TECHNICAL REPORT

DESIGNING FOR A CIRCULAR ECONOMY

Recyclability of polyolefin-based flexible packaging

June 2020
Phase 1

CEFLEX
A CIRCULAR ECONOMY FOR FLEXIBLE PACKAGING

Foreword

The CEFLEX initiative, Designing for a Circular Economy (D4ACE) Guidelines, will facilitate the development of a circular economy for flexible packaging by 2025. Only with near universal adoption of these and related guidelines will this ambition be realised.

Work to develop the guidance provided in this document commenced in 2017. The limited guidelines which existed for flexible packaging at this time, together with the Ellen MacArthur Foundation Project Barrier guidelines, formed a starting point for the CEFLEX guidelines.

This document represents the work of over 150 CEFLEX stakeholders from all parts of the flexible packaging value chain to identify best practice in the collection, sorting and recycling of polyolefin-based flexible packaging.

The guidance is forward-looking to 2025 but is based on what is considered best practice in 2020 for the 'best in class' sorting and mechanical recycling infrastructure available in Europe. At the same time, it recognises that the capabilities of sorting systems and mechanical recycling are likely to develop significantly in the coming five years. For this reason, the guidelines will be reviewed regularly and updated with input from the entire flexible packaging value chain.

CEFLEX recognises that waste prevention and reuse are important parts of the circular economy. The urgency for the industry however is to stop leakage into the environment.

Today (2020), only two-thirds of European countries collect flexible packaging with other dry recyclables despite approximately 70-80% of all consumer flexible packaging being reported as mono-material polyolefin-based materials which can be readily identified, sorted and recycled.

CEFLEX has consequently chosen to focus on driving collection and recycling rates to ensure these materials are returned to the economy. Realising this ambition will require the collection of all flexible packaging and the availability of the required infrastructure to sort and recycle it, in all European countries.

These guidelines recognise that delivering the circular economy for flexible packaging begins by designing all flexible packaging to be sortable and recyclable, whilst not compromising on product protection and providing necessary product information.

The underlying principles of the guidance respect the role of all packaging materials and recognise the preference in plastic waste streams destined for recycling, which prioritises polyolefin-based mono-materials over mixed polyolefins, over mixed plastics, over mixed multi-materials.

The guidance contained in this document should not be interpreted as a bale specification. Bale specifications must indeed be based on the quality needs of the end markets that will use the recycled materials from flexible packaging.

The CEFLEX guidelines have been developed in good faith by a broad representation from the entire flexible packaging value chain. The document is offered for all to adopt and use on a voluntary basis.

The CEFLEX initiative

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1 Introduction

Background and context

Flexible packaging[1] is an essential part of many elements of everyday life. It is a resource-efficient packaging choice which plays a key role in protecting food and other products, preventing food waste, minimising the use of resources and providing important packaging functionality.

Flexible packaging represents half of food primary packaging in Europe (in product units) while accounting for only one sixth of the packaging material used (in weight)[2]. The wide-ranging benefits of flexible packaging, such as its low weight and thus minimal use of materials, lead to it being increasingly used. However, these properties also mean consumer flexible packaging can be challenging to collect, sort and recycle economically.

This is one reason it is still not collected for recycling in all European countries, but also because the current legislated weight-based packaging recycling targets for plastics and other materials can be met by only collecting rigid packaging. This is no longer the case with the higher targets and recycling measurement point in the European waste legislation (2019).

However, as circular thinking permeates Europe, there is a societal requirement to shift from focusing solely on meeting legislative targets, to end of life systems which offer solutions to collect, sort and recycle all packaging, preventing it from leaking into the environment, returning it to the economy[3] and replacing virgin materials.

This concept of a circular economy is increasingly recognised as the solution to the issues resulting from a 'take-make-dispose' approach and is based on the following key principles[4]:

- Design out waste and pollution
- Keep products and materials in use
- Regenerate natural systems

Designing products and packaging for recyclability in a circular economy is a key part of making the transition to 'circular'.

For flexible packaging this starts with designing it to be easily sorted once collected at the end of its life cycle, to be suitable for efficient and high-quality recycling and ultimately for those recycled materials to be used in new market applications.

In addition to designing for recyclability, the move to become circular will require the value chain to develop, implement and adopt a wider spectrum of options and solutions.

CEFLEX is calling on the flexible packaging value chain to:

- Review existing flexible packaging portfolios and evaluate which structures fulfil the designing for recyclability in a circular economy requirement.
- Evaluate what changes can be made to further improve and optimise the design and end of life sorting and recycling processes for structures that do not currently fulfil the 'Designed for Recyclability' requirements.
  - For packaging design this could be by providing the required functionality from a mono-material equivalent where possible or by ensuring the structure disrupting the recyclable material streams can be identified and removed.
  - For improved sorting and recycling processes this could include identification of materials through enhanced optical sorting, mechanical recycling process development and new, emerging technologies.
- Use these guidelines as a tool when designing and specifying new flexible packaging structures.

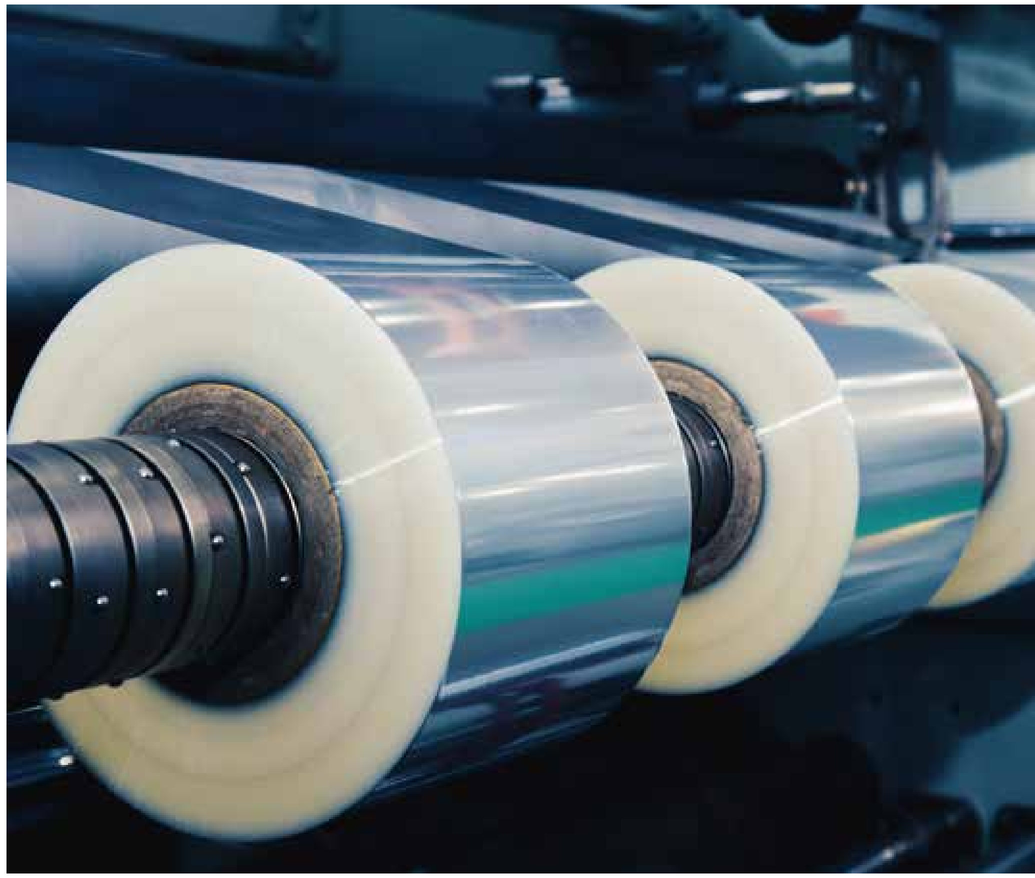
CEFLEX definition of flexible packaging

Flexible packaging structures typically bend easily and can include bags, pouches, envelopes, sachets, removable lidding/liners and wraps. Flexible packaging structures can be single or multi-layered, using a variety of materials including plastic film, paper, aluminium foil or any combination of these. The construction may be plain, printed, coated and/or laminated.

Flexible packaging is most commonly used to protect fast moving consumer goods products such as confectionery, snack foods, frozen foods, bakery, fresh produce, meat, dairy, pet food, processed foods, cosmetics, personal care, household detergents, beverage bottle/can wrappings, pharmaceuticals, medical and other technical products.

[1] CEFLEX definition of flexible packaging
[2] Flexible Packaging Europe study with ifeu
[3] These guidelines should be considered within the context of key pieces of legislation; Waste Framework Directive, Packaging and Packaging Waste Directive and the Landfill Directive
[4] https://www.ellenmacarthurfoundation.org/

EU flexible packaging volumes in 2019



The total consumer household flexible packaging market in Europe is estimated to be just under 3.7 million tonnes per annum[5].

Of this, approximately 70-80% (3 million tonnes) is reported as mono-polyethylene (PE), mono-polypropylene (PP) or potentially a polyolefin PE/PP mix[6,7].

These polyolefin-based materials can generally be regarded as being 'Designed for Recyclability' because the processes do exist to sort and recycle them. In other words, it is technically feasible to recycle these types of flexible packaging.

However, the processes and infrastructure required to collect, sort and recycle post-consumer flexible packaging are not yet widely established across the whole of Europe, nor is it uniform or harmonised. So, while the materials can be considered as being 'Designed for Recyclability', this flexible packaging can only be considered 'recyclable' in those countries where the infrastructure, capability and end markets are already in place.

The first phase of the CEFLEX guidelines and the focus of this document is on the 'Designed for Recyclability' polyolefin-based flexible packaging (mono-PE, mono-PP and PE/PP mixes). This is because as stated above this material makes up the largest proportion of the post-consumer flexible packaging waste stream and because the ability to sort and mechanically recycle these materials is already proven at industrial scale in some European countries (for example in Germany, The Netherlands, Italy, Spain and several other countries). In addition to the polyolefin-based streams mentioned above, paper-based and aluminium-containing flexible packaging structures are addressed where there is existing knowledge about their sortability and recyclability.

The remaining 20-30% of consumer flexible packaging includes multi-material structures containing other functional materials, such as aluminium foil, paper, polyamide (PA), polyethylene terephthalate (PET), ethylene vinyl alcohol (EVOH) as well as other polymers in addition to polyolefins. These structures are generally used when specific properties are required such as a barrier against oxygen or moisture, or improved mechanical strength.

Greater understanding of how these types of flexible packaging can be sorted and recycled is required. Any existing knowledge or current practices on the sorting and recycling of these multi-materials is included in this document, but this part of the post-consumer flexible packaging waste

[5] 2016 data: 3,987,000 tonnes including exports. Estimate based on data from 'Plastics – the facts 2016' and 'FPE Market Report Summary 2016'
[6] Refer to CEFLEX definitions
[7] CEFLEX is undertaking a waste compositional analysis study of post-consumer flexible packaging to provide robust data on the proportions of mono-material and multi-material structures

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stream will be the focus of the second phase of the CEFLEX guidelines.

All parts of the flexible packaging value chain have a role to play. Brand owners and retailers need to specify, design and place on the market flexible packaging which is 'Designed for Recyclability' so the recyclable waste streams are collected and made available for sorting and recycling according to the value of the materials.

Other parts of the value chain can, and need to, contribute to this in parallel including material producers, film producers and packaging converters, as well as equipment and technology suppliers.

This will boost confidence in the waste collection, sorting and recycling sector, where investment is required to develop and establish new infrastructure for post-consumer flexible packaging and facilitate the development of end markets.

The guidelines in this document are not a legal requirement, but a tool intended to provide advice and support to brand owners, retailers, packaging converters and their value chains in designing flexible packaging to be circular. It is important to note these guidelines are not (yet) developed to the stage where they can be used as the basis for a 'recyclability accreditation' and should not be used to make such a claim.

Although the CEFLEX initiative and guidelines are focused on Europe[8], it is recognised that many of the challenges faced in Europe are also relevant further afield. Consequently, the information and guidance presented in this document may be applicable to other regions of the world, but there may be important local and regional differences that are not reflected in this guide.

[8] The focus of the CEFLEX initiative is on the continent of Europe

2 Designing for a circular economy

Designing for recyclability in a circular economy

Recycling has a central role to play in enabling flexible packaging to contribute effectively to a circular economy and after waste prevention, this is where most progress is expected to be made in the short to medium term.

Designing for Recyclability is a requirement that will be aided by the development and harmonisation of collection, sorting and recycling facilities throughout Europe as we transition to a circular economy.

When flexible packaging was not widely collected for recycling at end of life, it made good business sense to focus on designing it simply to provide the required functionality with minimum resource use, thereby minimising product and packaging waste.

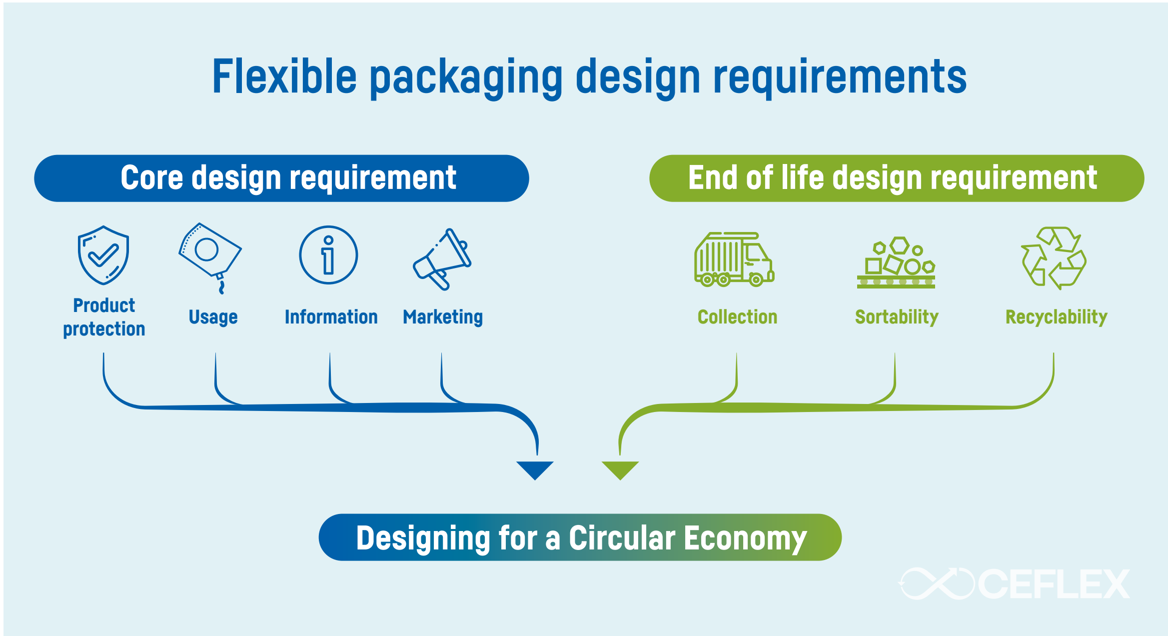
This remains key in a circular economy, but an equally important objective is to design flexible packaging so that it will be correctly disposed of, collected and efficiently sorted into suitable material fractions for recycling. These sorted materials must be recyclable into 'new' materials that can be used in market applications, displacing virgin material.

The packaging design process therefore presents the value chain with an opportunity to innovate and develop solutions to make flexible packaging circular by addressing both design and end of life challenges.

The CEFLEX guidelines recognise and are consistent with the waste hierarchy of reduce, reuse, recycle, recover and dispose. Solutions that move packaging design towards the top of the hierarchy will be preferred except where this increases the risk of product waste.

Compromising the protective qualities of packaging to improve its recyclability will typically have a higher cost and associated environmental impact than producing flexible packaging which is not recycled but which delivers the required product protection.

Figure 1



The CEFLEX initiative

The Circular Economy for Flexible Packaging (CEFLEX) initiative[9] is a collaboration of European companies, associations and organisations representing the entire value chain of flexible packaging. Together, we work to make all flexible packaging in Europe circular by 2025.

The initiative is committed to avoiding waste and pollution by redesigning consumer flexible packaging and ensuring appropriate collection and recycling infrastructure in all European countries.

This will enable used flexible packaging to be cost effectively collected, recycled and sustainable end markets developed to ensure resources are returned to the economy to be used again and again.

Stakeholders are invited to identify and participate as representatives in one of five groups, reflecting the role they play in the flexible packaging value chain.

They are:
- Material producers including plastic, paper and aluminium as well as inks, coatings, adhesives and additives
- Film producers and packaging converters
- Brand owners and retailers
- Waste collectors, sorters and recyclers
- Technology suppliers, end users and others

They collaborate and deliver activities across seven thematic workstreams, working to identify and implement solutions to achieve the CEFLEX vision.

CEFLEX vision and roadmap

Our aim is to enable collection of all flexible packaging and recycle 80% of it into new valuable materials; becoming either new packaging or flowing back into the wider circular economy.

Our vision is a Europe where flexible packaging is integral to a truly circular and sustainable future.

Together, this is our 'Mission Circular'; to create multiple lives for flexible packaging materials.

To achieve it, a 5-step roadmap to build a circular economy for flexible packaging has been endorsed by CEFLEX stakeholders, together with a set of actions needed by each part of the value chain.

Delivering it targets an established collection, sorting and reprocessing infrastructure and economy for post-consumer flexible packaging across Europe by 2025. It will be based on end-of-life technologies and processes which deliver the best economic, technical and environmental outcome for a circular economy.

Designing for a Circular Economy (D4ACE) guidelines are a key deliverable of the CEFLEX initiative. CEFLEX aims to ensure that by embedding circularity in the design phase, the flexible packaging made and placed on the market can be collected and sorted effectively so recycled materials can be used in sustainable end market applications.

CEFLEX recognises the capabilities of sorting systems and mechanical recycling are likely to develop significantly in the coming five years, potentially enabling structures currently considered to be non-recyclable, to be recycled. Enhanced mechanical recycling will also need to be augmented by the development of other technologies. Development of chemical recycling infrastructure will also be required to periodically 'renew' and rebuild the base polymer properties, to remove contaminants, residual fractions and recycle items which are too small to be handled by traditional mechanical recycling processes. Wherever possible, these future developments have been taken into consideration in this document, recognising that not all of them will be realised and there will be new technologies not yet considered.

CEFLEX encourages all users and specifiers of flexible packaging to critically review their existing and new flexible packaging portfolios against the D4ACE guidelines. Wherever possible changes should be made that allow end-of-life flexible packaging to be more easily sorted and recycled without critically compromising product protection or increasing product waste.

[9] https://ceflex.eu/

Figure 2

3 Purpose and approach of Designing for a Circular Economy Guidelines

Purpose

The purpose of the CEFLEX guidelines is to provide informed support, guidance and information to all in the value chain responsible for specifying and designing consumer flexible packaging.

The guidelines are based on widely accepted principles, industry practice or derived from actual testing to verify the sorting and recycling limits of flexible packaging structures.

Additional guidance is provided to explain what happens to flexible packaging when it enters the waste stream. This is intended to help build understanding with packaging specifiers and designers on how the packaging they design is managed at its end-of-life and take actions at the design stage to optimise collection, sorting and recycling possibilities.

Phased approach

The CEFLEX D4ACE guidelines are being delivered in phases (see Section 5, Tables 1 and 2).

Phase 1 guidelines

The focus is to provide information and guidance on the types of polyolefin-based flexible packaging that can currently be described as 'Designed for Recyclability'.

- Polyolefin-based structures that can be sorted and recycled using existing industrial scale technologies and processes
- This is supported by either test/trial data, by commercial practices somewhere in Europe or by broad consensus of the CEFLEX stakeholders

Phase 2 guidelines

The focus is on polyolefin-based flexible packaging that is not currently widely sorted or recycled and therefore cannot yet be regarded as being, or not being, 'Designed for Recyclability'.

- Testing is needed to better understand if/how these types of flexible packaging can be sorted and/or mechanically recycled[10]
- As the requirements for new sorting and recycling technologies such as chemical recycling of polymers become better understood and available, these requirements will be integrated into the guidelines
- Design changes may be needed to enable these structures to be regarded as 'Designed for Recyclability'
- If the structures cannot be regarded as 'Designed for Recyclability' then it may be necessary to ensure these structures do not 'disrupt' the sorting and recycling streams by ensuring that they can be easily identified and separated from the other 'Designed for Recyclability' structures

The scope also includes all flexible packaging structures other than those polyolefin-based structures (for example aluminium-based, paper-based, other polymers, etc.)

It is the intention to conduct a periodic review process (expected to be on an annual basis) for the CEFLEX guidelines to capture any changes in capabilities and requirements of emerging sorting and recycling technologies.

What is not possible today, might well be common practice tomorrow.

[10] A programme of testing for Phase 2 will commence in 2020 with guidelines produced towards the end of 2020/start of 2021. Section 5 identifies where phase 2 testing is needed and in Section 6 this is noted where relevant.

Terminology and definitions

CEFLEX recognises that definitions provided in this document may differ to those being proposed by other organisations.

As consensus is reached for each definition and these are adopted by organisations such as International Organisation for Standardisation (ISO) and European Standards (EN), CEFLEX will align the definitions in this document accordingly.

A full list of terminology and definitions is included in Appendix 1, but the key terms used within this document are:

Mono-material	Contains predominantly one material type, either PE (LDPE, LLDPE, HDPE), PP, PET, aluminium, paper or other.
	For plastics, this should be seen to mean >90% of one polymer type as this is the upper threshold when the other elements such as adhesives, additives and inks are included.
	The exception is if one of the minor components such as paper or biodegradable plastics will disrupt the plastic mechanical recycling process.
	Bi-axially oriented and non-oriented forms of the same base polymer are considered to be mono-material as are PE and PP copolymers and homopolymers as long as they have a neutral or positive effect on the recycled stream.
	This definition applies equally to paper and aluminium foil flexible packaging although the actual percentage may vary depending on the recycling process (to be confirmed in phase 2).
Multi-material[11]	Contains more than one layer of material where no material type is > 90% and the other layers are made of different materials.
	The different layers in the structure can be 'joined' together through adhesive bonding or tie-layers via an extrusion, co-extrusion or lamination process or via extrusion coating or extrusion lamination processes.
Recyclable	A pack can only be considered recyclable in a given country/market if there is a realistic chance (> 50%) that it will be (i) collected; (ii) sorted into a material fraction that is recycled in to a new material/product at scale and for which (iii) there are viable end market applications.
	This includes when the recycled material is used in conjunction with virgin or recycled materials from other sources (i.e. it does not only need to be used at 100% inclusion).
	The key test of recyclability is whether the recycled materials will replace the need for new material from virgin or recycled sources.[12]

HDPE	High density polyethylene	PET	Polyethylene terephthalate
LDPE	Low-density polyethylene	PO	Polyolefin
LLDPE	Linear low-density polyethylene	PP	Polypropylene
MRF	Materials Recovery Facility	PS	Polystyrene
MSW	Municipal solid waste	PVC	Polyvinyl Chloride
NIR	Near-Infrared	RDF	Refuse derived fuel
PA	Polyamide	SRF	Solid recovered fuel
PE	Polyethylene		

[11] See Appendix 1 for definition of multi-layer.
[12] Derived from ISO 14021: 2016 Environmental labels and declarations

Methodology

The guidelines have been developed by stakeholders participating in the CEFLEX initiative and representatives from across the value chain including:

- Raw material producers
- Ink, coating and adhesive suppliers
- Film producers
- Packaging converters
- Brand owners
- Waste management companies
- Recyclers
- Extended producer responsibility organisations
- Technology/machine suppliers.

Each part of the value chain has provided their input and expertise to ensure the guidelines encompass the views of, and challenges faced by all. The content of the guidelines is based on value chain consensus, using the best available data from testing and commercial practices. This has considered the 'best in class' current technologies and processes available to collect, sort and mechanically recycle polyolefin-based post-consumer flexible packaging that are already in operation at scale in Europe.

The phase 1 guidelines identified and evaluated flexible packaging structures currently placed on the market based upon:

Sortability: an assessment of whether the structure can be identified and sorted into an appropriate material stream using current technologies and processes in an industrial scale sorting facility

Recyclability: an assessment of whether the structure can be mechanically recycled using standard processes and technologies for polyolefin-based materials, on an industrial scale

The polyolefin-based structures that were evaluated as being able to be sorted and recycled are regarded as being 'Designed for Recyclability' and within the scope of this document.

This does not necessarily mean the packaging will be recycled but that if the collection and sorting infrastructure exists it is likely to be able to be recycled.

In addition, in some European regions, some flexible packaging structures not within the scope of the first phase of the guidelines will be collected, sorted and recycled and used in a variety of end applications.

Project Barrier

At the start of this process, CEFLEX used the work of the New Plastics Economy 'Project Barrier' pioneer project on recyclability guidelines for plastic-based flexible barrier packaging to inform the development of 'Designing for a Circular Economy'. There is clear alignment between the two sets of guidelines, though with some differences in scope, specific criteria and thresholds.

The objective of Project Barrier[13] was also to develop 'design for recyclability' guidelines for plastic-based flexible barrier packaging, focusing on post-consumer household flexibles, with the aim of influencing the design of packaging put on the market and, in turn, the quality of materials entering the recycling streams.

CEFLEX used this work as a starting point and incorporated input and expertise from each part of the value chain to ensure the guidelines encompass the views of, and challenges faced by all. The content is based on value chain consensus, using the best available data from testing and commercial practices.

[13] https://www.newplasticseconomy.org/projects/pioneer

4 Building understanding of the end-of-life processes for flexible packaging

Packaging disposal

Once a product contained in flexible packaging has been used or consumed and the packaging no longer has a purpose, the consumer must be able to easily identify how to dispose of it in the correct collection receptacle, so it is made available for sorting and recycling. Examples of this are the yellow bin in several European countries. This is a key stage in ensuring the packaging materials are made available after use to be sorted and recycled.

Emptyability

When a consumer has used or consumed a product it is important that the pack can be fully emptied. The 'emptyability' of a pack means that the consumer can easily remove the product with only a minimal amount (ideally none) of product remaining on or in the packaging. This reduces the level of residual product waste (for example food waste, detergents, personal care products) being present in the recycling stream and there will be less contamination to be removed during the recycling process. Removal of residual product waste adds cost to the recycling process and can impact the quality of the recycled material.

Separating different materials before disposal

Other considerations include whether different parts of a pack such as film lids, labels, zips, caps and spouts etc. should be separated. If the materials are compatible, then the different parts of the pack should remain together. If the pack contains different materials, then these parts should be easy to separate. However, the ideal design would not require the consumer to separate parts and incompatible materials should be avoided wherever possible.

Providing clear instructions to consumers on how to dispose of the packaging after use is key. This is clearly dependent on the different systems and infrastructure developed in different regions and countries.

Collection

Collection is the key step in developing the circular economy for flexible packaging and must include flexible packaging disposed of at both consumers' homes and out of home or on the go.

CEFLEX calls for the establishment of the infrastructure and systems to enable all post-consumer flexible packaging to be collected for sorting and recycling. This means collection of all packaging (including flexible packaging); and for this packaging to be separately collected from residual and organic waste.

There are a variety of options for how this collection infrastructure can be operated, for example a comingled stream of packaging including rigid plastics (bottles, pots, tubs and trays), metals and potentially glass, or a single stream of plastics.

It is not considered good practice to collect glass with the other dry recyclables due to the impact it has on the sorting equipment in the next stage of the process.

CEFLEX recognises that the choice of collection system is best made at the local, regional or national level to provide a degree of flexibility and to enable specific requirements to be met. Collection should occur primarily at the household level but also needs to ensure that flexible packaging used out of home and on the go can be captured and made available for sorting and recycling. Collecting and sorting on the go packaging is important for some formats, as this can represent as much as 50% of the number of units entering the waste stream and can help contribute to the prevention of littering.

There will also be some circumstances where alternative collection systems will be needed. For example, in some high-density population areas it may not be possible or practical for additional collection receptacles to be used and thus recyclable packaging will remain in the residual waste stream.

In these situations, there is an opportunity to use technologies and processes that enable flexible packaging to be post-segregated from the residual waste stream prior to incineration/disposal and for it to be made available for sorting and recycling. This is also the case for packaging consumed on the go and packaging not disposed of in household waste collection systems.

Sortability

Sorting facilities also called Materials Recovery Facilities (MRF) use a series of processing steps to identify and segregate the mix of materials into separate fractions for recycling.

The sorting processes exploit the different sizes, shapes and material properties of the recyclables to identify and segregate materials. Most MRFs in Europe use automated processes although some have operators to manually identify, pick and segregate specific packaging formats and material fractions.

The typical key sorting steps are shown in Figure 3. Individual sorting facilities may have different configurations of processes and equipment.

Once the different fractions of material have been separated, a baler is used to compact the loose sorted material fractions, reducing the overall volume and transportation costs. Each sorted fraction will have a technical bale specification detailing the characteristics and quality of the material required by the recycler, including factors such as minimum purity level, maximum humidity content, minimum and maximum bale density, acceptable levels of contaminants, any contaminants not acceptable at any level, bale wire and bale size.

Figure 3

DRUM OR TROMMEL SCREEN: this is a rotating cylinder that uses the size of the packaging to separate larger 'oversized' items from smaller 'undersized' particles. Smaller items and dirt will fall through the holes of the screen and typically this material will be classed as a residual fraction which is not sent for mechanical recycling. Larger items will continue through the subsequent processing steps. As a significant proportion of flexible packaging is smaller in size it is important that the screen size enables a good yield of flexible packaging to be sorted for recycling. Whilst 70mm and 50mm holes in a trommel screen are commonly used, the current trend and recommended screen size on new sorting facilities in Germany is circa 20mm.

BALLISTIC SEPARATION: a ballistic separator uses the shape and the ability of a packaging item to bounce to classify items as two-dimensional (2D) or three-dimensional (3D). The 'light' or 2D fraction will consist of flat and thin materials such as flexible packaging (pouches, bags, sachets, removable lids, wrappers), paper and cardboard; these materials are thrown upwards towards the top of the machine. The 'heavy' or 3D fraction consists of bottles, cans, pots, tubs and trays. For flexible packaging to be separated from rigid packaging it needs to be flat and 2D in shape/format when it arrives at the ballistic separator. This separation of 2D from 3D formats is important as the grades of PE and PP used in flexible packaging have very different properties to those used in rigid packaging and should be kept separate.

MAGNETIC AND EDDY CURRENT SEPARATION: these pieces of equipment are used to separate ferrous and non-ferrous metals. Over-band magnets are used to separate ferrous metals such as steel, whilst packaging containing aluminium foil can be separated by an eddy current separator, which uses a high-speed magnetic rotor to generate an electrical current. This produces a magnetic field which repels non-ferrous metals. Flexible packaging that contains aluminium foil (above a thickness of 5 microns) can theoretically be detected by eddy current separation technology, irrespective of the percentage of other materials in the structure. The capability of an eddy current separator to efficiently eject the packaging containing aluminium foil depends on the configuration of the machine, in particular the number of magnetic poles. For an infeed of waste containing mainly smaller items, a higher number of magnetic poles is recommended (24 or 32). The efficiency of the sorting is also dependent on the 'quality' of the infeed stream; the more homogeneous (not mixing very big heavy items with very small light items) and the more evenly distributed flow of material (not too crowded on the sorting belt) the better.

OPTICAL SORTING: a range of different plastics are used in packaging including PE, PP and PET, etc. Optical sorting systems such as Near-Infrared (NIR) can be used to identify and separate specific polymer types and material combinations. The NIR sorter uses a camera calibrated to identify the individual polymer types. However, as the camera can normally only see the plastic layer on the top surface of the packaging, in a multi-material flexible pack the NIR will typically only see the outer layer and miss inner layers of potentially different materials. Each optical sorting station can sort one or maximally two different materials or colours. NIR optical sorting is usually a compromise between quality and yield; if the NIR detector is programmed to reach maximum output quality this will be achieved at the expense of yield.

Note: NIR and other identification sorting technologies are improving continuously and are being retrofitted to improve the quality of the sorted fraction where this is needed. Other developments include for example digital watermarking with Project HolyGrail 2.0 developing a technique to 'tag' plastic packaging so that the exact packaging composition can be read from a database. Further work will be undertaken in phase 2 on optical sorting.

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Recyclability

Once different material types (paper, metals, plastics) have been separated into distinct fractions they can enter a recycling process.

The focus of these guidelines is on mechanical recycling processes, recognising that these will be the primary route for recycling flexible packaging in the short to medium term.

Mechanical recycling processes for flexible polyolefin-based materials are already proven and operated on a commercial scale in some European countries. Significant expansion of the mechanical recycling infrastructure across Europe will be required to manage and process the increasing volumes of materials as more regions and countries collect post-consumer flexible packaging for recycling.

The quality of the input material to the recycling process has a significant impact on the associated costs and yields for the recycler. Cleaner, less contaminated (by product residue and/or non-target material) input material is preferred as this reduces the cost of washing and subsequent processes and improves both the yield and quality of material obtained from the recycling process.

While for plastics and paper a mechanical recycling process is currently used, for structures containing aluminium the process will generally start with pyrolysis to recover the aluminium fraction by 'removing' the plastic and other non-aluminium materials at high temperature/low oxygen conditions. The hydrocarbon fraction is also recovered and is currently used to generate energy.

Other advanced recycling technologies, such as solvent-based recycling, are being developed and commercialised, opening further opportunities to improve the recyclability of flexible packaging structures.

In parallel the development of other types of processes and technologies such as chemical recycling is gaining momentum and is likely to have an important role to play as we move towards a circular economy. The term chemical recycling covers a range of technologies including pyrolysis, gasification and depolymerisation. For example, a pyrolysis process followed by steps to recycle the hydrocarbons back into a Naphtha can be used to produce new plastics and other chemicals replacing virgin Naphtha.

These guidelines will be updated to consider these emerging technologies as a more comprehensive understanding of their role, capabilities, environmental, financial and regulatory considerations is obtained.

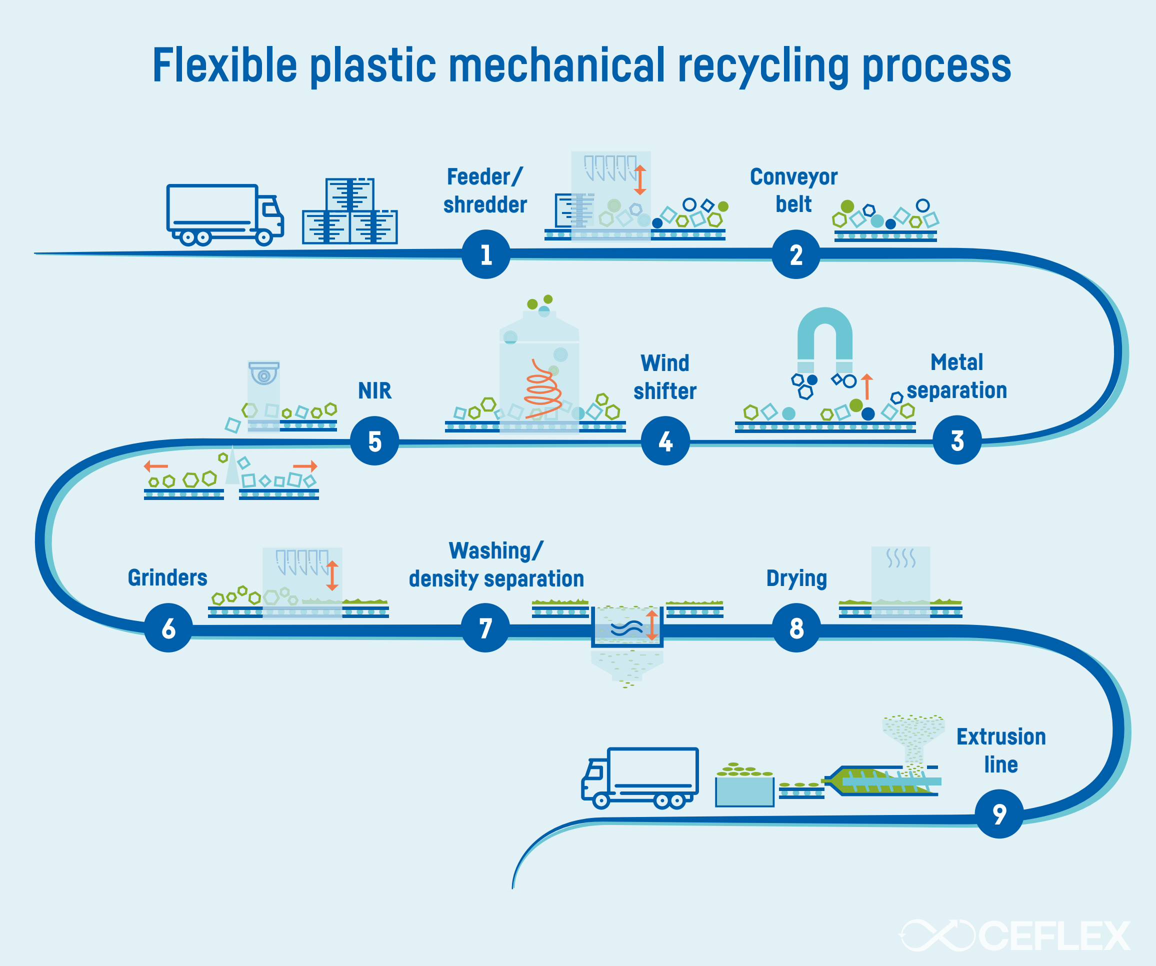
The key stages of a typical mechanical recycling process used for polyolefin-based flexible packaging are shown in Figure 4. Individual recycling facilities may have more, or less, processes and different configurations of equipment.

Some recyclers will sell plastic flake rather than extruding the flake to a pellet for use in end market applications.

Each application will have a technical specification, detailing the characteristics and quality of the material required such as melt flow index, colour, odour, food grade criteria, etc.

Further information will be provided on the recycling processes for paper and aluminium in phase 2 of the CEFLEX guidelines.

Figure 4



SORTING: it is common practice for most recycling facilities to perform some degree of additional sorting processes on the unbaled materials which can include magnetic separation, eddy current separation and NIR optical sorting stations.

SIZE REDUCTION AND WASHING: the waste plastics are typically size reduced i.e. shredded and washed in order to remove contaminants such as paper, residual food/product waste, dirt and sand. The more contaminated the flexible packaging is the higher the costs of washing and the lower the yield of recyclable material generated.

DENSITY SEPARATION: This process is used to separate polyolefins from other plastics such as PET, polyvinyl chloride (PVC) or polystyrene (PS). Polyolefins have a density of < $1g/cm^3$ (unless heavily filled) and will float in the process, whereas the non-polyolefins have a density of > $1g/cm^3$ and will sink (unless expanded).

DRYING AND EXTRUSION: the final stage is drying and extrusion, where the plastics are melted, filtered and pelletised.

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5 Phase 1 Designing for a Circular Economy Guidelines

The scope of phase 1 of the CEFLEX guidelines is those polyolefin-based primary and secondary flexible packaging structures that can be regarded as 'Designed for Recyclability' today; mono-PE, mono-PP and mixed polyolefin structures.

If these structures are collected and made available for sorting and recycling (where the infrastructure exists) then there is a realistic chance of the materials being mechanically recycled.

In addition, structures containing paper and aluminium have been referred to within these guidelines where there is existing knowledge about their sortability and recyclability.

Structures where aluminium and paper are the dominant materials are regarded as being 'Designed for Recyclability' in the same way as mono-PE, mono-PP and mixed PO structures. Further work is needed to fully understand how other paper-based structures and structures containing aluminium can be designed for recyclability which will be conducted in phase 2.

Mono-PET flexible packaging structures such as mono-PET lidding attached to a mono-PET tray can also regarded as being 'Designed for Recyclability'.

The use of the term 'mono-material' in this document is referring to what is considered 'mono' from a plastics recycling perspective. CEFLEX acknowledges this may be different to what a packaging designer or technologist would consider to be a mono-material. The 90% by weight of mono-PE or mono-PP accepts there will be up to a maximum of 10% other materials or elements included in the flexible packaging structure.

The list of flexible packaging structures that have been assessed as being 'Designed for Recyclability' are shown in Table 1 (refer to definitions in Appendix 1 for each polymer). The limits/percentages included in Section 6 should be taken into consideration with this table.

Those structures not covered in this document will be tested and covered in phase 2 of the guidelines and are shown in Table 2. In addition there are some structures (shown in Table 2) that are already covered by this document, however, further work is needed to better understand the impacts of these. If required, revisions will be made to the phase 1 guidelines.

Table 1: Phase 1 Designed for Recyclability flexible packaging structures[14]

Structures	Notes
Mono-PE and mono-PP structures (should be a minimum of 90% PE or PP)	Technologies exist to sort and recycle
PE/PE and PP/PP laminate structures (should be a minimum of 90% PE or PP)	Technologies exist to sort and recycle
PE/PP (mixed PO) laminate structures (should be a minimum of 90% PO materials)[15]	Technologies exist to sort and recycle
PE and PP structures with coatings and layers such as EVOH, PVOH, Acrylic, SiOx and AlOx	Technologies exist to sort and recycle
PE and PP structures with laminated and printed metallisation	Technologies exist to sort and recycle
Aluminium-based structures	Technologies exist to sort and recycle aluminium-based structures where aluminium is the dominant material. Further details and explanations to be provided in phase 2
Paper-based structures	Technologies exist to sort and recycle paper-based structures where paper is the dominant material. Further details and explanations to be provided in phase 2

Table 2: Phase 2 flexible packaging structures

Structures	Notes
PET laminate structures e.g. PET/PE, metallised PET/PE, PET/PP etc.	Further investigation required to evaluate sortability and recyclability
PA laminate structures e.g. PA/PE etc.	Further investigation required to evaluate sortability and recyclability
PE/PP (mixed PO) laminate structures[16]	Further investigation required to evaluate sortability and recyclability
Structures containing PVDC	Further investigation required to evaluate sortability and recyclability
Other mixed plastic laminate structures	Further investigation required to evaluate sortability and recyclability
Aluminium-based structures	Regarded as 'Designed for Recyclability' for structures with aluminium as dominant material as technologies exist to sort and recycle. Further details and explanations to be provided in phase 2
Structures containing aluminium foil	Further investigation required to evaluate sortability and recyclability
Surface metallised structures	Further investigation required to evaluate sortability
Paper-based structures	Regarded as 'Designed for Recyclability' for structures with paper as dominant material as technologies exist to sort and recycle. Further details and explanations to be provided in phase 2
Other paper structures	Further investigation required to evaluate sortability and recyclability
Other mixed material laminate structures	Further investigation required to evaluate sortability and recyclability
Other elements within flexible packaging structures e.g. tie layers, additives, adhesives, inks, coatings, varnishes, barrier coatings, etc	Further investigation required to evaluate impact on sortability and recyclability

[14] Refer to pages 27 and 28 for further information on thresholds for mono-PE, mono-PP and mixed polyolefin structures.
[15] Refer to pages 27 and 28 for further information.
[16] Refer to pages 27 and 28 for further information.

6 Circular economy flexible packaging design principles

General design principles

Flexible packaging includes a wide range of different formats and elements, with each structure and combination of elements designed to meet specific packaging functionalities, for example a certain requirement for gas and moisture barrier, resistance, stiffness, etc. Even with these specific functionality requirements there are some generic design principles that can be followed to support designing flexible packaging for a circular economy.

The guidance included in the following sections relates primarily to plastic-based flexible packaging.

References/guidelines relating to paper-based structures and those containing aluminium are given where there is an agreed understanding of the impact of the design of flexible packaging containing either paper or aluminium or both, on the sorting and recycling processes. However, these materials will be covered in more detail in phase 2 when the required testing has been completed.

In order to achieve the CEFLEX vision, a preference of recycling streams is required. CEFLEX advocates firstly collection of all flexible packaging, followed by sorting and recycling the polyolefin-based mono-material streams (mono-PE and mono-PP), over polyolefin mixes, over mixed plastics (including flexibles), over mixed materials.

This is required to keep as much financial value in the recycled materials as possible whilst realising the greatest environmental benefit. A key objective when designing flexible packaging for a circular economy is to produce packaging that is as high up the preferences outlined in Figure 5 as possible.

Within these plastic recycling stream preferences, market applications and uses for the recycled materials can also be listed in order of preference. This recognises that a range of market applications and products will be needed for the increased volumes of recycled materials from flexible packaging.

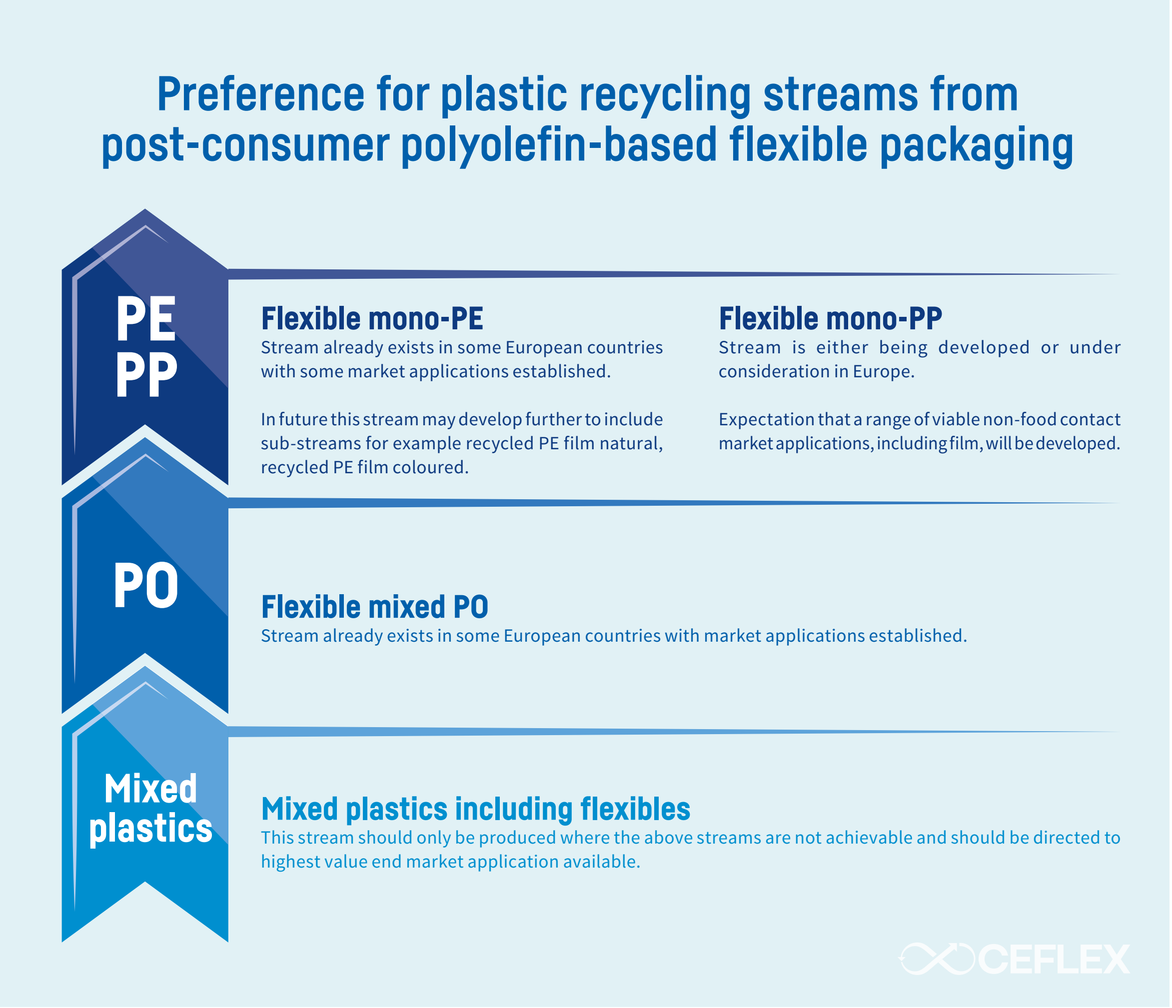
These guidelines have not been written to produce recycled polyolefin materials suitable for a specific end market application. The recycled materials produced by adhering to these guidelines will be suitable to use in a range of applications. Higher value applications such as film packaging may require a higher threshold of mono-material and a lower amount of 'other materials' than proposed in these guidelines. Work to understand this is in progress.

The preference is for recycled PE or PP to be used back in to film applications (film to film) as this will help to retain the greatest financial value in the material and to reduce the use of virgin plastics where it is appropriate to do so.

In addition, recycled plastic can be used in non-film applications (film to rigid) including injection moulding, again with the opportunity to reduce the use of virgin plastics. There are also opportunities to replace other materials, for example in wood plastic composite applications.

There is also the opportunity to produce energy (Solid Recovered Fuel (SRF) and Refuse Derived Fuel (RDF)) especially from the smaller sized or residue fractions that cannot be (mechanically) recycled for example through pyrolysis. This is classified as recovery, not recycling.

Figure 5



Guidelines for designing polyolefin-based flexible packaging for recyclability

The following sections provide guidance on designing the respective elements of a flexible packaging structure. When adopting and implementing the guidelines, the design and specification process should not result in an increased use of resources. For example, increasing the weight or thickness of a structure simply to meet the recyclability limits/percentages within this document or increasing the size of the packaging item to achieve the size and shape guidelines to support sortability is not desirable.

The decision to change the design of a packaging structure (assuming the product protection requirement can still be achieved) can influence the efficiency with which the packaging material can be processed. Factors including processing speed and the production of scrap material for instance should therefore be taken into consideration.

All the limits/percentages included in these guidelines should be considered as a holistic set of requirements.

The examples in Figure 7 are typical compositions of flexible packaging structures, to show how the limits/percentages for the elements of a structure work together.

A summary of the guidelines is provided in Appendix 3.

Figure 6

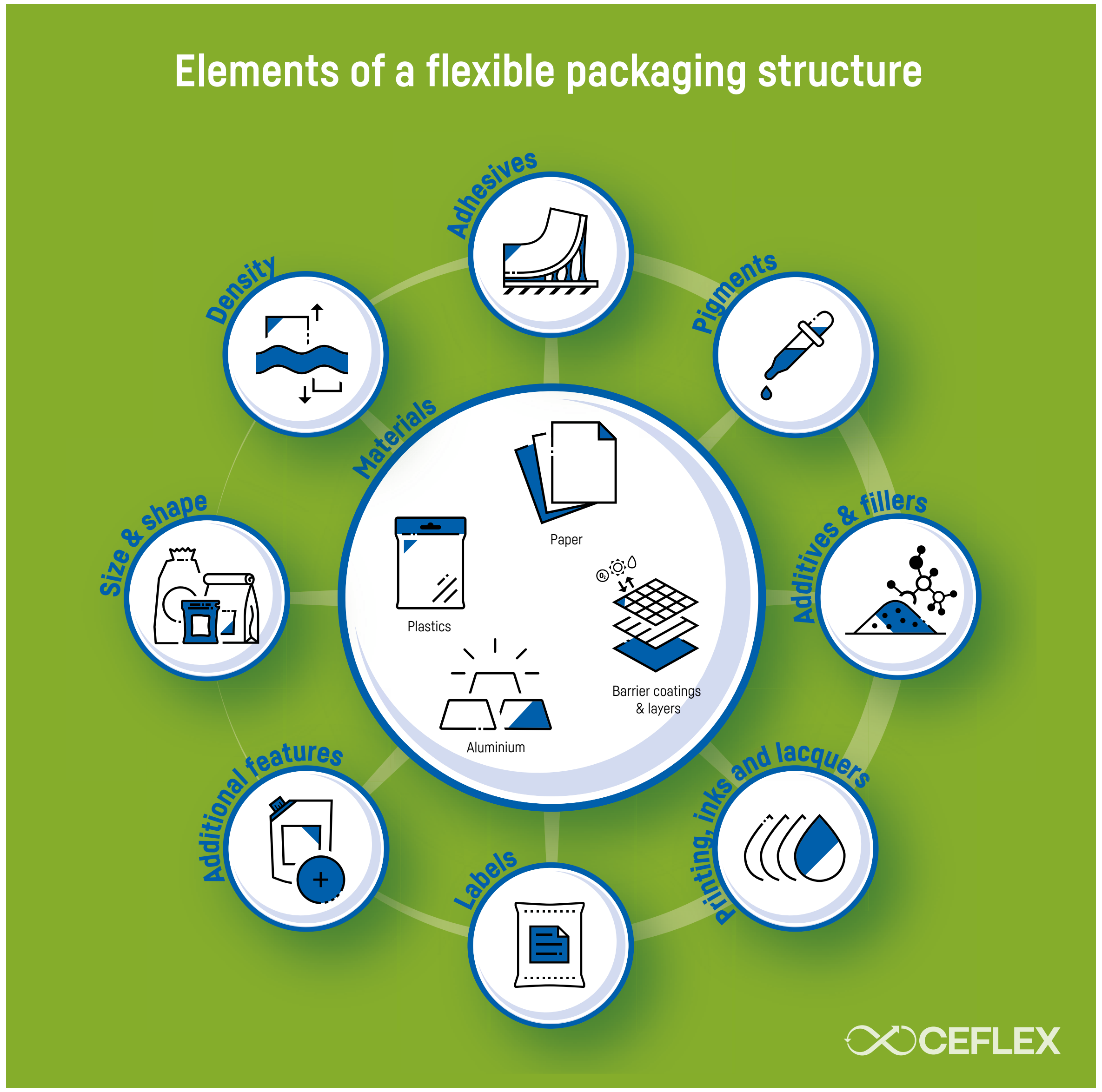
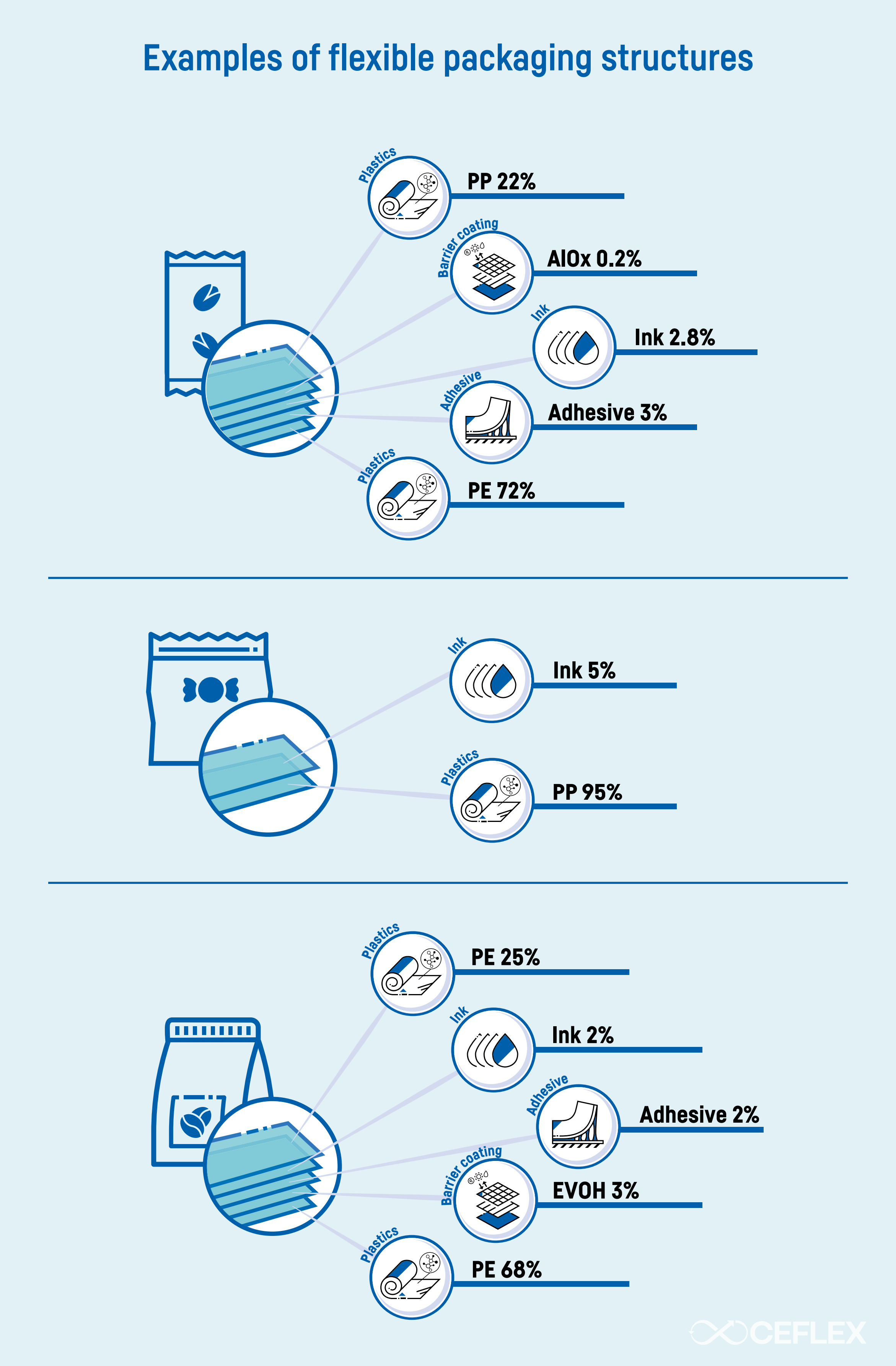


Figure 7



Material selection

The materials used in flexible packaging structures play a key role in determining the sortability and recyclability of the packaging.

This includes influencing how the flexible packaging is identified and disposed of by a consumer and how it is managed in the post-consumer waste stream. For example, a paper-based flexible packaging structure should be collected and managed separately to a plastic-based structure and be sorted into a paper stream for recycling.

The recycling stream that a pack is sorted into should be determined by the dominant material used in a structure. However, in practice the sorted fraction (recycling stream) a flexible pack ends up in is often determined by the surface layer(s) seen by NIR optical sorters. This is normally the outer layer of a pack but could also be the inside layer if there is a reasonable possibility that the inside layer is exposed and made visible during the use, disposal, collection or sorting process.

The layer detected by the NIR can also be the second layer of the packaging structure if the outer layer is transparent or translucent.

If the inside layer is the same material as the outer layer, then this is not an issue. However, if the inner layer of the pack is a different material to the outer layer i.e. multi-material, then there is a possibility that it will be sorted into an incompatible fraction and risk disrupting the recycling process at the next step of the chain.

The NIR visible layer(s) of the flexible packaging structure should be the material fraction it is sorted into:

- Plastic-based structures: PE or PP for those respective recycling streams or a mixed polyolefin recycling stream; or PET so any structures containing PET can be identified and removed from a polyolefin-based recycling stream
- Paper-based structures: paper
- Structures containing aluminium: eddy current separation technology works on structures containing aluminium foil, so the aluminium does not necessarily need to be on the outer layer of the structure or even a dominant material (see Sortability section on pages 16 and 17 for further information about detection of aluminium foil by eddy current separation technology).

This will improve the changes of the flexible packaging being correctly identified and sorted using the processes outlined in the Sortability section on pages 16 and 17.

Mono-material packaging is currently preferable as these structures are easier to recycle and should contribute to an improved quality, and therefore value, of the recyclate generated.

Plastics

POLYMER CHOICE

Polyolefins

Polyolefin-based structures designed for mechanical recycling of polyolefins could be:

- A single polymer type (a PE or a PP), for example a low-density polyethylene (LDPE) structure; including their copolymers, ethylene copolymers and propylene copolymers, polar and non-polar
- A combination of grades of a single polymer type (PE or PP), for example a mix of different grades of LDPE and linear low-density polyethylene (LLDPE)
- A polyolefin-based structure with a combination of PE and PP, including their copolymers, ethylene copolymers and propylene copolymers, polar and non-polar.

The use of the term 'mono-material' in this document is consistent with what is considered 'mono' from a plastics recycling perspective. CEFLEX acknowledges this may be different to what a packaging designer or technologist would consider to be a mono-material. The 90% by weight of mono-PE or mono-PP accepts that there will be up to a maximum of 10% other materials or elements included in the flexible packaging structure.

Thresholds for mono-PE structures

Compatible with PE or mixed PO mechanical recycling processes	Limited compatibility[17] with PE or mixed PO mechanical recycling processes	Not compatible with PE or mixed PO mechanical recycling processes
>90% PE	80-90% PE	<80% PE

Notes for mono-PE structures:

(i) A minimum of 90% PE by weight of the total packaging structure is needed for full compatibility with a PE mechnical recycling process, in order to maintain the quality and value of the final recyclate. This is the guideline threshold to be strived for. These structures are also considered to be compatible with a mixed PO mechanical recycling process.

(ii) Structures with 80-90% PE by weight will be accepted but will be of limited compatibility in PE mechanical recycling processes. This limited compatibility also applies to mixed PO mechanical recycling processes.

(iii) Structures with less than 80% PE will likely affect the overall yield of the respective PE or mixed PO mechanical recycling process and could negatively impact the recycled plastic quality and are thus considered to be incompatible.

(iv) For structures that combine PE and PP refer to thresholds for mixed polyolefin structures on page 28.

Thresholds for mono-PP structures

Compatible with PP or mixed PO mechanical recycling processes	Limited compatibility[18] with PP or mixed PO mechanical recycling processes	Not compatible with PP or mixed PO mechanical recycling processes
>90% PP	80-90% PP	<80% PP

Notes for mono-PP structures:

(i) A minimum of 90% PP by weight of the total packaging structure is needed for full compatibility with a PP mechanical recycling process, in order to maintain the quality and value of the final recyclate. This is the guideline threshold to be strived for. These structures are also considered to be compatible with a mixed PO mechanical recycling process.

(ii) Structures with 80-90% PP by weight will be accepted but will be of limited compatibility in PP mechanical recycling processes. This limited compatibility also applies to mixed PO mechanical recycling processes.

(iii) Structures with less than 80% PP will likely affect the overall yield of the respective PP or mixed PO mechanical recycling process and could negatively impact the recycled plastic quality and are thus considered to be incompatible.

(iv) For structures that combine PE and PP refer to thresholds for mixed polyolefin structures on page 28.

Note: Bio-based PE and PP are considered chemically identical to fossil fuel derived PE and PP and therefore indistinguishable. Bio-based PE and PP will not cause any issues with a mechanical recycling process.

Mixed polyolefin structures

The preferences described and shown in Figure 5 recognise that mono-materials are preferred to mixed PO materials in flexible packaging structures. This is justified by the increase in potential end markets for which mono-materials can be considered. A mono-PE or mono-PP material can be included in a mixed PO material stream without negative impacts, but not vice versa as some end markets for mono-materials, for example blown or cast films, require higher quality mono-PE or mono-PP respectively.

[17] Limited compatibility refers to those materials that are not preferred within a recycling process but do not present a significant risk of disruption to the process.
[18] Ibid.

Plastics

This preference for mono-materials will become increasingly important as the quantities of flexible packaging being collected, sorted and recycled increase and more end market applications are developed.

Currently it is not widely possible to sort out a mixed PO stream if the sorting operation seeks to sort out a mono-PE for recycling. If a mixed PO structure is seen by an NIR as a PE due to a PE layer being seen, then the PP material within the PO mix will be sorted into the mono-PE stream for recycling.

If the NIR sees the PP layer of the mixed PO structure, then it will not be sorted into the mono-PE stream for recycling but be sorted with the mixed PO fraction (or with the mono-PP fraction when/where that stream exists). The sorting of mixed PO structures is not an issue if the sorting operation is only targeting a mixed PO stream for recycling and not a mono-PE or mono-PP stream.

Due to this sorting dilemma, these guidelines have chosen to use the same threshold of 90% for the mixed PO structures as the mono-PE and mono-PP structures. This is in order to moderate any impact of these mixed materials on the mono-materials streams that CEFLEX believes are needed in the future to satisfy enough end markets for these mechanically recycled materials.

However, CEFLEX also recognises that mixed PO materials are mostly used in less demanding end market applications which may be able to tolerate PE, PP and/or mixed PO materials where the PE, PP and/or combination of the PE and PP represents only 80-90% of the total packaging structure by weight. The tolerable lower limit of 80% of the PE, PP and/or mixed PO material will be further explored in phase 2 and revised as necessary.

Thresholds for mixed PO structures

Compatible with mixed PO mechanical recycling processes	Limited compatibility[19] with mixed PO mechanical recycling processes	Not compatible with mixed PO mechanical recycling processes
>90% PO	80-90% PO	<80% PO

Notes for mixed PO structures:
(i) A minimum of 90% mixed PO by weight of the total packaging structure is needed for 'full compatibility with a PO mechanical recycling process, in order to maintain the quality and value of the final recyclate and this is the threshold to be strived for.
(ii) Structures with 80-90% mixed PO by weight will be accepted but will be of limited compatibility in mixed PO mechanical recycling processes.
(iii) Structures with less than 80% mixed PO will likely affect the overall yield of the respective mixed PO mechanical recycling process and could negatively impact the overall yields and/or recycled plastic quality and thus considered to be incompatible.

PET

PET is not compatible with a PE, PP or mixed polyolefin mechanical recycling process.

If PET is used in a PE, PP or mixed PO laminate then it should ideally be on the outer surface of the packaging structure so it can be identified by NIR optical sorting and removed as a disruptor to a PE, PP or mixed PO mechanical recycling process.

If the PET is within a middle layer of a PE or PP laminated structure it may be sorted out in the density separation process (depending on the proportion of PET to PE, PP or mixed PO material).

Note: the impact of flexible packaging laminated structures containing PET in polyolefin-based mechanical recycling process will be assessed in greater detail in phase 2.

PVC

PVC is a plastic which is problematic when used within packaging because no recycling infrastructure for PVC packaging exists in Europe today and also contaminates other types of plastic which could otherwise be recycled. It can be found in various forms, such as film around vegetables or in blister packs.

PVC should not be used in flexible packaging structures.

Biodegradable and compostable polymers

Biodegradable and compostable polymers even at low levels are expected to cause disruption of the mechanical PE, PP and mixed PO recycling processes and negatively affect the quality and value of final recyclate. They should not therefore be used in PE, PP or mixed PO structures intended to be mechanically recycled.

These polymers should be used only for targeted applications where the waste packaging is collected in an organic waste management system rather than a plastics mechanical recycling stream. This will help to ensure these polymers cannot contaminate the recycling of other materials and is to be composted under the required conditions.

Nylon (Polyamide)

There is a lack of robust trial data to understand and evaluate the impact of Nylon or Polyamide (PA) on the polyolefin mechanical recycling process. Polyamide has a pivotal role to play in providing oxygen, aromas and a grease barrier as well as excellent general mechanical and specific puncture resistant properties for flexible packaging structures. It also helps to reduce overall plastic consumption through down-gauging.

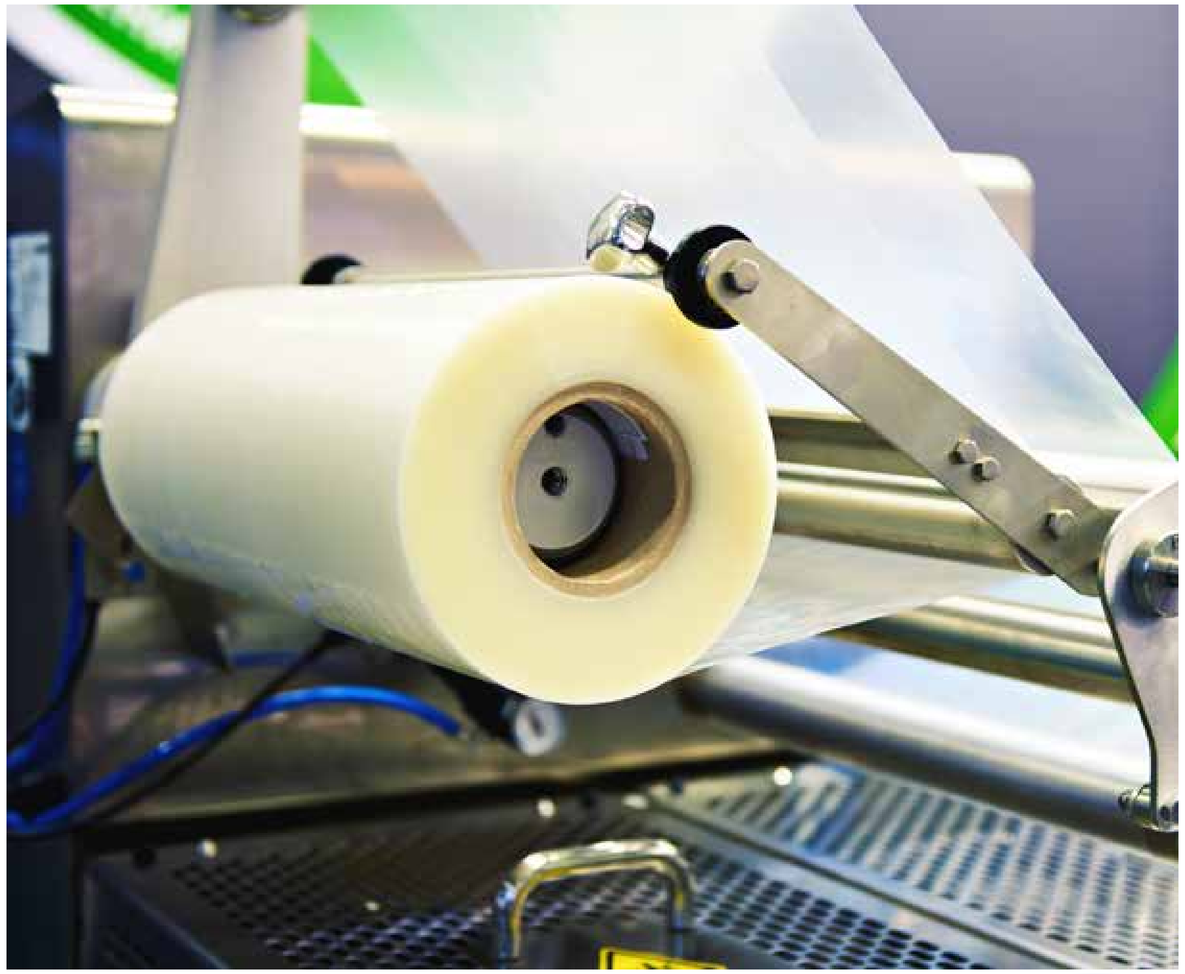
[19] Ibid.

It is thought that a certain amount of PA can be processed and tolerated in the polyolefin mechanical recycling process, however it has not yet been possible to quantify the level of PA in flexible packaging that may have an impact on the recyclability of mono-PE or mono-PP.

Further work will be undertaken in phase 2 to evaluate and agree a limit for PA in flexible packaging waste streams, as well as considering opportunities to sort and recycle structures containing PA.

Other polymers

It is recognised that other polymers are being developed out of specialist markets and may become more mainstream in consumer flexible packaging in the future. Whilst some of these materials are eminently recyclable, it will take some time to develop sufficient volumes of post-consumer waste materials where it warrants them being sorted out of the mixed stream into their own specific fraction. When specifying these materials in flexible packaging applications, precautions need to be taken to ensure that they are clearly identifiable as non-PE or non-PP so that they can be readily sorted out of the mono-material streams/fractions thereby avoiding disruption to the polyolefin-based recycling processes.



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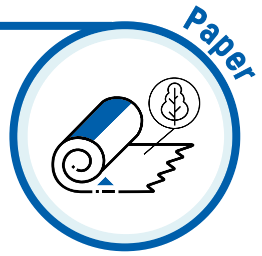
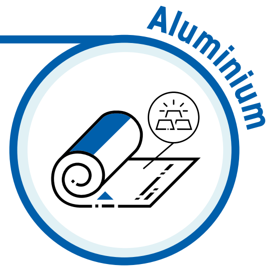


PAPER AND PAPER LABELS

Paper is a widely used flexible packaging material and is generally recyclable with the paper fraction consisting of other formats of paper. If paper properties are needed in the flexible packaging structure, then it should represent the dominant material by weight and be able to be identified as paper in the sorting process and be sorted into the paper fraction for recycling.

Whilst specialised paper recycling mills can manage and separate a certain quantity of non-fibre materials including plastic in the fraction, this is undesirable as it impacts the overall fibre yield and quality achieved from the recycling process and the plastic fraction needs to be managed (usually as RDF). This increases the costs for the recycler, although the plastic may have a value if sold to a plastics recycler.

Paper in the plastic recycling process is a serious disruptor as it is most often not possible to remove 100% of the fibres before extrusion and any remaining fibres carbonise during the extrusion process negatively affecting the recycled plastic quality.



ALUMINIUM FOIL

Flexible packaging containing aluminium foil can readily be sorted out of the packaging waste streams using eddy current sorting technology – see Sortability section on pages 16 and 17. This is typically done in the sorting process after the magnetic belt sorting although this varies by MRF and depends on how much aluminium foil is contained in the pack.

For smaller formats, for example chocolate foil portions, they are potentially directed into the fines fraction at the early sorting stage, so an additional eddy current sorting station is needed, which is the case in an increasing number of state-of-the-art sorting facilities.

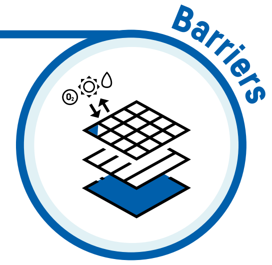
Laminated plastic-based structures containing a thin layer of aluminium foil, which is used for its high barrier function but is also undesirable in the plastic recycling process, can be separated from plastic streams by using eddy current sorting technology. The equipment needs to be set-up to recognise thin aluminium foil layers in the packaging structure enabling this fraction to be identified and segregated.

For sorted structures containing foil, the recovery of the aluminium content is possible via a pyrolysis process. It should be noted that the plastic proportion of the structure will not yet be recycled via this process[20].

If a structure containing aluminium does reach the plastic recycling process it is normally removed during the density separation process and can be recovered through applications such as a fuel for cement making.

Note: Sorting and recycling a flexible packaging structure containing a layer of aluminium foil is different to sorting and recycling of a metallised flexible packaging structure. See Metallisation section on page 32.

[20] Improved valorisation of pyrolysis products is recognised as an important opportunity, for example pyrolysis oil used as feedstock for food-grade polymers



BARRIER LAYERS AND COATINGS

Barrier layers and coatings are an important element of many flexible packaging structures, providing essential packaging functionality and in most circumstances significantly reduce overall use of materials and resources.

A barrier layer can be co-extruded into a material construction at low levels and coatings can be applied at even thinner levels, often less than a micrometre. Other barrier film materials are laminated as films into a structure using adhesive, as is the case with PA, PET and aluminium foil.

The choice of barrier material and coating, and the amount used, will have an impact on the sortability and recyclability of packaging. In order to take account of the product protection and functionality requirements, the use of barrier materials and coatings will still be required in certain applications. Where possible, the use of these should stay within the limits given for their recyclability in these guidelines.

The percentages of allowable barrier film materials in polyolefin-based structures are given here where this is widely accepted/tested. These tend to be materials that are applied at very low levels via coatings or co-extrusions. Where guidance is not given, further investigation will be carried out in phase 2.

However, where a barrier material is required, it is not considered appropriate to increase the overall weight or thickness of the material so that the percentage of barrier material is reduced and is below the limits included in this document.

The use of the following barrier layers and coatings for polyolefin-based structures is permitted within specific limits.

- Ethylene vinyl alcohol (EVOH) is often used in multi-layer polyolefin-based structures or applied as a coating to give a gas barrier. It is found in varying thicknesses depending on the overall structure and application. A maximum of 5% of EVOH of the total packaging structure is permitted. Quantities above this are thought to result in issues during reprocessing and impact the quality of the recyclate.
- Poly vinyl alcohol (PVOH) is a water-soluble barrier material and is used in specialist applications including multi-layer polyolefin-based structures and can be applied as a coating. A maximum of 5% of PVOH of the total packaging structure is permitted.
- Silicon oxide (SiOX) and aluminium oxide (AlOx) are applied as very thin layer coatings to give additional barrier properties. These are often at a nanometer level in a structure so would fall under the maximum of 5% each by weight of the total structure.
- Acrylic coatings are typically used to improve the surface of a material for printing, to improve sealability and seal integrity, and to prevent scratching of the overall material. A maximum of 5% of acrylic coatings is currently permitted.

Further work will be undertaken on all of the above points in phase 2.

PVDC

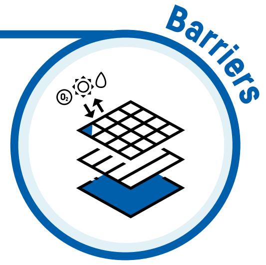
PVDC as part of a multi-layer structure with polyolefins is considered to be a material requiring further investigation due to the issues it could cause in mechanical recycling systems. However, PVDC has certain beneficial uses in some circumstances.

PVDC is used as a barrier in food packaging and since the environmental impact of food waste is higher than that of packaging, removal and/or substitution of it, or alleviating potential negative impacts during recycling should be carefully considered in order to mitigate the risk of increased food waste. It is recognised that there are technical challenges and solutions need to be developed in order to remove/substitute it.

Depending on the application, materials such as EVOH, SiOx and AlOx coatings etc, can be evaluated to determine if they are suitable alternatives to PVDC and if so, would be preferred. Each material and each application should be reviewed on a case by case basis, considering the holistic recommendations and guidelines in this document.

Further work will be undertaken to better understand the impact of PVDC on the mechanical recycling process for polyolefins, solutions to overcome any issues and whether opportunities exist to sort and recycle structures containing PVDC during phase 2.

Note: In the development of the phase 1 guidelines, it was realised that little fact-based trial work has been undertaken to understand and evaluate the impact of the different barrier systems listed here. This work will be carried out and the 5% limits revisited in phase 2.



Metallisation

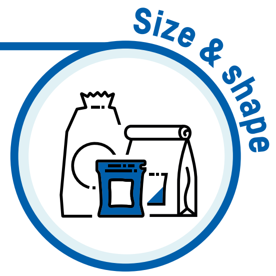
Flexible packaging structures with metallisation are notably different to structures containing aluminium foil.

Metallisation is a vapour deposition process which deposits a very thin layer of aluminium on the surface of a plastic film. This thin layer has a thickness of approximately 0.02 – 0.5 micron and provides a range of functional properties including oxygen, moisture and aroma barriers as well as light protection. Metallisation can be a layer within a laminated structure or on the surface of a packaging structure.

Laminated and printed metallised flexible packaging structures do not cause any sortability issues. The NIR is not affected as the reflective layer is within a laminated structure and can therefore not be seen. Metallisation is not regarded as a disruptor to the plastics mechanical recycling process as the layer of metallisation is too thin to be significant.

However, structures that have surface metallisation may result in sortability issues depending on the level of metallisation and printing due to the reflection disrupting NIR optical sorting processes.

Further work will be undertaken in phase 2 to explore the impact of surface metallisation on sortability. An evaluation of whether optical effects (sparkles) in recyclate are as a result of metallisation and the impact these have on end use applications will also be undertaken.



Size, shape and construction

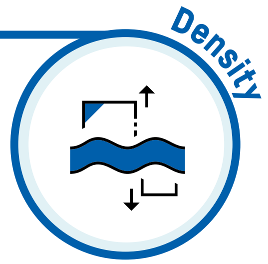
The size, shape and construction of the pack will determine how the packaging behaves in a sorting facility. Further details about how this influences sortability is covered on pages 16 and 17.

Trommel screen holes are commonly 50mm or 70mm in diameter, although there is a trend to reduce this to 20mm in new state-of-the-art facilities. Taking this into account the pack dimensions should ideally be greater than 20 x 20 mm. If an item is greater than 20 x 20 mm it will be sorted into the 'eject' (or targeted) stream passing though the trommel and made available for the subsequent sorting and recycling processes.

If individual packs (or detachable pieces of packs) are smaller than 20 x 20 mm then they are likely to fall through the holes in the screening equipment used to sort packaging materials. If this happens, these packs/pack elements will end up in the residual fraction that is typically sent for energy recovery (or is still landfilled in some countries).

However, these guidelines do not support increasing the size of individual packaging items to be greater than this threshold to facilitate sortability, in order to avoid increased use of resources.

To aid the separation of flexible packaging from rigid packaging formats such as bottles, pots, tubs and trays, the flexible packaging should be primarily flat and 2D in nature rather than 3D. Typical 2D formats include pouches, bags, sachets, removable lids and wrappers.



Density

For a polyolefin mechanical recycling process, the density of plastic-based structures must be < $1 g/cm^3$ to allow the polyolefin materials to be separated from the non-polyolefins. Care should be taken when using fillers as their presence can alter the density to be > $1 g/cm^3$ resulting in a polyolefin being sorted into the non-polyolefin fraction.

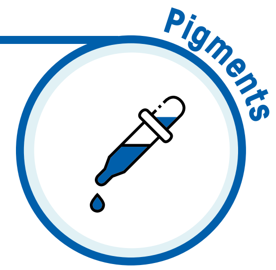
Adhesives

Adhesives play an important role in combining different materials for customising packaging functionality to suit the product or the environment where it will be used.

The total quantity of adhesives used should be below specific thresholds to prevent it negatively impacting the recyclate quality. It is reported that adhesives can give rise to gel formations during the extrusion process which can negatively affect the recyclate quality and block the screen filters on the extrusion line.

Adhesives such as polyurethane, acrylic or natural rubber latex adhesives, as well as non-PE or non-PP based tie-layers, are permitted to a maximum of 5% by weight of the total structure. The limit is to optimise the quality of the recyclate and to avoid disruption of the recycling process.

Note: In the development of the phase 1 guidelines, it was realised that little fact-based trial work has been undertaken to understand and evaluate the impact of the different adhesive systems listed here. This work will be carried out and the 5% limit revisited in phase 2.



Pigments

Carbon black containing masterbatch is generally not permitted as a pigment to plastic-based flexible packaging substrates as it is not recognisable by the NIR optical sorting technology used in MRFs.

There have been recent advances in material technologies which now allow detectable black plastics to be identified and sorted. This utilises pigments that do not contain carbon black. Therefore, if black is required, then NIR detectable pigments should be used.

This only applies to carbon black masterbatch colourant and not to black inks printed on flexible packaging, though further work will be undertaken to understand the impacts on inks in phase 2.

Low levels of pigments (of natural or lighter colours), or none, are preferred to improve recyclate quality and value as this will enable lighter coloured recyclate to be produced which has a higher value and can be used in a wider range of applications and products.

Additives and fillers

Additives and fillers not specifically mentioned above are permitted but their use should be at the minimum level needed for achieving required functionality. This includes thermal stabilisers, UV (ultraviolet) stabilisers, nucleating agents, mineral and polymer cavitating agents, antistatic agents, impact modifiers, chemical blowing agents and tackifiers.

Foamed thermoplastic non-polyolefin elastomers are not permitted in plastic-based structures due to their low density. These materials will be sorted and recycled with the PE, PP or mixed polyolefin fraction and have a negative impact on the final recyclate quality.

Compatibilisers have a role to play in rendering polymer blends that are not compatible and/or miscible, such as combinations of PE and PA, PE and PET, to be compatible with each other. If these multi-material structures are mechanically recycled in a polyolefin-based stream in the absence of compatibilisers, there will be issues with processing and the recyclate will have poor mechanical properties.

Compatibilisers are made up of at least two parts, with each part interacting with one of the two or more components of the incompatible mixture. The result is the minor component of the mixture will be dispersed within the major component and be bound to it. The more effective the dispersion and compatibiliser, the more homogeneous the resulting blend will be and the recyclate will have improved properties.

Further work will be undertaken in phase 2 on the role of compatibilisers.

Substances of very high concern (SVHC)[21] are not permitted in order to allow the recyclate to be suitable for the greatest range of end market applications.

Oxo-degradability additives are not permitted to maintain the quality and mechanical properties of the final recyclate.

Note: In the development of the phase 1 guidelines, it was realised that little fact-based trial work has been undertaken to understand and evaluate the impact of the different additives/fillers listed here. This work will be carried out and the guidance revisited in phase 2.

Inks and lacquers

Printing of flexible packaging provides important product information to the consumer, including ingredients, nutritional and allergy information and of course marketing and brand information. Lacquers and varnishes also provide barrier properties, water resistance and scuff resistance. There are a range of ink, lacquer and varnish types used and many different printing technologies.

However, whilst essential, inks are reported to negatively impact the final quality of the recyclate (unless they can be removed before the extrusion process) and are for the most part thought to be responsible for the grey-green colour of recycled PE and recycled PP. When inks are used at a relatively high level of coverage, they have been reported to also contribute to the overall level of gassing during the extrusion process.

Black ink layers printed on flexible packaging do not usually result in 100% coverage of the packaging, leaving enough spaces for NIR reflection thus enabling optical sorting. High levels of black ink coverage should be avoided so NIR reflection is not disrupted.

In general:

- The level of printing is a factor to be considered, with minimal levels of print coverage preferred, again to optimise the quality and value of the recyclate and to allow greater choice and freedom in terms of the colour of the final recyclate and end use applications
- De-inking technologies, whilst not yet widely commercial in plastics recycling, have the potential to significantly improve the quality of the recycled materials. However, these technologies have currently been demonstrated to only be effective on surface printed flexible packaging. Currently lamination printing (where the print is sandwiched between two materials and not in contact with the product) is often used in laminated structures for barrier functionality (so the inks don't come into direct contact with the product) as part of the total packaging design in order to protect the product. This might change due to barrier functionalities also offered by coatings or printed layers substituting those substrate layers acting as barriers
- Lighter colours of print are preferable as the colour of the final recycled material will be lighter and able to be used in a wider range of end use applications.

[21] https://echa.europa.eu/candidate-list-table

Lacquers and inks without PVC binders are permitted, up to a maximum of 5% by weight of the total structure. This limit is in place to optimise recyclate quality and value and to avoid disruption of the mechanical recycling process. However, criteria about maximum printing ink percentage needs to be better specified, also considering scientific or technical evidence.

Note: In the development of the phase 1 guidelines, it was realised that little fact-based trial work has been undertaken to understand and evaluate the impact of the different ink and lacquering systems listed here. This work will be carried out and the guidance revisited in phase 2.

Labels

As with inks and printing, labels include important product information for the consumer. If labels are used on flexible packaging structures the material type should ideally be the same as the material used for the main body of the packaging structure.

If a different material is used, then the label should be designed to be easily removable; either by the consumer after use (not preferred) or during the recycling process through the washing process; at present this should be via a cold wash process.

If the label is a different material to the main body of the packaging structure it should not be of a size where there is a risk that the label material is seen by the NIR as the identification material i.e. it should represent less than 30% of each packaging face presented to the NIR optical sorting equipment. Paper labels should not be used on packaging that will be recycled as a plastic.

Additional features

In terms of additional features such as zippers, spouts, closures, valves and taps incorporated into flexible packaging structures the same guidelines as outlined above in terms of polymer choices and pigments apply. From a recyclability point of view, it is preferred that the material type used is the same as the primary pack material.

It is known that some additional features such as large spouts/closures relative to the overall weight of the flexible packaging item can cause items to be sorted with a rigid packaging stream. However, it is not possible to give general advice on this, so it is suggested testing is undertaken if in any doubt.

7 Use of recycled materials from flexible packaging

These guidelines have not been written to produce recycled polyolefin materials suitable for a specific end market application. The recycled materials produced by adhering to these guidelines will be suitable to use in a range of applications. Higher value applications, for example film packaging may have higher level requirements and require a higher threshold of mono-material and a lower amount of 'other materials' than proposed in these guidelines.

Designers/specifiers of flexible packaging should consider if they can incorporate a quantity of recycled PE or PP from flexible packaging into their packaging.

For film applications, it is generally assumed that it is not yet possible to use 100% recycled PE (or recycled PP) but that lower levels of incorporation are possible. Similarly, where recycled PE, recycled PP or recycled PO can be used in non-film applications it should be encouraged to drive the development of end markets for these materials.

It is recognised that more than 70% of consumer flexible packaging applications are food related (direct or indirect contact). Currently, the European Food Safety Authority (EFSA) has not issued positive opinions for any flexible PE, PP or polyolefin mechanical recycling process for use in direct or indirect contact with food. This means that in the short to medium term, the use of recycled PE, recycled PP and recycled PO from flexible packaging will be limited to non-food contact applications[22]. Work on developing mechanical recycling processes that can be approved by EFSA is continuing.

The value chain is also working on commercialising chemical recycling for all polyolefins. This plastic to plastic recycling process renews the virgin polymer properties and can be used in food contact applications. Chemical recycling of plastics and other technologies will be included in more detail in phase 2 of the guidelines.

CEFLEX expects to see these emerging technologies playing an increasingly important, and complementary, role to mechanical recycling as we move towards a circular economy.

[22] CEFLEX is undertaking work to better understand what applications can utilise recycled materials from flexible packaging and at what levels.

8 Next steps

Phase 2 guidelines

Not all the flexible packaging structures currently placed on the market can be considered to be 'Designed for Recyclability'. These structures which make up about 20-30% of the overall flexible packaging on the European market tend to be multi-material structures. They are generally used for more demanding applications which require higher barrier or physical properties and subsequently result in the use of more complex combinations of materials, barrier layers, adhesives, etc.

CEFLEX is developing a testing programme to research and evaluate how these structures can be sorted and recycled. The objectives of this programme are to;

- Undertake testing to better understand if/how flexible packaging structures that are not currently widely sorted and/or mechanically recycled can be sorted and recycled
- Undertake testing to understand the impact of different elements of a flexible packaging structure on its sortability and recyclability. This will include inks, lacquers, adhesives, tie layers, additives, sealants and coatings.

This programme will produce robust, credible and independent data to be used as the basis for the development of phase 2 of CEFLEX guidelines. The testing programme will commence in 2020.

In the interim, where these structures are required, they should be designed so that they are easily identifiable at the MRF (sorting stage) so that they can be removed and prevent them disrupting the mono-material streams – see Sortability section on pages 16 and 17.

Future proofing

The CEFLEX guidelines will be reviewed on a regular basis. This is expected to be annually, but this has not yet been formally agreed or the review process put in place to do this.

These reviews will consider developments across the flexible packaging value chain, including new packaging materials and structures, as well as developments in the collection, sorting and recycling processes, technologies and infrastructure.

In this fast-changing environment, the CEFLEX guidelines will be regularly updated to ensure that relevant advancements and innovations are incorporated and that the guidelines reflect best practice in the flexible packaging value chain.

9 Appendices

Appendix 1: Definitions and terminology

Term	Definition
Aluminium foil	Rolled aluminium with a thickness 5 - 200 microns. Thicknesses for flexible packaging applications are generally below 50 microns. Aluminium foil is used in flexible packaging structures either as the major component (aluminium-based structures) or as a (barrier) layer within other material structures.
Aluminium Oxide (AlOx)	Is a very high gas and moisture barrier thin coating (typically 1- 10nm) that can be applied onto flexible films and can be used as an alternative to EVOH, PVDC, metallisation etc.
Aluminium-based flexible packaging	In the context of this document, aluminium-based flexible packaging contains aluminium as the predominant material with a percentage of aluminium (generally above 80%) highly dependent on the gauge of the aluminium foil base structure (the thinner the foil the lower the percentage in general). It must be noted that a lower percentage than 80% would not negatively influence the aluminium recycling process[23]. Note this is different to a metallised film.
Chemical (feedstock) recycling	Chemical recycling of polymer waste is defined as any reprocessing technology that directly affects either the formulation of the polymeric material or the polymer itself and converts them into useful products like monomers, basic-chemicals, alternative fuels and other value-added materials.[24] Additional note from the Ellen MacArthur Foundation: chemical recycling can be considered in-line with a circular economy if the technology is used to create feedstock, that is then used to produce new materials. However, if these same processes are used for plastics to energy or plastics to fuel applications, these activities cannot be considered as recycling (according to ISO) nor as part of a circular economy.
Coating	The application of a thin layer of a functional material onto a substrate.
Coextrusion	The application of different layers of polymer side-by-side in one extrusion process as a separate film, coating or lamination layer.
Compatibilisers	Compatibilisers are used to render polymer blends that are not compatible and/or miscible, such as combinations of PE and PA, PE and PET, which very often occur in multi-material structures, to be compatible with each other. Compatibilisers are made up of at least two parts, with each part interacting with one of the two or more components of the incompatible mixture. The result is the minor component of the mixture will be dispersed within the major component and be bound to it. The more effective this dispersion and compatibiliser, the more homogeneous the resulting blend will be and the recyclate will have improved properties.
Copolymer	A copolymer is a polymer derived from more than one species of monomer (for example ethylene is a monomer).[25]
Designed for Recyclability (D4R, DfR)	In the context of this document, Designed for Recyclability is when packaging is designed for collection, sorting and recycling, using end-of-life processes that are used commercially in at least one country in Europe, including where this collection, sorting and recycling infrastructure is not yet in place for the packaging to actually be recycled. *Note: 'Designed for Recyclability', 'Designed for Recycling', 'Recycling Ready' and 'Recycle Ready' are interchangeably used and reflect the same meaning.* The aim for CEFLEX is for post-consumer flexible packaging to go into an active recycling stream in each country. At this time, it is recognised that not all countries in Europe have a flexible packaging collection, sorting and recycling infrastructure. Designed for recyclability in one country can be different from another; therefore, a packaging specifier should check good practice locally to be consistent. Claims that a pack is designed for recyclability or recyclable in a country where the recycling infrastructure is not yet operating should be avoided. Designed for Recyclability or Recycle Ready are terms used to say the packaging design is moving in the right direction, but the end game is to be "recyclable" with the recycling infrastructure working in practice where the packaging is placed on the market. This definition is a CEFLEX one used to build this guideline document and should not be used to make marketing claims (by any in the value chain). *Note: Closed loop circularity (i.e. turning food contact packaging back into new food contact packaging) is not possible in most cases due to limitations such as food contact approval.*
Eddy Current Separation	An eddy current separator uses a powerful magnetic field to separate non-ferrous metals from waste after all ferrous metals have been removed previously by some arrangement of magnets. The device makes use of eddy currents (a manifestation of electromagnetic induction occurring when a magnetic field is applied to a conductor) to affect the separation.
Ethylene copolymers	Polymers derived from more than one species of ethylene monomer. By using a copolymer some of the properties of the material can be altered to enhance the material structure to suit an application.[26]
Ethylene Vinyl Alcohol (EVOH)	A copolymer of ethylene and vinyl alcohol. It offers outstanding barrier to gases, such as oxygen, carbon dioxide and nitrogen and has very high resistance to hydrocarbons and organic solvents. It is usually co-extruded but can be a laminated barrier layer or a coating in many food applications.[27,28]
Flexible packaging (CEFLEX definition)	Flexible packaging structures typically bend easily and can include bags, pouches, envelopes, sachets, removable lidding/liners and wraps. Flexible packaging structures can be single or multi-layered, using a variety of materials including plastic film, paper, aluminium foil or any combination of these. The construction may be plain, printed, coated and/or laminated. Flexible packaging is most commonly used to protect fast moving consumer goods products such as confectionery, snack foods, frozen foods, bakery, fresh produce, meat, dairy, pet food, processed foods, cosmetics, personal care, householder detergents, beverage bottle/can wrappings, pharmaceuticals, medical and other technical products.
High Density Polyethylene (HDPE)	Has a linear molecular structure, allowing for tighter packing of molecules, thus resulting in a denser material (relative density of 0.940 – 0.970 g/cm^3). It is a stiff material which has good tensile strength and heat resistance. It has poor clarity and can be recognised by its opaque appearance. It is used for retail and food bags via film extrusion processes. It is strong with good moisture barrier and is often used to impart moisture resistance. It can be used as an extrusion coating to give moisture and grease resistance to paper packaging materials. It has a high melting point which makes it suitable for boil-in-the bag applications. As a film it is more difficult to heat seal than low density versions.[29]
Laminate	Several layers of materials, films, foils, paper and coatings being bonded via adhesives or extruded polymer to form a new material with special properties. In a laminate, a minimum amount of each material can be used to meet the demands of an application.
Linear Low-Density Polyethylene (LLDPE)	The molecular structure differs from LDPE in that it lacks the long chain branching and has a narrower molecular weight distribution (it has a density of 0.912 – 0.928 g/cm^3). It generally has superior properties to LDPE, such as higher physical strength, and higher temperature tolerance. Greater elongation, higher tear, tensile and impact strength, all allowing a stronger material to be produced with less material. Typically, it is used for carrier bags, stretch films and heavy-duty sacking. It can also be used as a high-performance sealing film when in a metallocene-based resin.[30]

[23] Flexible Packaging Europe
[24] https://www.chemicalrecyclingeurope.eu/about-chemical-recycling
[25] Introduction to Polymers (2nd edition) RJ Young and PA Lovell
[26] Ibid.
[27] Ibid.
[28] Derived from The Wiley Encyclopaedia of Packaging Technology (2nd edition) Aaron L Brody & Kenneth S Marsh
[29] Derived from PIRA: Packaging Materials (2nd edition) Diana Twede and Ron Goddard
[30] Ibid.

Low-density Polyethylene (LDPE)	The molecular structure is characterised by long side-branches that give the resin their combination of flexibility, clarity and ease of processing (it has a density of 0.915 – 0.939 g/cm³). It is a widely used film, used for everything from food packaging, to garment bags, carrier bags, garbage bags, stretch and shrink films as well as being used as a coating. It is tough, flexible and shock resistant and has a good barrier to water vapour, but many organic vapours and essential oils will permeate it rapidly. It is a poor gas barrier to oxygen and carbon dioxide so is often found coated or laminated with relevant gas barrier materials. It is often used as a heat seal medium as a coating or lamination in multi-layer structures.[31]
Materials Recovery Facility (MRF)	Plants where collected recyclable materials from households are sorted into different categories (for example plastics, cardboard, metal, paper).[32]
Material recycling	Reprocessing, by means of a manufacturing process, of a used packaging material into a product, a component incorporated into a product, or a secondary (recycled) raw material; excluding energy recovery and the use of the product as a fuel.[33]
Mechanical recycling	An operation aiming to recover plastics waste via mechanical processes, i.e. grinding, washing, separating, drying, re-granulating and compounding, thus producing recyclates that can be converted into new plastics products, often substituting virgin plastics.[34] *Note: Paper and metals are also mechanically recycled.*
Metallisation	Metallisation is a vapour deposition process which deposits a very thin layer of aluminium on the surface of a plastic film. This thin layer has a thickness of approximately 0.02- 0.5 microns and provides a range of functional properties including oxygen, moisture and aroma barriers as well as light protection. Metallisation can be a layer within a laminated structure or on the surface of a packaging structure.
Mineral fillers	A mineral based additive used to improve the properties of a material. Fillers are most often used as a substitute for more expensive binding agents.
Mono-material	Contains predominantly one material type, either PE (LDPE, LLDPE, HDPE), PP, PET, aluminium, paper or other. For plastics, this should be seen to mean >90% of one polymer type as this is the upper threshold when the other elements such as adhesives, additives and inks are included. The exception is if one of the minor components, for example paper, biodegradable plastics etc, will disrupt the plastic mechanical recycling process. Bi-axially oriented and non-oriented forms of the same base polymer are considered to be mono-material as are PE and PP copolymers and homopolymers, as long as they have a neutral or positive effect on the recycled stream. This definition applies equally to paper and aluminium foil flexible packaging although the actual percentage may vary depending on the recycling process (to be confirmed in phase 2).
Multi-layer	Contains more than one layer of material where a ‘layer’ is only considered if it is greater than 1 micron thick (where no material type is >90% of PE, PP or PO (or >80% for aluminium))[35]. The different layers in the structure can be ‘joined’ together through adhesive bonding or tie-layers via an extrusion, co-extrusion or lamination process, or via extrusion coating or extrusion lamination processes. The different layers can be copolymer blends and do not need to be a single material. There is a difference between layers and depositions. The addition of lacquers, adhesives, coatings and other material deposition processes including metallisation where the layer of deposited material is in the order of 20 nanometres to 10 microns does not change the definition of mono or multi-material. *Note: not all multi-layer structures are multi-material structures and mono-materials can be multi-layered.*
Multi-material	Contains more than one layer of material where no material type is > 90% and the other layers are made of different materials. The different layers in the structure can be ‘joined’ together through adhesive bonding or tie-layers via an extrusion, co-extrusion or lamination process or via extrusion coating or extrusion lamination processes.

[31] Ibid.
[32] https://www.plasticsrecyclers.eu/glossary
[33] Ellen MacArthur Foundation definition
[34] https://www.plasticsrecyclers.eu/glossary
[35] Flexible Packaging Europe

Near-Infrared (NIR)	Near-Infrared is a region within infrared electromagnetic radiation. It is an often-used method of spectroscopy method, employed for the sorting of plastics waste.[36]
Paper-based flexible packaging	Within the context of this document, paper-based flexible packaging is flexible packaging that contains paper as a dominant material. Paper mills prefer to receive no plastic and paper laminations, or ones where the plastic is easily separated.[37]
Plastic-based flexible packaging	Within the context of this document, plastic-based flexible packaging is packaging that contains > 80% polymers. Within this context the definition of mono-material and thresholds for polyolefin-based materials within these guidelines should be noted.
Polyamide (PA) (includes PA6, PA66, PA12, PA11, PA611, PA612)	Polyamide, also known as nylon, is used in packaging in a film format typically ranging from 15 – 9 microns, which is then co-extruded or laminated with other film structures due to cost but also to give a heat seal layer. It is often used in an orientated form known as OPA or BOPA or in a cast form known as CPA. It is used for its toughness and strength over a broad range of temperatures, has excellent puncture resistance, grease resistance and barrier to gases, oil, fats and aromas.[38]
Polyethylene (PE)	A polyolefin polymer based on ethylene. There are three main types used in film applications HDPE, LDPE and LLDPE. It is valued for three main properties; toughness, heat-sealability and barrier to water and water vapour. It has a low coefficient of friction and little, if any, moisture absorption. It is a very low-cost packaging resin and has low process energy costs as it has the lowest softening point of the packaging plastics. It is formed of long chains of C_2H_4 (ethylene) units. The molecules are long straggling chains with branches, tangled together in various ways to form the tough, transparent, heat sealable material. The molecular structure of the types (HDPE, LDPE, LLDPE) of polyethylene vary.[39]
Polyethylene terephthalate (PET) (includes PET, PBT, PEN, PEF, PTF, LCP, PC, PETG, PCT, PCTA)	This is a high clarity film with moderate gas barrier and tolerates fairly high temperatures (typically over 200°C), though these properties can all be improved by orientating, coating or copolymerising the film. It is often laminated with PE to give the seal properties needed for a film application or it can have a sealable coating applied to it. It is typically found as a 12 micron film and is valued for its good clarity, aroma barrier and moderate moisture and oxygen barrier.[40]
Polyolefin (PO)	Group of polymer thermoplastics consisting of only PP and PE.[41]
Polyolefin-based flexible packaging	In the context of this document, polyolefin-based flexible packaging is packaging made up of more than 90% polyolefin materials.
Polypropylene (PP)	A member of the polyolefin family of polymers, PP is a versatile material used for a wide range of applications and its polymer structure can be tailored to meet diverse requirements. It has a very low density, excellent chemical resistance and good strength at low cost. It is often used for applications such as microwave packs due to its high melt point and provides a good moisture barrier. It is often produced as a film in the biaxially orientated form known as OPP (or sometimes BOPP). Some non-orientated PP is used in packaging, primarily for twist-wrap. Orientation improves its low temperature durability making it ideal for freezer applications and grease barrier properties. It is an economical film used across a variety of food applications.[42,43]
Polyvinyl Chloride (PVC)	Is part of the vinyl-based family of polymers. It is most often used in construction (pipes, windows, doors), but sometimes used for non-food packaging.[44,45]
Polyvinylidene Chloride (PVDC)	Is a copolymer of vinylidene chloride/vinyl chloride and acrylates. It is often used in food and medical applications. It has very good gas barrier properties and it is also a barrier to moisture, most flavours and aromas, has good chemical resistance and is heat sealable. It has been widely used in hot water shrink bag application for meat products, though lower cost polymers are increasingly being used for this. It is usually used as a co-extrusion sandwiched between other materials in a very thin form, to reduce costs.[46,47]
Post-consumer waste	Waste material generated by households or by commercial, industrial or institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose. This includes returns of material from the distribution chain.[48]

[36] https://www.plasticsrecyclers.eu/glossary
[37] https://cepi.org/
[38] Derived from: PIRA: Packaging Materials (2nd edition) Diana Twede and Ron Goddard
[39] Ibid.
[40] Ibid.
[41] https://www.plasticsrecyclers.eu/glossary
[42] Derived from: Introduction to Polymers (2nd edition) RJ Young and PA Lovell
[43] Derived from: PIRA: Packaging Materials (2nd edition) Diana Twede and Ron Goddard
[44] Derived from: Introduction to Polymers (2nd edition) RJ Young and PA Lovell
[45] Derived from: PIRA: Packaging Materials (2nd edition) Diana Twede and Ron Goddard
[46] Derived from: Introduction to Polymers (2nd edition) RJ Young and PA Lovell
[47] Derived from: PIRA: Packaging Materials (2nd edition) Diana Twede and Ron Goddard
[48] Ibid.

Post-industrial (Pre-consumer) waste	Waste material diverted from the waste stream during a manufacturing process. Excluded is reutilisation of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.[49]
Recyclable	A pack can only be considered recyclable in a given country/market if there is a realistic chance (> 50%) it will be (i) collected; (ii) sorted into a material fraction that is actually sent to be recycled in to a new material/product at scale and for which (iii) there are viable end market applications. This includes when the recycled material is used in conjunction with virgin or recycled materials from other sources (i.e. it does not only need to be used at 100% inclusion). The key test of recyclability is whether the recycled materials will replace the need for new material from virgin or recycled sources.[50]
Recycled content	Proportion, by mass, of recycled material in a product or packaging. Only pre-consumer and post-consumer materials shall be considered as recycled content.[51]
Recycled material	Material that has been reprocessed from recovered (reclaimed) material by means of a manufacturing process and made into a final product or into a component for incorporation into a product.[52]
Refuse Derived Fuel (RDF)	Is a fuel produced from various types of waste such as municipal solid waste (MSW), industrial waste or commercial waste. The World Business Council for Sustainable Development provides a definition: "Selected waste and by-products with recoverable calorific value can be used as fuels in a cement kiln, replacing a portion of conventional fossil fuels, like coal, if they meet strict specifications. Sometimes they can only be used after pre-processing to provide 'tailor-made' fuels for the cement process." RDF consists largely of combustible components of such waste, as non-recyclable plastics (not including PVC), paper, cardboard, labels, and other corrugated materials. These fractions are separated by different processing steps, such as screening, air classification, ballistic separation, separation of ferrous and non-ferrous materials, glass, stones and other foreign materials and shredding into a uniform grain size, or also pelletised in order to produce a homogeneous material which can be used as substitute for fossil fuels in, for example cement plants, lime plants, coal fired power plants or as reduction agent in steel furnaces.
Silicon Oxide (SiOx)	An extremely high gas and moisture barrier thin coating (typically 1-10nm) that can be applied to flexible films and can be used as an alternative to EVOH, PVDC, metallisation etc.
Solid Recovered Fuel (SRF)	SRF are solid fuels prepared from non-hazardous waste to be utilised for energy recovery in incineration or co-incineration plants and meeting the classification and specification requirements laid down in the EN15359 European standard.[53]
Solvent-based recycling	Solvent-based recycling is a kind of material recycling suitable for thermoplastics. Solvent-based recycling is a solvation process, in which the plastic material to be recycled is treated with selectively active solvent(s) to provoke the physical separation of two or more polymers contained in material mixtures (for example multi-layer plastic films). The macromolecular structure remains intact, so there is an insignificant degree of polymer degradation. After the solvation process, the dissolved polymers are in a liquid/viscous form (depending on the solvent concentration at every step) so they can be separated from insoluble components by conventional cleaning processes. Finally, the solvent will be recovered and recirculated, leaving a recycled polymer with negligible solvent content (in the order of ppm).[54]
Sortability (CEFLEX definition)	A material can be considered 'sortable' if it can be correctly identified by one or more of the commonly used material recognition systems in modern automated packaging sorting facilities, for example magnetic, eddy current, Near-Infrared (NIR), at normal speeds of operation, for example a conveyor speed of > 3m/s. As size, shape and weight can influence sortability, the identification should be (i) independent of orientation (top/bottom/sides should give the same result); and (ii) allow the pack to be successfully ejected into the appropriate sorted fraction.
Sorting	Process of classification of the mixed plastic waste in multi-material collection schemes; it consists of separating plastics from non-plastic content as well as plastic itself into different colours/ polymer categories.[55]

[49] ISO 14021: 2016 Environmental labels and declarations
[50] Derived from ISO 14021: 2016 Environmental labels and declarations
[51] ISO 14021: 2016 Environmental labels and declarations
[52] Ibid.
[53] ERFO (European Recovered Fuel Organisation)
[54] Definition provided by APK AG
[55] https://www.plasticsrecyclers.eu/glossary

Appendix 2: Materials and their properties

The following table is a top line overview and summarises the key materials used in flexible packaging structures, the barrier and other properties they provide and their typical uses. For more detailed information on each material type and suitability for a specific application please check with material suppliers.

Material	Description	Types	Moisture barrier	Gas barrier	Other properties	Heat sealable?	Uses
PE	Polyolefin-based polymer, very common use	HDPE, LDPE, LLDPE including copolymers and homopolymers	GOOD	POOR	Depending on grade, high tensile strength, high temperature tolerance, can be used in retort structures	YES	Multiple applications across many areas often used as a sealing layer. Combined with other materials to give the gas barrier that PE lacks - for use in food, personal care, household, pharmaceutical.
PP	Polyolefin-based polymer, very common use	PP, CPP, OPP, BOPP including copolymers and homopolymers	GOOD	POOR	Depending on orientation - good tear, strong tensile, high gloss, low temperature durability, grease barrier, can be used in retort structures	YES	Used particularly in freezer applications, in combination with other materials for food, pharmaceutical, beauty, household, applications.
EVOH	Thin barrier film or coating	EVOH	POOR	EXCELLENT	Good aroma barrier, highly resistant to hydrocarbons, organic solvents	NO	Where a gas barrier is needed, for example powders, coffee, cheese, meat, etc used as a layer or coating combined with other polymer materials.
PET	Typically found as a 12-micron film commonly used in many applications	PET, PBT, PEN, PEF, PTF, LCP, PC, PETG, PCT, PCTA	MODERATE	MODERATE	Very good clarity, good aroma barrier and stiffness, very good heat resistance (over 200°C), can be used in retort structures	NO*	Cheese, meat, ready meals, ovenable applications, wet wipes, personal care, household detergents. *combined with coatings and other polymers to make heat sealable though PETG can be sealed against PET. Some PET copolymers have sealable properties and some PET can seal to other PET in the same family
PA	Film / co-extruded layer which provides high barrier with very good puncture resistance	PA, OPA, BOPA, PA6, PA6/6, PA12, PA11, PA611, C-PA, PA612	POOR	VERY GOOD	Good grease barrier, puncture resistance, barrier to gases, oils, fats and aromas. Good strength toughness, over a broad temperature range, can be used in retort structures	NO*	Cheese, meat, pharmaceuticals are some of the main applications. *combined with coatings and other polymers to make heat sealable.
PVDC	Very high barrier used in thin layers/coatings	PVDC	GOOD	VERY GOOD	Good flavour, aroma barrier and chemical resistance	YES	Meat, pharmaceuticals are typical applications. Mainly used as in combination with other materials.
SiOx	Very high barrier used in thin coatings	SiOx	EXCELLENT	EXCELLENT	n/a	NO	Where high gas barrier is needed and applied to other material substrates.
AlOx	Very high barrier used in thin coatings	AlOx	EXCELLENT	EXCELLENT	n/a	NO	Where high gas barrier is needed and applied to other material substrates.
PVOH	Water soluble film	PVOH	POOR	EXCELLENT	Resists most chemicals	YES	Used to package dry goods such as agricultural chemicals and detergents which are added to water in the package where it dissolves. Used in disposable bags used for hospital laundries, powder dyes and agrochemicals. It can also sometimes be used as a top coating without being declared in the specification.
Metallisation	Laminated and printed or surface metallisation	Various application methods	VERY GOOD	VERY GOOD	n/a	NO	Where high gas barrier is needed and applied to other material substrates.
EVA	Typically, a coating or a co-extrusion	EVA	n/a	n/a	To improve stretch, heat-sealability and cling	YES	Applied as a sealing layer on other materials to improve sealing.
Acrylic	Usually in a coating form	Acrylic	n/a	n/a	Broaden sealing range and improve hot tack and gloss and printability for holographic applications	YES	Applied on PP films for dried goods applications etc.
Al (Aluminium)	Foil thickness 6 -50 micron	Al aluminium foil	ABSOLUTE	ABSOLUTE	Dead-fold property, heat conductivity, heat resistance, push-through ability, can be used in retort structures	NO	Where very high barrier against gas and/or light is needed (for example coffee, powders, pharmaceuticals, etc.) and/or for retortable packs (for example wet pet food) (can be made sealable by applying coatings or laminating with sealable polymers).
Paper	Many grades at 10gsm to in excess of 250gsm depending on application	Various types, bleached, virgin, recycled materials, with various finishes	n/a	n/a	Good dead-fold property, easily printed	NO	Used laminated with polymers or coatings to give sealability, food contact, gas and moisture barrier, grease resistance and improved printing characteristics. Applications include food, personal care, pharmaceuticals).

Appendix 3: D4ACE phase 1 guidelines summary

The following table summarises the Designing for a Circular Economy Guidelines for the key elements of a flexible packaging structure. For each element, guidance is given in terms of compatibility with a PE or PP mechanical recycling process. Reasons are provided for the guidance, along with general design advice. The table also identifies the materials and elements to be investigated in phase 2. Please refer to Section 6 of this document for full details.

	Guidance			Reasons	Advice	Materials and components for investigation in phase 2
	Compatible with PE or PP mechanical recycling	Limited compatibility with PE or PP mechanical recycling	Not compatible with PE or PP mechanical recycling			
Materials – Plastics	Mono-PE and mono-PP including co-extruded, orientated, co-polymers Laminated PE/PE or PP/PP with or without barrier layers and coatings as indicated below	Co-extruded or laminated PE/PP (mixed PO) with or without barrier layers and coatings as indicated below	PET layers Non-PE and non-PP foamed polymer layers PVC layers Biodegradable and compostable materials	Facilitates higher value recyclate. Materials may move towards being more compatible as technology and infrastructure evolve. Foamed polymers alter the density of the material and impacts the flotation sorting within mechanical recycling plants. Biodegradable and compostable materials are known to disrupt the mechanical recycling of PE, PP, mixed PO materials and should be diverted from mechanical recycling collection streams and should not be used in any packaging designed for mechanical recyclability	It is recognised that the materials in the **limited compatibility** and **not compatible** columns have a role to play in packaging in some applications and should not be replaced if there is a negative impact on product protection (there is often a greater environmental impact in product waste than the packaging).	Impact of PET in polyolefin-based mechanical recycling processes PA
MATERIAL COMPOSITION THRESHOLDS FOR MONO-PE AND MONO-PP STRUCTURES	Greater than 90% PE Greater than 90% PP	80-90% PE 80-90% PP	Less than 80% PE Less than 80% PP	Facilitates higher yields and higher value recyclate	-	Impact of material composition
MATERIAL COMPOSITION THRESHOLDS FOR MIXED PO STRUCTURES*	Greater than 90% PO	80-90% PO	Less than 80% PO			
Materials – Aluminium, Paper	n/a	n/a	Paper Aluminium foil	Paper in the plastic mechanical recycling process is a serious disruptor as any remaining fibres carbonise during the extrusion process negatively affecting the recycled plastic quality	If paper properties are needed in a flexible packaging structure, then it should represent the dominant material by weight and be able to be identified as paper in the sorting process and be sorted into the paper fraction for recycling Although aluminium foil is not compatible with a plastic mechanical recycling process, these structures can be identified and removed in the sorting process by using eddy current separation technology. Sorted structures containing aluminium foil can be recycled via a pyrolysis process although the plastic proportion will not yet be recycled via this type of process	-

* The information in this row of the table relates specifically to the material composition of mixed PO structures in relation to compatibility to PO mechanical recycling processes rather than compatibility with PE and PP mechanical recycling processes.

		Guidance: Compatible with PE or PP mechanical recycling	Guidance: Limited compatibility with PE or PP mechanical recycling	Guidance: Not compatible with PE or PP mechanical recycling	Reasons	Advice	Materials and components for investigation in phase 2
Barriers		For each barrier layer and coating maximum 5% of total packaging structure weight - AlOx, SiOx, EVOH, PVOH, Acrylic Laminated and printed metallised layers	For each barrier layer and coatings over 5% of total packaging structure weight - AlOx, SiOx, EVOH, PVOH, Acrylic	To be determined	Facilitates higher yields and higher value recyclate. Materials may move towards being more compatible as technology and infrastructure evolve.	Barrier materials have a role to play in providing light-weight high-performance packaging in some applications and should not be replaced if there is a negative impact on product protection (there is often a greater environmental impact in product waste than the packaging).	Impact of barrier layers and coatings above 5% of total packaging structure weight PVDC coatings PA layers Surface metallised films
Size & shape	MATERIAL THICKNESS	The minimum viable amount of material should be used			Prevention and reduction of packaging in all its forms should always remain the priority in design of flexible packaging.	Increasing material thickness to improve recyclability of the packaging is not encouraged - waste prevention and reduction should always be a priority.	
	PACK SIZE	Above 20mm x 20mm	Above 20mm x 20mm	Below 20mm x 20mm	Waste sorting facilities use screens to separate larger 'oversized' items from smaller 'undersized' items. Smaller items fall through the holes of the screen and the material will usually be classed as a residual stream and not be recycled.	Pack size should not be increased to improve recyclability; waste prevention and reduction should always be a priority.	n/a
	PRODUCT RESIDUE IN PACK	Low quantities of product residue	Moderate quantities of product residue	Large quantities of product residue	The pack should be designed to leave as little amount of product residue as possible to facilitate higher yield of recyclate.	-	
Density		< 1 g/cm^3	< 1 g/cm^3	> 1 g/cm^3	Density separation is commonly used to separate polyolefins from other materials. Polyolefins have a density of < 1 g/cm^3 and will float in the process, whereas material with a density of > 1 g/cm^3 will sink and not be included in the PO-based recycling process.	-	n/a
Adhesives		Polyurethane, acrylic or natural rubber latex adhesives, as well as non-PE or non-PP based tie-layers, are permitted to a maximum of 5% by weight of the total packaging structure	Above 5% of total packaging structure weight	To be determined	Facilitates higher quality recyclate.	-	Impact of adhesives on recyclability

		Guidance: Compatible with PE or PP mechanical recycling	Guidance: Limited compatibility with PE or PP mechanical recycling	Guidance: Not compatible with PE or PP mechanical recycling	Reasons	Advice	Materials and components for investigation in phase 2
Pigments		Clear, natural or paler colours	Black and darker colours	Carbon black containing masterbatch	Facilitates higher value recyclate as more natural/ lighter colour. The paler the polymer colour the less cross colour contamination when being recycled. As plastics are recycled it is known that the colour becomes greyer over time. Carbon black containing masterbatch is not recognisable by NIR optical sorting technology.	If black is required, NIR detectable pigments should be used.	n/a
Additives & fillers		Additives and fillers are permitted but usage should be minimised. This includes thermal stabilisers, UV (ultraviolet) stabilisers, nucleating agents, mineral and polymer cavitating agents, antistatic agents, impact modifiers, chemical blowing agents and tackifiers.	To be determined	Fillers in non-PE and non-PP structures which modify the density to be < 1 g/cm^3 Substances of very high concern (SVHC) Oxo-degradability additives Foamed thermoplastic non-polyolefin elastomers	Facilitates higher value recyclate. Materials may move towards being more compatible as technology and infrastructure evolve. SVHC are not permitted to allow the recyclate to be suitable for the greatest range of end market applications. Oxo-degradability additives are not permitted to maintain the quality and mechanical properties of the final recyclate	-	Impact of additives, fillers, tie layers and compatibilisers on sortability and recyclability
Inks & lacquers	COLOUR	Lighter, paler ink colours	Darker ink colours	n/a	Facilitates higher value recyclate as more natural/ paler colour and avoids disruption of mechanical recycling process. PVC binders are known to disrupt the recycling process.	-	Impact of inks, lacquers and varnishes on sortability and recyclability
	TYPE AND COVERAGE	Lacquers and inks (without PVC binders) up to a maximum 5% of total packaging structure weight	Lacquers and inks (without PVC binders) above 5% of total packaging structure weight	Lacquers and inks containing PVC binders			
	PRINTING SURFACE	Surface printing Lamination printing	To be determined	n/a	Facilitates higher quality recyclate.		Impact of both printing methods and printing surface on sortability and recyclability

	Guidance			Reasons	Advice	Materials and components for investigation in phase 2
	Compatible with PE or PP mechanical recycling	Limited compatibility with PE or PP mechanical recycling	Not compatible with PE or PP mechanical recycling			
Labels	Same as the main material i.e. mono-PE or mono-PP	If the label is of a different material to the main material, then a maximum size of 30% of each packaging face and should be easily removable	Above 30% of the total surface area of the pack if material is different to the main material	Ensures correct sorting and facilitates higher quality recyclate.	-	n/a
Additional features: ZIPPERS, SPOUTS, CLOSURES, VALVES AND TAPS	The material type used is the same as the main pack material	If the pack contains different materials, then these parts should be easy to separate. However, the ideal design should not require the consumer to separate parts and different materials should be avoided wherever possible.		Facilitates higher yield of recyclate.	-	n/a
Recycled content	The use of recycled content in flexible packaging to reduce the use of virgin material and create markets for recycled materials is encouraged. *Note: this is for non-food applications. For food contact and indirect food contact applications all materials must adhere to food safety regulations and at this time recycled materials from polyolefin-based flexible packaging are not approved as food safe.*					

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