CIRCULARITY BY DESIGN GUIDELINE FOR FIBRE-BASED PACKAGING

VERSION 2

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4ever green

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Introduction

Fiber-based packaging designers, manufacturers, and recyclers are continuously striving to innovate and develop new products and technologies to actively drive the transition towards a more sustainable industry. The development of recyclable fiber-based packaging plays a crucial and positive role in shaping Europe's climate-neutral future, as it maximizes the potential for circularity within the sector.

Packaging needs to fulfil various functions, such as protecting the contents, communicating information about the product, representing a brand, and facilitating both, the storage and the transportation of the packed product.

Depending on the packaging and end use different combinations of materials in fiber-based packaging can be utilized to achieve all of these performance criteria. The right combination of materials in packaging allows for significant advantages, including longer shelf-life and increased protection against external damage. Thus, suitable packaging has the potential to reduce food losses and make a positive contribution to sustainability. It is important to highlight that the diverse range of fiber-based packaging solutions necessitates different recycling processes to ensure optimal material recovery. Additionally, as the amount and types of fibre-based packaging on the market is set to grow further, investments and innovative solutions will play a role in both maintaining and further increasing recycling rates across Europe.

This document, the Circularity by Design Guideline, has been developed by the 4evergreen alliance, involving packaging and sustainability experts of companies acting across the entire supply chain in the fibre-based packaging industry. The publication aims to help packaging designers and industry experts to specify and design fibre-based packaging that is recyclable at scale in Europe.

Therefore, the primary purpose of the document is to explain how different components, elements and materials of fibre-based packaging impact recyclability in a fiber recovery and subsequent pulping reject recovery processes. The first version of the guideline document, issued in 2022 (PART I), indicated whether the different components can be classified as "fully compatible with the standard recycling process", "conditionally compatible with the standard recycling process" or "not compatible with the standard recycling process".

The following document is an extended version which addresses the compatibility of fibre-based composite packaging components (such as beverage cartons and paper cups) with the recycling process in specialised recycling mills (PART III), explicitly applicable for mills that treat used beverage cartons. Recommendations for other fibre-based composite packaging (FBCP) mills and flotation-deinking mills (PART II) will follow in a subsequent version of the guidelines.

This Circularity by Design Guideline is based mainly on expert opinions. Reviews according to an updated test method are ongoing and a follow-up edition will be published once the methodology has been finalised.

Any fibre-based packaging that is not (fully) compatible with the standard recycling process (i.e. Recyclability Evaluation Protocol under PART I) can potentially be recycled in specialised recycling mills or flotation-deinking mills. Thus, a negative compatibility assessment in terms of the standard recycling process does not suggest that the packaging is 'not' recyclable per se. Therefore, this guideline document includes a decision tree to support designers in determining the relevant type of recycling mill the assessed packaging should be recycled in. This flowchart will enable designers to apply the correct design tables (PART I or PART III) for assessing the compatibility of fibre-based packaging with the particular recycling process.

Scope of this document

This design guideline provides recommendations for the design of fibre-based packaging and addresses all actors along the entire value chain, from manufacturers to retailers, including packaging designers.

This document addresses all types of fibre-based packaging, but particular emphasis is placed on household and on-the-go consumer packaging This guideline is intended to be applied in the EU, as it reflects the requirements of recycling technologies used in Europe.

For the duration of the alliance, 4evergreen will continue the ongoing dialogue with members and external stakeholders to review this and other guidelines regularly, amending them in response to changes in collection, sorting, and recycling technologies, as well as future material developments.

DISCLAIMER

Valuations basis and test requirements
This document represents general recommendations on how to design better recyclable fibre-based packaging The given recommendations are based on the expertise and knowledge of the 4evergreen members. Final packaging designs following the principles laid out in the guideline should still be tested for actual recyclability, as the behaviour of fibre-based packaging in the recycling process depends on specific material grades/chemistry and the final composition of the converted packaging. The aim is to provide a comprehensive and fact-based guideline, for standard and specialised processes, hence the current recommendations will be verified with the new Cepi Harmonised European Laboratory Test Method, and the 4evergreen Recyclability Evaluation Protocol PART I/II/III once results have been evaluated and finalised within 4evergreen.

Applicability
This document is intended for the evaluation of compatibility with standard mill and specialised recycling mill processes. The guideline is therefore applicable to fibre-based packaging that is likely to be recycled in standard recycling mills or in specialised recycling mills, provided that product-specific regulations of the packaging are observed. The given recommendations in PART III are explicitly applicable for fibre-based composite packaging recycling in specialised mills for used beverage cartons, Recommendations for other types of fibre-based composite packaging in specialised mills will follow in subsequent versions. Recommendations on the suitability of flotation-deinking mills will be implemented in further versions.

Innovations and future versions
This guideline is intended to support the use of fibre-based packaging and innovation as novel solutions to improve the environmental performance of packaging. The predominant focus of the guideline is to ensure that materials and packaging solutions currently on the market are suitable for recycling. Packaging using novel technologies requires testing to assess its compatibility with recycling processes. Future trends and innovations will be observed and evaluated by 4evergreen in the course of future versions.

List of abbreviations

ABS	Acrylonitrile Butadiene Styrene
AKD	Alkyl Ketene Dimer
Alu	Aluminium
ASA	Alkenyl Succinic Anhydride
BOPP	Biaxially Oriented Polypropylene
Cepi	Confederation of European Paper Industry
CMC	Carboxymethyl cellulose
COD	Chemical Oxygen Demand
DIN	German Institute for Standardisation (Deutsche Institut für Normung)
EB	Electro-Beam
EVOH	Ethylene-Vinyl-Alcohol
EEA	Ethylene and Acrylic Acid
EPRC	European Paper Recycling Council
EuPIA	European Printing Ink Association
EVA	Ethylene-Vinyl-Acetate
EPRC	European Paper Recycling Council
EVOH	Ethylene-Vinyl-Alcohol
FBB	Folding Boxboard
FBCP	Fibre based composite packaging
HDPE	High-Density Polyethylene
INGEDE	International association of the deinking industry
INOX	Stainless Steel
ISO	International Organisation for Standardisation
LDPE/PE-LD	Low-Density Polyethylene
LLDPE	Linear Low Density Polyethylene
LPB	Liquid Packaging Board
mPET	Metallised Polyethylene Terephthalate
MG	Machine Glazed
NIR	Near-infrared
OBA	Optical Brightening Agents
OCC	Old Corrugated Container
OPP	Orientated Polypropylene
PA	Polyamide
PAE	Polyamide-epichlorohydrin
PCC	Precipitated Calcium Carbonate
PET	Polyethylene Terephthalate
PE	Polyethylene
PFA	Perfluoroalkoxy Alkanes
PLA	Polylactic Acid
PfR	Paper for Recycling
PP	Polypropylene
PolyAL-Recycling	Recycling of the residual of polyethylene and aluminium
PPWD	Packaging and Packaging Waste Directive
PPWR	Packaging and Packaging Waste Regulation
PS	Polystyrene
PVA	Polyvinyl Acetate
PVOH	Polyvinyl alcohol
SB	Solvent-Based
SBB	Solid Bleached Board
SiOx	Silicon Oxide
UBC	Used Beverage Carton
UV	Ultra Violet
WB	Water-Based
w/w	Weight per weight

GENERAL INFORMATION

1. REGULATORY BACKGROUND

The packaging industry is working to improve recycling processes and enhance sustainable/ecological packaging design to meet legal requirements (e.g. mandatory recycling targets) and improve the circular economy by closing the loop on material and production cycles.

The circular economy package by the European Union, which was published in July 2018, is a major driver of progress in environmental standards and actions. Among other things, the package led to modifications of several regulations concerning packaging, including EU Directive 94/62/EC, also known as the Packaging and Packaging Waste Directive (PPWD), and the European Waste Directive 2008/98/EC (European Parliament, 2008).

The PPWD lays down measures to prevent the production and promote the reuse and recycling of packaging waste.

As part of the European Green Deal and Circular Action Plan, the European Commission put forward a revision of the PPWD in November 2022, in the form of a regulation. (Packaging and packaging waste Regulation, PPWR). Hence this legislation will be directly binding an no adaption to national law is necessary.

The PPWR introduced performance grades to further classify packaging according to its recyclability and 'Design for Recycling' criteria, with the aim that all packaging placed on the European market is recyclable by 2030. It also aimed to reduce over-packaging and packaging waste.

The table below provides an overview of the European regulations concerning packaging and packaging waste.

Regulation	Abbreviations	Enforcement Date	Implementation in National Law	Content
Packaging and Packaging Waste Directive 94/62 (PPWD)	**94/62/EC**	1994	July 1996	> Recycling targets for packaging materials > Encourage producers to use recycled content for packaging > Essential requirements for packaging composition
Proposal for Packaging and Packaging Waste Regulation	**2022/0396 (COD)**	Enforcement is expected for 2024/2025[1]	Directly binding, as it is a regulation	> Packaging performances grades and design for recycling criteria in 2030. > Mandatory use of recyclates > Waste and Packaging minimization, Minimisation of packaging sizes and avoiding overpackaging > Mandatory unified recyclability labelling requirement for packaging and waste containers
Amendment to PPWD (2018)	**2018/852/EC**	July 2018	July 2020	> Revision of all recycling targets: Paper - 75% by 2025 - 85% by 2030 > New calculation method for recycling rates
Waste Framework Directive 2008/98 (WFD)	**2008/98/EC**	December 2008	December 2010	> Definition of waste terms (recycling, waste, reuse) > Waste hierarchy > Promotes separate collection and high-quality recycling
Amendment to WFD	**2018/851/EC**	July 2018	July 2020	> Recycling target for municipal waste > Mandatory separate collection > Ecomodulation of Extended Producer fees

Table 1. European packaging and waste regulation

Food contact materials

The main target of 4evergreen, therefore, is to improve the compatibility-for-recycling process of on-the-go and household packaging. Food packaging represents a large part of this sector. Besides the directives concerning recycling and circular design, food packaging needs to fulfil safety requirements – parts of the packaging can be in direct contact with food. The two most important regulations concerning packaging material in direct contact with food are the Regulation (EC) No. 1935/2004 and Regulation (EC) No. 2023/2006. They establish the framework for producing food packaging materials and defining the materials allowed on the European market.

For additional information, please refer to the "Food Contact Guideline for the compliance of Paper and Board" by Cepi, 2019.

[1] Depending on the legislative procedure

2. DEFINING RECYCLABILITY IN THIS GUIDELINE

Recyclable packaging implies systems enabled for industrial-scale recycling. The exact scale of the activity in different countries and regions is better understood by examining the current collection, sorting and recycling technologies and systems being deployed. Generally, the recycling process seeks to deliver a safe and viable substitute for so-called "virgin material" (i.e. "secondary materials" that meet the quality and safety standards to replace "primary materials"). Moreover, recycled fibres need to fulfil food-safety requirements if they are intended to substitute material for food packaging. Recycling in the sense of this Guideline does not include energy recovery.

The Circularity by Design Guideline includes recommendations that refer to the recyclability of fibre-based packaging by classifying the components according to their compatibility with:

- Standard recycling processes (PART I)
- De-inking flotation recycling processes (PART II)
- Specialised recycling processes (PART III)

The recommendations included in this document refer to standard recycling processes (PART I) and specialised recycling processes (PART III) only. The table below shows the definition by which the components are classified.

Fully compatible with dedicated process	**Conditionally compatible with dedicated process**	**Not compatible with dedicated process**	**Compatibility with recycling process unknown**
> compatible with sorting according to standard paper grades > no disturbing parts within the recycling process > expected positive output quality after recycling for target product > **existing test results show good compatibility with dedicated recycling process**	> sorting not guaranteed in all cases > the efficiency of the recycling process is affected > **compromised output quality after recycling with dedicated recycling process**	> major issues during sorting and/or recycling > non-feasible output quality for further treatment after recycling > **existing test results show low compatibility with dedicated recycling process**	> based on current knowledge no clear guidance is possible > **testing is required to examine the recyclability of the packaging with dedicated recycling process**

Table 2. Description of compatibility with dedicated recycling process

NOTE: The definition of recyclability referring to different dedicated recycling processes (standard mill, flotation-deinking mill or specialised mill) can be different. **4evergreen's current testing and assessment is expected to provide more detailed guidance in future.**

2.1 Pre-requisite for fibre-based packaging

Definition of paper and fibre-based packaging in this guideline

Paper consists mainly of natural fibres (min. 50% w/w, both of primary and secondary fibre source) and can possibly contain other ingredients such as filling material, starch, coating colourants and binding material, as well as additives typically used in the paper industry, such as wet-strength agents, sizing agents and water.

These constituent parts may or may not contribute positively to the final recycling quality. The packaging designer should refer to the respective design parameters. Broadly, however, the higher the fibre content the better the suitability for paper recycling.

Fibre-based packaging material essentially means papermaking fibres, fillers, coatings, pigments, binders and other wet components, but also starch and a range of "dry strength" agents as well as functional and process chemicals used in "wet-end" paper machining, including printing inks, overprint varnish, adhesives (e.g. binding paper and plastic film), polymeric barrier layers, and other accompanying elements (e.g. tape, label).

The paper content calculation effectively grades the packaging material's fibre content and is derived from the *Paper weight/Fibre-based packaging material weight*100%*.

In this guideline, the paper content of the packaging should therefore be at least **50%** to be classified as fibre-based packaging.

Components to avoid in fibre-based packaging

The presence of certain elements may lead to undesired consequences even for all types of packaging

In general, all sources of toxic (including toxic to reproduction), mutagenic, cancerogenic, endocrine disrupting chemicals must be avoided in any package or packaging component.

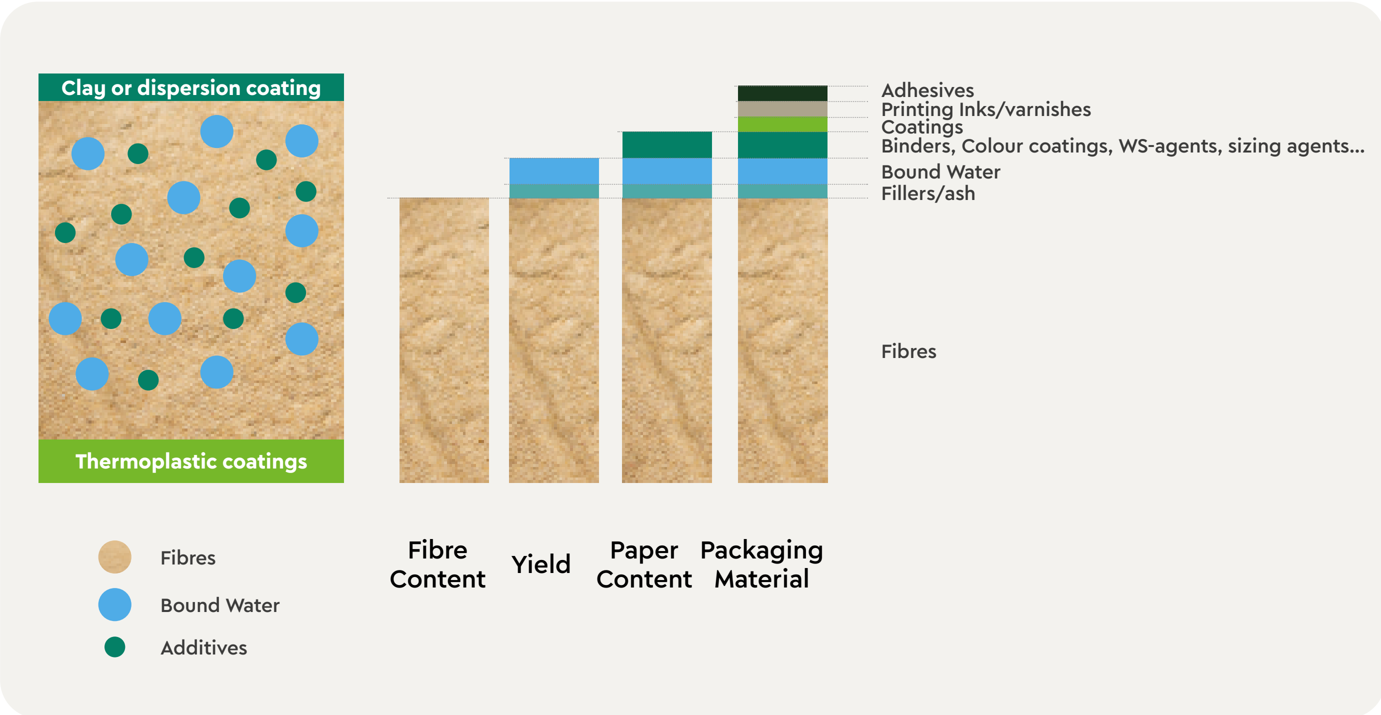


Figure 1. Distinction of fibre-content, yield and paper-content

2.2 Recyclability definitions

Recyclability by design

Recyclability by design means that the packaging can be collected, sorted, and recycled with state-of-the-art technologies. Recyclability by design encourages the development of infrastructure (when not at scale) by making higher quality waste available.

If the packaging under investigation complies with this guideline, it is considered recyclable by design. If not, it can still be proven recyclable with the Cepi's European Harmonised Laboratory Test Method and the 4evergreen Fibre-based Packaging Recyclability Evaluation Protocol.

Packaging can be assessed as recyclable at scale if:

- The material used is collected by specific national or regional collection systems. *
- Sorting technologies for the packaging exist. *
- Processing technologies for the (material) recycling process exist. *
- There is market potential for the resulting secondary raw materials and their substitution for virgin material.

Recyclability at scale can only be assessed on national levels, as the waste management structure is country specific. Currently, there is no harmonised European-wide method for the calculation of the recyclability.

* Sufficient capacity is available

RECYCLING INFORMATION AND DESIGN RECOMMEN-DATIONS

3. RECYCLING PROCESS OF FIBRE-BASED PACKAGING

Recycling of fibre-based packaging enables certain environmental benefits. Depending on the requirements of the actual packaging applications, recycled fibres can be used in combination with or to replace virgin fibres. However, recycled fibres and virgin fibres are not two separate streams but are interconnected and interdependent. With every papermaking (re)cycle, the fibres gradually deteriorate until they may be rejected during preparatory pulp-cleaning process. According to Kreplin, Schabel and Putz (December 2019), thanks to low losses during recycling, fibres from corrugated boxes can be recycled 25 times without experiencing signs of a "recycling collapse". Depending on the specific fibre-based product/fibre type and the corresponding recycling processes and losses during recycling, the average number of cycles can be lower. Introducing virgin fibres helps to maintain pulp volume, quality and mechanical properties.

Recycling processes in paper mills

When reprocessing fibre-based packaging, the process needs to be carefully set up and calibrated to handle the different components from the packaging conversion process. Recycling facilities (mills) for fibre-based packaging diverge from each other in how they handle different types of fibre-based packaging.

Common to all types of paper packaging recycling is a pulping stage which disintegrates the paper and board structure into individual fibres, and several cleaning and screening stages.

a) Standard mills typically treat Old Corrugated Containers (OCC) and/or mixed paper and mainly remove non-paper components and the foreign parts. The output is a brownish pulp.
b) Deinking mills have similar cleaning and screening stages but additionally remove the ink. The inputs are paper and board products on white or off-white substrates. The output is a white or off-white pulp.
c) Specialised mills are using further process steps or different conditions which are not part of the setup of standard mills, to recycle more complex fibre-based packaging. One well-established recycling method used for liquid packing board (typically with two-sided lamination) requires enhanced pulping action and a reject system due to the higher quantities of reject. Similar processes can be adapted and optimised for wet-strength products and those with high non-paper content, they will have a different repulping time and energy consumption.

The suitability of specific recycling processes can be evaluated using the Cepi recyclability laboratory test method and corresponding fibre-based packaging recyclability evaluation protocols listed in Table 3.

Part	Scope	Release (*expected)
Part I	Standard recycling mill	Q4. 2022
Part II	Flotation-Deinking mill	2023*
Part III	Specialised recycling mill	2023*

Table 3. 4evergreen Fibre-based Packaging Recyclability Evaluation Protocol

4. DECISION TREE

The compatibility of fibre-based packaging with the recycling process depends on the type of mill in which it is handled. Packaging may not be recyclable in standard recycling mills but could be easily recycled in flotation-deinking or specialised mills.

The following decision tree is intended to show the users of this guideline in which type of facility the designed or planned packaging can be expected to be processed.

National collection and sorting infrastructure in each country can determine the designation of paper waste fraction to different types of mills. The decision-tree explains in a simplified way how packaging paper waste can reach different types of mills, it not claim to cover all infrastructure scenarios or detailed settings that exist in Europe. A real example is that beverage cartons are likely to be collected via the lightweight packaging stream (e.g. Austria, Germany), but can also be collected via the paper and board stream (as conducted in Italy), in both scenarios they will be recycled in specialised recycling mills for used beverage cartons.

Therefore, it is highly relevant to examine which conditions apply to the distribution country of the packaging.

In addition, a useful source is the Guidance on the improved collection and sorting of fibre-based packaging for recycling published by 4evergreen in September, 2022, which includes more detailed information.

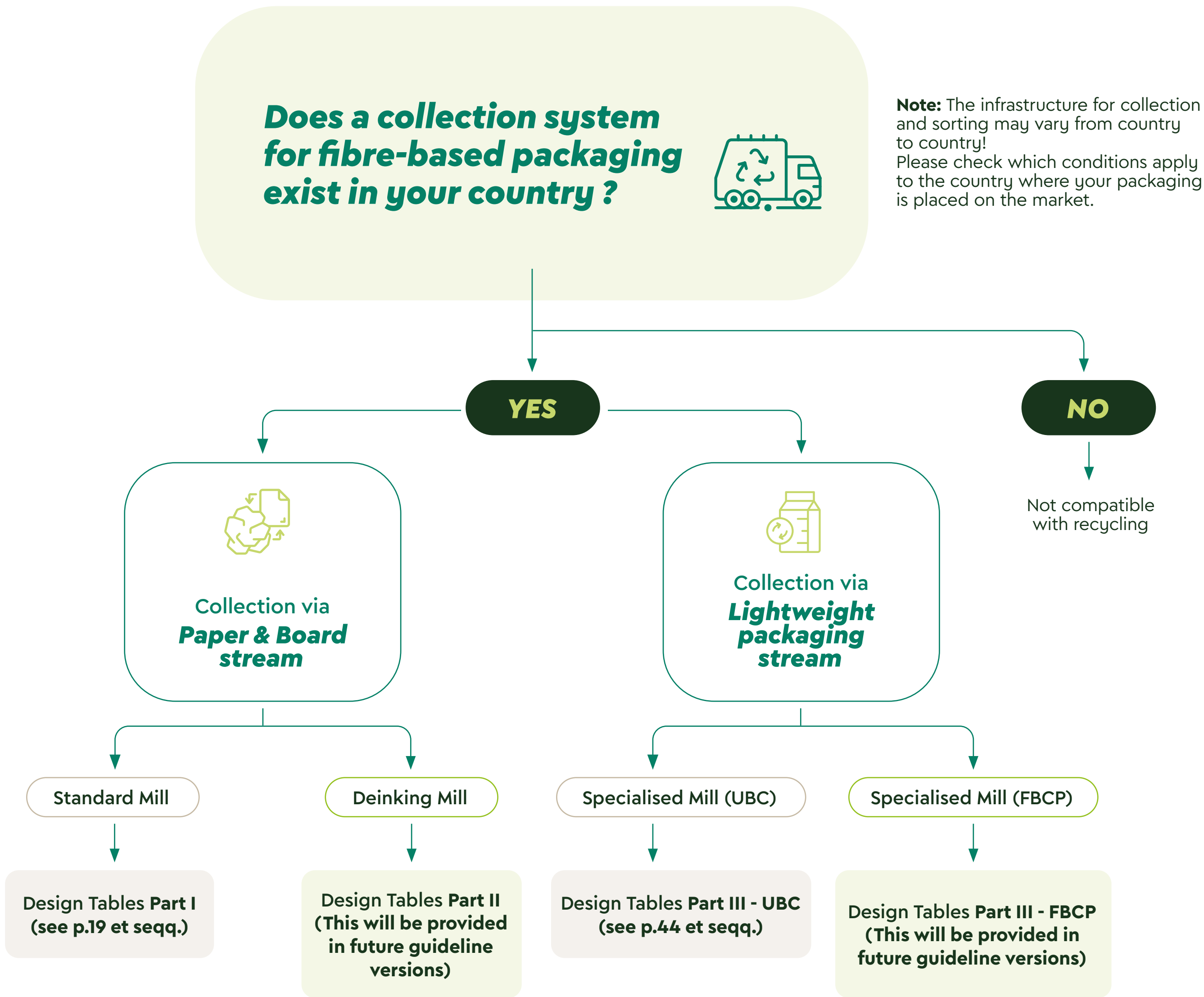
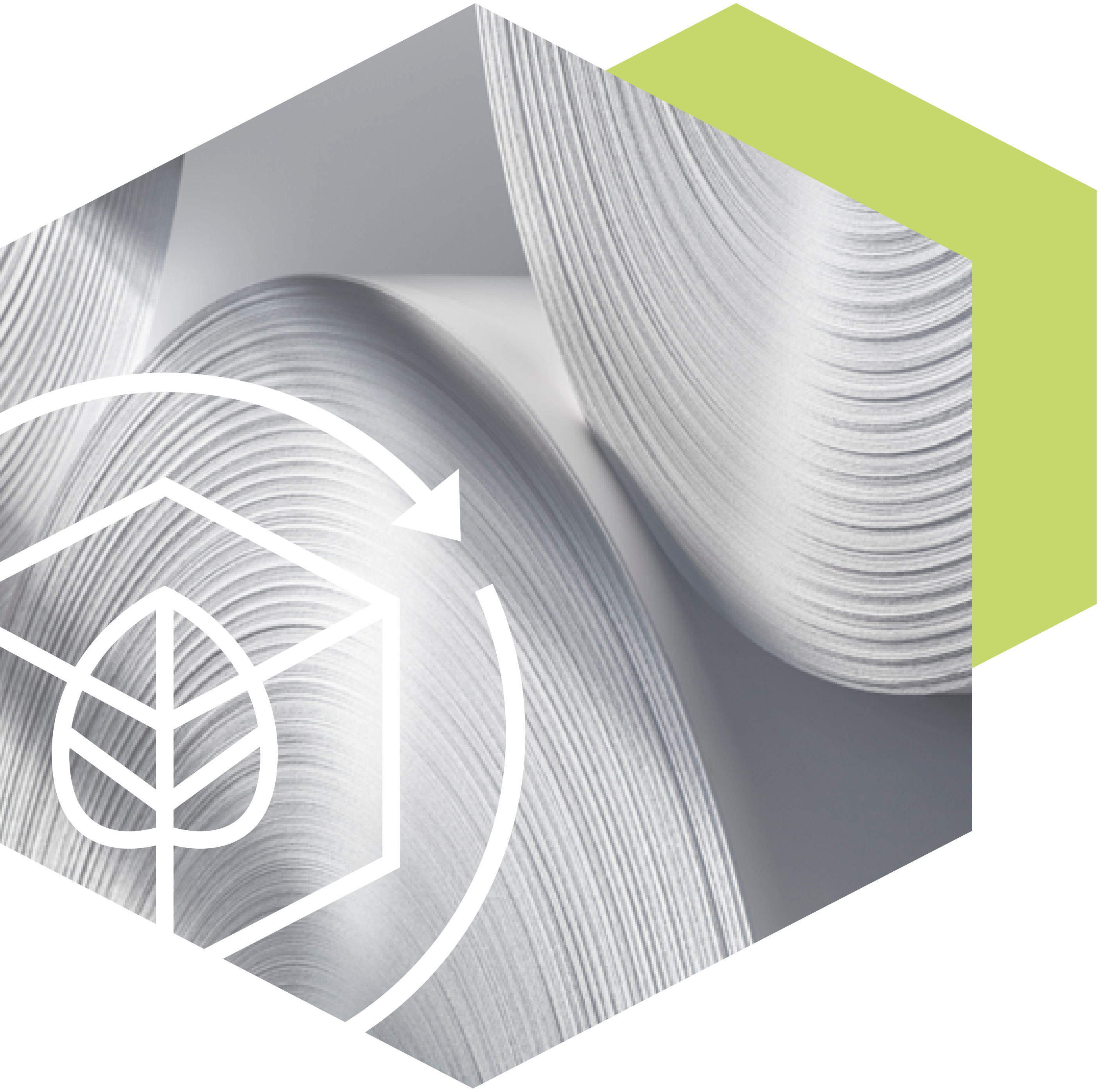


Figure 2. Decision tree

5. PART I — STANDARD RECYCLING MILLS



5.1 Recycling in standard recycling mills

Most standard mills typically utilise the EN 643 grades group 1-4. The fibre-based packaging recycling process typically includes the following steps:

Repulping
The purpose of pulping is to disintegrate the paper and separate fibres from other components. In this step, the paper for recycling is blended with water, the temperature is typically around 40°C and the pH value is typically close to 7 (usually not regulated by addition of acids or alkaline). These mills typically have a low-consistency pulper (5% fibre concentration). The aim of this first step is to desintegrate and seprate fibres from other materials.

Deflakers
Deflakers are used to separate the fibre bundles and break down any pieces of paper that are not defibred properly after pulping.

Coarse and fine screening
Screening is the process of removing impurities from the pulp, to separate the fibres from potential contaminants. This can be divided into coarse and fine screening. Coarse screening can already be implemented after the pulping step itself as the fibre suspension flows through screening holes and large non-fibre particles are retained. The objective of the fine screening is to remove smaller-sized particles.

Packaging examples likely to be recycled in standard mills

Rigid Paper Packaging

- ✓ like boxes, folding cartons, paper tubes, corrugated boxes, single-side coated paper cups
- ✓ with minimal or no proportions of non-paper material
- ✓ not printed or inks not listed in EUPIA exclusion policy

Flexible paper packaging

- ✓ like paper bags, wrappers, sheets
- ✓ with minimal or no proportions of non-paper material
- ✓ not printed or inks not listed in EUPIA exclusion policy

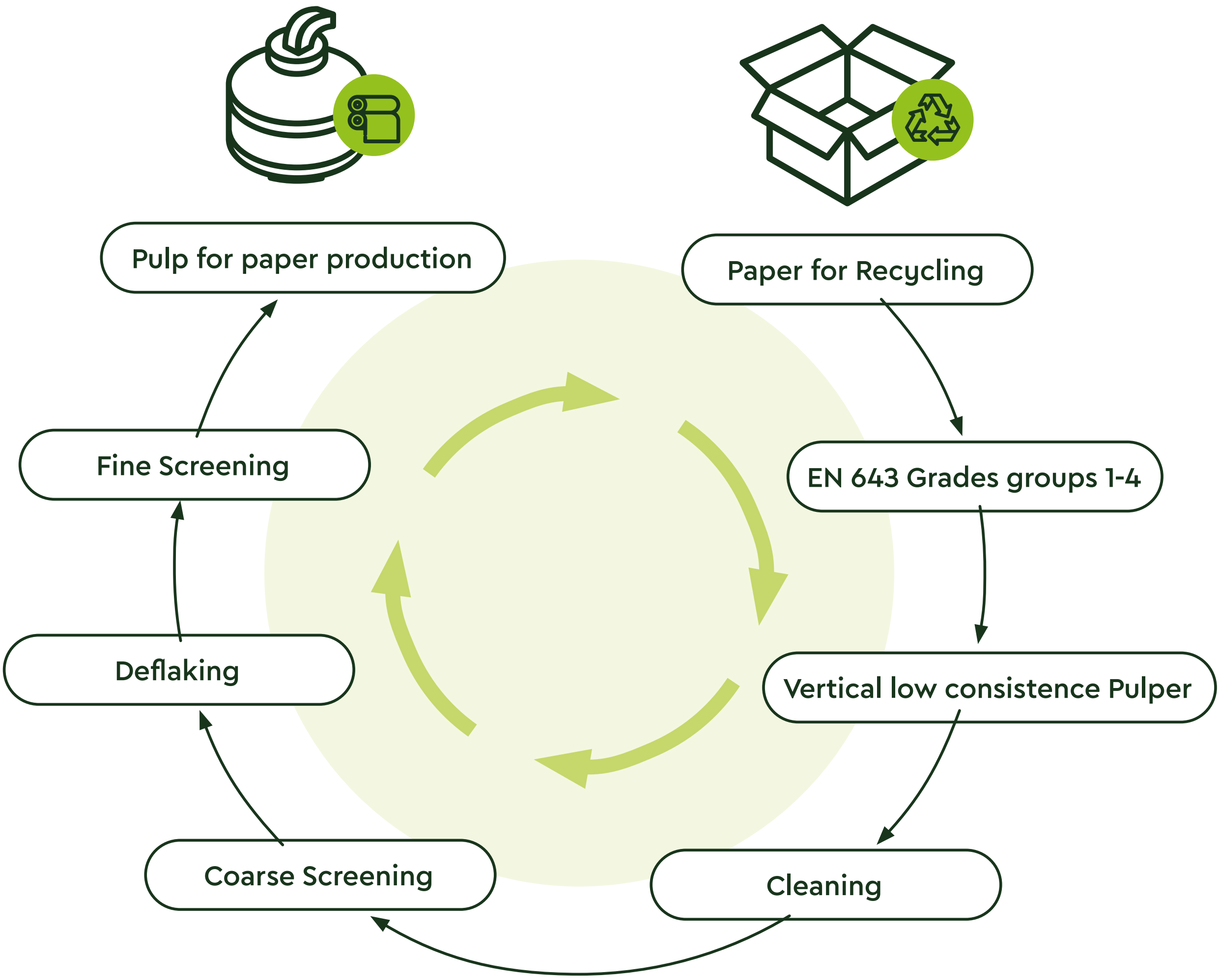


Figure 3. Recycling in standard recycling mills

5.2 Design recommendations (PART I)

The sustainability and circularity of fibre-based packaging is improved by increasing recycling rates. The design recommendations given in this chapter serve as guidance for choosing suitable materials and processes to assure the quality of the recycled fibre.

The key is to explain why and how different components affect the recycling process. Following a "design for recycling" approach helps packaging designers learn which components might have a negative impact on the recycling process, already in the design phase of packaging.

This guideline provides specific design recommendations for certain packaging groups, to help designers refine their designs. The recommendations are presented in a compact design table, for the following materials and components, and their compatibility with the standard recycling process:

- 5.2.1 Fillers, additives, and agents
- 5.2.2 Barrier coatings and treatments
- 5.2.3 Adhesives
- 5.2.4 Inks and varnishes
- 5.2.5 Metallic components
- 5.2.6 Additional components

The guideline also gives some more general advice on choosing the right base material and design packaging to minimise the residual product content in packaging. A corresponding design recommendation chapter for Specialised Recycling processes (PART III) is provided with chapter 7. 2.

The design tables in chapter 5.2 refer to single components categorised as:

- Fully compatible with standard recycling process
- Conditionally compatible with standard recycling process
- Not compatible with standard recycling process
- Compatibility with standard recycling process unknown

NOTE: The given design recommendations are widely based on expert opinion of the entire value chain represented in 4evergreen, and valid for either recycling in standard recycling mills or specialised recycling mills. Actual testing prevails the given recommendations in the guideline, therefore the guideline will be updated in line with recyclability lab test results and the corresponding 4evergreen fibre-based packaging recyclability evaluation protocol (PART I, II and III).

5.2.1 Fillers, additives and agents

Paper and board used in fibre-based packaging mainly consists of virgin fibres from wood pulp and fibres extracted from paper recycling. A certain amount of so-called "processing and functional" chemicals used to achieve different specifications are also present. Some paper (mainly Paper for Recycling, PfR) can contain mineral-based additives like fillers or pigments such as calcium carbonate or clay. Other chemical additives are used as sizing agents, strengthening additives, binders, and other functional additives. The design table below provides a compact overview of fillers, additives and agents used in paper production, and their compatibility with standard recycling process.

NOTE: The given design recommendations are based on expert opinion and valid for recycling in standard recycling mills. Ongoing testing (i.e. 4evergreen Recyclability Evaluation Protocol) is likely to supersede the present recommendations and inform a future update of the guideline.
The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

Component	Sub-category	Fully compatible with standard recycling process	Conditionally compatible with standard recycling process	Not compatible with standard recycling process	Compatibility with recycling process unknown	Comment
Filler/ Inorganic pigments	Clay (kaolin)	⊗				High ash content may have a negative impact on mechanical strength depending on the relative amount in the PfR stream.
	CaCO3	⊗				
	Talc	⊗				
	Titanium dioxide	⊗				
Binder	S/B latex	⊗				
	S/A latex	⊗				Depending on amount, adhesive strength, etc.
	Starch-biobinder	⊗				
Sizing, wet end	AKD	⊗				
	ASA	⊗				
	Rosin	⊗				
Dry strength	Starch	⊗				
	CMC	⊗				
	Polyacrylamide	⊗				
	Guar gum	⊗				
Wet strength	PAE		⊗			Recyclability depends on a number of factors, such as relative wet-strength (WS) level, amount of WS agent, etc. Recyclability can be improved by increased pulping temperature and time, chemicals, high consistency pulping, etc.
	Urea/ Formaldehyde				⊗	Recyclability depends on a number of factors such as relative wet strength level, amount of WS agent etc. Recyclability can be improved by e.g. increased pulping temperature and time, chemicals, high consistency pulping etc.
	Urea/Melamine				⊗	
	Glyoxylated polyacrylamide (GPAM)	⊗				
Sizing, surface	Starch	⊗				

Component	Sub-category	Fully compatible with standard recycling process	Conditionally compatible with standard recycling process	Not compatible with standard recycling process	Compatibility with recycling process unknown	Comment
Other	Colorants/ dye for shading	⊗				Physically recyclable but certain dyes are not approved for food packaging applications and such dyes should be avoided.
	Colorants/ pigments	⊗				
	Polyvinyl alcohol	⊗				
	PAC	⊗				
	Retention polymers	⊗				
	Siliconising agents			⊗		Used, for example, in release papers for labels. Siliconised papers can be recycled in specialised mills yielding high value fibres.

Table 4. Part I - Design recommendations additives, fillers and agents

5.2.1.1 Fillers, additives and agents used in fibre-based packaging

Retention agents
Retention agents are those added in the wet-end of the paper machine that improve the retention of fine fibre particles, fillers and other additives, while increasing the "runability" of the paper machine. They are not intended to have any impact on the paper and board properties.

Fillers
Fillers are used to improve the optical properties, such as opacity, printability and brightness, but can also be used as volume filler in terms of hydrous kaolin (Gliese and Kleemann, 2013; McLain and Ingle, 2009). However, there are normally processes, additives and equipment in place to reduce potential strength-loss effects, e.g. screening and chemicals can be used to compensate for the strength loss.

OBAs and Colorants
Optical brightening agents (OBA) absorb and emit light in the visible spectrum, which makes paper appear whiter (Gliese and Kleeman, 2013). Soluble colourants (dyes) can also be used to give paper a certain shade and colour effect. Colourants for light shading and OBAs do not have any significant negative effect on the technical recyclability, but their fit for use in food packaging needs to be reviewed in light of the prevailing regulations and research.

Dry strength additives
Various strength additives are added to paper and board to improve the mechanical properties of the paper in its dry state such as tensile, burst and compression strength.

Wet-strength agents
Wet-strength agents are used to enhance the strength of paper and board in wet/humid conditions.
Technically, a distinction needs to be made between temporary and permanent wet-strength agents. Temporary wet-strength paper loses some of its strength after a certain period in wet conditions. Permanent wet-strength paper retains its strength over time.

Sizing agents
Sizing agents are used to give temporary hydrophobic properties to the fibres resulting in an even and controlled absorption of liquids. This is important for further converting processes such as printing and barrier coating. Sizing can have short-term positive effects on the water resistance of the paper as it decreases/delays water absorbing into the fibre structure.

Grease resistance agents
For grease resistant/greaseproof paper and board a barrier or treatment can be applied to allow greasy, fatty and oily food to be packed in direct contact with paper. Common chemicals used as surface treatment for greaseproof paper are starch and carboxymethyl cellulose (CMC) which can be applied at the wet-end of the paper machine.

Silicone treatment agents
For siliconised paper there are two main grades of silicone treatment on the market; glassine paper which is "super-calendered" and "uncalendered" types like clay coated or machine-glazed (MG) paper. The silicone used for these paper types is present as a solid and insoluble with high thermal stability. Siliconised paper is used as "release paper" and also for grease-proofing.
Binders in dispersion coatings
Binders are usually used in pigment dispersion coatings applied in the papermaking process, as they bind pigments together and fix them on the base paper. The binders ensure that the coating withstands the stress during production, converting, and use. Commonly used materials are latex, starch, polyvinyl alcohol, and carboxymethyl cellulose (CMC) (Sangl, 2013).

Pigments in dispersion coatings
Pigments are often used in coatings and should meet further treatment and printing process requirements. The use of dispersion pigment coatings improves the optical properties, such as opacity and brightness, as well as the printability of paper and board (Gliese and Kleemann, 2013).

5.2.1.2 Effect on the recycling process and general recommendation for recyclable design

The combination of paper and board with fillers and chemical additives must be implemented in a way that does not hamper recycling while ensuring that the expected functionality of packaging is fulfilled.

Most paper and board constituents are fully compatible with existing recycling technologies, but outside that, the key is to give preference to packaging materials that do not limit future or end uses of the recycled fibre This means, they don't contain substances considered by the EU's REACH regulation to be of "very high concern", for example rendering them unsuitable for food contact, and/or accumulating over several cycles.

Use only the required quantity of wet-strength agents to fulfil the expected functions of the packaging Consider replacing fluorochemicals with other alternatives due to their environmental concerns Use special paper and board treatments only for applications where such functionality is absolutely necessary That way, it keeps their presence in Paper for Recycling at a manageable level – as in standard recycling processes – so no specialised process is required for recycling which increases the probability of being recycled.

For fibre-based packaging material that have no (or low) compatibility with standard processes there are potentially EN 643 grades defined (grades 5 XX) which enable recycling in specialised mills with dedicated processing setups.

5.2.2 Barrier Coatings and Polymer Content

Fibre-based packaging including paper and paperboard do not have intrinsic barrier properties. Barriers are required to provide adequate protection to food and non-food goods from external factors, such as moisture caused by high relative humidity, oxidation, contamination introduced through mineral oils, and other hazardous substances. To ensure an appropriate level of protection, minimising food loss and ensuring the safety of the packed product, fibre-based packaging is "functionalised" – which means treatments like coatings and lamination (polymeric barrier layers) are applied. Typical examples include but are not limited to polyethylene (PE) extrusion coating, polyester (PET) and metallised polyester (mPET), adhesive lamination, and dispersion coating (using different polymers and formulated latexes).

The following design table aims to give a compact overview of typical barrier coatings and treatments used in industry and their compatibility with standard recycling processes.

NOTE: The given design recommendations are based on expert opinion and valid for recycling in standard recycling mills. Ongoing testing (i.e. 4evergreen Recyclability Evaluation Protocol) is likely to supersede the present recommendations and inform a future update of the guideline. The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

Component	Sub-category	Fully compatible with standard recycling process	Conditionally compatible with standard recycling process	Not compatible with standard recycling process	Compatibility with recycling process unknown	Comment
Extrusion barrier coating	Thermoplastic (one side coated, inside the pack only)	⊗	⊗			The outside lamination will predominantly affect the sorting process (as it is detected by NIR), in very few cases is the inside lamination detected by NIR. The method is considered fully or conditionally compatible with recycling, until further information from the Cepi recyclability laboratory test method is available.
	Thermoplastics (two sides coated)			⊗		This is considered as not compatible with the standard recycling process until further information from Cepi recyclability laboratory test method is available. It can only be recycled in specialised recycling mills with a dedicated pulper.
Adhesive barrier film	Adhesive lamination with water-soluble adhesives (among others some grades of PVOH, starch, etc.)	⊗				Needs thorough cleaning in the milling to prevent issues like foam forming. The COD load will be higher for soluble polymers.
	Adhesive lamination (inside of pack) of PET, mPET, PET/PE etc.		⊗			This is more challenging than extrusion barrier solutions: the polymer will penetrate more deeply into the fibre and have an effect on fibre yield. The thickness and strength of the lamination foil are difficult to ascertain; adhesives tend to increase the potential of stickies.
	Lamination with Alu containing film (6 micron +) (Alu/PE or PET/Alu/PE) etc.		⊗			Alu may impact on induction-based flowmeters and lead to metal being detected in the finished product.
	Lamination that is designed to be peeled easily by consumer	⊗				Considered to have no impact on recycling if separated by consumer, though not the same as one side extrusion coating.
Wet-barrier coatings	Aqueous polymer dispersions (among others some grades of acrylics, EEA, SB, ABS, PVDC, etc.)	⊗	⊗			Testing required, as properties of polymer dispersion coatings depend on the amount and strength of the adhesives and the presence of fillers.
	Solvent-based coatings	⊗	⊗			Testing required.
	Wax dispersion (incl. microcrystalline waxes)		⊗			This is expected to have a potential impact on stickies.
	Water soluble coatings (among others some grades of PVOH, EVOH EVA Biobased, etc.)	⊗	⊗			Needs thorough cleaning in milling to prevent issues like foam forming. The COD load will be higher for soluble polymers.

Component	Sub-category	Fully compatible with standard recycling process	Conditionally compatible with standard recycling process	Not compatible with standard recycling process	Compatibility with recycling process unknown	Comment
Wax coatings	**Dipping of paper in molten wax (two sided)**		⊗			May impact on stickiness and cause screen clogging.
Barrier metalliza-tion	**Direct metallization (Primer, Alu nanoscale, Protective coating) - inside**		⊗			May have a "stardust" effect in visual appearance, plus potential stickiness issues and yield impact, which depends also on the overall amount (testing required).
	Transfer metallisation (adhesive + transfer metallisation) - Inside		⊗			May have a "stardust" effect in visual appearance, potential stickiness issues and yield impact, which depends also on the overall amount (testing required).

Table 5. Part I- Design recommendations barrier coatings and polymer content

5.2.2.1 Barrier applications used in fibre-based packaging

There is no widely adopted or standardised classification of polymeric treatments, coatings, and laminations, which are used to create barrier properties on paper, thus the classification below has been put forward and validated by experts acting in 4evergreen:

- Extrusion barrier coatings
- Adhesive barrier film lamination
- Wet (water-based and solvent-based dispersions and solutions) polymeric coatings
- Wax coatings
- Barrier metallisation treatments
- Fluorinated barrier/repellent coatings (not a polymer per se, but allocated to this group on the basis of their function)

These coatings can be applied online during the papermaking process using blade, rod, curtain, or similar applications, offline at the paper mill using dedicated coating assets, or offline using typical converting equipment and processes such as extruders, gravure coating, lamination, etc.

Extrusion and co-extrusion barrier coatings

Extrusion is the process of applying molten polymer (LDPE, LLDPE, PLA, etc.) or polymers (PE-EVOH-PE, etc.) to paper or paperboard where adhesion between two layers is achieved via mechanical interlocking and the formation of hydrogen and covalent bonds between polymer and cellulosic fibres. The typical thickness of the polymeric layer, as applied, ranges from 8 to 40 microns.

Extrusion coatings in this guideline are classified as follows:

- One-side thermoplastic film extrusion coating of paper and board
- Two-side thermoplastic film extrusion coating of paper and board
- Water-soluble extruded coatings (among others some grades of PVOH, EVOH EVA Biobased, etc.)

Adhesive lamination with barrier films

Paper and board can be laminated with blown or cast polymeric films such as PET, OPP, Cellophane, etc. using water-based, solvent-based, or solventless adhesives, such as polyurethane, polyvinyl alcohol, polyvinyl acetate, ethylene vinyl acetate, to create a barrier and sealing functionality.

Adhesive lamination with barrier films in this guideline are classified as follows:

- Adhesive lamination with water-soluble adhesives (PVOH, starch, etc.)
- Adhesive lamination (inside of pack) of PET, mPET, PET/PE, etc.
- Lamination with aluminium-containing film (6 microns+) (Alu/PE or PET/Alu/PE)
- Lamination that is designed to be peeled by consumers

Peelable and tear-off solutions are recommended for the packaging formats where contamination with the food residuals is inevitable (chilled and frozen ready meals, rigid containers for pet food, etc.) and where plastic films are used as windows and cannot be replaced by alternative materials. In this case, contaminated plastic liner and residual paper or paperboard structure shall be disposed of separately. Peelable solutions can only be used where clear instructions on how to dispose of the materials are communicated on the pack.

Wet-barrier coatings
Wet-barrier coatings can be either water-based or solvent-based and represented either by polymer particle dispersions (also known as latexes or binders), colloidal and real solutions of polymer in water, or organic solvents. Water-based coatings include polymers like polyvinylidene chloride (PVDC), acrylics, styrene butadiene copolymers, vinyls, etc. The total coating amount can vary between 5 and 20 g/m². Solvent-based coatings include polyesters, polyurethanes, polyvinyl alcohol and nitrocellulose which typically dissolve in ethyl acetate. Typically, these coatings can be applied to a substrate using different technologies like curtain coating, printing or spraying the coating onto the surface. Wet coatings allow film formation of as little as 1-2 micron thickness, and so are easier to separate from fibre, which makes recycling easier compared to laminated materials.

Wet-barrier coatings in this guideline are classified as follows:

- Aqueous polymer dispersions (among others some grades of acrylics, EEA, SB, ABS, PVDC, PVOH etc.)
- Solvent-based coatings
- Wax dispersion coating (incl. microcrystalline waxes)
- Water-soluble coatings (among others some grades of PVOH,EVOH, EVA Biobased, etc.)

Wax coating (dipping paper in a molten wax bath)
Waxing paper is a traditional process where paper is given waterproofing properties ("hydrophobized") by passing it through a bath of melted wax. This process was used before the introduction of new methods such as extrusion coating with PE. It typically utilises paraffin wax, which is blended with PE or EVA.

Barrier metallisation
Metallisation has been traditionally used for decorative effects on paper. Recently, however, direct and transfer metallisation processes have been explored as a method of inducing effects or properties on paper, such as light, water vapor and oxygen barriers. For barrier-direct metallised paper, the metallisation is usually applied on the inside of the pack and composed of aqueous dispersion coating combined with an approximately 50 nm-thick (ca. 0.14 g/m2) aluminium layer that is applied in a vacuum deposition process. The metallisation is transferred on paper using adhesive (acrylic, polyurethane, EVA, etc.) courtesy of release-coated PET film. The overall polymer thickness and protective layers, along with metallisation, is usually not more than 5 µm.

Barrier metallisation coatings in this guideline are classified as follows:

- Direct metallisation (primer, Alu nanoscale, protective coating)
- Transfer metallisation (adhesive and transfer metallisation)

Fluorinated barrier/repellent coatings (wet end or surface application)
Fluoroalkyls are applied in the wet-end of the paper machine as well as on the surface of the substrate. Though fluorinated coatings are fully compatible with recycling, it is recommended to avoid their usage due to the potential food safety and environmental (bio-persistence) concerns. Fluorine content in the wastewater and sludge may be controlled more stringently in the future, which may lead to challenges for paper mills.

5.2.2.3 Effect on the recycling process and general recommendation for recyclable design

The introduction of barriers in fibre-based packaging may have negative impacts on recyclability, for example:

- Decrease recycling yield of fibre-based packaging by reducing the share of the recoverable fibres in the overall weight of the packaging
- Increase in the repulping time and decrease in fibre yield due to the complicated separation of fibres from the polymeric matrix
- Reduction in coarse and fine screening capacity, and impact on wastewater quality (COD , BOD, etc.)
- Sticky deposits which may lead to increased paper machine breakdowns (downtime)
- Impact on the visual appearance of the finished recycled paper product
- Interference with magnetic induction-based flowmeters and web visual inspection devices

The extent of these impacts defines whether the fibre-based packaging material is considered to be compatible with a standard recycling process. This is typically operating with OCC and mixed paper (from separate collection) paper grades. Otherwise, the material would need to be recycled at a mill with special equipment to mitigate the effects of barriers being present.

5.2.3 Inks and varnishes

Printing inks are used to colour the substrate surface to produce an image, text or design. They are composed of colorants, binders, additives and diluents (i.e. substances used for dilution). Colorants are responsible for the colour impression and consist mostly of organic or inorganic pigments. Binders contain polymers, which wrap and stabilise the pigment particles in the ink mixture and fix the pigment on the substrate. They determine the ink properties depending on packaging application, printing technology and ink chemistry. Additives are used to fine-tune the ink properties towards the desired application. The diluent dissolves the binder and determines the flow properties of

NOTE: The given design recommendations are based on expert opinion and valid for recycling in standard recycling mills. Ongoing testing (i.e. 4evergreen Recyclability Evaluation Protocol) is likely to supersede the present recommendations and inform a future update of the guideline. The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

Component	Sub-category	Fully compatible with standard recycling process	Conditionally compatible with standard recycling process	Not compatible with standard recycling process	Compatibility with recycling process unknown	Comment
Offset	Oil-based (mineral)	X				Inks based on mineral oils are fully compatible with the recycling process. Due to legal restriction, the use of the recovered fibers is limited to non-food applications. Therefore, the use of mineral oil-based inks is not recommended for food-applications.
	Oil-based (vegetable)	X				
	Ultra-violet cured/ EB-cured	X				
Flexo	Solvent-based	X				
	Water-based	X				
	Ultra-violet cured	X				
Gravure	Solvent-based	X				
	Water-based	X				
	Ultra-violet cured	X				
Varnish	Solvent-based	X				
	Water-based	X				
	Ultra-violet cured	X				
	Two component	X				
Digital	Water-based	X				Digital printing technologies emerging; continuous surveillance required
	Ultra-violet cured	X				
	Liquid toner	X				
	Solid toner	X				
	Hot melt				X	Testing is required
Screen	Ultra-violet cured	X				

Table 6. Part I - Design recommendations inks and varnishes

the ink in order to ensure a good transfer to the substrate. Typical diluents are water, oil and organic solvents.

Varnishes are unpigmented systems and contain binders, additives and solvents. They have a variety of functions. As a medium, varnishes are added to the ink during printing to adjust the pigment concentration. Applied as a primer, varnishes help to improve the printout behaviour of inks. The most common application of varnishes is their use as overprint varnishes (OPVs). OPVs have a huge variety of functions, including protection against mechanical and environmental factors and decorative finishes to printed surfaces (gloss, matt, haptic, etc.). If varnishes have a barrier function they are treated as barriers, as described in chapter Barrier coatings and polymer content.

The following design table aims to give a compact overview of typically used inks and varnishes in the industry and their compatibility for the standard recycling process. The design areas with high share of carbon black-based inks or metallic inks might cause problems in the sorting process. Sorting tests are thus needed to define the exact threshold for each individual packaging.

5.2.3.1 Inks and varnishes used in fibre-based packaging

Oil-based
Oil-based inks and varnishes contain either mineral or vegetable oils, or vegetable esters as solvent. Used mainly in offset printing, these inks and varnishes dry either physically by the solvent evaporating or by oxidation using dryers.

Solvent-based
Solvent-based inks and varnishes use organic solvents (alcohols, esters, etc.) and are used in gravure and flexographic printing. Solvent-based systems dry physically by the solvent evaporating.

Water-based
Water-based inks and varnishes use water as a solvent and are applied in gravure, flexographic and digital printing. Water-based systems dry physically by the solvent evaporating.

UV-curing
UV-curing inks and varnishes are solvent-free systems. They use monomers (acrylates) as a diluent, which polymerise with the aid of photo initiators and under irradiation (UV-light).

EB-curing
As with UV-curing systems, EB-curing inks and varnishes are solvent-free and contain monomers. EB-systems do not contain any photo initiators. The polymerisation is initiated using a high-energy electron beam.

2K-varnishes
These systems consist of the varnish itself formulated with a special binder and a hardener. The hardener is added to the varnish prior to printing to set off the polymerisation process.

Liquid and dry toner
Liquid and dry toners are used in electrophotographic digital printing and are composed of pigments, resins, and various additives. For dry toner, magnetisable metal oxides may also be present. In contrast to dry toners, liquid toners use a carrier liquid to disperse the pigments and resins. The toner is transferred from a photoconductor to the substrate and then fixed by applying heat and/or pressure.

5.2.3.2 Effect on the recycling process and general recommendation for recyclable design

Printing inks and varnishes can be subject to two different recycling processes: (1) recycling including a flotation process to separate ink particles from the paper fibres (recycling process with deinking); and (2) recycling without a flotation process where the ink particles remain in the pulp (standard recycling process).

In this version of the guideline, only the compatibility of inks and varnishes for the standard recycling process and specialised processes is considered. Recommendations including the compatibility for recycling in deinking mills will be implemented in further versions.

Based on industry feedback, inks and varnishes as classified in Table 6 typically do not cause problems in mechanical recycling. This is confirmed by a study conducted by FFI/PTS, Recyclability of Folding Cartons and Material Combinations (October 2020).

5.2.4 Adhesives

In today's packaging industry, a wide range of adhesives is used to form, seal and close fibre-based packaging. As adhesives fulfil many different needs in modern packaging, multiple chemistries and application technologies have been developed.

The following design table aims to give a compact overview of the most typically used adhesives in the industry. However, other applications / chemistries exist that also fulfil the technical and recyclability requirements.

NOTE: The given design recommendations are based on expert opinion and valid for recycling in standard recycling mills. Ongoing testing (i.e. 4evergreen Recyclability Evaluation Protocol) is likely to supersede the present recommendations and inform a future update of the guideline. The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

Component	Sub-category	Fully compatible with standard recycling process	Conditionally compatible with standard recycling process	Not compatible with standard recycling process	Compatibility with recycling process unknown	Comment
Corrugated board making	Starch-based	⊗				# for hotmelts with suitable softening point (higher than 68 °C according to DIN EN 1427:2015) and applied larger than 1,6mm in diameter (see EPRC scorecard for the removability of adhesives) * Only valid for materials with a positive rating according to Cepi recyclability laboratory test method, 2022. Existing positive results according to the legacy methods such as but not limited to Aticelca MC501:2019, Cyclos-HTP CHI-PTS-C6/2.0, Ingede 12 and PTS-RH:021/97 should also be accepted.
	PVA	⊗				
Window patching	Hotmelt	⊗ #				
Box-making	Hotmelt	⊗ #				
	Protein Glues				⊗	
Side seaming	Starch-based	⊗				
Box closing/ End-of-line	Hotmelt	⊗ #				
Palletising	Pressure sensitive hotmelt	⊗ *				
Cross-pasting (sacs)	Starch-based	⊗				
	PVA	⊗				
Bottom pasting (sacs)	Starch-based	⊗				
	PVA	⊗				
Handle making and patching (bags)	PVA	⊗				
Lamination	Starch-based	⊗				# for hotmelts with suitable softening point (higher than 68 °C according to DIN EN 1427:2015) and applied larger than 2mm in diameter (see EPRC scorecard for the removability of adhesives)
	Protein glues, Acrylic, Other dispersions, UV curing acrylics, Polyurethanes				⊗	

Component	Sub-category	Fully compatible with standard recycling process	Conditionally compatible with standard recycling process	Not compatible with standard recycling process	Compatibility with recycling process unknown	Comment
Litho-lamination	PVA	⊗				* Only valid for materials with a positive rating according to Cepi recyclability laboratory test method, 2022. Existing positive results according to the legacy methods such as but not limited to Aticelca MC501:2019, Cyclos-HTP CHI-PTS-C6/2.0, Ingede 12 and PTS-RH:021/97 should also be accepted.
Cold seal	Natural rubber latex	⊗ *				
Heat seal	PVA	⊗ *				
	Acrylic	⊗ *				
	Hotmelt				⊗	
Water-based labelling	Protein Glues				⊗	
	Acrylic				⊗	
Pressure sensitive applications (self-adhesive labels, tapes)	Pressure sensitive emulsion acrylics	⊗ *				
	Pressure sensitive hotmelt	⊗ *				
	Pressure sensitive UV-curable acrylic adhesives	⊗ *				
	Water-based adhesives	⊗ *				
Pressure sensitive closures	Pressure sensitive hotmelt	⊗ *				
	Pressure sensitive UV-curable acrylic adhesives	⊗ *				
	Water-based adhesives	⊗ *				
Bonding of supple-ments	Hotmelt	⊗ #				
	Polyurethane hotmelt	⊗ #				
Multipack attachment	Hotmelt	⊗ #				# for hotmelts with suitable softening point (higher than 68 °C according to DIN EN 1427:2015) and applied larger than 2mm in diameter (see EPRC scorecard for the removability of adhesives) * Only valid for materials with a positive rating according to Cepi recyclability laboratory test method, 2022. Existing positive results according to the legacy methods such as but not limited to Aticelca MC501:2019, Cyclos-HTP CHI-PTS-C6/2.0, Ingede 12 and PTS-RH:021/97 should also be accepted.
	Pressure sensitive hotmelt	⊗ *			⊗	
	Water-based adhesives	⊗ *				
	Pressure sensitive acrylic adhesive	⊗ *				
	UV-curable acrylic adhesives	⊗ *				

Table 7. Part I - Design recommendations adhesives

5.2.4.1 Adhesives used in fibre-based packaging

The following section aims to provide a simple classification of the different adhesive types based on whether they are cold-applied water-based adhesives, hotmelt adhesives, or reactive adhesives.

Water-based adhesives
Water-based adhesives can be solutions or dispersions. They are applied as liquids at room temperature or slightly elevated temperature to the paper substrates. These adhesives set when the water evaporates and/or it is absorbed (penetrates) into the substrate. Dispersion adhesives therefore usually require at least one porous, water-absorbent surface but no additional drying. Unless they are used for pressure sensitive applications, they are not sticky after drying.

Water-based adhesives in this guideline are classified as follows:

- Water-based adhesives based on natural polymers
- Water-based adhesives based on synthetic polymers
- Acrylic

Hotmelt adhesives
Hotmelt adhesives are heated before their application to form a "melt", typically at temperatures well above 100°C. The adhesive is then applied in liquid (molten) form to the substrate(s). A physical setting or hardening takes place during cooling and converts the liquid hotmelt back into a solid.

Hotmelt adhesives in this guideline are classified as follows:

- (Non-pressure sensitive) hotmelts
- Pressure sensitive hotmelts

Reactive adhesives
Reactive adhesives, as their name suggests, do not rely on a purely physical setting process. They contain elements that react chemically within the adhesive itself and in certain cases also with the substrate surface.

The chemical reaction leads to very resistant final adhesive applications. Once cured, reactive adhesives can generally not be dissolved in water or softened by temperatures that are encountered during the paper recycling process.

Reactive adhesives in this guideline are classified as follows:

- UV-curing adhesives
- Polyurethanes

5.2.4.2 Effect on the recycling process and general recommendations for recyclable design

As they make up only a small weight percentage of any given item they are used in, adhesives themselves are today not the target of any recycling process and they are therefore not as such considered "recyclable". At the same time, adhesives can impact the yield and quality of the recycling processes of their substrates, such as paper and paperboard. Consequently, adhesives should be suitably compatible with these processes to allow successful and effective recycling of the base materials. Compatibility refers to adhesive applications being designed in such a way that they neither cause unacceptable impacts on the recycling process nor unacceptably deteriorate the quality of the output.
As a general principle, as for all non-target materials of a recycling process, the amount of adhesives used in a given paper or paperboard item should be optimised to the minimum amount required to achieve its function. Doing so will minimise the amount of adhesive that the recycling process needs to handle. To facilitate easy removal of adhesive applications, they should, where technically possible, be made large enough to be screened out effectively. Very thin film applications should be avoided because they could be less resistant to shear forces introduced in pulping, resulting in very small particles that can't be removed by screening.

5.2.5 Decorative metallic components

In order to increase the functionality and visual appearance of paper, decorative metallisation is a suitable method to achieve various paper properties. Metallised paper is widely used in food packaging, tobacco packaging, and labelling. As demand for flexible packaging is constantly increasing, the use of metallised fibre-based products is growing as well (Dahlgren et al., 2015).

The following design table aims to give a compact overview of typically decorative metallic elements used in the industry and their compatibility with standard recycling process.

NOTE: The given design recommendations are based on expert opinion and valid for recycling in standard recycling mills. Ongoing testing (i.e. 4evergreen Recyclability Evaluation Protocol) is likely to supersede the present recommendations and inform a future update of the guideline. The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

Component	Sub-category	Fully compatible with standard recycling process	Conditionally compatible with standard recycling process	Not compatible with standard recycling process	Compatibility with recycling process unknown	Comment
Decorative metallic components	hot and cold transfer	⊗				Designers should not cover the surface of fibre-based products fully with metallization, as this could cause issues regarding the detection as fibre product.
	PP/PET metallised laminates			⊗		In the case the metallised film is covering the full surface , as this could affect the sorting process (only if NIR detection will detect the metallized side).
	PET metallised film			⊗		In the case the metallised film is covering the full surface , as this could affect the sorting process (only if NIR detection will detect the metallized side).
	Direct Vacuum Metallized Paper		⊗			The outside metallization could affect the sorting process (only if NIR detection will detect the metallized side)
	Direct metallisation		⊗			Designers should not cover the surface of fibre-based products fully with metallization, as the outside metallization could affect the sorting process (only if NIR detection will detect the metallized side).

Table 8. Part I - Design recommendations decorative metallic components

5.2.5.1 Decorative metallic components used in fibre-based packaging

The following methods are used to metallise papers, after the papermaking process:

- Direct metallisation
- Hot and cold foil stamping
- Printing (see chapter 5.2.3 Inks and varnishes)

5.2.5.2 Effect on the recycling process and general recommendation for recyclable design

Metallic components with a thickness lower 1 micron do not cause any issue during the recycling process, but the recognition of these papers during the sorting process is crucial. If the papers' surface is not fully covered with metallic decoration, it will not cause major issues regarding the detection as fibre product and end up in the right recycling stream. If the surface is covered with a very high share of metallization, it may cause detection issues, as the metallic effect reflects the NIR light, and the fibre-based packaging may end up in the wrong recycling stream during sensor-based sorting.

To mitigate this issue, it is recommended to:

- minimise the percentage of plastic used it is recommended to use hot stamping or cold transfer instead of lamination.
- Designer should not fully cover the fibre-based packaging with metallization to avoid problems during the sorting process

5.2.6 Additional Components

The following design table aims to provide a compact overview of typical additional components used to improve the functionality of fibre-based packaging.

NOTE: The given design recommendations are based on expert opinion and valid for recycling in standard recycling mills. Ongoing testing (i.e. 4evergreen Recyclability Evaluation Protocol) is likely to supersede the present recommendations and inform a future update of the guideline.
The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

Component	Sub-category	Fully compatible with standard recycling process	Conditionally compatible with standard recycling process	Not compatible with standard recycling process	Compatibility with recycling process unknown	Comment
Security label	Fibre-based	⊗				
	Polyolefins		⊗			
	PET		⊗			
Pull strip	Fibre-based	⊗				
Windows	Cellulosic based				⊗	Strongly attached windows should be avoided[2]
	Polyolefins		⊗			
	PET		⊗			
Carrying handle	Fibre-based	⊗				
	Polyolefins		⊗			
	PET		⊗			
	Metal			⊗		
Zipper	Polyolefins		⊗			
	PET		⊗			

Table 9. Part I Design recommendations additional components

2 https://thecpi.org.uk/library/PDF/Public/Publications/Guidance%20Documents/CPI_guidelines_2022-WEB.pdf

5.2.7 Base material and alternative fibres

Wood-based fibres (chemical and mechanical pulp fibres) are traditionally the primary or dominant resource for fibre-based packaging in Europe, hence the majority of mills have been designed and are optimised to handle wood-based fibres. The structure and composition of wood fibre is especially suitable for the production of paper and board. Both hardwood (aspen, birch, eucalyptus) and softwood (pine, spruce) types are utilised to give fibre-based packaging various properties (Holik, 2013).

Alternatives to wood-based fibres can be sourced mainly from bagasse, bamboo, straw, grass and other plant fibres. The compatibility with the recycling process of the various alternative fibres is the subject of ongoing investigation.

5.2.7.1 Effect on the recycling process and general recommendation for recyclable design

Most mills are set up to reprocess wood-based fibres, hence manufacturers are encouraged to use wood fibres. The multitude of existing and alternative fibres as well as newly evolving materials requires further recyclability testing for the individual packaging.

5.2.8 Product Contamination (residual content)

Product residues (food and non-food) present in the packaging at the moment of disposal may result in contamination of the recovered fibres, which potentially affects the recycling process and pulp quality. The main reason for concerns regarding contamination of the recovered fibres, especially when it comes to food safety issues, are:

- Excessive microbial growth leading to contamination of the finished paper product
- Increased risks of infestation with insects and rodents
- Increased load on wastewater treatment plants due to increased soluble matter

Even though various well-proven and effective techniques are available for reducing the contaminant, it is impossible to completely eliminate the presence of product residuals in fibre-based packaging. Minor contamination and/or staining are tolerated by most recyclers as long as it does not cause severe microbial growth in collected paper material.

5.2.8.1 Effect on the recycling process and general recommendation for recyclable design

To ensure that the residual content of the packaging does not hinder the recycling process, packaging design should make it as easy as possible to completely empty the contents. As such, the following aspects should be taken into consideration:

- If the packaging format allows, provide a tear-off or other facility to separate and remove the contaminated layer from the fibre-based packaging after use
- Design should enable cleaning of the surface in contact with food (when applicable, design the opening in a way that the surface in contact with food is accessible, so the food can be taken out as completely as possible)
- End-users should be informed to remove product residues from the packaging before disposal (i.e. producers or product distributors need to ensure that the packaging offers information on how to handle residues prior to disposal)

6. PART II — RECYCLING IN FLOTATION DEINKING RECYCLING MILLS

IT IS IMPORTANT TO NOTE

It is important to note that recommendations for fibre-based packaging that require reprocessing or are expected to be sorted into the stream recycled in flotation-deinking recycling mills are currently under development in 4evergreen, thus not included in the design recommendations tables of this guideline. The implementation of deinking mills will follow in updated versions.

7. PART III — RECYCLING IN SPECIALISED RECYCLING MILLS

7.1 Recycling in specialised mills

A different recycling process is used for fibre-based composite packaging designed to meet more demanding performance criteria in the cases of liquid packaging board, beverage cartons and double-side coated paper cups or when additional elements or additives, or higher pulp quality is required for the end product.

Mills with specialised operating conditions, additional equipment and use of enhanced technology are able to process fibre-based packaging raw materials which are different than the materials processed in standard recycling mills. These types of specialised mills can recycle EN 643 Grade 5 papers, as well as some papers from Grades 1-4. In general, specialised mills are preferred for grades that benefit

from longer pulping time and require gentle slushing conditions, to avoid cutting off the reject and/or have higher amounts of reject.

EN643 defines a standard for paper grades including 5.03.00 used liquid packaging board and 5.14.00 used paper cups and other tableware. Other laminated or plastic-coated paper and board, especially the increasing types of new fibre-based composite packaging where plastic packaging is being replaced by fibre-based solutions, are not always defined clearly under EN643.

Non-paper components are typically a constituent part of these novel forms of packaging. The ability to recycle some of these materials depends on new or enhanced equipment. Input requirements will be based on the quality and type of the fibre and the amount of non-paper components that need to be removed. Although these mills have equipment to treat special grades, there are also limitations on the range of input material they can accept. Input will also depend on the end-market for recovered pulp and the quality requirements for end products.

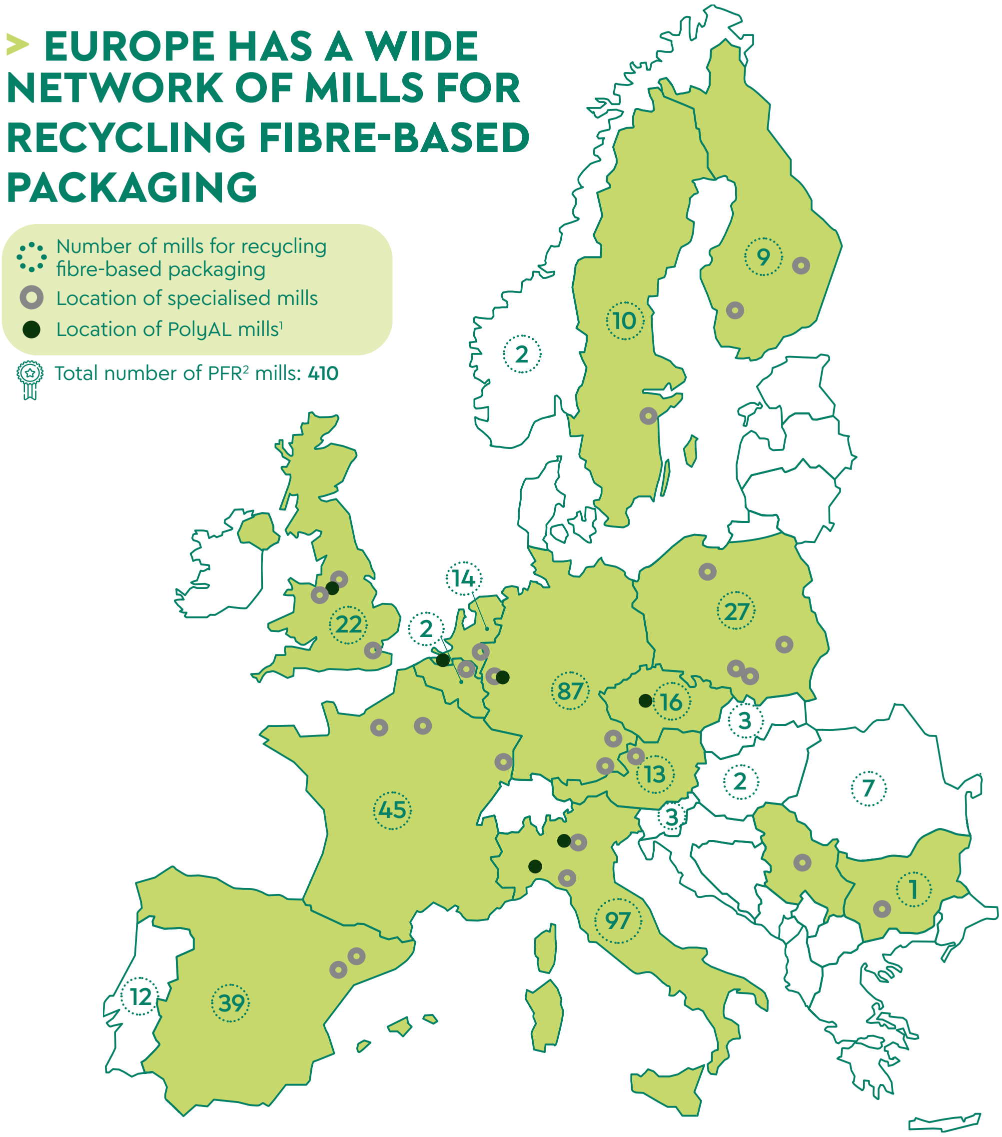


Figure 4. Recycling mills for fibre-based packaging in Europe (Source: Cepi, Extr:act 2022)

Recycling mills evaluate the quality of the input based on the type of raw material, not the type of packaging. Also, for non-paper components, recycling mills clearly look at materials best suited to further recycling and avoid those that are not recyclable in order to improve sustainability. For this reason, specialised recycling mills will apply specific input requirements beyond classification and descriptions in EN643, establishing a de facto specification for sorting plants to produce these qualities.

Two product specifications describing specific input conditions have been developed for fibre-based packaging fit for recycling in specialised mills. The first is product specification **No. 512/510** for liquid packaging board and the second is specification **No. 550** for other fibre-based composites (for example in Germany: PPK from LWP[3]). Different from EN643, these specifications are not describing a dedicated fibre quality but are more an agreement between value chain partners on the acceptable composition of bales sent from sorting facilities to recyclers.

Although both qualities will go to specialised mills, not every specialised mill will be able or willing to recycle both qualities. This will depend on the available equipment and the quality of fibres needed for the paper end product and on other restrictions (e.g. food contact regulation) needed for the paper end product. Therefore, a specialised mill will require a choice to potentially use these materials as separate input qualities. It is therefore recommended to have these materials sorted into separated qualities under agreed rules like the mentioned standards No. 512 or 550 (or additional requirements to be defined by the Recyclability Evaluation Protocol: Part I for standard mills).

The recycling path for used beverage cartons (UBC) is a European wide well-defined stream. Currently all collected and sorted packages are recycled by the existing mills and the capacities will increase in line with growing collection and sorting of UBC.

It should be noted that the available capacity to collect and recycle other fibre-based composite packaging remains still limited in certain parts of Europe.
Efforts to increase recycling capacity are still ongoing and setting clear industry standards sends a positive signal to specialised recycling mills about the security and quality of future inputs, which is also needed to support investments in additional recycling capacity for these materials when sorted properly.

Across Europe, there are approximately 20 recycling facilities specifically dedicated to recovering this fibre-based composite packaging stream, and more reprocessing plants are in the planning stage (see figure below).

The fibres are recovered from used beverage cartons at specialised recycling mills with dedicated processing equipment (see flowchart, Figure 5).

Specific pulping conditions and process equipment are used in specialised recycling facilities, which use water and agitation processes to separate the paper fibres from the plastic and aluminium. Typically, this is achieved by incorporating a drum pulper or a vertical pulper – large cylindrical vessels with impellers (rotors) at the bottom which break paper fibres apart and produce a suspension that is further processed within a recycling line using cleaning and screening stages. The recovery of fibres can be performed in two processes, either as a batch or in continuous flow. In the pulper, the paper layer comes in contact with water, resulting in the paper layers separating from each other due to physical forces. To remove disturbing materials, pulpers are equipped with filter screens. Rejected caps, seals and closures, and other non-fibre layers of beverage cartons will be further treated in the PolyAl recycling process .

Additionally, washing drums are used to further clean the PolyAl fraction, to accomplish additional fibre recovery and eliminate fibre contamination for the PolyAl recycler. The repulping process, e.g. the required dwell and pulping time in the pulper for recovering fibres from used beverage cartons primarily deviates from the repulping process in standard recycling mills. A considerably longer repulping time is required for the fibre recovery from UBCs. Additionally, the capacity to remove and process the PolyAl fraction is better in a specialised process compared to the standard recycling mill.

PolyAl process

In order to recover the polyolefin and aluminium components (PolyAl) from beverage cartons a number of technologies are currently used. This process is only applied for materials originating from UBC-mills recycling used beverage cartons (EN 643 Grade 5.03.00 / 5.03.01). Currently, all commercial technologies for recycling of the PolyAl fraction are preserving the molecular structure of the polymer after being mechanically pre-treated (e.g. shredding, washing, cleaning and/or drying) and transformed into the requested end product.
The available processes today treat and process the

[3] PPK is the German acronym for paper/cardboard/board and LWP stands for lightweight packaging

plastic layer, caps and closures and aluminium foil in the same facility. The available recycling technologies can be classified in two principal types of processes:

- Recycling that produces a composite of plastic and aluminium
- Recycling that produces separated fractions

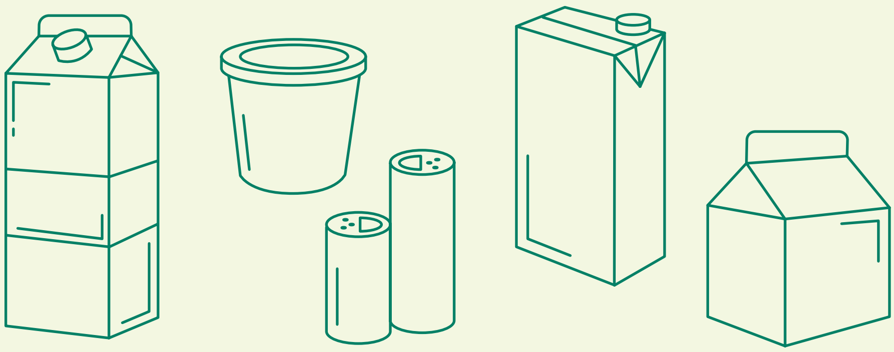
In both cases, it is common practice to separate the soft foil fraction (polymer film and aluminium barrier layers) from the hard plastic fraction (caps, closures, etc.), which is then processed separately into flakes as a mixed polyolefin stream. The lower the residual fibre in the PolyAl stream, the better the quality of output material from the recycling process.

In 2022, the Alliance for Beverage Carton and the Environment (ACE) published Design for Recycling guidelines[4] dedicated to Beverage cartons and specialised recycling mills. These guidelines provide well-defined and detailed information and recommendations for designing recyclable beverage cartons, including the PolyAl recycling requirements, mostly for injection moulding applications. The ACE guidelines therefore complement 4evergreen's own guideline recommendations.

Packaging examples likely to be recycled in specialised recycling mills

Rigid Packaging

- ✓ Like aseptic/non-aseptic beverage cartons, double-side coated paper cups
- ✓ Selection of non-fibre material that does not disturb recovery processes.



[4] ACE (2022), Design for Recyclability Guidelines

Flowchart (UBC mills)

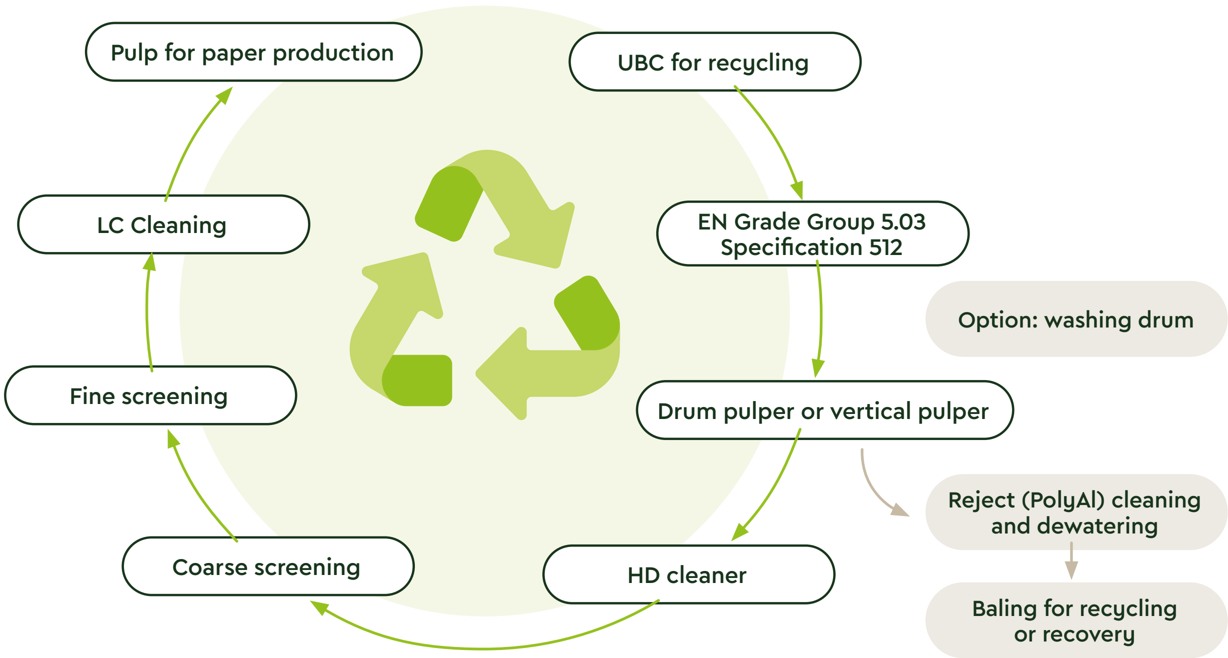


Figure 5. Recycling process in UBC-mills

Flowchart recycling process (FBCP mills)

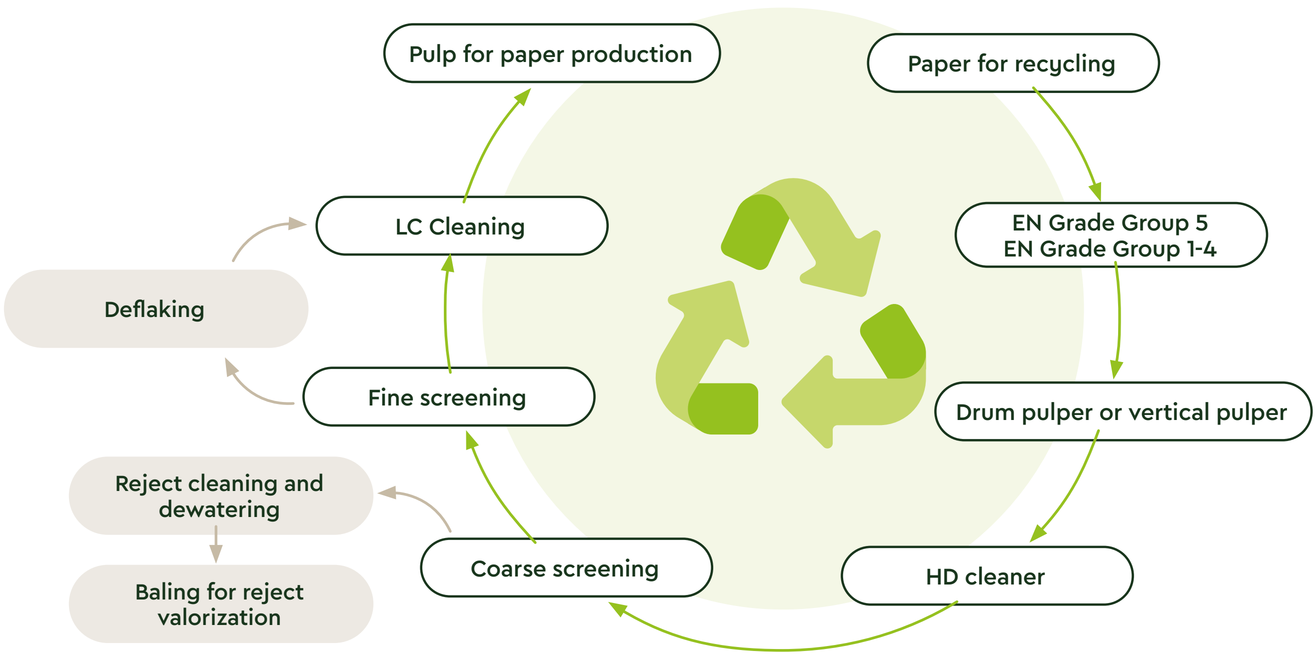


Figure 6. Recycling process in FBCP mills

7.2 Design recommendations PART III

This chapter provides specific design recommendations for single packaging groups, to help designers refine their work.

In 2022, the Alliance for Beverage Carton and the Environment (ACE) published Design for Recyclability Guidelines[1] dedicated to Beverage cartons and specialised recycling mills. These guidelines provide well-defined and detailed information and recommendations for designing recyclable beverage cartons, including the PolyAl recycling requirements, mostly for injection moulding applications. The ACE guidelines therefore complement 4evergreen's own guideline recommendations.

The design recommendations tables in the sub-chapters 7.2.1 to 7.2.6 are applicable for the recycling process in specialised mills. The given tables are developed especially for conditions in specialised recycling mills for used beverage cartons. In future versions of the Circularity by design guideline further design tables will be incorporated, that focus on the specialized recycling mills for other types of fibre-based composite packaging not mentioned here.

The design tables provide information for the following components:

- 7.2.1 Fillers, additives, and agents
- 7.2.2 Barrier coatings and treatments
- 7.2.3 Adhesives
- 7.2.4 Inks and varnishes
- 7.2.5 Metallic components
- 7.2.6 Additional components

The design tables in this chapter refer to single components categorised as:

- Fully compatible with UBC recycling processes
- Conditionally compatible with UBC recycling processes
- Not compatible with UBC recycling processes
- Compatible with UBC recycling processes unknown

NOTE: The given design recommendations are widely based on expert opinion of the entire value chain represented in 4evergreen and valid for either recycling in standard recycling mills or specialised recycling mills. Actual testing prevails the given recommendations in the guideline, therefore the guideline will be updated in line with recyclability lab test results and the corresponding 4evergreen fibre-based packaging recyclability evaluation protocol (PART I, II and III).

7.2.1 Fillers, additives and agents

Component	Sub-category	Fully compatible with UBC recycling process	Conditionally compatible with UBC recycling process [5]	Not compatible with UBC recycling process [5]	Compatibility with UBC recycling process unknown [5]	Comment
Filler/ Inorganic pigments	Clay (kaolin)	⊗				High ash content may have a negative impact on mechanical strength depending on the relative amount in the PfR stream.
	CaCO3	⊗				
	Talc	⊗				
	Titanium dioxide	⊗				
Binder	S/B latex	⊗				
	S/A latex	⊗				Depending on amount, adhesive strength, etc.
	Starch-biobinder	⊗				
Sizing, wet end	AKD	⊗				
	ASA	⊗				
	Rosin	⊗				
Dry strength	Starch	⊗				
	CMC	⊗				
	Polyacrylamide	⊗				
	Guar gum	⊗				

(1) ACE (2022). Design for Recyclability Guidelines

Component	Sub-category	Fully compatible with UBC recycling process [5]	Conditionally compatible with UBC recycling process [5]	Not compatible with UBC recycling process [5]	Compatibility with UBC recycling process [5] unknown	Comment
Wet strength	PAE		⊗			Recyclability depends on various factors, such as relative wet-strength (WS) level, amount of WS agent, etc. Recyclability can be improved by increased pulping temperature and time, chemicals, high consistency pulping, etc. Testing is needed to evaluate the recyclability and set thresholds for acceptable levels in the PfR stream.
	Urea/ Formaldehyde		⊗			(cont.)
	Glyoxylated polyacrylamide (GPAM)	⊗				(cont.)
Sizing, surface	Starch	⊗				
Other	Colorants/dye for shading	⊗				Physically recyclable but certain dyes are not approved for food packaging applications and such dyes should be avoided.
	Colorants/ pigments	⊗				
	Polyvinyl alcohol	⊗				
	PAC	⊗				
	Retention polymers	⊗				
	Siliconising agents	⊗				

Table 10. Part III - Design recommendations fillers, additives and agents

NOTE: The behaviour in the recycling process strongly depends on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

7.2.2 Barrier coatings and treatments

Barrier coatings and their placement on Liquid Packaging Board help ensure that packaging meets demanding performance criteria. They impact on recycling process compatibility for used beverage cartons and also influence the compatibility with sorting technology in light-weight packaging stream and require enhanced technology and recycling equipment in order that they can processed in specialised mills. Furthermore, the material composition of barriers is also a deciding factor in how compatible the pulping reject material is with subsequent PolyAl recycling. The following design table covers these aspects, including subsequent PolyAl recycling.

4evergreen summarises industry expertise, in particular guidelines by ACE for Liquid Packaging Board barrier coatings and their placement. More details, thresholds and information on Liquid Packaging Board, as well as beverage cartons, is available in the ACE – Beverage Carton – Design for Recyclability Guidelines.
In general terms and for better overall recycling results, barrier content of liquid packaging board should be minimised, fibres should ideally be separable from barrier layers, and barrier material should be 'screenable', and compatible with PolyAl recycling.

[5] Including PolyAl recycling

Component	Sub-category	Fully compatible with UBC recycling process [6]	Conditionally compatible with UBC recycling process [6]	Not compatible with UBC recycling process [6]	Compatibility with UBC recycling process [6] unknown	Comment
Extrusion barrier coating	Thermoplastic (one side coated, inside the pack only)				⊗	Not relevant in UBC recycling. Design guidelines will be defined in a separate design table for Part III – Fibre-based Composite Packaging (FBCP), which will be included in future version of the Circularity by Design guideline. . Packaging with coating only on the inside of a packaging would potentially not be recognised as UBC target material in sorting plants.
	Thermoplastics (two sides coated)	⊗[7]				Specialised recycling mills for UBC recycling are designed to process two sides barrier coated paper packaging. Barrier coating needs to be made predominantly of PE, with a possible limited share of PP or other polymers. Thresholds and material compatibility as defined in ACE Design for Recyclability Guidelines apply.
Adhesive barrier film	Adhesive lamination with water-soluble adhesives (PVOH, starch, etc.)	⊗				Adhesive lamination with water-soluble adhesives is fully compatible with LPB recycling.
	Adhesive lamination (inside of pack) of PET, mPET, PET/PE etc.		⊗	⊗[7]		PET content with <5% share of weight relative to polymer structure is non-desirable but manageable. PET content with higher share than 5% relative to polymer structure is not compatible with current subsequent PolyAl recycling.
	Lamination with Alu containing film (Alu/PE)	⊗				Alu/PE lamination is compatible with UBC recycling. For PET/Alu/PE barriers, please refer to guidance on adhesive lamination containing PET in the line above.

[6] Including PolyAl recycling
[7] Detailed information on material compatibilities and thresholds as defined in the ACE Design for Recyclability Guidelines

Component	Sub-category	Fully compatible with UBC recycling process [6]	Conditionally compatible with UBC recycling process [6]	Not compatible with UBC recycling process [6]	Compatibility with UBC recycling process [6] unknown	Comment
Wet-barrier coatings	Aqueous polymer dispersions (acrylics, EEA, SB, ABS, PVDC, etc.)				⊗	Application of materials in LPB products and performance in UBC recycling is unknown.
	Solvent-based coatings				⊗	Application of materials in LPB products and performance in UBC recycling is unknown.
	Wax dispersion (incl. microcrystalline waxes)		⊗			Level of compatibility of wax coated LPB products needs to be determined with a recycling test.
	Water soluble coatings (PVOH, EVA Biobased, etc.)				⊗	Application of materials in LPB products and performance in UBC recycling is unknown.
Wax coatings	Dipping of paper in molten wax (two sided)				⊗	Not relevant in UBC recycling. Design guidelines will be defined in a separate design table for Part III – Fibre-based Composite Packaging (FBCP), which will be included in future version of the Circularity by Design guideline.
Barrier metallization	Direct metallisation on paper (primer, Alu nanoscale, protective coating) - inside	⊗ 7				Vapour deposition of thin layer metallisation can be applied. Thresholds and material compatibility as defined in ACE DfR Guidelines apply.
	Direct metallisation on polymer (Primer, Alu/AlOx/SiOx nanoscale, protective coating) - inside	⊗ 7				Vapour deposition of thin layer metallisation can be applied. Thresholds and material compatibility as defined in ACE DfR Guidelines apply.
	Transfer metallisation (adhesive + transfer metallisation) - inside				⊗	Not relevant in UBC recycling. Design guidelines will be defined in a separate design table for Part III – Fibre-based Composite Packaging (FBCP), which will be included in future version of the Circularity by Design guideline.

Table 11. Part III - Design recommendations barrier coatings and polymer content

NOTE: The behaviour in the recycling process strongly depends on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

6 Including PolyAl recycling
7 Detailed information on material compatibilities and thresholds as defined in the ACE Design for Recyclability Guidelines

7.2.3 Adhesives

The following design table aims to give a compact overview of the most typically used adhesives in the industry. However, other applications / chemistries exist that also fulfill the technical and recyclability requirements.

Component	Sub-category	Fully compatible with UBC recycling process[8]	Conditionally compatible with UBC recycling process[8]	Not compatible with UBC recycling process[8]	Compatibility with UBC recycling process[8] unknown	Comment
Bonding of supplements	Hotmelt	⊗ #				# For hotmelts with suitable softening point (higher than 68°C according to DIN EN 1427:2015) and applied larger than 1,6mm in diameter (see EPRC scorecard for the removability of adhesives). * Only valid for materials with a positive rating according to Cepi recyclability laboratory test method, 2022. Existing positive results according to the legacy methods such as but not limited to Aticelca MC501:2019, Cyclos-HTP CHI-PTS-C6/2.0, Ingede 12 and PTS-RH:021/97 should also be accepted
	Polyurethane Hotmelt	⊗ #				
Cap/straw attachment for beverage cartons	Hotmelt[9]	⊗				
Multipack attachment	Hotmelt	⊗ #			⊗	
	Pressure sensitive hotmelt	⊗ *			⊗	
	Pressure sensitive emulsion acrylics	⊗ *				
Pressure sensitive applications (self-adhesive labels)	Pressure sensitive emulsion acrylics	⊗ *				
	Pressure sensitive hotmelt	⊗ *				
	Pressure sensitive UV-curable acrylic adhesives	⊗ *				
	Water-based adhesives	⊗ *				
Water-based labelling	Protein Glues				⊗	
	Acrylic				⊗	

Table 12. Part III - Design recommendations adhesives

NOTE: The behaviour in the recycling process strongly depends on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

[8] Including PolyAl recycling
[9] All beverage cartons in use and being recycled today employ hotmelts for cap and straw attachment.

7.2.4 Inks and Varnishes

In order to assess the compatibility of inks and varnishes in specialised recycling mills two different cases in applying them on liquid packaging board have to be considered:

Case 1 – Inks and varnishes are applied on board: The main technology used is water-based inks and varnishes for flexographic printing. As board is mechanically separated from other non-fibre components in the recycling process the same recyclability evaluation applies as for standard recycling mills.

Case 2 – Inks and varnishes are applied on outer PE-layer: The main technologies used are solvent-based inks and varnishes for gravure printing and radiation-curing inks and varnishes for offset and flexographic printing. Because of the mechanical separation of the PE-layer and board, ink and varnish particles remain in the reject mix. Therefore, a recyclability evaluation does not apply here. There is a given probability that ink and varnish particles unintendedly detached from the PE-layer and thus can be found in the pulp. In this case the recyclability evaluation for standard recycling mills applies.

Component	Sub-category	Fully compatible with UBC recycling process[10]	Conditionally compatible with UBC recycling process[10]	Not compatible with UBC recycling process[10]	Compatibility with UBC recycling process[10] unknown	Comment
Offset	Oil-based (mineral)		⊗			Nor relevant for UBC-recycling process. Inks based on mineral oils are fully compatible with the recycling process. Due to legal restriction, the use of the recovered fibers is limited to non-food applications. Therefore, the use of mineral oil-based inks is not recommended for food-applications.
	Oil-based (vegetable)	⊗				
	Ultra-violet cured/EB-cured				⊗	This printing technique and printing ink combination is fully compatible with fibre recovery processes, but its influence on some PolyAl recycling processes when print is applied directly to the outer LDPE layer may require further investigation.
Flexographic	Solvent-based	⊗				
	Water-based	⊗				
	Ultra-violet cured				⊗	This printing technique and printing ink combination is fully compatible with fibre recovery processes, but its influence on some PolyAl recycling processes when print is applied directly to the outer LDPE layer may require further investigation.

[10] Including PolyAl recycling

Component	Sub-category	Fully compatible with UBC recycling process[10]	Conditionally compatible with UBC recycling process[10]	Not compatible with UBC recycling process[10]	Compatibility with UBC recycling process [10] unknown	Comment
Gravure	**Solvent-based**	⊗				
	Water-based	⊗				
	Ultra-violet cured				⊗	This printing technique and printing ink combination is fully compatible with fibre recovery processes, but its influence on some PolyAl recycling processes when print is applied directly to the outer LDPE layer may require further investigation.
Varnish	**Solvent-based**	⊗				
	Water-based	⊗				
	Ultra-violet cured				⊗	This printing technique and printing ink combination is fully compatible with fibre recovery processes, but its influence on some PolyAl recycling processes when print is applied directly to the outer LDPE layer may require further investigation.
	Two component	⊗				
Digital [11]	**Water-based**	⊗				
	Ultra-violet cured				⊗	This printing technique and printing ink combination is fully compatible with fibre recovery processes, but its influence on some PolyAl recycling processes when print is applied directly to the outer LDPE layer may require further investigation.
	Liquid toner	⊗				
	Solid toner	⊗				
	Hot melt				⊗	Testing is required.
Screen	**Ultra-violet cured**		⊗			This printing technique and printing ink combination is fully compatible with fibre recovery processes, but its influence on some PolyAl recycling processes when print is applied directly to the outer LDPE layer may require further investigation.

Table 13. Part III - Design recommendations inks and varnishes

NOTE: The behaviour in the recycling process strongly depends on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

[11] Digital printing technologies emerging; continuous surveillance required.

7.2.5 Decorative metallic components

Metallic components with a thickness lower 1 micron are not causing any issue during the UBC recycling process, but the recognition of these papers during the sorting process could be impacted if only NIR detection system is in place, as the metallic effect reflects the NIR light.
Paper fully printed with black inks containing carbon black pigments, may also impact the sorting, if only NIR detection system is in place, as the carbon black pigments adsorb the NIR light.
Paper laminated with Metallized PET Film has shown limitation in the compatability with the UBC recycling process. Moreover, if the surface is fully laminated to a metallized film, this may impact the sorting, if only NIR detection system is in place.
To mitigate this issue, it is recommended to:

- minimise the percentage of Metallized PET Film laminates used, it is recommended to use hot stamping or cold transfer or lamination of Direct Vacuum Metallized paper.
- minimise the use of carbon black pigments, it is recommended to use black inks not containing carbon black pigments.

Component	Sub-category	Fully compatible with UBC recycling process [12]	Conditionally compatible with UBC recycling process[12]	Not compatible with UBC recycling process[12]	Compatibility with UBC recycling process [12] unknown	Comment
Decorative metallic components	Hot and cold transfer	⊗				Designers should not cover the surface of fibre-based products fully with metallisation, as this could cause issues regarding the detection as fibre product.
	PP/PET metallised laminates			⊗		Since PET content share should be lower than 5% to be compatible with current PolyAl recycling, metallized PET laminates should be avoided for decorative purposes”
	PET metallised film			⊗		Since PET content share should be lower than 5% to be compatible with current PolyAl recycling, metallized PET laminates should be avoided for decorative purposes”
	Direct vacuum metallized paper		⊗			The outside metallisation could affect the sorting process (only if NIR detection will detect the metallized side).
	Direct metallisation		⊗			Designers should not cover the surface of fibre-based products fully with metallization, as the outside metallization could affect the sorting process (only if NIR detection will detect the metallized side).

Table 14. Part III - Design recommendations decorative metallic components

NOTE: The behaviour in the recycling process strongly depends on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

[12] Including PolyAl recycling

7.2.6 Additional components

The following design table aims to provide a compact overview of typical additional components used to improve the functionality of fibre-based packaging. The design is applicable for the recycling in specialised mills, including the subsequent PolyAl procedure.

Component	Sub-category	Fully compatible with UBC recycling process [13]	Conditionally compatible with UBC recycling process[13]	Not compatible with UBC recycling process[13]	Compatibility with UBC recycling process [13] unknown	Comment
Caps and closures	PE	⊗				Thresholds and material compatibility as defined in ACE DfR Guidelines apply.
	PP	⊗ [14]				
	PET			⊗ [14]		
	Biodegradable polymers			⊗		
Spouts	PE	⊗ [14]				
	PP		⊗ [14]			
	Metal			⊗		
Straw	Fibre-based	⊗				Consumers should be encouraged to push the straw into the packaging, after consumption.
Protective wrapper	Fibre-based	⊗				
	PE (fossil based and bio-based)	⊗				
	PP (fossil based and bio-based)	⊗				Due to the low mass percentage of protective wrappers, it is not foreseen that PP has a negative impact on the PolyAl recycling process.
	PET			⊗		

Table 15. Part III - Design recommendations additional components

NOTE: The behaviour in the recycling process strongly depends on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
The behaviour in the recycling process may depend on the chemistry and grades of the materials, thus the design recommendations given here cannot cover all existing possibilities of material types. A recyclability test is recommended to determine the exact behaviour of each material.
Please be aware that the recommendations in the design tables only refer to the recyclability of the components. Further environmental impacts and safety aspects must be considered when creating efficient and sustainable packaging.

[13] Including PolyAl recycling
[14] Detailed information on material compatibilities and thresholds as defined in the ACE Design for Recyclability Guidelines

8. GLOSSARY

Chemical pulp
Pulp obtained by a chemical treatment in which a considerable part of non-carbohydrate (lignin and other plant extractives) is removed from the fibre matrix.

Collection
The gathering of discarded fibre-based packaging and/or other recycleables from various sources (i.e. household, commercial, industrial) which ultimately, directly or indirectly, are destined for recycling at a dedicated plant.

Converting
Manufacture of products by processes or operations applied after the normal paper or board manufacturing process. The operation of treating, modifying, or otherwise manipulating the finished paper and paperboard so that it can be made into end-user products, such as special coating, waxing, printing, and gumming, and envelope, bag, and container manufacturing.

Corrugated board
Board consisting of one or more sheets of fluted paper glued to a flat board.

Directive on Waste (2008/98/EC)
Also known as the "Waste Directive", it defines key elements such as waste, the waste hierarchy and recovery. The directive sets the legal framework for waste management in all member states of the European Union.

Deinking
Deinking (also de-inking) is any process, in addition to slushing and incidental washing, intended to remove most of the ink particles from pulp made from recovered printed paper or board (ISO 4046-2, 2016).

EU Circular Economy Package
The Circular Economy Package, which entered into force July 2018, sets new targets towards a circular use of raw materials and on increasing the recycling rates for all packaging materials.

EU Packaging and Packaging Waste Directive (PPWD)
The Directive (94/62/EC) defines recycling targets for the main packaging materials and serves as guidance to improve the sustainable performance of packaging in the European Union.

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

Fibre-base composite packaging
Packaging composed of paper and a considerable share of non-paper elements that by design are not separated after use.

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

Fibre-based packaging material
The sum of papermaking fibres, fillers added in the wet-end, pigments used in printability coating, binders used as a minor fraction in pigment printability coating, starch and other dry strength agents, and other functional and process chemicals used in the wet-end of paper machine, printing inks, overprint varnish, as well as adhesive used to bind two layers of paper (or paper and plastic film) together, polymeric barrier layers, and any additional/auxiliary items (closure, tape, label).

Mechanical pulping
High-yield pulp in which defibration is achieved intentionally by means of mechanical energy. Among pulps of this category are refiner mechanical pulp, groundwood pulp, pressurized groundwood pulp, thermo-mechanical pulp, chemi-mechanical pulp, chemi-thermomechanical pulp and bleached chemi-thermomechanical pulp.

Multiply board
Paper or board consisting of more than three furnish layers combined together during manufacture (ISO 4046-3:2016).

Near-infrared (NIR) sorting
Near-infrared sorting technologies measure the reflected light of an object in the range of 760 and 2,500 nm. NIR is used in the sorting process to separate packaging from each other based on reflected surface material.

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.

Paperboard
Generic term applied to certain types of paper frequently characterised by their relative high rigidity (ISO 4046-3:2016). 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.

Paper for Recycling (PfR)
Natural fibre based paper and board suitable for recycling and consisting of - Paper and board in any shape. Products made predominately from paper and board, which may include other constituents that cannot be removed by dry sorting, such as coatings and laminates, spiral bindings, etc.

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

Pulp
Fibrous material, generally of vegetable origin, obtained with 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.

Pulping
The act of processing wood (or other plant) and slushing paper and board for recycling to obtain the raw material for making paper and board. The fibres are separated from one another into a mass of individual fibres (see Pulp).

Standard recycling mill
Such mills typically produce high quality end-products based on EN 643 groups 1 to 4. In large mills, high consistency drum pulpers are common. Often such processes operate deflakers to separate fibre bundles into individual fibres, as well as coarse and fine screening 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).

Specialised recycling mill
These mills treat a mix of special grades (group 5 of EN 643) and grades from other groups (1-4 from EN 643). Each recycling mill determines the optimal mix and adds one or more piece of dedicated equipment, such as a horizontal high density drum pulper, a separate batch pulper with longer pulping time, de-inking, fine cleaners, hot dispersion, special process and waste water systems. These specialised recycling mills can treat fibre-based packaging that has been coated with non-water soluble products such as wax, plastic film or other layers such as aluminium, polyester and polyethylene entering the recycling process in homogeneous lots. In order to optimise the recycling process, fibre-based composite packaging, which cannot be handled in standard processes, should be delivered to specialised paper mills in EN 643 identified flows. As in standard mills, the result of the process is also very high quality fibrous material suspended in water ready for papermaking.

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ABOUT 4EVERGREEN

4evergreen is a cross-industry alliance perfecting the circularity of fibre-based packaging to contribute to a climate-neutral and sustainable society. Our goal is to raise the overall recycling rate of fibre-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 fibre-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.

4ever green

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