in accumulations of paper or plastic waste

1. Biological and chemical oxidation: Bacteria and other microorganisms present in paper and some types of biodegradable plastics can break down organic matter, releasing heat in the process. If this heat is not properly dissipated, the temperature inside the waste pile can rise, eventually reaching the ignition point of the materials.

2. Presence of oxidising substances: The presence of chemicals such as certain types of inks, adhesives, and chemical contaminants can accelerate the oxidation process. These substances can react with paper or plastic, releasing heat and promoting self-combustion. In addition, industrial or commercial waste containing peroxides or other oxidants significantly increases the risk.

3. Compaction and thermal insulation: The way waste is stored also plays a crucial role. Compacting paper and plastic creates an environment where the heat generated by decomposition cannot easily escape. This heat build-up, combined with poor ventilation, can raise the internal temperature to the point of self-combustion.

4. Presence of moisture: Moisture in waste piles can encourage microbial growth and the breakdown of organic materials, thus generating heat. In addition, moisture can interact with certain chemical components, promoting exothermic reactions that contribute to the increased temperature.

5. Organic materials and pollutants: The presence of organic materials and contaminants, such as food debris, oils, fats, and other biodegradable waste, can increase microbial activity and chemical reactions within the waste accumulation. These pollutants act as additional fuel and speed up the decomposition process, which releases heat.

6. Environmental conditions: Conditions such as high external temperatures, low relative humidity, and high winds can contribute to self-combustion. Ambient heat can increase the temperature of accumulated waste, while wind can provide the oxygen needed to sustain combustion reactions once started.

Annex 2.

Deep dive into sorting systems used for paper-based packaging

1. Introduction

The purpose of this annex is to further elaborate on existing and future technologies for sorting paper-based packaging, mentioned within the 4evergreen Guidance. A key recommendation of which is a two-bin collection system to achieve a 90% recycling rate for paper-based packaging by 2030. The two-bin system is necessary to separate recovered fibre into distinct streams so that it can be recycled efficiently. In this Guidance, the stream 1 P&B may not always require sorting, but the lightweight packaging (LWP) bin will always require sorting. In the following sections the above-mentioned guidelines should be considered in full.

This annex takes an in-depth look at sorting activities, to identify the existing and best available technologies and techniques to achieve the specific grades (complying with EN 643) desired by paper mills with conventional recycling process and paper mills with specialised recycling processes.

Sorting plant layouts, sorting techniques and main output fractions are assessed for the two main indicated recycling routes in the 4evergreen guidelines: paper mills with conventional recycling process and paper mills with specialised recycling processes. Note that sorting techniques and processes can vary between sorting plants. Furthermore, the document provides a brief analysis of innovations in the sorting of paper-based packaging.

2. Sorting plant requirements

The type of plant required to sort paper, and paper-based packaging, will depend on the collection system in place, which in turn determines the material composition entering the sorting plant. Sorting requirements can also be determined by the desired end-use specifications for the produced materials from paper mills. Some materials can be sorted and sent to paper mills with conventional recycling process, while others will need recycling in paper mills with specialised recycling processes. Sorting adds value for both the sorter and the paper mills to produce dedicated high-quality material (e.g. separated graphic paper, white fibre grades or cardboard fractions).

Sorting plants must be equipped to produce paper and board complying with the EN 643 list of standard grades (see Guidance Chapter 3). Additionally, in the countries where ‘end-of-waste’ regulations are in force, the sorting plants must guarantee the compliance of their end-products to the national regulatory framework (based on EN 643 standard grades).

The methods of sorting paper-based packaging can vary, and as previously mentioned, are influenced by the collection systems in place, and resulting feedstock composition. The quality of the output fractions is strongly affected by the collection system, whereby contamination can occur (moisture, food residue, organic materials, non-paper materials, other unwanted material). 4evergreen recommends two co-existing streams for collection:

- **Stream 1 P&B:** Paper (household collection) for paper mills with conventional recycling process.
- **Stream 2 LWP:** Lightweight packaging (household collection) for paper mills with specialised recycling processes.

End-of-waste criteria

End-of-waste criteria specify when certain waste ceases to be waste and becomes a product, or a secondary raw material.

According to the Waste Framework Directive, certain specified waste ceases to be waste when it has undergone a recovery operation (including recycling) and complies with specific criteria:

- the substance or object is commonly used for specific purposes
- there is an existing market or demand for the substance or object
- the use is lawful (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products)
- the use will not lead to overall adverse environmental or human health impacts

This criteria for specific materials is set by the Commission through the "comitology" procedure. A mandate to set end-of-waste criteria was introduced to provide a high level of environmental protection and an environmental and economic benefit. They aim to further encourage recycling in the EU by creating legal certainty and a level playing field as well as removing unnecessary administrative burden.

Source: Waste Framework Directive – European Commission (europa.eu)

2.1. Paper mills with conventional recycling processes

For materials suitable for recycling in paper mills with conventional recycling process, the main determinant will be the sorting step and intended purpose of the output fraction, whether for deinking grade or paper-board, kraft paper (i.e. brown packaging material). In the latter case, sorting may not be required.

2.2. Paper mills with specialised recycling processes

For materials going to paper paper mills with specialised recycling processes, sorting requirements will be determined by the quality of fibres used in the different paper-based packaging and the composition of non-fibre components. In some instances, the sorting plant is located at the paper mill, which allows it to source and sort feedstock to its own specification.

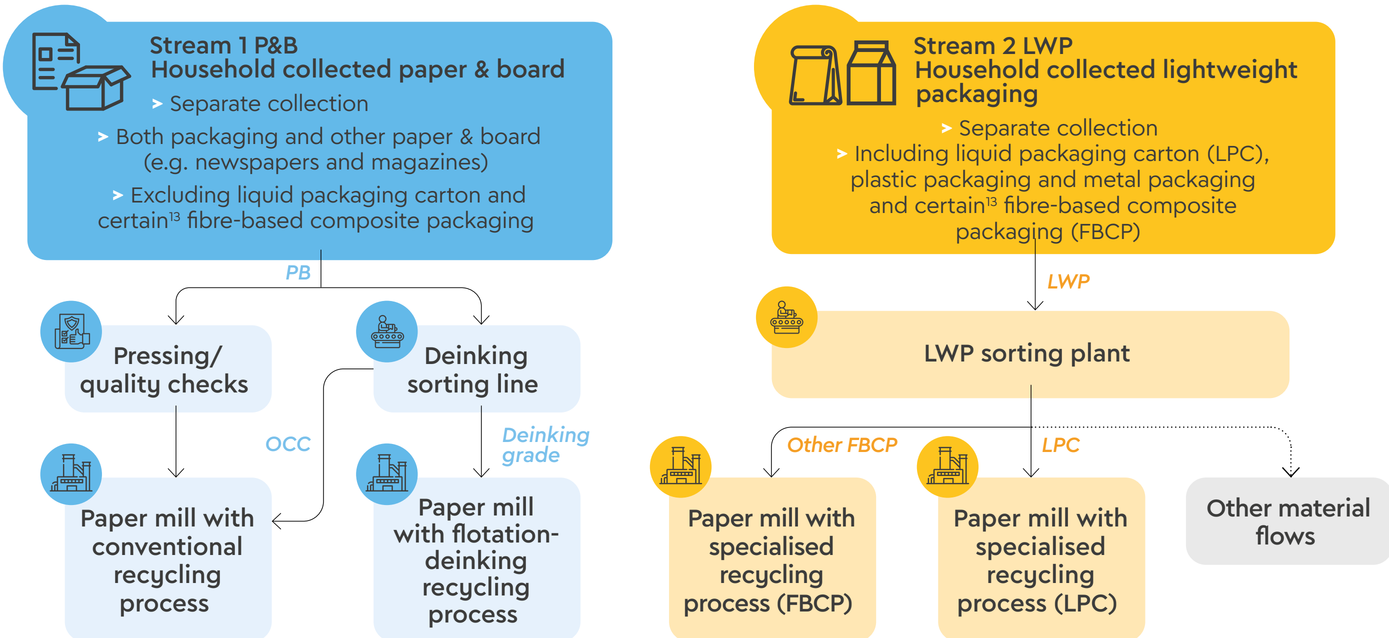


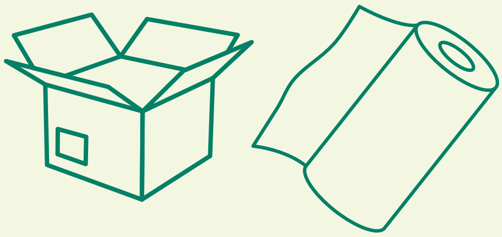
Figure 22. Paper mills with conventional recycling process and paper mills with specialised recycling processes

[13] Specific information on this topic can be found in the 4evergreen Recyclability Evaluation protocol.

3. Main sorting output fractions for paper-based packaging

The following section describes the potential output qualities for recovering fibres required by paper mills, and the equipment needed for these output streams. Generally, sorting at source in households or relevant services (HORECA, office buildings) positively impacts the material output quality, particularly in terms of moisture and contaminants that are impossible to remove completely in automated sorting processes.

Stream 1 P&B

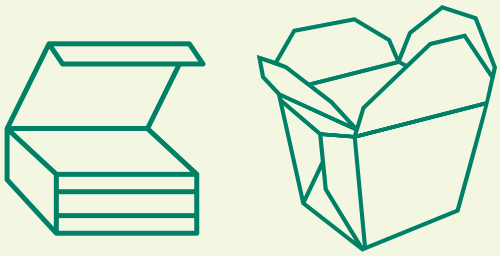


Paper-based packaging* potential outputs from source-separated paper sorting plant, or deinking sorting plant output fractions containing paper-based materials (not exhaustive):

- **Old corrugated containers (OCC)**
  Typically >160mm, mainly brown fibres (e.g. EN 643 1.04.00). OCC sorted from a deinking sorting plant is also suitable for papermaking.
- **Paper for deinking**
  High-quality paper grade capturing long, white paper fibres, to be further treated by deinking processes to remove printing inks, e.g. white office paper, magazines, newspaper (e.g. EN 643 1.06.01).
- **Mixed paper/Small cardboard boxes**
  Small cardboard, and also some brown/grey fibres (e.g. EN 643 5.01.01).
- **Other fibre-based composite packaging (e.g. LPC)**
  If, as an exception, other fibre-based composite packaging is included in the collection, sorting is mandatory to secure proper input quality for both paper mills with conventional recycling process and paper mills with specialised recycling processes.

*Paper-based packaging having been assessed as recyclable in paper mills with conventional recycling process can go in Stream 1 and the rest must go to Stream 2

Stream 2 LWP



Lightweight packaging sorting plant, paper-based packaging* potential output fractions:

- Mixed paper/paper composites like food trays, cups, etc./Small cardboard boxes (e.g. German specification 550).
- Liquid packaging board, e.g. LPC (e.g. EN 643 5.03.00, German specification 512).

*Paper-based packaging having been assessed as recyclable in paper mills with conventional recycling process can go in Stream 1 and the rest must go to Stream 2

Not all sorting facilities are equipped or designed to sort all the different paper qualities. The intended end use of the PfR will determine the level of sorting required into sub-fractions. Equipment needed for sorting is also indicated per output fraction.

Design for recycling criteria meeting paper-based packaging requirements for the different collection routes are described in the 4evergreen Circularity by Design Guideline.

A special test can confirm if a package can be sorted within the recommended stream. Although no harmonised sorting test is available (see Annex 4 for further detail) there are existing industrial methodologies to confirm that paper-based packaging can be sorted into the recommended stream.[14,15,16,17]

[14] https://www.cyclos-htp.de/publications/chi-test-methods
[15] https://www.tomra.com/en/waste-metal-recycling/test-centers
[16] https://www.pellencst.com/test-and-training-center/#TestCenter
[17] https://www.circpack.veolia.com/make-your-packaging-recyclable/tests-advice

4. Layout examples for sorting plants

There are a variety of different layouts for paper, cardboard and LWP sorting plants, and the following intends to give an overview of the main steps and equipment needed to sort the above-mentioned output qualities.

The conventional recycling mill route for separately collected paper and board.

Sorting plants intended for a paper mills with conventional recycling process route typically sort material collected from households which may have been source separated by the consumer. For this reason, mechanical sorting may not be required, but may be undertaken for other reasons.

The example below represents the main equipment for household paper sorting plants for separately collected paper, often referred to as a 'household collection paper sorting plant' to produce high-quality PfR. The primary objective is to separate out the 'deinking' or 'graphical' papers from the other, non-graphical paper materials, such as cardboard fractions. In addition, incorrectly disposed material and non-fibre content (e.g. plastics) and residues will be sorted out as waste.

4.1. Example of separately collected paper sorting plant

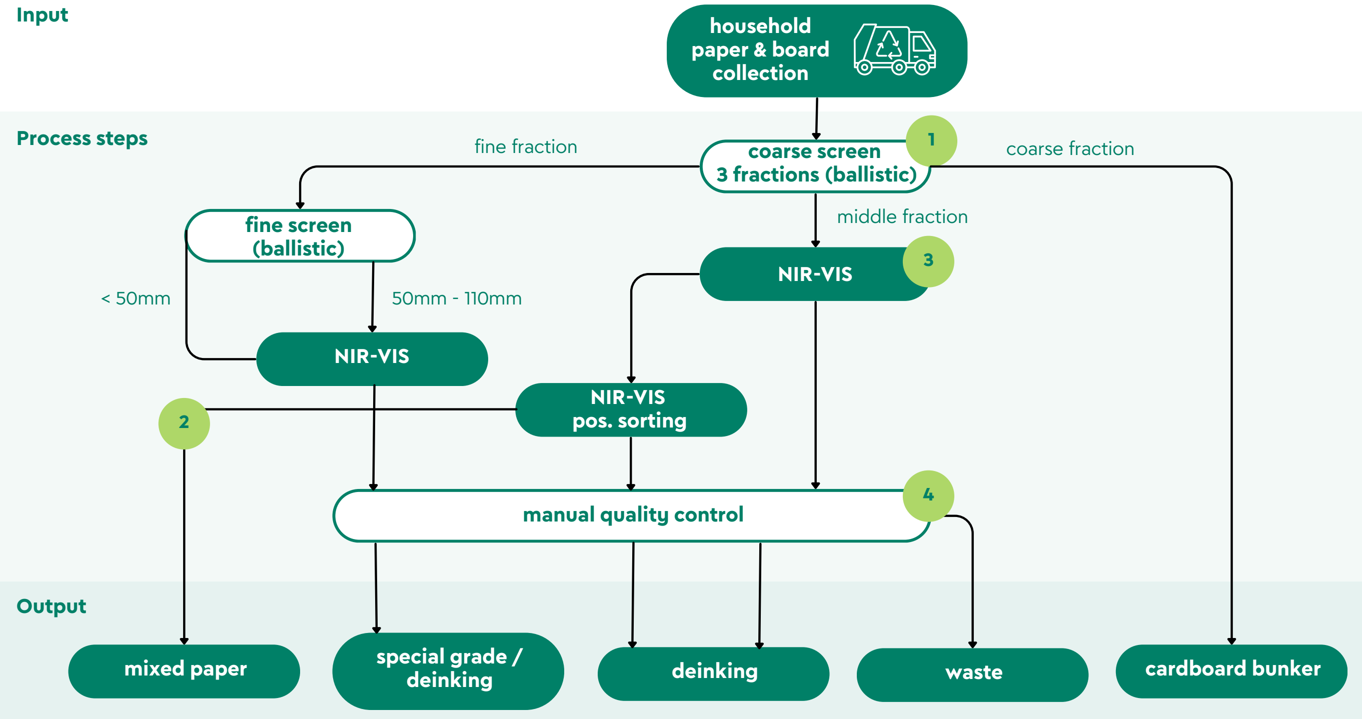


Figure 23. Sorting steps for separate household collection scheme for paper and board

The process for sorting paper and board from separate household collection thus involves (Figure 23):

1. A **ballistic separator screen** is usually the first sorting step in the process to mechanically separate any material. The screens are a series of rotating discs sorting the material by paper and other objects falling through the disc and cardboard floats over the top. A first screen captures the larger materials, typically 300mm or more, while the second screen captures materials with dimensions up to 50x300mm.

   Some paper sorting plants have an additional screening to sort fines, which is material smaller than 50mm, as found at some of the newer sorting facilities.

2. **OCC** material is captured at this step and sent to an OCC bunker. Anything smaller than 50mm and sorted by the **ballistic separator screen** (the lower size limit can vary depending on sorting plant) or identified by **NIR** is typically sent to the **mixed paper** output.

3. **NIR** is an optical sorter using near infrared spectroscopy to identify unique material wavelength spectra to separate materials. At this step, deinking or other paper grades may be sorted. It may also be used to identify non-fibre items arising or appearing as contamination in the material stream.

4. Most sorting plants will have a **manual picking cabin** as an additional quality control step. Here, additional rejects, such as plastic, metal and other contaminants, can be sorted from the different output grades to ensure higher overall quality with less impurity.

Note that there may be no capability to remove LPC or laminated grades as these packaging formats are not typically collected with household paper streams. If LPC is collected with other materials suitable for paper mills with conventional recycling processes, additional sorting to extract this LPC is mandatory.

4.2. The specialised recycling mill route for LWP sorting plants

This type of sorting plant is typically set up to separate materials collected with other packaging types. In most countries, collection includes all 3D plastic packaging (trays, bottles, etc.), metal packaging, and LPC. Notable examples of this are found in the Netherlands and Belgium. In Germany, other fibre-based composite packaging is also included in this collection flow. Systems like this are normally combined with a separate paper collection for source-separated paper and board.

The sorting process for lightweight packaging differs from sorting plants for separately collected paper and cardboard but utilises the same NIR-VIS optical sorting technology to sort material into different material fractions.

As there is separate collection of all other paper and board materials, there is no need for further separation of paper-based materials in the LWP sorting plant, other than to recover any paper and paper-based materials (mixed paper, paper composites and cardboard) and LPC separately.

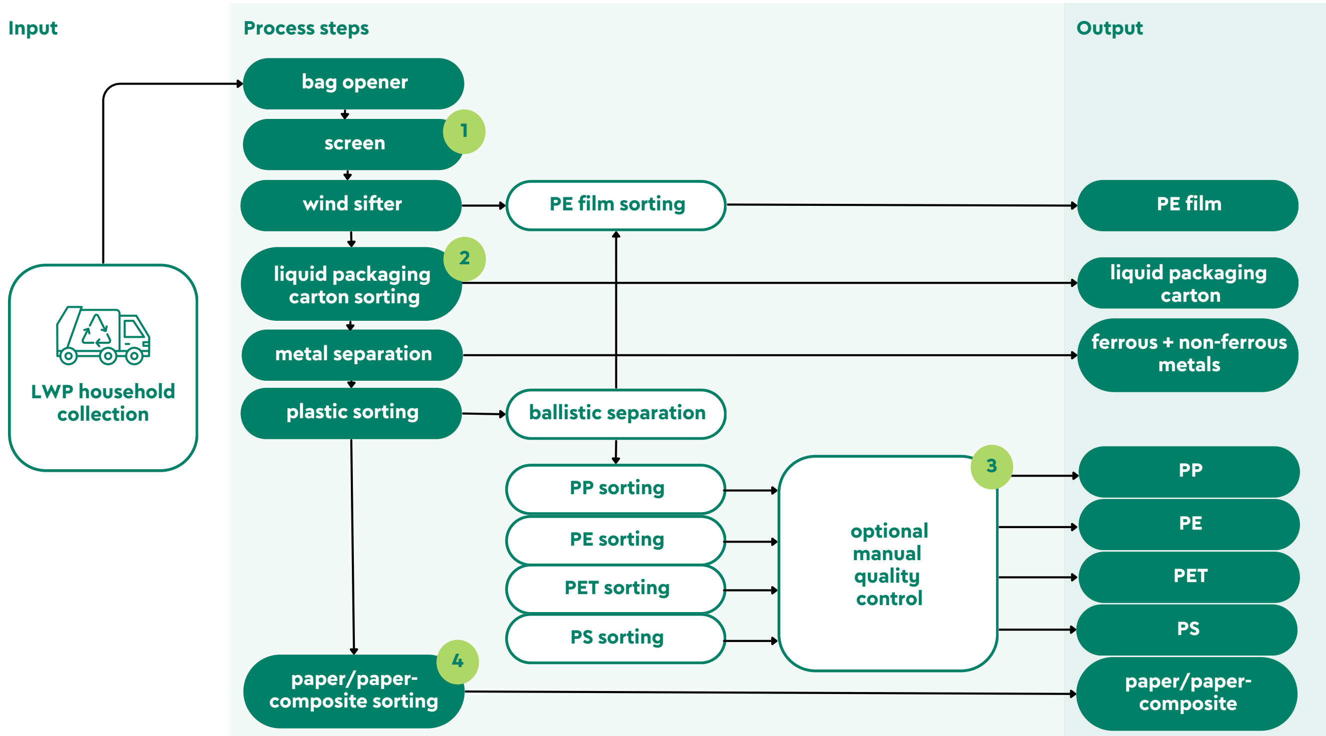


Figure 24. Example of a lightweight packaging sorting plant

4.3. Example of a lightweight packaging sorting plant

1. A **ballistic separator screen** or sorting drum is usually the first step in the process to mechanically separate any packaging material. The screens are a series of rotating discs or drums sorting the material by size. A first screen/drum captures the larger materials, typically 220mm or more, while the second screen captures materials between typically between 50-220mm. The minimum size for modern state-of-the-art LWP sorting plants is 20mm. The 'fines' are sorted out as waste and are not being further recycled.
2. **NIR** spectroscopy is used to identify the unique spectral wavelength reflected by the typical composition of LPC.
3. Most sorting plants will have a **manual picking cabin** as an additional quality control step. Here, additional reject, such as plastic, metal and other contaminants, can be sorted out from the different output grades to ensure higher overall quality with less impurity.
4. Separation of fibre-based composite packaging with **NIR** technology as a distinct fraction.

4.4. Future innovations in sorting paper-based packaging

As a wider diversity of packaging and packaging materials enters the market, innovative sorting technologies are being developed to help identify, sort and recycle paper-based packaging. This is needed to further improve the quality of sorted materials and ensure the best fit for the different available recycling solutions. These innovative technologies in their current development level are complementary to the existing mechanical- and NIR sorting technologies , which are referenced in annex 4.

4.5. Artificial intelligence and deep learning

Artificial intelligence (AI) is a development in machine learning enabling computers to mimic human intelligence. Machine learning uses algorithms and statistical models, relying on patterns and inference, which enable computer systems to perform a specific task without using explicit instructions and discussed further in Annex 4.

Deep learning (DL) is the use of artificial neural networks, inspired by information processing and distributed communication nodes in biological systems (e.g. human brain). It enables us to train machines to carry out sorting tasks previously completed by a human. For example, sorting waste streams by shape, colour, texture, visual differences, etc.

DL data-kits are an add-on feature to existing sorting plants, and they can be incorporated into current NIR sorting processes. As such, DL can be used for quality control, replacing manual picking stations. DL would be advantageous for some paper-based packaging that is difficult to categorise/separate by NIR alone, such as paper-based packaging with particular integrated components or constituents (e.g. decorative metallisation or wax).

4.6. Markers/tracers – chemical or fluorescent tracers, digital barcodes

Invisible markers or tracers on packaging can be either 2D prints, using specific inks, or 3D effects that apply micro-embossing techniques, which are reviewed in Annex 4. For example, instead of having one visible barcode, the entire package could be covered with invisible codes, which would allow much better detection especially under challenging conditions at sorting facilities. These markers or tracers offer a more granular sorting solution and, thus, provide higher qualities for recycling afterwards and/or create a new stream of material which could be valuable for recyclers. Utilised alongside AI and DL, this can aid the visibility of packaging for the various sorting systems, and can be linked to existing mechanical and robotic sorting technologies.

5. Conclusion

To achieve the 90% target recycling rate for paper by 2030, sorting systems should be optimised to ensure that paper-based packaging grades are effectively sorted from the input fractions, and directed to the correct type of recycling process. For separately collected paper and board, suitable for paper mills with conventional recycling process, sorting is not always required. For the LWP bin, and any variation of collection system which may mix items from the two recommended streams, sorting will always be required, and should be considered mandatory.

Consideration is also needed for effective sorting of non-fibre grades, with sorting plants aiming to minimise losses and cross-contamination. The consequences of which may be that recyclable materials are sent to reprocessing facilities unable to recycle them; resulting ultimately in disposal via incineration or landfill.

Typically, such fractions are:

a) A by-product or reject stream from sorting facilities, e.g. not correctly sorted and incorrectly detected by NIR. These rejected materials may also include paper-based packaging contaminated by food and organic waste (see Annex 1).
b) A secondary fraction from deinking sorting (where the deinking material is removed first).
c) An additionally sorted fraction from MSW (co-mingled) and LWP sorting facilities, generally without further processing.

Greater focus on further sorting and capturing materials in these fractions will contribute to an increased overall recycling rate. By combining existing technologies, including manual sorting and new or innovative technologies, effective and efficient paper-based packaging separation of both collected and LWP streams is possible, leading to higher quality PfR outputs.

Annex 3.
HORECA and on-the-go recycling systems

1. Introduction

This annex will explore examples of the best practices for collection, sorting and recycling of paper-based packaging for food and beverage in both the HORECA – hotel, restaurant, cafeteria, catering facility – and on-the-go sectors. This type of packaging includes, for example, cups for beverages, food containers, packets and wrappers, beverage containers and plates which primarily consist of paper without any barrier coating or paper with barrier coating such as polyethylene (PE) or alternative barrier coating solution. While paper-based packaging for food and beverage in HORECA and on-the-go represents a very small amount of the overall paper-for-recycling market in Europe (total market 47 million tonnes each year), it is still very visible. Such packaging is recyclable and should be collected, sorted, and recycled at scale to recover its value as a secondary raw material, and avoid its loss to incineration or landfill. Paper-based packaging for food and beverage is already collected and recycled in many instances, but more can be done to encourage further activity and increase recycling rates to meet the 4evergreen goal of a 90% recycling rate for paper-based packaging by 2030.

2. Paper-based packaging in HORECA and on-the-go

HORECA covers operators such as 'quick service restaurants' and the 'fast food' segment along with cafés and industrial catering sectors. Consumer packaging, foodservice packaging and single-use packaging are often used interchangeably to describe different packaging types typically used in HORECA and retail settings and in retail settings when products are intended for immediate consumption – i.e. takeaway salads, hot/cold beverages, sandwiches, etc. – followed by disposal of the used packaging near the point of sale, on the go, or sometimes later at offices or at home. This chapter discusses these packaging types in relation to paper-based packaging for food and beverage. In addition, the growing market for delivery complements traditional HORECA and on-the-go. More and more consumers purchase food and beverage delivered to their home or the office or somewhere else where the disposal of packaging takes place.

The purpose of paper-based packaging for food and beverage is to protect the goods inside, enable hygienic and convenient consumption, and provide information to consumers. It serves this purpose regardless of where it is being used, but conditions related to the disposal of packaging may vary in different environments. Opportunities for interaction and timely communication with the consumer, as well as waste management infrastructure and consumer behaviour, play different roles depending on the environment in which they are used. Figure 25 shows multiple end-of-life options that are needed when solving the recycling of paper-based packaging for food and beverage.

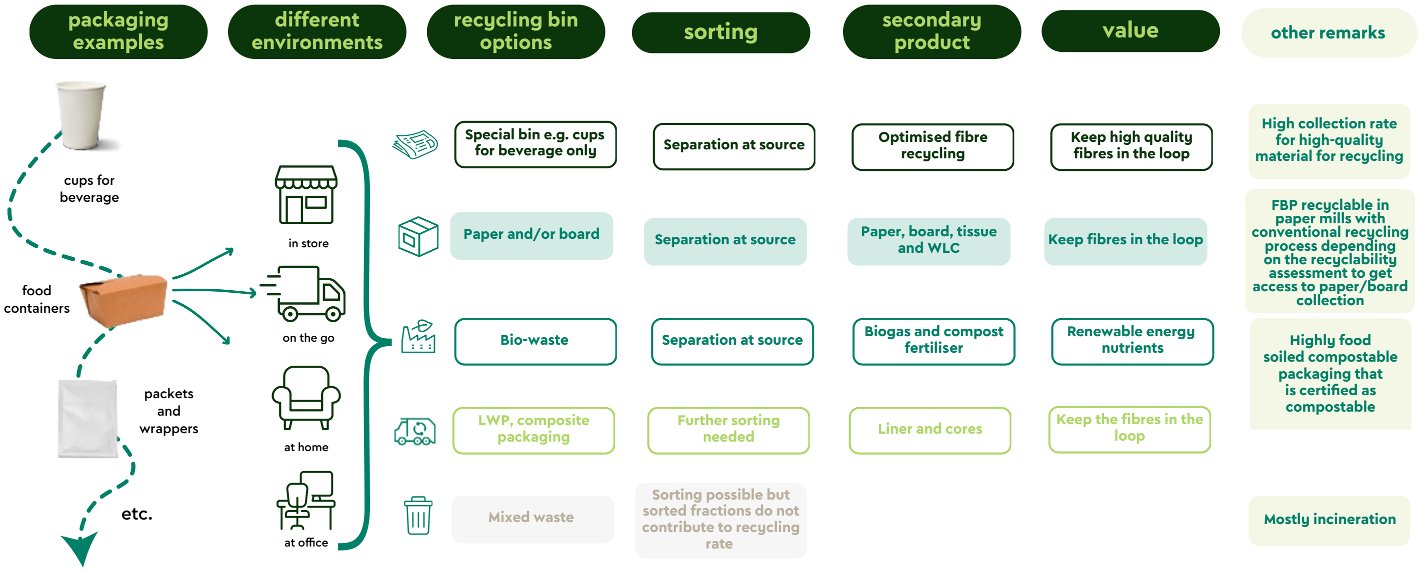


Figure 25. Multiple end-of-life options are required in the recycling of single-use paper-based packaging for food and beverage

Consumer behaviour in relation to waste management

Different factors and conditions have an influence on consumer behaviour in relation to waste management. Individual, contextual, and infrastructural conditions and factors seem to best predict pro-environmental consumer behaviour (PECB). In terms of individual factors, these include attitudes, norms, perceived behavioural control, past behaviour, and identity. In relation to contextual conditions, spillovers, proximity effects and past exposure play a key role. From infrastructural conditions and factors point of view, access to services is the key. (Concari et al., 2020).

3. Collection of paper-based foodservice packaging

According to a recent study by the Foodservice Packaging Institute (2023), the vast majority of food and beverage packaging in the residential recycling stream was divided into 'clean packaging with no food residue' or 'clean packaging with some stains and traces'. Stains and traces are not considered to be detrimental to collection and recycling when the packaging is otherwise empty (see Annex 1).

Analysis conducted by Comieco (2023) in quick service restaurants regarding the composition of paper-based packaging for food and beverage collected for recycling has demonstrated that the majority of separately collected paper-based foodservice packaging is clean for recycling. The level of contamination – including, for example, food residues, foreign materials, and other impurities – is marginal. Thus, separately collected paper-based foodservice packaging in quick service restaurants has potential for providing material of good quality for recycling if grade-specific tolerance levels for non-paper integrated components and constituents and contamination are not exceeded (Comieco, 2023).

Separate collection provided in-store and on-the-go should mirror residential recycling systems. According to 4evergreen Guidance on the Improved Collection and Sorting of Paper-based Packaging for Recycling, paper-based packaging is to be collected in either the regular paper and board stream or LWP stream. Experience from quick service restaurants having introduced separate collection, mirroring residential recycling systems and/or special bins in-store, demonstrates potential for a high collection and recycling rates.

Separation at source includes preparation for disposal, for example, by emptying the food, liquid or other contamination from the packaging. If this contamination remains inside the packaging, it can detrimentally impact collection, sorting and recycling, as described in Annex 1. Thus, proper separation at source at the point of disposal is recommended.

In the in-store environment, as well as at home and the office, consumers can easily empty the packaging before recycling. However, proper emptying of packaging can be problematic on the go due to a lack of time and tools for emptying the packaging for proper disposal. Yet it is still worthwhile informing consumers of their responsibility to dispose of empty and dry packaging in the recycling bin.

Organic recycling, a complementary end-of-life solution for compostable packaging

More than 80% of paper and cardboard packaging is recycled in Europe, making it the most recycled packaging material in Europe. Organic recycling provides a complementary end-of-life solution for compostable paper-based packaging where material recycling is not possible (e.g. because of food contamination or in an environment where compostable paper-based packaging is used). Control of food residues can be difficult to manage in certain settings, such as festivals and events, due to the nature of the environment and related consumer behaviour. In addition, when collection rates increase across packaging types, volumes of highly food contaminated packaging can also increase. Here, organic recycling may help to collect more materials for recycling that would otherwise be incinerated, landfilled, or worse, be lost as litter. Compostable paper-based packaging entering aerobic or anaerobic treatment may be counted as recycled where that treatment generates compost, digestate, or other output with a similar quantity of recycled content in relation to input, which is to be used as a recycled product, material or substance.

4. Recycling in different environments

Disposal of paper-based packaging for food and beverage takes place in different environments. This includes in-store and on-the-go formats both in managed and unmanaged areas as well as at home.

In-store

An in-store environment is where packaging is disposed of inside a restaurant, a café or similar closed environment enabling direct interaction and timely communication with consumers. It provides conditions where waste management infrastructure can be designed to support proper disposal of packaging and other waste. This may include establishing separate collection mirroring residential recycling system or with special bins that further strengthen separation at source and reduce contamination.

Well-designed recycling stations with good signage and communication for consumers are an effective way of encouraging consumers to separate their waste properly for recycling. The recycling station should be simple and intuitive, so consumers don't have to stop and think about their action. They usually want to leave the premises swiftly if they are in groups, with families, or when the premises are busy (i.e. new customers looking for an available table).

Consumer-and employee-led sorting

In consumer-led sorting, within a recycling station there should be space for the consumer to place a tray prior to sorting. Without this space, consumers are unlikely to be able to sort effectively while holding their tray. Additionally, retailers may benefit from employee-led sorting, rather than consumer-led sorting, to further reduce contamination and improve quality for recycling. Employee-led sorting may take place at the back of the store.

Whether consumer-led or employee-led sorting is in use, the recycling station should encourage separation of components, with food and liquid waste being removed, and the different packaging materials being placed in separate and clearly marked receptacles. Separation of cups for beverages is recommended because of their high-quality fibres for recycling and the potential for substantial volume reduction through stacking cups by using appropriate collection stations (tubes for instance, see Figure 31). This can also lead to cost reductions for waste services.

Consumer-led sorting, that is often seen in the industrial catering segment such as office canteens, has become increasingly successful. Also, this is being used in the in-store environment. Adopting separation at source more widely in in-store environment is likely to lead to further consumer engagement and become the norm for increased recycling.

Figure 26. Example of a consumer-led sorting in a restaurant in Paris (FR)

Figure 26 illustrates an in-store collection environment in a restaurant in Paris (FR) in 2019, and how waste management infrastructure can be designed to support proper separation at source of packaging and other waste to strengthen separation at source and reduce contamination, and where direct interaction and timely communication with the consumer is possible. This is a clear example of a separation at source.

Figure 27. Example of a separation at source in a restaurant in Brussels (BE)

A restaurant in Brussels (BE) in 2024 captured in Figure 27, again illustrates how the in-store environment and waste management infrastructure can be designed to support proper separation at source of packaging and other waste, in turn strengthening separation at source and reducing contamination. This is another example of consumer-led sorting.

Figure 28. Example of a separation at source in a restaurant in Milan (IT)

A restaurant in Milan (IT) in 2024 presented in Figure 28, shows another version of in-store waste management layout and infrastructure strengthening separation at source and reducing contamination.

Figure 29. Example of an employee-led separation at source in a restaurant in Mannheim (DE)

Figure 30. Example of an employee-led separation at source in a restaurant in Frankfurt (DE)

A restaurant in Mannheim (DE) in 2024 captured in Figure 29 demonstrates employee-led separation at source. The consumer returns a tray including used packaging and separates paper cups in holes on top of the recycling station. Then, employees take the full collection units back-of-house for further separation at source.

In another example of employee-led separation at source in a quick service restaurant in Frankfurt (DE) in 2024 captured in Figure 30, the consumer returns a tray including used packaging and preferably separates paper cups in holes on top of collection unit and employees then take full collection units to the back of store for further separation at source.

Special bin

Special bins within the in-store environment, or other environments, are designed for a particular waste. They enhance separation at source whilst reducing contamination. Direct interaction guides consumers through proper separation at source of waste enabling efficient separation of packaging components and leftovers from used packaging. Experience shows this is an excellent method of collection, and the quality of packaging for recycling has proven to be high. Some special bins may be designed to target specific items, such as paper cups, where there is an expectation of high demand in that area, for example, at train stations or music festivals.

Figure 31. Example of a special bin in Dublin (IE)

Figure 31 illustrates an example of a 'special bin' in front of a café in Dublin (IE) in 2023 that enables the collection of targeted items such as paper cups – a high-quality material for recycling. This form of stacked collection enables substantial volume reduction versus loose collection, and consequently the opportunity for cost savings.

On-the-go in managed areas

On-the-go collection that takes place in managed areas such as railway stations, shopping malls or music festivals is best undertaken with collection bins which mirror residential recycling systems, ensuring access to separate collection while enabling placement of additional special bins to increase collection of targeted items. Communication with the consumer is limited, and so collection bins should have signage and colours appropriate for quickly identifying the correct bin for disposal. Mirroring the residential system in this way gives the best possible chance of consumers quickly understanding how to separate at source properly.

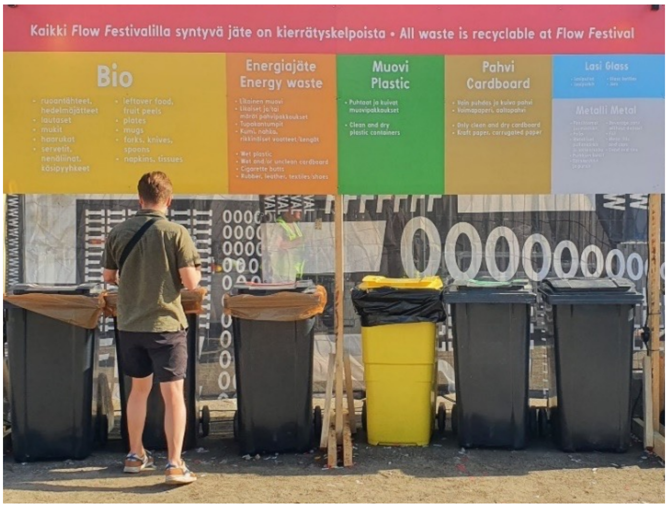


Figure 32. Example of on-the-go waste sorting in managed areas

An image captured in Figure 32 shows music festival in Helsinki (FI) in 2023 illustrating on-the-go waste separation at source in managed areas, providing access to separate collection through collection bins that are in line with residential collection system.

Figure 33. Example of on-the-go waste sorting in managed areas

In Figure 33, a shopping mall in Warsaw (PL) in 2024, illustrates on-the-go waste collection in managed areas, providing access to collection through collection bins similar to residential collection system.

Figure 34. Example of on-the-go waste sorting in managed areas

Helsinki-Vantaa Airport (FI) in 2024 in Figure 34, shows another example of source separation related to on-the-go collection mirroring bins typically found in the residential collection system. From the left, the bins include, yellow for plastic, blue for cardboard, grey for mixed waste, green for paper, and brown for bio-waste. In addition, on the right, there is a special bin for plastic bottles highlighted with orange. The shape of the special bin is the same as recycling bins commonly found in the residential collection system. This system is missing a metal bin for cans. In Finland, aluminium cans are included in a deposit return system (DRS) together with plastic and glass bottles. Thus, in this case the special bin for plastic bottles on the right could also include aluminium cans and glass bottles to mirror the Finnish DRS.

Figure 35. Example of a special bin in on-the-go environment in managed areas

Figure 35 illustrates on-the-go waste collection in managed areas such as a train platform in Genoa (IT) in 2024 highlighting the use of special bins to increase collection of targeted items. This reverse vending machine is dedicated to separate collection of plastic bottles and beverage cartons.

On-the-go in unmanaged areas

On-the-go collection in unmanaged areas provides limited opportunities for communication with consumers aimed at supporting the proper disposal of packaging. In this case, the emphasis is on providing access to enough collection bins in line with the residential recycling system to ensure proper disposal of packaging even in unmanaged areas.

At home

Disposal of packaging 'at home' in domestic recycling bins helps to secure higher levels of separation at source. Such residential collection systems are increasingly common in European municipalities, cities and even the countryside. Harmonised labelling and the use of waste symbols is often found on recycling bins. The same symbols should ideally be used on packaging and other products intended for recycling. This makes sorting easier and thus encourages consumers to separation at source more.

Figure 36. Example of on-the-go waste collection in unmanaged areas

Figure 37. Example of residential collection system

Figure 36 captures public garden in Fiskars (FI) in 2024, illustrating on-the-go waste collection in unmanaged areas with recycling bins that are compatible with residential collection system enabling separation at source.

Figure 37 shows residential collection system in Barcelona (ES) in 2023, illustrating a harmonised system of icons and colours that makes separation at source easier and, hence, helps consumers to separation at source more.

5. The importance of stakeholder collaboration

Achieving high recycling rates requires collaboration across the entire value chain (Figure 38). This includes authorities, packaging recovery organisations (PROs), HORECA operators, consumers, and waste management service providers. Each stakeholder has a unique and critical role to play in enabling collection and recycling of foodservice packaging. Authorities may need to accelerate separate collection in public spaces to support proper disposal of packaging on the go while PROs can allocate the needed funds for collection. PROs should ensure the acceptance of similar packaging items in various collection systems and areas. HORECA operators can establish direct interaction and timely communication with consumers in HORECA premises, crucial to ensure separation at source. Waste management service providers can support authorities and HORECA operators by providing more frequent collection for recyclable materials and less frequent collection for general waste.

More frequent collection of lower weight material comes with higher cost for the operator. Typically, operators would be prioritising waste collection from their sites at the lowest possible cost. So, a call for a change in attitude is needed. Agents involved should be willing to pay more, to ensure their packaging is frequently collected and recycled properly. Frequent collection of properly sorted paper-based packaging is crucial to ensuring supplies of valuable material for recycling.

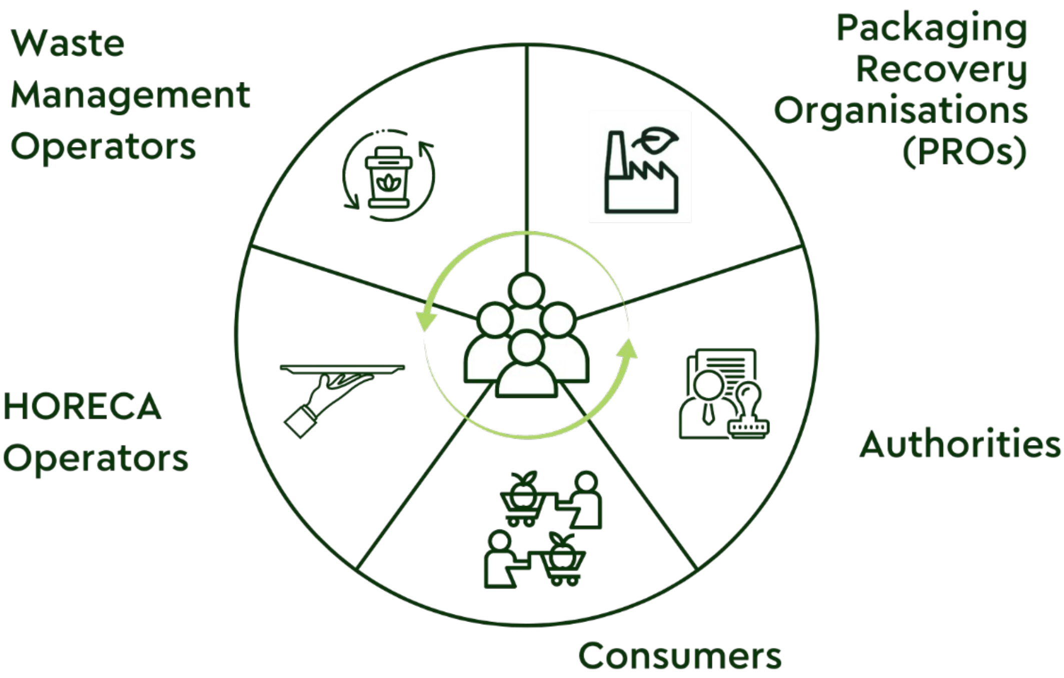


Figure 38. Achieving high recycling rates requires collaboration across the entire value chain

6. Recommendations to enhance recycling in HORECA and on-the-go

Paper-based packaging for food and beverage from HORECA and on-the-go environments can be effectively collected, and suitable quality and sufficient quantity achieved for recycling. **Sorting is essential** to achieve different grades of paper and board for recycling within specifications required by paper mills, by minimising the risk of cross-contamination of non-fibre materials, food, and liquids.

In **in-store**, **on-the-go in managed areas, and at home**, source separation through the Stream 1 P&B or LWP stream should be in place, while post-consumer sorting can further improve the quality of the material for recycling. Well established examples of in-store separation at source and collection should be widely shared for best practice, other examples of on-the-go in managed areas such as railway stations, shopping centres and closed environments like events and stadiums are actively being developed and form a foundation for future success.

In **on-the-go in unmanaged public areas**, achieving clean source-separated fractions will be more challenging due to different consumer behaviour. A choice should be made between collecting smaller volumes of high-quality material (i.e. separate collection of cups only through special bins), or collecting higher volumes of lower quality material (i.e. collection of co-mingled waste sent to post-consumer sorting facilities to separate plastics, metals, fibres and organics). On-the-go waste is more homogenous than residential waste, and therefore post-consumer sorting provides an opportunity.

Residential collection systems with **harmonised labelling or waste symbols**, including icons and colours, encourage consumers to separate at source more by making sorting easier, and the same approach should be **mirrored in HORECA and on-the-go locations**. This will increase common consumer understanding on separation at source. Meanwhile, potential synergies in waste collection between residential and commercial areas can be identified.

To achieve this consistency, it is important that the **same types of packaging are accepted** in the paper and board stream or the LWP stream wherever collection takes place. This is not yet the case everywhere, with items like paper cups, which are accepted in residential paper and board stream or LWP stream, but not always in similar bins in restaurants or on-the-go.

If in HORECA or on-the-go locations, waste separation is organised in a different way to residential systems – because of distinct packaging portfolios or consumer behaviour patterns – it is advisable to **clearly mark this distinction** by using different colour codes and pictograms to avoid consumer confusion.

Clear consumer information about **how and why separating waste is critical** to ensure suitable quality and sufficient quantity of recyclables. In addition to using waste symbols in labelling with explanatory text and harmonised icons and colours (preferably in line with residential systems), illustrations of the type of packaging that can go into each bin are effective.

In **in-store environments**, if customers are expected to separate at source waste from a tray, a place to store that tray while they perform the task makes it easier. Separation at source can be done either at collection stations in a line allowing customers to 1) empty their packaging from food and liquid, 2) dispose of recyclables and 3) dispose of general waste, or from a centre with organics and general waste to one side, and recyclables to the other.

On-the-go, customers won't be stopping long to separate at source, so recycling bins should be open enough to use as they walk past, while not being so open as to encourage larger waste being deposited or risk waste being blown out by wind or taken by animals. Clean and empty bins are more inviting to use.

In addition, harmonised labelling or waste symbols as well as illustrations of the type of packaging that can go into each bin and greater **consumer engagement** (i.e. on-pack information, digital tools, campaigns, etc.) can help increase awareness and improve the collection of suitable quality and sufficient quantity for recycling.

Whether waste collection is organised by public or private collectors, waste management practices for locations where a lot of foodservice packaging is disposed for recycling should be adapted to maintain value of secondary raw material for longer.

Both the **frequency of collection and storage conditions** need to be considered. On the one hand, frequent collection is needed to avoid food contamination sitting on packaging too long to secure suitable quality for recycling. On the other hand, collection should not take place too often to ensure sufficient quantity for collection. Compression of collected material is possible for storage as long as packaging has been emptied from food and liquid and thus collected materials are relatively dry. Meanwhile, airing can help maintain material value. Waste management service providers can optimise collection from multiple sites with similar waste streams. This will increase volume while maintaining material value.

By following the best practices outlined in this annex in a harmonised way, both the quality and quantity of PfR generated by HORECA and on-the-go environments will improve across Europe.

[18] **References for Annex 3**

Concari, A.; Gok, G.; Martens, P. (2020) A Systematic Literature Review of Concepts and Factors Related to Pro-Environmental Consumer Behaviour in Relation to Waste Management Through an Interdisciplinary Approach. Sustainability 2020, 12(11), 4452; https://doi.org/10.3390/su12114452

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Annex 4.

Review of existing sorting procedures and technologies

1. Introduction

The success of a circular economy for paper-based packaging depends on the establishment of a unified framework that ensures materials are designed, collected, sorted, and recycled in a consistent and efficient manner across Europe. This framework is key to achieving the EU's sustainability goals and minimising waste.

Under the Packaging and Packaging Waste Regulation (PPWR), the term "recycled at scale" is defined as packaging that is separately collected, sorted, and recycled through established and operational infrastructure. This must occur at volumes sufficient to meet the recycled at scale targets, which are set at 55% for all packaging materials, and 30% for wood. The PPWR also acknowledges "at-scale opportunities", which refer to the ongoing advancements in sorting and recycling technologies.

This means that packaging that cannot yet be recycled at scale using current infrastructure may still be considered viable in the future, as long as credible technological developments are expected to enable its separate collection, sorting, and recycling in the future.

In addition to 4evergreen's Guidance on Improved Collection and Sorting, Circularity by Design Guideline and Recyclability Evaluation Protocol, this review aims to provide industry experts with an overview of sorting technologies and methods in the market. It emphasises the need for a sorting protocol to be considered alongside the established recyclability protocol, that would help bridge the gap between packaging placed on the market and the practical sorting and recycling processes that transform these materials into new paper-based products. This will, in turn, ensure that both the design and end-of-life processes are fully optimised for a circular economy.

About this annex

This annex focuses on sorting technologies and methods for paper-based packaging, examining both existing technologies in use in materials recovery facilities (already adopted to separate from waste paper-based packaging, typically EN 643 grades, to make them available for the downstream recycling process), as well as emerging technologies that are expected to be adopted on an industrial scale in the future. It begins with an overview of established processes such as mechanical treatment and optical sorting, before exploring the potential of emerging sorting technologies.

In addition, the annex highlights independent, OEM-agnostic sorting methods (those not tied to specific original equipment manufacturers), offering flexibility and broad applicability.

The annex's primary aim is to evaluate the current sorting landscape, with conclusions focused on establishing a harmonised evaluation protocol for sorting paper-based packaging within European collection and recovery systems. This annex provides recommendations for a harmonised approach, supporting consistency across the Europe's recycling efforts.

It is intended to serve as a practical reference for stakeholders across the value chain, including brand owners, packaging manufacturers, and policy makers, offering a review of current sorting tests and principles, with clear objectives to:

- Support recycling in practice, ensuring paper-based packaging is directed towards the most appropriate recycling pathways.

- Enable consistency across markets, promoting a common language and methodology for sorting that complements existing guidance and standards.
- Guide stakeholders (brand owners, packaging designers, and policy makers) on how packaging features such as material composition, integrated component geometry, and constituents such as barrier layers, coatings, and print, affect sorting behaviour and results. It also covers emerging technologies that could improve sorting outcomes in the future.
- Strengthen the circular value chain, ensuring that paper-based packaging is not lost to incineration or landfill, and are instead properly recycled to their highest potential.

This review is designed to work in conjunction with the other 4evergreen annexes, forming a comprehensive suite of tools aimed at driving alignment across the packaging value chain. Together, these tools will help accelerate progress toward achieving higher recycling rates for paper-based packaging.

Methodology

To evaluate the available sorting technologies and testing processes, leading companies in the waste recycling sector were contacted. These companies were selected based on their involvement in the design, construction, and operation of waste sortation plants, as well as their expertise in optical and robotic sorting systems. Additionally, these companies own or operate test centres where relevant assessments are regularly conducted, and selectivity protocols are already in place.

The companies were engaged through email outreach and interviews, as well as during technical meetings within 4evergreen working groups. Their input has been invaluable in identifying not only best practices and available technologies, but also in confirming emerging trends in the industry.

While the information gathered does not represent the entire market, it offers a snapshot of how major players are approaching the challenges and opportunities of sorting paper-based packaging and particularly fibre-based composite packaging. Given the variety of paper mills and collection methodologies, this study does not take into consideration end applications and output requirements which particular paper mills may have.

Summary of findings

The industry currently benefits from a broad range of at-scale sorting technologies capable of processing much of today's paper-based packaging. However, significant challenges remain, particularly when dealing with materials of diverse or specialised compositions.

Emerging technologies such as artificial intelligence (AI), and digital watermarking – which requires modification of the packaging print itself – offer promising opportunities to enhance detection accuracy and sorting efficiency in the near future. These innovations could play a crucial role in overcoming current limitations.

One of the key obstacles is the lack of a harmonised sorting protocol across technology providers, which leads to inconsistent results and complicates the accurate assessment of recyclability. Without common testing methods or evaluation criteria, it becomes difficult to compare technologies or predict sorting outcomes reliably.

While today's mechanical and optical sorting systems are capable of handling a substantial share of current packaging formats, meeting 4evergreen's recycling targets (particularly the accurate allocation of packaging to paper mills with conventional recycling process vs. paper mills with specialised recycling processes) will require a coordinated rollout of next-generation solutions. These advancements must be paired with the development of clear, industry-wide performance benchmarks to ensure consistent, scalable progress.

2. Recommendations for industry to take forward

- Define **clear metrics** and minimum **performance thresholds** for sorting efficiency, purity, and recovery rates.
- Build on **existing approaches** and support harmonisation, adapting as needed for FBCP.
- Facilitate **cross-industry collaboration** between packaging producers, technology providers, and recycling operators.
- Encourage **investment in plants** that integrate mechanical, optical, and AI systems in sequence to maximise efficiency.
- Ensure both collection streams (paper and LWP) are supported with the **right downstream equipment**.
- Develop a **unified testing framework** to allow objective comparison of different sorting technologies.

3. Overview of sorting processes

Mechanical treatment

Rotating trommel:
This equipment is typically installed in waste sortation plants that process streams containing a high content of mixed materials or undesired fractions. It is also useful for untangling compacted waste masses. Separation is based on the size of the elements. Generally, screen apertures increase from the feed point to the exit, allowing the smallest and most undesirable particles to be separated early on. In the final stages, over-sieve and under-sieve target fractions are typically separated for recycling. At this stage, FBCP is usually sorted into the 50–220mm under-sieve fraction and then sent for further treatment. It should be noted that sifting drums determine what can proceed to NIR, if an NIR step is in place.

Ballistic screen separation:
This equipment is usually installed as an alternative to, or in series downstream from, a rotating trommel. It is used for sorting mixed streams composed of various materials, including sorted fibre or container streams, municipal single-stream collections, mixed solid waste, and even construction and demolition materials. Separation is based on both the geometry and gravimetric properties of the materials being inspected.

Flat materials move forward to the upper end, while 3D items fall backward to the lower end. Simultaneously, the paddle perforations allow smaller materials to be screened out. Some manufacturers offer the option to stack one to three units to handle higher throughput or to perform multiple screenings using different paddle perforations on each deck.

FBCP is typically intercepted within the 50–220mm sieving fraction or among the rolling items, though sieving fractions down to 20mm are also used.

Mechanical treatments, which may be integrated with magnetic and eddy current separators (for ferrous and non-ferrous metal separation), are necessary to prepare the correct mix of materials for subsequent optical sorting systems. Typically, an eddy current separator (used for aluminium packaging) is installed downstream of a first optical sorting stage that separates LPC.

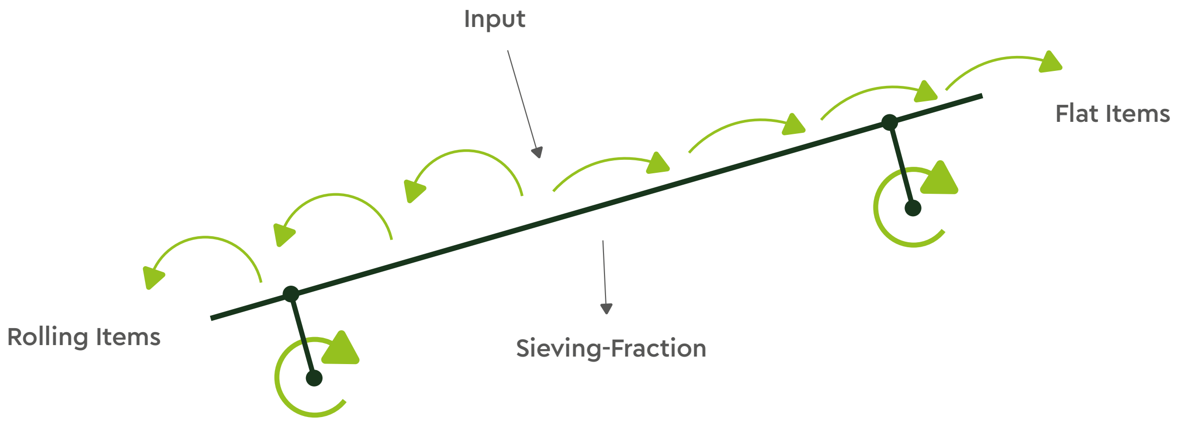

Figure 39. Sorting schematic for ballistic separator screen

Optical sorting

Mechanical sorting steps are usually followed by optical sorting. The number of optical sorters used is variable and directly proportional to the number of material types to be separated. Most optical sorters installed in waste treatment plants are NIR-VIS systems, which are considered an at-scale solution.

Traditional NIR-VIS systems work by analysing the spectrum of light absorbed and reflected by a sample to determine its composition or properties, and are highly efficient in separating cellulosic materials such as:

- White graphic paper and paper-based packaging from coloured materials (deinking)
- Liquid packaging cartons (accurate detection of constituent materials: fibre + PE or PP), which emit a readily recognisable spectrum

Most other paper-based packaging types (excluding LPC) have a spectrum that is generally detected as paper, fibre-based composite packaging, or as the material class of LPC. However, several areas of concern still need to be considered:

Reflective surfaces:
Shiny or metallised outer surfaces (including hot/cold foil or the use of metallic inks) can reflect light, preventing the spectrum from being assigned to any material group. This presents a disadvantage compared to more easily identifiable materials.

NIR-absorbing dark colours:
Some dark-coloured packaging (i.e. those containing carbon black) absorb NIR rays and therefore may not be detected. For instance, dark-coloured packaging might not be identified by traditional NIR-VIS systems and may require specific testing to confirm their suitability.

Misclassification:
Certain composite packaging types can be misclassified as textiles due to spectral similarities between paper and some textiles (both being cellulose-based) in certain detection systems. In such cases, the paper outer layer may be wrongly identified as textile, while the inner layer may not register as a known plastic (e.g. due to a weak or thin signal).

Fortunately, these challenges can generally be resolved by adjusting the classifier to the characteristics of the specific waste stream being treated.

Further detail of sorting disruptors for NIR systems, leading to misclassification can be reviewed in Table 1, below.

Table 1. Sorting disruptors

Component/constituent	Sorting disruptor	Note
Inks/pigments	Metal pigments applied over a large area on outer surface [1], [2]	If applied over a large surface (several studies indicate >50% surface coverage or when printing small areas beneath each other a total area coverage of >50% can still be compatible with sorting), metallic coatings reflect or scatter the near-infrared light used by optical sorting systems, while carbon black absorbs it, preventing the sensors from detecting and correctly identifying. However, this shall be further investigated with harmonised sorting protocol, where relevant.
	Carbon black inks that cover large portion of the surface area [1], [2]	
	Black dyed pulp [1], [2]	Black-dyed pulp is a sorting disruptor because the carbon black absorbs most of the near-infrared light used by optical sorting systems, leaving insufficient reflected signal for sensors to distinguish the pulp's material type, causing it to be misidentified or rejected during automated sorting. However, this shall be further investigated with harmonised sorting protocol, where relevant.
Ferromagnetic components	Integrated ferromagnetic component [1]	Integrated ferromagnetic components can trigger false metal detections or stick to magnetic separators. This can be considered relevant when weight of the component in relation to packaging is more than 5% as a preliminary guidance. However, this shall be further investigated with harmonised sorting protocol, where relevant.

Component/constituent	Sorting disruptor	Note
Aluminium foil layer	Aluminium foil layer applied over a large area on outer surface [1], [2]	Both aluminium foil layers and vacuum metallisation applied to the outer surface of the packaging (several studies indicate >50% surface coverage) can be sorting disruptors if applied over a large surface because their highly reflective metallic surfaces scatter or reflect near-infrared and visible light, preventing optical sensors from detecting the underlying material and causing the item to be misclassified or rejected in automated sorting systems. However, this shall be further investigated with harmonised sorting protocol, where relevant.
Vacuum metallisation	Metallised paper surface applied over a large area on outer surface [3]	
Coatings	Thick outer surface plastic coatings [1], [2]	Thick outer-surface plastic coatings are sorting disruptors because they shield the underlying material from optical or NIR sensors, preventing the system from detecting the substrate's spectral signature and causing the item to be misidentified or rejected during automated sorting. Non-exhaustive studies highlight that up to 40 µm outer surface coating allows successful detection.[19] This shall be further investigated with harmonised sorting protocol, where relevant.
	Inner plastic coatings when paper is too thin [1], [2]	
Integrated components (such as window)	Non-paper based integrated components that cover a large area on outer surface [3]	Integrated components, such as plastic windows, are sorting disruptors because they introduce materials with different optical or physical properties than the main substrate, causing sensors to misread the packaging composition and leading to misclassification or rejection during automated sorting. This shall be further investigated with harmonised sorting protocol, where relevant.
Design	Liquid packaging cartons that have outer layer different than PE/ paperboard combination or PP/paperboard combination [1], [2], [3]	When the outer layer of LPCs, or composite paper/ cardboard packaging with material structure and composition corresponding to liquid packaging cartons that deviates from the common PE/paperboard or PP/ paperboard combinations, it can affect sorting in MRFs, as optical and NIR sensors rely on the characteristic spectral 'fingerprint' of these common structures for accurate identification. LPCs with uncommon outer layers may not produce the expected NIR signature, so their compatibility with sorting must be verified.

The information provided herein is derived from non-exhaustive internal testing results and reflects the key insights of the referenced sources. It is important to note, however, that a harmonised sorting protocol is necessary to comprehensively evaluate the sorting disruptors identified above, with the objective of establishing more robust thresholds to guide designers. Currently, the protocols used across the industry may vary, resulting in minor differences in thresholds; notwithstanding, the general conclusions remain valid. Furthermore, as sorting is an inherently dynamic field, this information is intended to offer preliminary guidance to designers regarding sorting-relevant considerations. Updates shall be provided as appropriate, and further testing is recommended where necessary to ensure accuracy and applicability.

[1] *Minimum Standard for Determining the Recyclability of Packaging Subject to System Participation pursuant to Section 21 (3) VerpackG*, 2025.

[2] *Recyclability Guidelines and Assessment (CHI – cyclos-HTP Institute), Version 6.1.*

[3] *Circular Packaging Design Guideline: Design Recommendations for Recyclable Packaging*, FH Campus Wien, Version 6.

[19] Typical protective and decorative lacquers, as they are applied in printing presses, are below this value.

4. Emerging technologies

At-scale technologies (including mechanical, magnetic and eddy current separators, and optical treatments) can, if properly implemented and sequentially integrated, enable the effective sorting of most existing paper-based packaging. However, as the previously mentioned challenges demonstrate, further improvements are necessary to fully meet 4evergreen's recycling targets and to ensure that selected materials are directed to the appropriate paper mill, whether a paper mill with conventional recycling process or a paper mill with flotation-deinking recycling processes.

Promising solutions to current and future issues are likely to emerge from some of the most advanced technological developments currently available or coming to market:

Artificial intelligence (AI):
AI is already being integrated into leading sorting systems (e.g. Tomra GAINEXT, Pellenc CNS BRAIN) as a booster to traditional NIR-VIS machines, allowing facility operators to detect and recover materials that cannot be sorted using conventional technologies. Existing robotic sorting systems are also powered by AI and can efficiently pick targeted materials, provided they are correctly trained.

Each AI system is based on deep learning technology, which continues to evolve rapidly, suggesting significant improvements are expected in the near future. For example, optical sorters equipped with NIR-VIS-AI processors could potentially recognise the brand on a package and, by matching the logo, spectrum, and materials used, direct it to the correct recycling pathway.

Digital watermarks:
Digital watermarking represents another promising innovation. Development is already at an advanced stage, with major industry players (such as paper-based material producers and sorting equipment suppliers) actively participating in an international working group gathering experimental data. This research will inform the potential industrial-scale adoption of the technology. Watermarks could make all categories of fibre-based composite packaging detectable and also allow for further separation, such as distinguishing between food and non-food streams, where relevant for paper-based packaging.

5. Sorting test procedures

The following section provides a brief summary of the information collected through interviews and meetings with leading companies involved in the design, construction, and operation of waste recycling plants. The sorting test procedures described below represent methods currently implemented by these producers to evaluate the sorting potential of various materials using their available equipment. This includes, upon customer request, the evaluation of new composite packaging intended for market introduction.

It is important to note that this represents the initial phase of a broader research effort. While the findings presented here reflect credible and current industry practices, they are intended as a starting point to support the development of more comprehensive, harmonised protocols for the sorting of paper-based packaging across different systems and markets, enabling packaging to be sortable using all modern sorting methods available on the market.

Table 2. Comparative table of sorting procedures

OPTICAL SORTING				
Company	**Pre-analysis**	**Technology adopted**	**Sample characteristics**	**Recording and result evaluation**
Pellenc	Spectrum Analysis	Standard (all available Pellenc machines)	Target packaging mixed with other waste to simulate plant-scale conditions	Test results recorded in a data base to be verified at plant-scale Qualitative and quantitative evaluation (%)
Tomra	Spectrum Analysis	Standard (the best available Tomra machine for the spectrum of target material)	Target packaging mixed with other waste to simulate plant-scale conditions	Test results recorded in a data base to be verified at plant-scale Qualitative and quantitative evaluation (%)
Cyclos HTP - NIR Test	Spectrum Analysis	Standard (available NIR VIS machine)	Target packaging	Quantitative (%)
MULTI SORTING SYSTEMS				
Company	**Pre-analysis**	**Technology adopted**	**Sample characteristics**	**Recording and result evaluation**
CIRCPACK	Target materials are tagged with RFID labels before test for a quantitative analysis of their selection in sorting line sectors	Standard	Target packaging mixed with other waste to simulate plant-scale conditions	Test results recorded in a final report Recyclass Test Qualitative and quantitative evaluation (%)
Stadler	Sorting process is designed according to the wishes and requirements of customers	Standard and customised (on customer request external machines can be used in the test, e.g. sorters from different suppliers)	Target packaging mixed with other waste to simulate plant-scale conditions	Test results recorded in a final report The test is also filmed through cameras along the sorting line, to study the behaviour of target materials Qualitative and quantitative evaluation (%) EPR assessments (ref. RecycleMe GmbH)
ROBOTIC SORTING				
Company	**Pre analysis**	**Technology adopted**	**Sample characteristics**	**Recording and result evaluation**
Recycleye	Machine learning phase. Sample preparation: target material and mix to use in the test	Recycleye Qualibot (at scale technology)	100 pieces of target material are tested to assess the highest efficiency Target material mixed with others to simulate efficiency reachable in plant-scale conditions	Proprietary application Recycleye Insights records test performance Test recorded in a final report Qualitative and quantitative evaluation (%)
Zen Robotics	Machine learning phase. Sample preparation: target material and mix to use in the test	Robotic arms equipped with RGB camera, NIR and VIS sensors	250kg of target materials Target material mixed with others to simulate efficiency reachable in plant-scale conditions	Test recorded in a final report Qualitative and quantitative evaluation (%)

6. Conclusion

The current landscape of sorting technologies demonstrates that much of today's paper-based packaging can be effectively processed using existing at-scale systems. However, persistent challenges such as inconsistent detection of complex materials, lack of harmonised protocols, and evolving packaging formats, highlight the need for continued innovation and alignment. Emerging technologies like AI and digital watermarking show strong potential, but their success will depend on coordinated industry adoption and clear performance benchmarks. This initial research lays the foundation for developing harmonised sorting protocols, with the goal of enabling more accurate material recovery and supporting 4evergreen's recycling targets.

NOTES

NOTES

GUIDANCE ON THE IMPROVED COLLECTION AND SORTING OF PAPER-BASED PACKAGING FOR RECYCLING

VERSION 4

February 2026

ABOUT 4EVERGREEN

4evergreen is a cross-industry alliance perfecting the circularity of paper-based packaging to contribute to a climate-neutral and sustainable society. Our goal is to raise the overall recycling rate of paper-based packaging to 90% by 2030. We bring a particular focus on packaging with a lower circularity performance today, namely the types used for household, out-of-home and on-the-go consumption.

The alliance brings together industry representatives from across the paper-based packaging value-chain, from pulp, paper and board manufacturers and recyclers to packaging producers and converters, including brand owners, retailers and waste management companies. It also comprises non-fibre material suppliers (e.g. adhesives, inks, coatings), technology providers (e.g. machinery, collection, and recycling solutions), and leading research institutes.

For general enquiries please contact 4evergreen@cepi.org

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